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Recent and Prospective Adoption of Genetically Modified Cotton: A Global CGE Analysis of Economic Impacts

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Abstract

This paper provides estimates of the economic impact of initial adoption of genetically modified (GM) cotton and of its potential impacts beyond the few countries where it is currently common. Use is made of the latest version of the GTAP database and model. Our results suggest that by following the lead of China, South Africa and most recently India, adoption of GM cotton varieties by other developing countries – especially in Sub-Saharan Africa – could provide even larger proportionate gains to farmer and national welfare than in those early-adopting countries. Furthermore, those estimated gains are shown to exceed – and reinforce – those from a successful campaign under the WTO's Doha Development Agenda to reduce/remove cotton subsidies and import tariffs globally.

JEL codes: D58, F17, Q16, Q17

Key words: GMOs, cotton biotechnology, computable general equilibrium modeling, economic welfare, subsidy and tariff reform

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1. Introduction

Cotton is important for many developing countries, either as a cash crop and/or as an input into their textile industry. It is receiving more attention of late for two reasons. One is because, thanks to genetic modification using modern biotechnology, new insect-resistant and herbicide-tolerant cotton varieties are emerging that are proving to be more productive than traditional varieties of cotton. Over the decade following their first release, genetically modified (GM) cotton rose to account for 28 percent of all land sown to cotton globally and to one-ninth of the world's total area of GM crops by 2005. The United States and China accounted for almost all of that, where the proportion of plantings that are GM are already more than four-fifths and two-thirds, respectively (Table 1).[1] The only other countries with high GM adoption rates by 2005 were Australia and South Africa, both with slightly more than four-fifths of their cotton areas under GM varieties. Apart from India and Mexico, where legal adoption began to take off only in 2003-04, and an unknown extent of GM plantings in Argentina and Brazil, no other developing countries had widespread adoption of this new technology.[2]

The other reason cotton is in the news is because four poor cotton-exporting West African countries (Benin, Burkina Faso, Chad and Mali) have demanded that cotton subsidy and import tariff removal be part of the World Trade Organization's Doha Development Agenda. However, cotton subsidies are mostly provided by governments in high-income countries, and those governments have yet to be persuaded by other cotton-exporting countries to abandon them – notwithstanding the fact that part of the US cotton subsidy program has been ruled illegal following a WTO dispute settlement case brought by Brazil.

What is at stake here in terms of economic welfare in various developing countries? Specifically, how much are low-income countries foregoing by procrastinating in their approval of GM cotton production? How does that compare with the effects on developing country and global welfare of removing cotton subsidies and import tariffs? And how much greater would be the gains to cotton-producing developing countries from GM cotton adoption if global cotton markets were not distorted by subsidies and tariffs?

After presenting a brief background to the world's cotton market in Section 2, this paper seeks to address these questions by using a well-received model of global economy known as GTAP (developed by Purdue University's Global Trade Analysis Project) and the current version of its related trade and protection database, described in Section 3. Empirical simulation results are presented in Section 4, including some sensitivity analysis. These are followed by a discussion of caveats in Section 5. The concluding section summarizes the findings and draws policy implications for developing countries.

This paper adds value in several respects to our earlier analysis of GM food crop adoption in Sub-Saharan Africa (Anderson and Jackson 2005). The policy setting for this fiber crop is clearly different. On the one hand, it does not involve the consumer health issue associated with GM food, and the environmental and farmer health contributions are almost certainly net positives in the case of GM cotton.[3] On the other hand, it involves the sensitive North-South issue of trade-distorting cotton subsidies. Also, from a methodological viewpoint the present analysis extends our previous work by looking not only at the mean but also the standard deviation of effects, and by examining not only Hick-neutral but also partial factor productivity shocks. And we go beyond previous GM cotton studies (e.g., Elbehri and MacDonald (2004) on West and Central Africa and Huang et al. (2002) and Hossain at al. (2004) on China) by taking a multi-regional global approach that is able to show the adverse terms of trade effects for a region of not adopting when other significant producing regions adopt this new biotechnology.

2. The global cotton market

Cotton production is highly concentrated in several respects. One is that most production is in a few countries: as of 2005/06, nearly half is produced by just China and the United States, and that rises to more than two-thirds when India and Pakistan are added and to more than three-quarters when Brazil and Ukbekistan are included. Also highly concentrated are exports of cotton lint, with the US, Australia, Uzbekistan and Brazil accounting for almost two-thirds of the world's exports, while the cotton-four in West Africa and the other four countries in Central Asia bring that total to almost four-fifths (Table 2).

Cotton usage, on the other hand, is distributed across countries roughly in proportion to their volumes of textile production. Because of high domestic usage by exporters of textiles and clothing in developing Asian countries (and Mexico because of its preferential access to the US and Canadian markets under NAFTA), even large cotton producers such as China, Pakistan and India export only a small fraction of their crop, in contrast to Sub-Saharan Africa and Central Asia where textile production is relatively minor. This explains the pattern of net exports of cotton and textiles across regions (columns 3 and 4 of Table 3), an understanding of which is helpful in explaining the signs of the welfare effects of some of the technology and policy shocks that are simulated below.

3. The GTAP model and database

The standard Global Trade Analysis Project (GTAP) model of the global economy is used to provide insights into the effects of governments allowing GM technology adoption in some countries without and then with cotton trade and subsidy policy reform globally. As explained in the Appendix, GTAP is a neo-classical multi-regional, static, applied general equilibrium model that assumes perfect competition, constant returns to scale and unchanging aggregate national employment of all factors of production (Hertel 1997). We use the Version 6.1 of the GTAP database, which draws on global economic structures, policies and trade flows of 2001 (Dimaranan 2006). The GTAP model has been aggregated to depict the global economy as having 27 sectors and 39 regions (Appendix Table 1), so as to highlight the main participants in the world's cotton markets.

4. Model simulations and results of GM cotton adoption

Studies of Bt cotton adoption are available for several GM-adopting countries, including by Huang et al. (2002), Pray et al. (2002) and Hossain et al. (2004) for China, Ismail,. Bennett, and Morse.(2002) for South Africa, and Qaim (2003) for India. To model GM cotton technology productivity shocks using the GTAP Model, we initially assume that the technical change can be represented as a Hicks-neutral, output-augmenting productivity shock of 5 per cent for most new adopting regions and 15 percent for regions with huge yield potential, namely India and Sub-Saharan Africa (other than South Africa –see final column of Table 2).

We also undertake two forms of sensitivity analysis. One involves estimating the standard deviations of variables in addition to their mean with respect to the magnitude of the exogenous TFP shocks. This is done using the Gaussian Quadrature numerical integration procedure that has been efficiently implemented into the GTAP framework by Pearson and Arndt (2000). We follow Elbehri and Macdonald (2004) in assuming total factor productivity shocks have a uniformly triangular distribution, with the extreme values ranging from 0.5 to 1.5 times the initial shock level (chosen to adequately cover the current range of estimates and expectations for different regions). This process involves 78 solutions, 2 for each (exogenous) regional TFP shock, from which the mean and standard deviations are then calculated (see Appendix).

The other form of sensitivity analysis involves assessing the effect of factor bias in the productivity shocks – as alternatives to Hicks-neutral TFP shocks. In our scenarios we examine labor and land partial factor-saving productivity. The magnitude of the biased technical shock is obtained through a normalization of the percent increase in the productivity of all factors. This consists in scaling up the Hicks-neutral TFP shock by the inverse of the factor cost share, thus giving the same overall cost savings. The cost shares of inputs into cotton production in various regions are shown in Appendix Table 2.

The impact of productivity growth is to change cotton prices and the level of cotton output and trade flows globally. The GTAP Model also provides a comprehensive decomposition of changes in national economic welfare as measured by the equivalent variation in income resulting from the productivity shocks. The current GTAP database provides information about the use of land, unskilled labor, skilled labor, and capital in the agricultural sectors. After solving the model we also calculate the change in the returns to primary factors of production in the cotton sector in each region.

To simulate the economic effects of adoption of GM cotton, we assume initially that total factor productivity (TFP) in cotton production would rise by 5 percent in most adopting countries, net of any higher cost of GM seed and allowing for less-than-complete adoption.[4] This output-augmenting, Hicks-neutral TFP shock is a conservative estimate of the gain to farmers, according to experience to date (FAO 2004, Table 7; Marra, Pardey and Alston 2002; Qaim and Zilberman 2003; Huang et al. 2004) and bearing in mind that typically, in a small number of years after GM cotton adoption is allowed, more than four-fifths of production moves to GM varieties. In India and Sub-Saharan Africa other than South Africa, however, we assume a TFP shock of 15 percent. Even that higher value is conservative for those countries, according to Qaim and Zilberman (2003), because those countries' yields per hectare with conventional varieties are less than half the yields in the rest of the world (see last column of Table 2) and the GM field trials in India have raised yields by as much as 60 percent. More-recent commercial planting data suggest yield per hectare gains in India of more than one-third from adopting GM cotton varieties, and higher net profits despite the fact that GM seed costs three times as much as non-GM seed (Qaim et al. 2006, Bennett et al. 2006).[5]

Three GM cotton adoption simulations are presented below. The first one aims to measure the market and welfare effects of adoption that had already taken place by 2001 in the United States, China, Australia, and South Africa. In this simulation we examine how the world would have been had that productivity shock not taken place. This is implemented by applying a negative 5 percent Total Factor Productivity (TFP) shock to cotton production in these countries (but for comparative purposes we express the results with the opposite signs). In China’s case it was only about half way through its adoption process as of 2001, so only a 2.5 percent TFP shock is applied in this case.

The second simulation represents a situation in which all other countries except the rest of Sub-Saharan Africa adopt GM cotton (and China completes its adoption process). The TFP shock is 5 percent except for India (where it is 15 percent) and for China (where it is just an extra 2.5 percent).

In the third simulation, the rest of Sub-Saharan Africa join South Africa in adopting, with a TFP shock is 15 percent. The net effect of this new biotechnology is thus the sum of effects from the first simulation (what had already taken place by 2001) and from the third simulation (what still remained to be embraced after 2001). In presenting our results, the first simulation is compared with the other two. The reason it is worth examining separately the impact of adoption by the rest of Sub-Saharan Africa is that the region has a history of very slow adoption of new agricultural technologies in the 1970s and 1980s, and during the 1990s its investments in agricultural R&D grew only 1 percent per year and spending actually fell in about half the countries for which data exist (Science Council 2005).

At the end of this section we then compare the results from these GM experiments with ones examining the effects of cotton subsidy and trade policies.

First simulation (what had already taken place by 2001)

Results from the first simulation, presented in the final three columns of Table 3, 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 percent as a result of this initial adoption, according to our model).[6] Globally, both value added by cotton farmers and the value of cotton exports were reduced by about 1 percent, and by more than that in most non-adopting regions. Note in particular that the largest changes in value added in cotton production are in Sub-Saharan Africa, with a rise in South Africa of 3.5 percent and a fall in the rest of Sub-Saharan Africa of 4.4 percent. Note also that among the GM cotton adopters, value added in cotton production were lowered 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. For China, its small volume of cotton exports also was lowered, as most output is used by its domestic textile industry which expanded in response to the lower price of raw cotton.

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 due to their terms of trade deterioration and, in all but Australia’s case, a small loss from domestic resource reallocation to the cotton sector (the latter because resources are attracted from sectors that were less assisted by government policies than cotton). But notice also that welfare improves 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 this technology's adoption as of 2001, plus whatever net profits have accrued to the biotech and seed firms (which are not explicitly captured in this model).

Second and third simulations (technology catch-up)

If 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 (compare the final columns of Tables 4, 5 and 6). Note too that the value of global exports shrinks more in these two simulations than in the first one, indicating that more cotton would be grown in the regions where it is consumed the more developing countries adopt this technology.

Global welfare could be 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, even though that would lower slightly Sub-Saharan Africa's (and Australia's) welfare (Table 5). But adoption by the rest of 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 loss shown in Table 4 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 2.4 percent in this scenario (and 4.1 percent when Sub-Saharan Africa also adopts, as compared with 2.5 percent from GM adoption by just the first four adopting countries). Note though that Australia's earlier gain would be erased by the fall in its cotton export price in this scenario. With complete catch-up as in this third scenario, the gains to Central Asia, Sub-Saharan Africa and South Asia are ten, thirteen and twenty-three times greater than the global gains when expressed as a percentage of regional GDP (last column of Table 6, and Figure 1). South Asia's are especially large because it is a large producer of both cotton and textiles (see Table 1).

Clearly, there are large benefits being foregone by developing countries that are procrastinating in their release of GM cotton varieties. It is gratifying to see that the governments of India and Mexico are now allowing their growers access to those varieties (see Table 1), and hopefully other governments will soon follow suit.

For the third scenario, we present in Table 6 not only the means but also the standard deviations of key variables. Note that the latter are a small fraction of the former in almost all cases, indicating that there are relatively small confidence bands around the mean results. Then in Table 7 we present the third scenario results again, this time assuming either a labor-saving or a land-saving element only in the productivity shock which give the same overall cost savings as a Hicks-neutral shock.[7]

The overall thrust of the results is much the same in all three cases, but the magnitude of the welfare gains is somewhat less for many regions with these extreme factor-biased shocks. So too is the impact on cotton value added in Sub-Saharan Africa, while in other regions their cotton earnings are more or less adversely affected (relative to the Hicks-neutral case) depending on whether the bias is labor- or land-saving. Not surprisingly, this suggests estimates of impacts of adoption by any particular region require identifying the specific nature of the cost savings involved. But it should be kept in mind that GM cotton technology involves not only higher yields per hectare and savings in labor but also large reductions in expenditure on insecticides (see the review of numerous studies that are summarized in Elbehri and MacDonald 2004, Table 3). Hence the Hick-neutral assumption is more reasonable than either of the two extremes considered in Table 7.

What if cotton subsidies and tariffs were removed?

How do the above prospective gains from adopting GM cotton compare with the effects of eliminating all cotton subsidies and tariffs, as called for by several African cotton-exporting countries as part of the WTO's Doha Development Agenda? And how much greater would be the developing countries' gains from GM cotton adoption if the world was free of cotton subsidies and tariffs?[8]

The extent of subsidies to cotton production and exports, and of tariffs on cotton imports, is non-trivial (see Anderson and Valenzuela 2006, Appendix Table A3). Large though some of the interventions are, the estimated global welfare gain from removing them ($283 million per year) is only one-eighth the above estimate of the gain from completing the adoption of GM cotton technology ($2.3 billion).[9] Furthermore, most of that protection cost is felt by the countries imposing those distortions. Indeed many developing countries – as net importers of cotton (see Table 3) – benefit from those subsidies and tariffs because they lower prices for cotton in international markets.

What is striking about the distribution of the welfare effects that would result from removing those distortions, however, is the relatively large benefit it would bestow on Sub-Saharan Africa. Indeed that potential gain of $147 million per year is almost as large as the region's estimated gain from joining with the rest of the world in embracing GM cotton technology. Such reform would boost the international price of cotton by an average of 12.9

percent,[10] and lead to an estimated increase in Sub-Saharan African cotton output and value added of nearly one-third. The real value of cotton exports from Sub-Saharan Africa would increase by more than 50 percent, while cotton output and exports would fall by one-quarter in the United States and would halve in the EU (Table 8). That would raise Sub-Saharan Africa’s share of global cotton exports from 12 to 17 percent, and the share of all developing countries from 52 to 72 percent.

Also striking is a comparison of the welfare result from cotton reform with that from removing *all* merchandise tariffs and agricultural subsidies. While the latter gain is nearly 300 times as great as the former globally, for Sub-Saharan Africa cotton reform is crucial: its potential contribution to the region’s welfare of $147 million per year is one-fifth of the estimated $733 million gain for the region from the freeing of *all* goods markets globally.

If those distortions to cotton markets were removed, how different would be the estimated effects of further GM cotton adoption beyond that achieved by 2001? Globally it would be virtually no different,[11] but the gains to developing countries in the absence of distortionary cotton policies would be slightly greater (12 percent so in the case of Sub-Saharan Africa), while those to high-income countries would be less (middle columns of Table 6).

Were these two reforms (GM catch-up and subsidy removal) to occur simultaneously, they would reinforce each other in Sub-Saharan Africa as each expands the region’s cotton production and exports and so makes the gain from the other change larger. This is evident in the final column of Table 9, which shows that the gain to Sub-Saharan Africa would then be ($223m + $147m =) $370m. This is equivalent to $199m + $172m, the former appearing in column 1 of Table 9 and the latter being the gain to Sub-Saharan Africa from global removal of cotton subsidies and tariffs had GM catch-up occurred before that reform. With these two reforms the average price of cotton in international markets would be 7.4 percent above the baseline, instead of 4.1 percent below as in the case of just GM catch-up alone. That is why the loss shown in Table 8 for South Asia following subsidy removal becomes a gain in the final column of Table 9 when that reform is accompanied by GM cotton adoption. Clearly this is an example of complementarity between the trade and development components of the Doha Cotton Initiative.

5. Caveats

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. If that intellectual property is held by a firm in a country other than the GM-adopting country, then the gain from adoption is overstated in the adopting country and understated for the home countries of the relevant multinational biotech companies to whom those profits would be repatriated.

Because of the uncertainty surrounding the relationships among various economic and environmental variables, the GTAP model does not include environmental or human health externalities, so the welfare consequences of any such externalities are not measured. There could be positive or negative net environmental effects of producing GM crops, but that is equally true for producing non-GM crops. On the one hand, there is concern that some long-term and possibly irreversible negative environmental effects might occur in the future, although we are not aware of significant scientific evidence of such adverse effects.[12] It happens that, prior to GM varieties, cotton farming in all but dry low-income countries has involved one of the most chemical-intensive forms of agricultural production. By switching to GM cotton, farmers have been able to lower substantially their applications of insecticides, thereby reducing soil, water and air pollution and improving the health of farm operators and their neighbors. For cotton farmers in low-income countries who have not yet had access to insecticides and other farm chemical and hence have relatively low yields and profits (including in much of India and Sub-Saharan Africa – see final column of Table 2), GM cotton varieties offer an opportunity to leapfrog the chemical-intensive technology and provide a win-win-win for farm profits, human health, and the environment.

6. Conclusions

Adaptation and adoption of new genetically modified (GM) cotton varieties are within the powers of developing countries themselves. Unlike the Cotton Initiative in the WTO's Doha Development Agenda, governments in Sub-Saharan Africa and elsewhere do not need to wait until that round concludes to boost the incomes of their cotton farmers. Indeed the above results suggest that developing country welfare could be enhanced by more from allowing GM cotton adoption than by the removal of all cotton subsidies and tariffs.[13] Furthermore, our results support the notion that the gains to developing countries from the Doha Cotton Initiative will be even greater if GM cotton is adopted first, providing yet another reason not to delay approval of this new biotechnology.

Those developing countries with well-developed public agricultural research and extension systems (such as India) are well placed to benefit promptly from the new biotechnology by working in partnership or in parallel with private biotech and seed companies. Approving investments in those activities by the private sector – and the overall investment climate – will allow the process of adaptation and adoption to move forward. The experiences in

China, India and South Africa all indicate that rapid and widespread adoption is then possible, including by small farmers. Many of Sub-Saharan Africa’s low-income countries have poorly developed public agricultural research and extension public research agencies and unattractive investment climates though (Beintema and Stads 2004; Sithole-Niang, Cohen and Zambrano 2004; Cohen 2005). As those systems and associated intellectual property rights are improved, so the payoff from R&D spending to adapt appropriate local crop varieties will be enhanced. The potential benefits shown above from this new biotechnology should make that expenditure even more affordable now.

Moreover, the fear of adverse environmental or food safety issues have not been vindicated during the first decade of adoption by those countries and the US and Australia, not least because scientists and regulators have found ways to manage those risks. Indeed farmer, water and soil health have all improved thanks to the lesser pesticide needed with Bt varieties of GM cotton. Nor does GM cotton carry the stigma that GM food carries in high-income countries of Europe. If embracing GM cotton helps developing country governments to streamline also the process of approving the release of GM varieties of food crops (given the steady flow of scientific reports such as by King (2003) concluding that there is no evidence that GM foods are harmful either to the environment or to human or animal health), these economies would be able to multiply that $2 billion gain from GM cotton adoption by at least two, according to the numbers presented in Anderson and Jackson (2005) and Anderson, Jackson and Nielsen (2005).

Appendix: The GTAP Model

The GTAP (Global Trade Analysis Project) model used in this analysis is a well-received multi-regional, static, applied general equilibrium model of the global economy that is routinely used by hundreds of modelers in scores of countries for agricultural and trade policy analysis. Comprehensive model documentation is provided in Hertel (1997) and at www.gtap.org. The global production, consumption, trade and protection policy data in the model are regularly updated, the latest version used here being Version 6.1 which is based on 2001 data (Dimaranan 2006). The GTAP model is run with the widely used GEMPACK software package developed at the Centre of Policy Studies at Monash University in Australia (www.monash.edu.au/policy/gempack.htm).

The version of the GTAP model used in this analysis is based on neo-classical microeconomic theory (perfect competition, constant returns to scale). International trade is described by an Armington (1969) specification which means that products are differentiated by country of origin, with detailed bilateral trade, transport and protection data characterizing economic linkages among regions. Detailed country level input-output data characterize intersectoral linkages within regions so that, like other global economy-wide general equilibrium models, GTAP describes both the vertical and horizontal linkages between all product markets both within the model's individual countries and regions as well as between countries and regions via their bilateral trade flows. For present purposes the database was aggregated to depict the global economy as having 27 sectors and 39 regions to highlight the main participants in the world’s cotton markets (Appendix Table 1).

The firms' production structure in the GTAP model assumes Constant Elasticity of Substitution (CES) functional forms among the five productive factors: skilled labor, unskilled labor, agricultural land, other natural resources, and other (non-human) capital. The assumed values for those commodity-specific CES values are taken from Jomini et al. (1991), who reviewed estimates from international cross-section studies for various industries for a wide range of countries. Natural resources are used only in production of non-agricultural primary industries, and land is specific to agricultural uses. Both types of labor and capital are assumed to be perfectly mobile throughout the economy. The mobility of these endowments is defined by a Constant Elasticity of Transformation revenue function (Powell and Gruen 1968), with a (negative) unitary elasticity of transformation for land, and equal to - 0.001 for natural resources. The greater the CET value in absolute terms, the greater the degree of mobility and hence the extent to which rental rates across alternative uses move together.

Separability is assumed between primary factors of production and intermediate inputs, and Leontief fixed coefficients are assumed for the purchase of intermediate inputs (see Appendix Figure 1). That is, there is no substitution allowed among the intermediate inputs, nor between them and primary factors. This is somewhat restrictive but, even if we made it more flexible, we do not have reliable econometric estimates to warrant modifying the production structure.[14]

Firms are able to purchase intermediate inputs from domestic sources and from foreign sources. Imported intermediates are assumed to be separable from domestically produced intermediate inputs. That is, firms decide on the sourcing of their imports; then, based on the resulting composite import price, they determine the optimal mix of imported and domestic goods (Armington assumption). The elasticities used for the sourcing of imports are based on econometric estimates by Hertel et al. (2007).

On the demand side, there is a regional representative household in each region in the GTAP Model. That household is assumed to dispose of total regional income according to a Cobb-Douglas per capita utility function specified over three forms of final demand: private household expenditure, government expenditure, and savings. Private household expenditures are modeled using a Constant Difference of Elasticities (CDE) system that permits differential price and income responsiveness across countries (McDougall 2003). In the GTAP database version 6.1, the CDEs are calibrated to income and own-price elasticities of demand. The calibration to income elasticities draws on work by Reimer and Hertel (2004) who estimate an implicit, directly additive demand system (AIDADS) first using cross-country data on consumer expenditures from the International Comparison Project (ICP) and then using GTAP data. Once the income elasticity estimates are chosen, the values for own-price elasticities of demand are computed following the procedure and formula outlined in Jomini et al. (1991).

The closure used in this model is the standard neo-classical general equilibrium closure in which investment adjusts endogenously to accommodate changes in savings, and all factor markets clear. In particular, this closure assumes endogenous wages and full utilization of currently employed resources.

Each of the economic relationships in the GTAP model is based on literature reviews, and the most important relationships have been econometrically estimated. Nonetheless, when they are used together in the context of a global general equilibrium model, the question arises as to how well the model performs relative to the historical record. Valenzuela et al. (2007) address this question in a validation exercise aimed at investigating how well the model performs in reproducing historical price variability in world markets for agricultural products. They focus on the wheat markets, and their conclusion of reasonable replication of historical price variability provides support for the use of the GTAP model in agricultural market analysis.

For the present application of the GTAP Model, sensitivity analysis is conducted around the size of the total factor productivity shocks. Following the approach of Arndt (1996) and Pearson and Arndt (2000), the distribution of factor productivity shocks is characterized as symmetric and triangular, as the basis for stochastic simulation with the GTAP Model. The extreme values of the shocks distribution range from 0.5 to 1.5 times the initial regional shock level to adequately cover the wide range of estimates and expectations for different regions. Formally, consider a general equilibrium model defined as:

$$G\ (k, e) = 0 \tag{1}$$

where k represents a vector of endogenous variables, and e a vector of exogenous variables. A solution to equation (1) in the form of $k^r(e)$ produces a vector of results of interest $k^r(e) \equiv H(e)$. In our framework, e is the vector of cotton total factor productivity shocks which yields a distribution of endogenous variables attributable only to this productivity variation. Thus, the endogenous variables are characterized by both the following mean and the variance formulae:

$$E[H(e)] = \int_{\Omega} H(e) g(e) de \tag{2}$$

$$E\left[(H(e) - E[H(e)])^2\right] = \int_{\Omega} (H(e) - E[H(e)])^2 g(e) de \tag{3}$$

where $g(e)$ represents the multivariate density function, and Ω is the region of integration.

Arndt (1996) shows that treating a general equilibrium simulation as a problem of numerical integration enables us to deal simultaneously with the solution for the general equilibrium and the randomness of exogenous variables. In this process a new equilibrium is found after each random draw from the calculated distributions of regional cotton productivity shocks. As an alternative to Monte Carlo approaches, we employ the Gaussian Quadrature (GQ) numerical integration technique developed by Stroud (1957) and Haber (1970), and implemented for policy analysis by DeVuyst (1993) and DeVuyst and Preckel (1997). They show that an approximating discrete distribution can be obtained based on known lower-order moments of the model parameters. In turn, selectively solving the model based on the moments of this approximate distribution generates results consistent with the Monte Carlo approach, with far fewer simulations required.[15] This numerical evaluation yields resulting moments of endogenous variables with respect to variation in total factor productivity in cotton consistent with equations (2) and (3).

Sensitivity analysis is also conducted around the nature of the technology shock, to see how much difference it makes if that shock is factor biased rather than Hicks-neutral. For that purpose we draw on the cost shares in the GTAP database, which are reproduced in Appendix Table 2.

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[1] China's adoption share is lower because insect infestations are low in the Western part of China where much of the crop is grown, so the gains from switching to available varieties of GM cotton in that region have been less than elsewhere. The drop in China's GM cotton acreage in 2005 (see Table 1) paralleled a drop in its non-GM cotton acreage as farmers moved away from land-intensive to labor-intensive crops.

[2] For a thorough review of recent developments, see FAO (2004, Ch. 4). The acceleration in 2006 of Bt cotton planting by an additional one million farmers in India (James 2007) has raised the GM share to more than one-third of global plantings. Also, experimental work has begun in numerous other developing countries, including in countries as poor as Burkina Faso (Vitale, Glick and Greenplate 2006). Monsanto has recently finished a third consecutive year of field testing Bollgard II in Burkina Faso, with indications that it can perform well in that West African setting (boosting cotton yields by an average of 35 percent while reducing insecticide applications by two-thirds). Since no special equipment or investments are required, the African smallholder could benefit from Bt cotton as much as large commercial farmers. For the average Burkinabe smallholder, who farms about three hectares of cotton, Bollgard II would increase cotton income by an estimated 29 percent ($220/ha, see Traoré et al. 2006).

[3] The chemicals used in conventional pesticide practices are applied manually using hand-held sprayers. Farm operators (often children or teenagers do the spraying) are in direct contact with the chemical plume, as are nearby animals.

[4] In the GTAP database, cotton is part of a sector called 'plant-based fibers' but it represents well over 90 percent of the value of that sector. The only country for which this is likely to be of any significance is Bangladesh, which is still a large flax producer.

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[5] There are also benefits from insect-resistant Bt cotton in terms of improved health for farmers (see Hossain et al. 2004), and also less pesticide damage to soil and water, but these benefits are ignored in what follows.

[6] 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.

[7] It is not possible to separately include a saving just on pesticide, as that input is aggregated with all other manufactured inputs in our database. In any case, that is never the only input that is saved.

[8] The juxtaposing of gains from trade reform with gains from new technology adoption is uncommon among CGE modelers, but an early exception in the case of Africa is Hertel, Masters and Elbehri (1998).

[9] Of course if textile and clothing tariffs also were removed, global welfare would increase far more: by an extra $6.8 billion per year, according to our model's results.

[10] This is close to the 10 percent estimated by Sumner (2006, p. 282), which is also the simple average of the studies surveyed by Baffes (2005, p. 122) of full global liberalization of cotton markets. The international price effect tends to be larger in studies examining just cotton reform as distinct from reform of all goods trade.

[11] As explained in Alston, Edwards and Freebairn (1988), the main impact of market distortions on the estimated effect of adopting a new technology is to alter the distribution, while having little or no impact on the aggregate size of the net benefits. Even in a simple partial equilibrium model, the precise effects depend on the nature of the market distortions in place, the nature of the market itself, and the nature of the new technology. In a global economy-wide model the

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distributional effects are more complex because there are also terms of trade and other indirect effects to consider. It is therefore difficult to generalize a priori, hence the need for empirical analysis of the sort presented here. See also Anderson and Nielsen (2004) on this point.

[12] Fedoroff and Brown (2004) give reasons why that null finding is not surprising from the viewpoint of a molecular biologist.

[13] There is no expectation that *all* cotton subsidies and tariffs will be removed as a result of the Doha round (see Sumner 2006, and Anderson and Valenzuela 2006), so the gains from GM adoption are even greater relative to prospective trade policy reform over the next decade.

[14] In their attempt to introduce cotton and synthetic fiber substitution in the GTAP model, Elbehri, Hertel and Martin (2003), the lack of empirical estimates on fiber substitution elasticities required them to use a ‘guesstimate’ of 2.5 and do some sensitivity analysis around that value. Even that approach is not without at least two compromises though. One is that Zhang, Fletcher and Ethridge (1994) found different relationships between cotton and cellulosic versus noncellulosic fiber, which suggests that aggregating cellulosic and noncellulosic fibers into one fiber category is undesirable. The other concern is that, in order to preserve the overall balance between supply and demand, expenditures and revenues, and income and outlay characteristics of a general equilibrium database, the procedure must be based on detailed regional share-based splits. This involves separating out exports from domestic use and implementing the appropriate inter-industry mapping of usage among sectors by every one of our 39 modeled regions.

[15] Stroud Quadrature requires two draws from the approximation of the multivariate distribution for each of *n* stochastic exogenous variables. Thus for this sensitivity analysis, the model defines

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the resulting moments for the endogenous variables after solving for 39 regions * 2 = 78 solutions.

Table 1: Area of GM cotton and other GM crops, by country, 2002 to 2006

(million hectares)

(a) Total area

	2002	**2003**	**2004**	**2005**	**2006**
United States	4.2	3.9	4.2	4.8	5.7
China	2.1	2.8	3.7	3.3	3.5
Australia	0.2	0.1	0.2	0.3	0.2
South Africa	0.0	0.0	0.02	0.03	0.1
India	0.0	0.1	0.5	1.3	3.8
Mexico	0.0	0.0	0.07	0.1	0.1
Total, cotton	**6.8**	**7.2**	**9.0**	**9.8**	**13.4**
TOTAL of all GM crops	**58.7**	**67.7**	**81.0**	**90.0**	**102.0**

(b) Area by product and variety, 2005

		Global GM area (m. ha)	Crop's share of global GM area (%)	Area under GM varieties as a % of crop's global area
Cotton:	Bt (insect resistant)	4.9	6	
	herbicide tolerant	1.3	2	
	Bt/herbicide tolerant	3.6	4	
	ALL COTTON	**9.8**	**11**	**28**
Soybean		54.4	60	60
Maize		21.2	24	14
Canola		4.6	5	18
TOTAL of four crops		**90.0**	**100**	**30**
TOTAL of all crops				**5**

Source: James (2007) and earlier issues.

Table 2: Volume of cotton[a] production, yield, trade and utilization, 2005-06

	Output (Kt)	Change in stocks (Kt)	Exports (Kt)	Imports (Kt)	Utilization (Kt)	Share of supply[b] exported (%)	National share of global output(%)	National share of global exports (%)	Yield per ha, % of global average
China	5819	9	10	2800	8600	0	23.5	0.1	163
United States	4735	408	3039	7	1296	70	19.1	37.5	122
India	4250	550	225	125	3600	6	17.1	2.8	63
Pakistan	2308	42	100	250	2415	4	9.3	1.2	103
Brazil	1191	-85	425	50	900	33	4.8	5.2	161
Uzbekistan	1100	14	837	1	250	77	4.4	10.3	110
Turkey	805	0	25	770	1550	3	3.2	0.3	181
Australia	496	-97	582		11	98	2.0	7.2	258
Greece	358	6	258	5	100	73	1.4	3.2	144
Syria	298	-9	150		158	49	1.2	1.9	192
Egypt	263	-8	125	75	220	46	1.1	1.5	137
Burkina Faso	254	-14	264		4	99	1.0	3.3	64
Mali	250	-1	247		4	98	1.0	3.0	68
Turkmenistan	219	6	114		100	54	0.9	1.4	52
Tajikistan	162	6	132		25	85	0.7	1.6	80
Argentina	155	-5	50	20	130	31	0.6	0.6	63
Mexico	152	-33	45	287	428	24	0.6	0.6	169
Kazakhstan	147	5	134	5	12	94	0.6	1.7	99
Benin	140	-49	186		3	98	0.6	2.3	67
Côte d'Ivoire	124	11	103		10	91	0.5	1.3	62
Iran	120	0	10	10	120	8	0.5	0.1	114
Cameroon	112	-78	57	1	132	30	0.5	0.7	69
Spain	110	0	63	15	62	57	0.4	0.8	178
Sudan	96	0	92		4	96	0.4	1.1	67
Tanzania	96	-24	104		16	87	0.4	1.3	31
Paraguay	90	42	43		5	90	0.4	0.5	49
Nigeria	87	2	30	15	70	35	0.4	0.4	33
Zambia	76	0	55		20	72	0.3	0.7	39
Chad	72	-5	77		1	100	0.3	0.9	33
Zimbabwe	72	-13	58		26	68	0.3	0.7	36
Peru	70	1	2	23	90	3	0.3	0.0	118
Togo	70	-9	79		0	100	0.3	1.0	54
Myanmar	59	0	11		47	19	0.2	0.1	29
Colombia	55	21		78	111	0	0.2	0.0	109
Azerbaijan	55	5	41		8	82	0.2	0.5	71
Kyrgyzstan	38	0	39	3	3	103	0.2	0.5	121
Uganda	37	-5	38		4	90	0.1	0.5	52
Mozambique	25	-3	26		2	93	0.1	0.3	16
Ethiopia	22	0	2		20	9	0.1	0.0	38
South Africa	21	0		39	60	0	0.1	0.0	73

[a] Cotton, refers to ginned lint or raw cotton. It does not include seed cotton, linters, cotton mill waste, or cotton fibers subjected to any processing other than separation of lint from seed by the gin. Annual data are for the cotton year beginning 1 August.

[b] Supply is output plus change in stocks. Source: ICAC (2005).

Table 3: Global market shares and net exports of cotton, and effects of GM cotton adoption as of 2001 on cotton output, exports and value added, 2001

	Share (% by value) of global cotton:		*Net exports[a] ($b) of:*		TFP shock [b]	% change from GM cotton adoption in:		
	output	*exports*	*cotton*	*textiles and clothing*		cotton output volume	value of cotton exports	value added in cotton prod'n
Adopters as of 2001:								
United States	*18*	*27*	*2.2*	*-60.7*	-5	4.8	4.4	-0.1
China	*17*	*1*	*-0.1*	*41.9*	-2.5	0.4	-4.3	-1.6
Australia	*3*	*13*	*1.1*	*-2.6*	-5	7.2	4.3	2.1
South Africa	*0.1*	*0.3*	*-0.0*	*-0.2*	-5	8.1	4.3	3.5
Non-adopters as of 2001:								
Other high-income countries	*5*	*13*	*-1.7*	*-28.4*	0	-3.5	-5.7	-3.2
Eastern Europe and Central Asia	*16*	*18*	*0.2*	*7.4*	0	-1.0	-4.5	-0.8
Southeast Asia (ex China)	*1*	*1*	*-1.5*	*18.4*	0	-2.3	-8.4	-1.4
South Asia	*21*	*3*	*-1.0*	*24.5*	0	-1.0	-8.8	-0.6
Middle East and North Africa	*8*	*7*	*0.3*	*-3.3*	0	-1.6	-7.8	-1.5
Sub-Saharan Africa (excl S. Africa)	*5*	*13*	*1.1*	*-1.5*	0	-4.6	-7.5	-4.4
Latin America and Carib.	*6*	*4*	*-0.5*	*4.9*	0	-2.5	-8.9	-2.1
World	***100***	***100***	***0.0***	***0.0***		**0.2**	**-1.1**	**-1.0**

[a] Exports minus imports, both valued at f.o.b. prices as in the GTAP database 6.1

[b] 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 results with the opposite signs in the three right-most columns).

Source: Authors' GTAP model simulation results and (for columns 1 to 4) the GTAP database (Dimaranan 2006).

Table 4: Effects of GM cotton adoption on national economic welfare as of 2001

(equivalent variation in income, 2001 US$m)

	TFP shock [a]	Welfare changes due to effects of:			Total welfare change
		resource re-allocation	new technology	terms of trade change	
Adopters as of 2001:					
United States	-5	-47	485	-114	324
China	-2.5	-18	214	-34	162
Australia	-5	2	63	-39	26
South Africa	-5	-1	2	1	2
Non-adopters as of 2001:					
Other high-income countries	0	46	0	101	147
Eastern Europe and Central Asia	0	0	0	5	5
Southeast Asia (ex China)	0	-15	0	51	36
South Asia	0	4	0	10	14
Middle East and North Africa	0	5	0	9	14
Sub-Saharan Africa (excl S. Africa)	0	-4	0	-13	-17
Latin America and Carib.	0	7	0	22	29
World		-22	764	0	742

[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).

Source: Authors' GTAP model simulation results

Table 5: Prospective effects of GM cotton adoption by non-adopters as of 2001 on cotton output, exports and value added, and on national economic welfare, without Sub-Saharan Africa participating

	TFP shock	Percent change from baseline			Welfare changes (in US$m) due to effects of:			Total welfare change	
		cotton output volume	value of cotton exports	value added in cotton prod'n	resource re-allocation	new technology	terms of trade change	in US$m	as % of GDP
First adopters as of 2001:									
United States	0	-3.8	-9.5	-2.7	106	0	-45	61	0.001
China	2.5	0.2	-0.9	-1.7	-13	204	-78	113	0.010
Australia	0	-6.1	-8.2	-5.6	1	0	-15	-14	-0.004
South Africa	0	-4.7	-7.5	-5.0	1	0	4	5	0.004
New and prospective adopters:									
Other high-income countries	5	5.0	0.9	0.0	54	93	124	271	0.002
Eastern Europe and Central Asia	5	2.0	0.3	-2.3	3	323	-1	325	0.049
Southeast Asia (ex China)	5	3.5	0.7	-0.7	-1	26	6	31	0.008
South Asia	5[a]	6.2	10.4	-2.9	75	880	9	964	0.157
Middle East and North Africa	5	2.1	1.3	-2.7	10	133	14	157	0.018
Sub-Saharan Africa (ex S. Africa)	0	-7.4	-11.8	-7.2	-4	0	-14	-18	-0.009
Latin America and Carib.	5	3.0	2.0	-1.7	12	116	-4	124	0.006
World		**1.0**	**-5.3**	**-2.7**	**244**	**1775**	**0**	**2018**	**0.006**

[a] Except for India, where the TFP is 15 percent.

Source: Authors' GTAP model simulation results

Table 6: Prospective effects of GM cotton adoption by non-adopters as of 2001 on cotton output, exports and value added, and on national economic welfare, with Sub-Saharan Africa participating

	TFP shock	Percent change from baseline						Total welfare change in US$m		Welfare changes (in US$m) due to effects of:			Total welfare change as % of GDP
		cotton output volume		value of cotton exports		value added in cotton prod’n							
		Mean (%)	Std dev (%)	Mean (%)	Std dev (%)	Mean (%)	Std dev (%)	Mean	Std dev	resource re-alloc’n	new techol’y	terms of trade change	
First adopters as of 2001:													
United States	0	-5.4	0.4	-13.7	0.9	-3.8	0.3	57	9	139	0	-83	0.001
China	2.5	-0.1	0.2	-8.5	2.2	-1.9	0.3	100	34	-14	204	-90	0.009
Australia	0	-10.1	0.8	-13.5	1.0	-9.2	0.7	-28	3	0	0	-28	-0.008
South Africa	0	-13.7	0.9	-14.3	1.1	-14.7	1.0	12	1	1	0	11	0.010
New and prospective adopters:													
Other high-income countries	5	0.5	2.8	-5.9	2.8	-4.0	2.9	337	21	82	91	165	0.003
Eastern Europe and Central Asia	5	0.6	0.9	-6.4	2.3	-3.1	0.1	317	42	0	321	-5	0.048
Southeast Asia (ex China)	5	1.9	1.3	-2.8	3.1	-1.9	0.1	63	5	-11	25	49	0.009
South Asia	5[a]	5.7	1.5	3.3	6.8	-3.2	0.4	970	150	80	877	13	0.158
Middle East and North Africa	5	0.2	1.1	-6.3	3.4	-4.5	0.2	175	25	14	132	28	0.020
Sub-Saharan Africa (ex S. Africa)	15	26.9	8.6	22.3	8.4	10.0	19.2	187	31	36	221	-69	0.091
Latin America and Carib.	5	1.1	1.4	-6.3	3.7	-3.4	0.1	135	13	12	115	9	0.007
World		**1.1**	**3.9**	**-6.2**	**3.6**	**-2.8**	**1.1**	**2323**	**166**	**338**	**1985**	**0**	**0.007**

[a] Except for India, where the TFP is 15 percent.

* We do sensitivity analysis by using the Gaussian Quadrature numerical integration procedure implemented into the GTAP framework by Pearson and Arndt (2000). We assume TFP shocks are triangular distributed with the extreme values at 0.5 and 1.5 times the initial shock level.

Source: Authors’ GTAP model simulation results

Table 7: Prospective effects of GM cotton adoption by non-adopters as of 2001 on cotton output, exports and value added, and on national economic welfare, with Sub-Saharan Africa participating, assuming a factor-biased instead of an unbiased factor productivity shock (but the same overall cost saving)*

	Percentage change from baseline						Total Welfare changes (in US$m)		Welfare changes (in US$m) due to effects of:					
	cotton output volume		value of cotton exports		value added in cotton prod'n				Labor saving			Land saving		
	Labor saving	Land saving	Labor saving	Land saving	Labor saving	Land saving	Labor saving	Land saving	resource re-allocation	new technology	terms of trade change	resource re-allocation	new technology	terms of trade change
First adopters as of 2001:														
United States	-4.3	-4.4	-10.9	-11.3	-3.1	-3.2	30	32	104	0	-74	134	0	-102
China	0.0	0.4	-6.5	-0.4	-5	-1.2	122	67	12	185	-75	-26	172	-80
Australia	-8.1	-7.9	-10.8	-10.7	-7.4	-7.3	-20	-26	0	0	-20	1	0	-28
South Africa	-11.0	-9.8	-11.4	-11.3	-11.7	-10.4	10	8	0	0	10	0	0	8
New and prospective adopters:														
Other high-income countries	3.7	-0.7	-1.0	-5.6	-9.6	-2.8	255	313	41	97	116	115	37	162
Eastern Europe and Central Asia	0.4	0.6	-6.1	-4.2	-14.0	-2.0	276	155	33	245	-2	11	129	15
Southeast Asia (ex China)	1.5	4.3	-2.8	3.7	-4.9	1.2	60	37	-7	23	44	-7	23	22
South Asia	3.7	6.9	-0.4	12.4	-8.7	1.9	794	760	93	694	7	62	670	29
Middle East and North Africa	0.7	0.4	-3.6	-4.8	-9.3	-1.6	177	133	25	122	30	16	63	55
Sub-Saharan Africa (ex S. Africa)	22.2	10.8	18.9	7.5	-0.8	7.7	173	41	36	190	-54	18	73	-49
Latin America and Carib.	1.4	2.7	-3.9	-0.2	-7.1	0.0	140	58	17	106	18	10	80	-31
World	**0.9**	**1.1**	**-4.5**	**-5.7**	**-6.6**	**-0.7**	**2016**	**1578**	**354**	**1663**	**0**	**333**	**1245**	**0**

*This consists in scaling up the assumed Hicks-neutral TFP shock by the inverse of the factor cost share, thus giving the same overall cost savings. This calculation is implemented in the model for each of its 39 regions.

Source: Authors' GTAP model simulation results

Table 8: Impact of removing cotton subsidies and tariffs[a] on cotton output, exports and value added, and on national economic welfare

(percent and 2001 US$ million)

	Change in cotton output volume (%)	Change in cotton value added (%)	Change in value of cotton exports (%)	Welfare changes ($m) due to effects of:		
				resource re-allocation	terms of trade change	TOTAL
All high-income countries	**-20.4**	**-15.4**	**-18.2**	**187**	**275**	**462**
Australia	25.0	22.2	38.1	12	125	137
United States	-24.6	-17.9	-29.0	-15	443	428
EU25	-54.0	-53.3	-48.8	124	-109	15
Japan	0.7	1.5	61.9	25	-49	-24
Korea-Taiwan	11.9	6.9	33.6	21	-84	-63
Other High income	-36.1	-36.6	-41.7	190	-293	-103
All developing countries	**5.7**	**4.3**	**46.3**	**96**	**-275**	**-179**
E. Europe and Central Asia	7.0	3.3	35.9	21	-36	-15
China	2.0	1.5	75.7	5	45	50
Other East Asia	8.7	5.1	65.3	39	-82	-33
India	-0.6	-0.4	31.1	-5	-79	-84
Other South Asia	6.0	3.5	59.8	9	-20	-11
Middle East & North Africa	6.2	6.1	37.4	-7	26	19
South Africa	19.4	20.6	46.5	2	-2	0
Other Sub-Saharan Africa	32.1	30.6	55.0	32	115	147
Argentina	13.6	10.7	66.1	1	6	7
Brazil	9.8	10.3	57.6	1	12	13
Mexico	13.0	10.5	42.3	11	-136	-125
Other Latin American & Car.	9.4	7.3	44.7	-13	-34	-47
World	**-0.8**	**-1.8**	**7.9**	**283**	**0**	**283**

[a] Removal of those distortions left after the eventual phase-out of the quotas under the Multifibre Agreement at the end of 2004.

Source: Authors' GTAP model simulation results

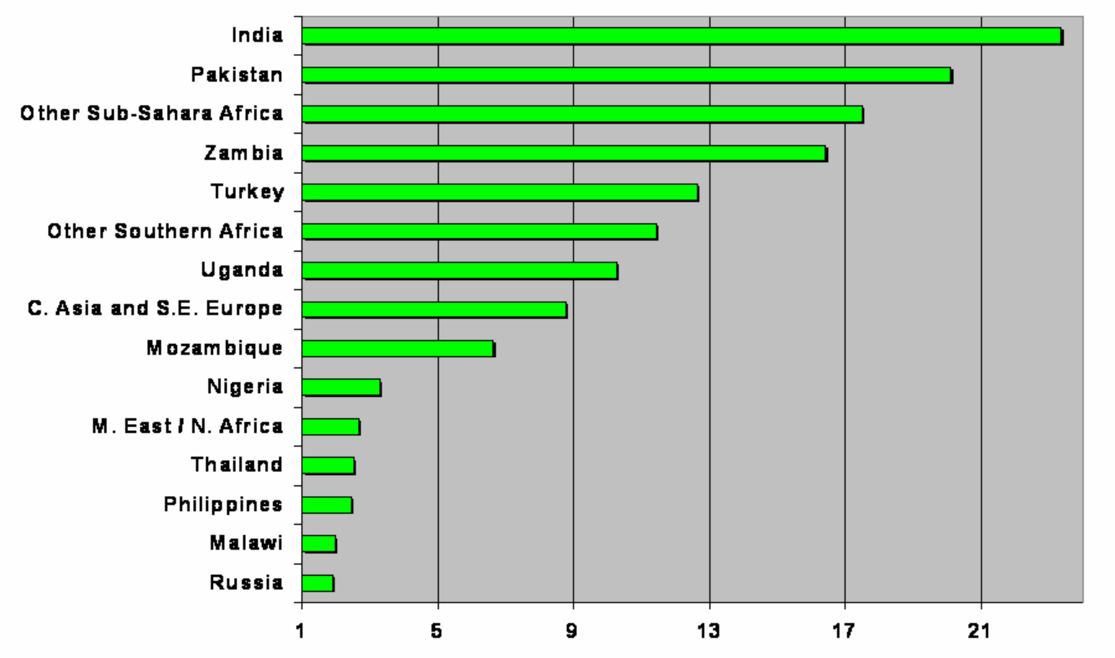
Table 9: Prospective effects of GM cotton adoption by non-adopters as of 2001 on national economic welfare, without and with cotton subsidies and tariffs removed first

(equivalent variation in income, 2001 US$ million)

	Without subsidy and tariff reform	With cotton subsidies and tariffs first removed	With simultaneous cotton subsidy/tariff removal and GM catch-up
All high-income countries	366	279	744
Australia	-28	-58	80
United States	57	-25	404
EU25	269	281	295
Japan	36	37	14
Korea-Taiwan	-14	-6	-68
All developing countries	1957	2043	1866
E. Europe and Central Asia	317	317	303
China	100	94	144
Other Southeast Asia	63	83	-48
India	822	855	771
Other South Asia	148	151	140
Middle East & Nth Africa	175	211	194
Sub-Saharan Africa	199	223	370
Latin American & Carib.	135	146	-8
World	**2323**	**2322**	**2610**

Source: Authors' GTAP model simulation results

Figure 1: Welfare gain from GM cotton adoption as a percent of GDP, as a multiple of the percentage gain to the world as a whole



Source: Authors' GTAP model simulation results

Appendix Table 1: Regional and sectoral aggregation used in the GTAP model

Regions	**Sectors**
Australia	Paddy rice
New Zealand	Processed rice
United States	Wheat
Canada	Other Coarse grains
Mexico	Fruits & vegetables
European Free Trade Area	Oil seeds
European Union 25	Vegetables oils and fats
Japan	Sugar cane, sugar beet
Korea-Taiwan	Sugar
Hong Kong	Cotton
Singapore	Other crops
Russia	Other animal products
Turkey	Poultry, pigs
Other East Europe and Central Asia	Other primary
China	Cattle,sheep,goats,horses
Indonesia	Meat: cattle,sheep,goats,horse
Malaysia	Raw milk
Philippines	Dairy
Thailand	Other Food
Vietnam	Beverages and tobacco
Other South East Asia	Textiles
Bangladesh	Wearing apparel
India	Leather
Pakistan	Manufacturing from primaries
Sri Lanka	Metals Ferrous
Other South Asia	Other manufacturing
Middle East and North Africa	Services
Argentina	
Brazil	
Other Latin America	
South Africa	
Southern African Customs Union	
Malawi	
Mozambique	
Zambia	
Other Southern Africa	
Nigeria	
Uganda	
Other Sub Saharan Africa	

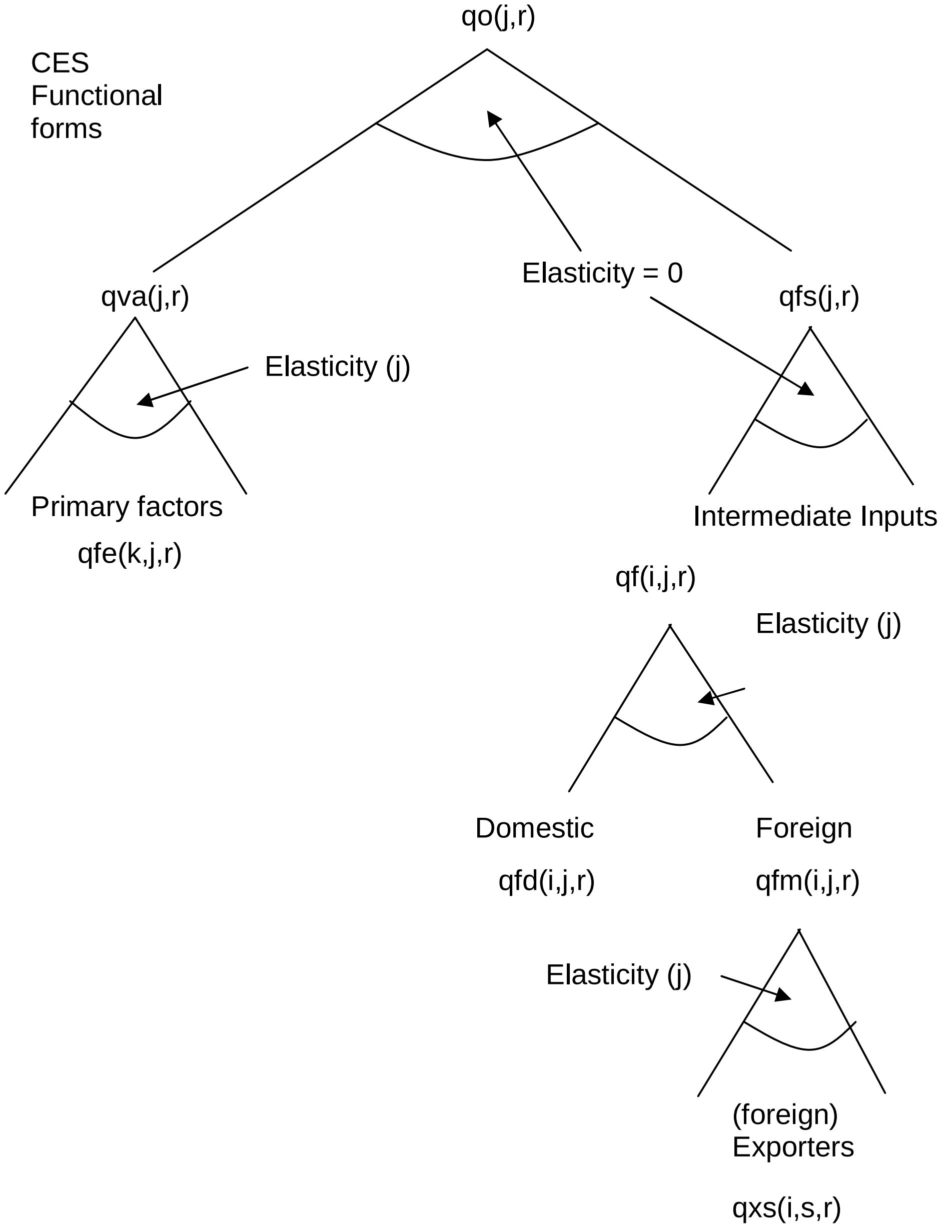
Source: Authors' compilation, drawing on the GTAP database at www.gtap.org (see Dimaranan 2006).

Appendix Table 2: Shares of various productive factors and inputs purchased from other sectors in the total cost of cotton production, according to the GTAP Database, by region

	Land	Unskilled labor	Skilled labor	Capital	Seed	Other agric	Manuf-acturing	Services	Total
United States	21	15	1	16	1	0	16	29	100
Australia	12	30	2	16	7	4	13	16	100
Other high-income countries	9	17	1	10	6	5	22	30	100
Eastern Europe and Central Asia	5	14	0	6	7	15	31	22	100
China	13	24	0	5	0	3	39	16	100
Southeast Asia	32	31	0	4	3	1	18	11	100
South Asia	31	27	0	13	2	6	8	14	100
Middle East and North Africa	5	25	0	15	2	7	29	16	100
South Africa	8	21	0	24	4	2	23	17	100
Other Sub-Saharan Africa	8	44	0	12	0	2	18	17	100
Latin America and Caribbean	13	18	0	22	3	8	19	18	100
World	17	21	1	11	3	5	22	20	100

Source: Authors’ compilation, drawing on the GTAP database at www.gtap.org (see Dimaranan 2006).

Appendix Figure 1: Production structure in the GTAP Model



where j = set of commodities (ouput); i = set of commodities (input to processing); k = set of endowments commodities; r = region (importer); s = region (exporter). Changes in quantities are in percentages: qo = change in output quantity; qva = change in composite quantity of endowments; qfe = change in quantity of endowments; qfs = change in composite quantity of intermediate inputs; qf = change in quantity of intermediate inputs; qfd = change in quantity demanded of domestically produced commodity; qfm = change in quantity demanded of composite foreign produced commodity; qxs = change in quantity demanded of foreign produced commodity.

Source: Hertel (1997) and www.gtap.org.

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