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Biotechnology boosts to crop productivity in China: trade and welfare implications

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Abstract

Genetically modified (GM) cotton is widely adopted and the list of GM technologies in trials is impressive in China. At the same time there is an active debate on when China should commercialize its GM food crops. This paper provides an economy-wide assessment of some of the issues surrounding the adoption and commercialization of biotechnology. Based on unique data from empirical micro-level study and field trials in China and a modified GTAP model, our results indicate that the development of biotechnology has an important impact on China's production, trade and welfare. Welfare gains far outweigh the public biotechnology research expenditures. Most gains occur inside China, and can be achieved independently from biotech-unfriendly polices adopted in some industrialized countries.

JEL classification: C68; D58; F13; O33; Q17; Q18

Keywords: Biotechnology; Productivity; China; Economic impacts; Trade

1. Introduction

Because biotechnology—one of this century's most promising and innovative technologies—employs genetic modification techniques, it has spurred worldwide debate. The debate has been going on for decades now and has had a significantly depressing impact

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on the supply of biotechnology. In the meantime, the demand for the technology has continued to grow rapidly: the global area of GM crops increased from 1.7 million hectares in 1996 to 52.6 million hectares in 2001 (James, 2002).

China was one of the first countries to introduce a GM crop commercially, and currently has the fourth largest GM crop area, after the USA, Argentina and Canada (James, 2002). China's agricultural biotechnology development is an interesting case and is unique in many respects. The public sector dominates the industry and the list of GM crops undergoing trials differs from those being worked on in other countries where the technologies are dominated by the private sector (Huang et al., 2002a). The Chinese government views agricultural biotechnology as a tool to help China improve the nation's food security, increase agricultural productivity and farmers' incomes, foster sustainable development and improve its competitive position in international agricultural markets (SSTC, 1990). In 2001, approximately four million small farmers in China adopted Bt cotton (Pray et al., 2002).

On the other hand, there is growing concern among policy makers regarding the impact of the ongoing global debate about biotechnology on China's agricultural trade, biosafety and the potential opposition derived from public concerns about the environmental and the food safety of GM products. Because of this, although GM crops are still cultivated in public research institutes, the approval of GM crops (and particularly of food crops) for commercialization has become more difficult since late 1998 (Huang et al., 2001). This reflects the influence of the global debate about GM crops on Chinese policy makers, in particular restrictions on imports to EU countries. China also appears to take a more cautious stance. For example, in January 2002 the Ministry of Agriculture (MoA) announced three new regulations on the biosafety management, trade and labeling of GM farm products. These regulations came into effect on 20 March 2002 and require importers of GM agricultural products to apply to China's MoA for official safety verification approval, leading US producers to accuse Beijing of using the new rules to hinder imports and protect Chinese soybean farmers.

China, like many other developing countries, now has to decide how to proceed on the further commercialization of GM crops. Policy makers have raised several issues. Should China continue to promote its agricultural biotechnology and commercialize its GM food crops (i.e. rice and soybean)? How important are the trade restrictions imposed on GM products, particularly those imposed by the EU and by other countries in East Asia? What will be the impact of alternative biotechnology policies (in both China and the rest of world) on China's agricultural economy and trade? Answers to these questions are of critical importance for policy makers and the agricultural industry.

The central theme of this paper is to provide a cost–benefit analysis of research and development of GM crops in China in the face of likely international policy developments. To achieve this, the paper is organized as follows. In Section 2, a general review of agricultural biotechnology development in China is provided. The impacts of Bt cotton adoption in China are presented in Section 3. The results from the empirical studies on Bt cotton and the hypothesized results of GM rice commercialization are the data used for the later simulation analyses with a tailored version of the multi-country general equilibrium GTAP model. Section 4 presents the model and scenarios that are used in the impact assessments. The results of the impacts of alternative biotechnology development strategies are discussed in Section 5. The final section provides concluding remarks and areas for policy actions.

2. Agricultural biotechnology development in China

2.1. An overview

Biotechnology in China has a long history. Several research institutes within the CAAS (the Chinese Academy of Agricultural Sciences), the CAS (the Chinese Academy of Sciences) and various universities initiated their first agricultural biotechnology research programs in the early 1970s.[1] However, the most significant progress in agricultural biotechnology has been made since China initiated a national high-tech program (the '863' program) in March 1986. Since then, agricultural biotechnology laboratories have been established in almost every agricultural academy and major university. There are now over 100 laboratories in China involved in transgenic plant research (Chen, 2000). By 2000, eighteen GM crops had been generated by Chinese research institutes; four of these crops have been approved for commercialization since 1997.[2] GM varieties in such crops as rice, maize, wheat, soybean, peanut, etc., are either in the research pipeline or are ready for commercialization (Chen, 2000; Li, 2000; Huang et al., 2002a).

A cotton variety with the Bacillus thuringiensis (Bt) gene to control the bollworm is one of the most oft-cited examples of the progress of agricultural biotechnology in China. Since the first Bt cotton variety was approved for commercialization in 1997, the total area under Bt cotton has reached nearly 1.5 million hectares (2001), accounting for 45% of China's cotton area (Table 1). In addition, other transgenic plants with resistance to insects, disease and herbicides, or which have been quality-modified, have been approved for field release and are ready for commercialization. These include transgenic varieties of cotton resistant to fungal disease, rice resistant to insect pests and diseases, wheat resistant to the barley yellow dwarf virus, maize resistant to insects and with improved quality, soybeans resistant to herbicides, transgenic potato resistant to bacterial disease, and so on (Huang et al., 2002a).

Progress in plant biotechnology has also been made in recombinant microorganisms such as soybean nodule bacteria, nitrogen-fixing bacteria for rice and corn, and phytase from recombinant yeasts for feed additives. Nitrogen-fixing bacteria and phytase have been commercialized since 1999. In animals, transgenic pigs and carps have been produced since 1997 (NCBED, 2000). China was the first country to complete the shrimp genome sequencing in 2000.

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[1] The research focus of biotechnology in the 1970s was cell engineering, tissue culture and cell fusion. Research in cell and tissue culture covered such crops as rice, wheat, maize, cotton, vegetables, etc. (KLCMCB, 1996). Several advanced rice varieties were generated through another culture in the 1970s and 1980s.

[2] These are Bt cotton, tomatoes with resistance to insects or with improved shelf-life, a petunia with altered flower colour, and sweet pepper resistant to diseases. However, before these four crops were approved for commercialization, the first commercial release of a GM crop in the world occurred in 1992 when Chinese farmers first adopted transgenic tobacco varieties. But Chinese farmers have not been allowed to grow GM tobacco since 1995 due to strong opposition from tobacco importers in the USA and certain other countries.

Table 1
Bt cotton adoption in China

	1997	1998	1999	2000	2001
Cotton area (000 ha)	4091	4064	3423	3732	4447
Region I	1641	1530	1366	1655	2012
Region II	919	848	573	613	731
Region III	1531	1686	1484	1464	1704
Bt cotton area (000 ha)	27	254	633	1153	2011
Region I	21	237	594	1043	1704
Region II	0	1	8	33	131
Region III	6	16	31	77	176
Bt cotton (%)	1	6	18	31	45
Region I	1	15	43	63	85
Region II	0	0	1	5	18
Region III	0	1	2	5	10

Region I includes Hebei, Shangdong and Henan, regional II includes Anhui, Jiangsu and Hubei, and all rest of China are in region III.
Source: Author's surveys.

2.2. Research priorities

Rice, wheat and maize are the three most important crops in China. Each accounts for about 20% of the total area planted. The production and market stability of these three crops are a prime concern of the Chinese government as they are central to China's food security. National food security, particularly related to grains, is a central goal of China's agricultural and food policy and has been incorporated into biotechnology research priority setting (Huang et al., 2001).

China's biotechnology program has also selected cotton as a targeted crop because of its large sown area, its contributions to the textile industry and trade, and the serious problems with the associated rapid increase in pesticide applications to control insects (i.e., bollworm and aphids). Pesticide expenditures in cotton production in China increased considerably in the past decades, reaching RMB yuan 834 (approximately US$100) per hectare in 1995. In recent years, cotton production alone consumed about US$500 million annually in pesticides.

Genetic traits viewed as priorities may be transferred into target crops. Priority traits include those related to insect and disease resistance, stress tolerance, and quality improvement (Huang et al., 2002a,b). Pest resistance traits have top priority over all traits. Recently, quality improvement traits have been included as priority traits in response to increased market demand for quality foods. In addition, stress tolerance traits—particularly resistance to drought—are gaining attention with the growing concern over water shortages in northern China.

2.3. GM cotton and rice

China is one of the world's leading countries in the production of GM cotton and rice and the related technology (Table 2). The Biotechnology Research Institute (BRI) of CAAS developed insect-resistant Bt cotton. The Bt gene's modification and plant vector

Table 2
Research priority and available GM plant events in China by 1999

Crop	Introduced trait	Field trial	Environmental release	Commercialized
Cotton	Insect resistance			
	Bollworm (Bt)	Yes	Yes	Yes
	Bollworm (Bt + CpTI)	Yes	Yes	Yes
	Bollworm (CpTI)	Yes	Yes	No
	Bollworm (API)	Yes	No	No
	Disease resistance			
	Verticillium and Fusarium (Chi)	Yes	Yes	No
	Verticillium & Fusarium (Glu)	Yes	Yes	No
	Verticillium & Fusarium (Glu + Chi)	Yes	Yes	No
Rice	Insect resistance			
	Stem borer (Bt)	Yes	Yes	No
	Stem borer (CpTI)	Yes	Yes	No
	Rice planthopper	Yes	Yes	No
	Disease resistance			
	Bacteria blight (Xa21)	Yes	Yes	No
	Fungal disease	Yes	Yes	No
	Rice dwarf virus	Yes	Yes	No
	Herbicide resistance	Yes	Yes	No
	Salt tolerance (BADH)	Yes	No	No
	Ac/Ds (rice mutant)	Yes	No	No

Source: Authors' surveys.

construction technique was granted a patent in China in 1998. The Bt gene was introduced into major cotton varieties using the pollen tube pathway developed in China (Guo and Cui, 1998, 2000). By early 2002, sixteen Bt cotton varieties with resistance to bollworms generated by China's public institutions and five Bt cotton varieties from Monsanto had been approved for commercialization in nine provinces.

The BRI of CAAS recently made the other breakthrough in plant disease resistance by developing cotton resistant to fungal diseases (Table 2). Glucanase, glucoxidase and chitnase genes were introduced into major cotton varieties. Transgenic cotton lines with enhanced resistance to *Verticillium* and *Fusarium* were approved for environmental release in 1999 (BRI, 2000).

More efforts have been put on the GM rice sector. Numerous research institutes and universities have been working on transgenic rice resistant to insects since the early 1990s. Transgenic hybrid and conventional Bt rice varieties, resistant to rice stem borer and leaf roller were approved for environmental release in 1997 and 1998 (Zhang, 1999). The transgenic rice variety that expressed resistance to rice plant hopper has been tested in field trials. Through the anther culture, the CpTi gene and the Bar gene were successfully introduced into rice, which expressed resistance to rice stem borer and herbicide (NCBED, 2000; Zhu, 2000).

Transgenic rice with Xa21, Xa7 and CpTi genes resistant to bacteria blight or rice blast were developed by the Institute of Genetics of CAS, BRI, and China Central Agricultural University. These transgenic rice plants have been approved for environmental release since 1997 (NCBED, 2000). Significant progress has also been made with transgenic plants expressing drought and salinity tolerance in rice. Transgenic rice expressing drought and salinity tolerance has been in field trials since 1998. Genetically modified nitrogen fixing bacteria for rice was approved for commercialization in 2000. Technically, various types of GM rice are ready for commercialization. However, the commercializing GM rice production has not yet been approved as the policy makers' concern about food safety, rice trade (China exports rice though the amount traded is small compared to its consumption) and its implication for the commercialization of other GM food crops such as soybean, wheat and maize.

3. Impact of Bt cotton in China: factor biased technical change

One cannot simply assume that the GM technologies imply a Hicks-neutral productivity boost.[3] The productivity impact of GM technologies in crops is typically factor-biased.[4] That is, cost reductions on some of the production factors can be achieved in varying degrees. See for example European Commission (2001) for a survey and Van Meijl and van Tongeren (2002) for an application to Bt maize and Ht soybean technology.

To examine the impact of biotechnology on various input uses and crop yield (after control for input uses) in the cotton production, Pray et al. (2001) and Huang et al. (2002b) used both farm budget analysis and damage control production function approach based on the production practices of 282 cotton farmers (including Bt and non-Bt farmers) in 1999 in Hebei and Shandong provinces, where the bollworm has seriously damaged the local cotton production (Region I in Table 1). A budget analysis by Pray et al. (2001) shows that while there is no significant difference in fertilizer and machinery uses between Bt and non-Bt cotton production, significant reductions were recorded in pesticide and labor use (labor used for spray pesticide). More sophisticated measures based on the same data that applied multivariate regression to estimate the pesticide use and cotton production functions show similar results for the effect of Bt cotton on input uses. The results of their studies demonstrate that Bt cotton adopters spray 67% fewer times and reduce pesticide expenditures by 82% (Huang et al., 2002b). Because the reduction on the farmers spraying pesticide time (from an average of 20 times during one crop season to eight times), Bt cotton technology is also considered as a labor-saving technology.

While costs of pesticides and labor inputs are reduced, seed costs of Bt varieties are higher than those of non-Bt cotton by about 100–250% (based on author's survey in 1999, 2000 and 2001 in five provinces where Bt cotton is adopted, the price difference between Bt and non-Bt cotton declined over time). But this is much lower than the market price ratio of Bt cotton seed (40–50 yuan/kg) and non-Bt conventional cotton seed (4–8 yuan/kg) in our sampled areas. The lower seed use per hectare in Bt cotton production and farmers' saved Bt cotton seed partly offset the seed price difference.

[3] For example Anderson and Yao (2001) recently investigated the potential economic effects of China's adoption of GMOs based on a hypothesized 5% Hicks-neutral gain in productivity with GMO adoption.

[4] Factor biased technical change was introduced by Hicks (1932) to describe techniques that facilitate the substitution of other inputs for a specific production factor. He called techniques that facilitated the substitution of other inputs for labor "labor saving" and those designed to facilitate the substitution of other input for land "land saving".

Table 3
Hypothesized yield and input difference (%) between GM and non-GM crops and GM adoption in 2001–2010

	Yield by region				Input cost at national level		
	National	Region I	Region II	Region III	Pesticide	Seed	Labor
Bt cotton							
2001	5.85	8.30	5.80	3.00	−51	120	−5.1
2002	5.97	8.47	5.92	3.06	−53	120	−5.3
2005	6.34	8.98	6.28	3.25	−58	120	−5.8
2010	7.00	9.92	6.93	3.59	−67	120	−6.7
GM rice							
2002	6.00				−52	50	−7.2
2005	6.37				−56	50	−7.9
2010	7.03				−65	50	−9.1
	Adoption rate (%)						
	National	Region I	Region II	Region III			
Bt cotton							
2001	45	85	18	10			
2002	51	90	30	15			
2005	78	95	85	55			
2010	92	95	90	90			
GM rice							
2002	2						
2005	40						
2010	95						

Source: author's estimates.

After controlling for all input differences and geographical location, Huang et al. (2002b) found that adoption of Bt cotton also impacts on cotton yield. Bt cotton contributed to about 7–15% (with an average of about 10%) of yield increase in the Hebei and Shangdong (cotton region I) in 1999.[5] These results are re-confirmed by two similar surveys conducted in 2000 (which also covered Henan province) and in 2001 (which also covered Anhui and Jiangsu provinces, cotton region II). However, new surveys in 2000–2001 also revealed that the extent of the impacts (pesticide and labor inputs and yield) decline with moving Bt cotton from the region I to region II (authors' survey).

We derive productivity effects of Bt cotton based on our 3 years (1999–2001) surveys of primary cotton farmers (1052 farms) in five provinces, including the two major cotton producing regions (regions I and II). We compute the average inputs of pesticides, seed and labor and yield of cotton per hectare for both Bt cotton and non-Bt cotton. The productivity impacts are measured as the difference of input use and yield between Bt and non-Bt cotton. These differences or impacts for regions I and II are reported in the first row (2001) of Table 3. Impacts of Bt cotton in region III in 2001 was estimated by interviewing provincial agricultural bureaus in the region and from interviews of scientists from

[5] The range of the impacts (7–15%) reflects the different specifications of the production function models used in the regression.

Biotechnology Research Institute of CAAS. We estimated the impacts separately by region because bollworm and other insect diseases differ among the three cotton production regions. The national level figures are the aggregation of the regional data based on the area shares observed in 2001.

3.1. Projecting adoption rates

Chinese farmers have adopted Bt cotton at an impressive speed. The question is whether and how the adoption behavior develops in the future and how the associated productivity differentials can be expected to behave. While we have the benefit of historic observations on Bt cotton, the likely technology diffusion of GM rice must necessarily be based on some assumptions.

Existing theory on technology diffusion provides some guidance. New technologies with superior characteristics compared to their predecessors are typically not adopted at once by all potential users (see e.g. Karshenas and Stoneman, 1995; Geroski, 2000; Sunding and Zilberman, 2001 for overviews). One approach that describes innovation adoption as a process of information spread is the epidemic diffusion model.[6] An alternative approach is to take different characteristics of potential adopters into account in a decision theoretic framework (see e.g. Griliches, 1957; Hategekimana and Trant, 2002; Diederen et al., 2003a,b). Potential adopters vary over characteristics like farm size, market share, market structure, input prices, labor relations, farm ownership, and current technology. These factors affect the profitability of adoption, and hence the adoption behavior.

Given the uncertainty about adoption patterns we follow a rather stylized approach to the projection of adoption rates. Our basic projection assumes that technical change in GM technologies is higher than in non-GM technologies. The new technologies are assumed to be so attractive to farmers that the maximum technically feasible adoption will be realized. As this assumption may be too optimistic we subsequently subject the adoption rates to a sensitivity analysis.

For the impacts after 2001, we assume that the technical progress of Bt cotton will be continued as there is a range of forthcoming improved technologies (Table 2). Based on the above empirical study on Bt cotton adoption and its impacts on various inputs and yield, we hypothesize the future patterns of Bt cotton adoption by region and its impacts on inputs and yield as those presented in Table 3. All figures in this table represent the difference (in percentage) of input and yield between Bt cotton and non-Bt cotton. For Bt cotton adoption, we estimated them by region as bollworm and other insect diseases differ among three cotton production regions. The national level figures are the aggregation of the regional data based on the area shares observed in 2001.

Because the commercialization of GM rice has not been approved yet, examination of its impacts on rice production inputs and yield are impossible from the farm level survey. However, the government has approved a number of insect, disease and herbicide resistant

[6] Markets for new technologies are characterized by a lack of transparency, by imperfect information and by uncertainty on the operating conditions, risks and performance characteristics of the new technology. The number of adopters of the innovation increases as information is generated in the process of innovation use and gradually spreads among potential adopters.

GM rice varieties for field trial and environmental release since the late 1990s. Interviews were conducted in the trial and environmental release areas by the authors. The results from these interviews are used to hypothesize the impacts of GM rice commercialization on rice yield and input uses (Table 3). It should be noted that Table 3 assumes the seed price difference between GM and non-GM varieties to be constant over time. This is a conservative assumption, which will tend to an underestimation of GM gains if seed prices will in fact converge to a lower level in the future. On the other hand, the hypothesized adoption rates for rice are perhaps overestimating the speed of GM rice adoption.

4. Methodology and scenarios

4.1. Baseline

The impact assessment of Chinese biotechnology developments has been done with the help of the well-known GTAP modeling framework. This is a multi-region, multi-sector computable general equilibrium model, with perfect competition and constant returns to scale.[7] The model is fully described in Hertel (1997). This model enables us to incorporate the detailed factor specific GM cost savings as estimated in Section 3. In addition, the multi-sector framework captures backward and forward linkages between the GM crops and the using and supplying sectors. In the GTAP model, firms combine intermediate inputs and primary factors land, labor (skilled and unskilled) and capital. Intermediate inputs are composites of domestic and foreign components, and the foreign component is differentiated by region of origin (Armington assumption). On factor markets, we assume full employment, with labor and capital being fully mobile within regions, but immobile internationally. Labor and capital remuneration rates are endogenously determined at equilibrium. In the case of crop production, farmers make decisions on land allocation. Land is assumed to be imperfectly mobile between alternative crops, and hence allow for endogenous land rent differentials. Each region is equipped with one regional household that distributes income across savings and consumption expenditures. Furthermore, there is an explicit treatment of international trade and transport margins, and a global banking sector, which intermediates between global savings and consumption. The model determines the trade balance in each region endogenously, and hence foreign capital inflows may supplement domestic savings.

The GTAP database contains detailed bilateral trade, transport and protection data characterizing economic linkages among regions, linked together with individual country input–output databases which account for intersectoral linkages among the 57 sectors in each of the 65 regions. All monetary values of the data are in USD million and the base year for the version used in this study (version 5, public release) is 1997 (Dimaranan and McDougall, 2002). For the purposes of this paper, the GTAP database has been aggregated into 12 regions and 17 sectors. The aggregation scheme is found in Appendix Table A.

The comparative static model has first been used to generate a so-called baseline projection for 2001–2010. In the second step, the impact of alternative biotechnology

[7] For an overview of agricultural world trade models and their design choices, see van Tongeren et al. (2001).

scenarios is assessed relative to the baseline projection for 2010. The baseline is constructed through recursive updating of the database such that exogenous GDP targets are met, and given exogenous estimates on factor endowments—skilled labor, unskilled labor, capital and natural resources—and population. For this procedure see Hertel et al. (1999), the exogenous macro assumptions are from Walmsley et al. (2000). The macro assumptions for Asia have been updated with recent information from the ADB economic outlook 2002.

The baseline projection also includes a continuation of existing policies and the effectuation of important policy events, as they are known to date. The important policy changes are: implementation of the remaining commitments from the GATT Uruguay round agreements, China's WTO accession between 2002 and 2005; global phase out of the Multifibre Agreement under the WTO Agreement on Textiles and Clothing (ATC) by January 2005; and EU enlargement with Central and Eastern European countries (CEECs). Next to those macro- and policy assumptions, the baseline incorporates new data for the Chinese economy. We have incorporated an updated Input–Output table for China, which better reflects the size and input structure of agriculture. An important feature of the new table is an improved estimate of primary factor cost shares in agriculture and improved estimates of crop yields. The new estimates use micro data from farm surveys conducted by a number of ministries led by the State Price Bureau. Another feature of the adjusted database is a drastic adjustment to agricultural trade data for China, which incorporates trade information for 2001. Between 1997 (the base year for GTAP version 5) and 2001 the structure and size of Chinese trade has changed dramatically, and we have adjusted the GTAP data to reflect these changes. We also incorporated econometric estimates for income elasticities for livestock products, rice and wheat (Huang and Rozelle, 1998). The updated estimates for income elasticities are lower than the original GTAP estimates, and are provided in the Annex. This matters especially for the medium-term projections for livestock consumption. Given all this base information for 2001, we project the model in two steps: 2001–2005 and 2005–2010. Summary information on the baseline projection is provided in the Annex.

4.2. Scenarios

The central question of this paper is the assessment of economic benefits of research and commercialization of GM crops in the face of likely international policy developments. Towards this end four scenarios have been developed. The first scenario is designed to study the impact of Bt cotton adoption. This impact consists of the part that is already realized in 2001 (Tables 1 and 3) and the subsequent productivity gains during the period 2001–2010, as summarized in Table 3. Since the potential cost savings affect only farmers who have adopted the GM crop varieties, we weigh the productivity and seed cost estimates by adoption rates to arrive at an average impact on the cotton sector.

The second scenario adds the commercialization of GM rice during 2002–2010 to the adoption of Bt cotton. Again, we use the productivity estimates and adoption rates from Table 3. Given the uncertainty in the magnitude of the GMO impacts on input usage and yields and the uncertainty with regard to the adoption rates we conduct a sensitivity analysis on these parameters. The third scenario focuses on a possible import ban on GM products from China. Given that China has commercialized both Bt cotton and GM rice, an import ban on GM rice by the main trading partners is simulated.

Finally, we investigate the effects of the recent regulation on labeling of imported soybeans that came into effect in March 2002. This scenario is unfolding in the situation where both the cotton and rice crops have been commercialized. In addition to labeling imported soybeans, the scenario includes labeling of domestic GM rice. The scenario design is 'additive', by adding new elements one at a time, and we disentangle the separate effects of each new element where appropriate.

5. Economic impact assessment

5.1. The impacts of commercializing Bt cotton

The farmers' decision to adopt Bt cotton weighs the cost savings due to its increased yields, labor cost savings and reduced pesticides cost against increased seed costs. Table 4 shows the total impact of adopting Bt cotton and the contributions of these components to the supply price of cotton, relative to the situation without Bt cotton in 2010.

The supply price will be 10.9% lower in 2010. The yield increasing and labor saving impacts of Bt cotton contribute, respectively, 7%-point and 3.3%-point to this total effect. The pesticides saving impact lowers the price with 1.7% while the higher seed price increases the supply price with 1.1% (Table 4).

The lower supply price increases demand. Domestic demand increases with 4.8% and exports with 58%. However, the share of exports in total demand is very low at 0.24%, and export growth does therefore contribute only mildly to the total cotton demand growth. The rise in domestic demand is almost completely caused by increased demand from the textiles sector. The lower domestic price also implies that cotton imports decrease with 16.6%, relative to the 'no-Bt' case. Higher exports and lower imports imply that the trade balance for cotton will improve with 389 million USD (Table 4).

The textiles sector is the other main benefiting sector from adopting Bt cotton. The lower supply price of cotton implies that the supply price of textiles decreases with 0.3%. The cost share of cotton in textiles amounts to 2.5% of total cost. The 10.9% decrease in cotton price leads to 0.27% ($-10.9\% \times 2.5\%$) decrease in textiles costs. Output and exports increase with 0.7% and 0.9%, respectively, while imports decrease with 0.3%. This causes the textiles trade balance to improve with 1067 million USD.

5.2. The impact of commercializing both Bt cotton and GM rice

5.2.1. Impact on the rice sector

This scenario assumes GM rice commercialization on top of the adoption of Bt cotton during 2002–2010. This mimics the current adoption process, where Bt cotton continues its rapid adoption path, but GM rice is yet to be released for commercial purposes. Consequently, the results incorporate both the Bt cotton effect and the GM rice effect, but the interaction effects between rice and cotton are negligible. This becomes evident by comparing the second and third column in Table 5. The adoption of GM rice generates cost

Table 4
Main sectoral effects of adopting Bt cotton (percent change, relative to situation without Bt cotton in 2010)

	Total impact	Yield increasing	Labor saving	Pesticide saving	Higher seed price
Cotton					
Supply price	– 10.9	– 7	– 3.3	– 1.7	1.1
Output	4.9	3.1	1.5	0.8	– 0.5
Dom demand	4.8	3	1.5	0.8	– 0.5
Exports	58	37.3	17.5	9	– 5.8
Imports	– 16.6	– 10.8	– 4.9	– 2.5	3.1
Trade balance (million USD)	389	253	114	59	– 71
Textiles					
Supply price	– 0.3	– 0.2	– 0.1	0	0
Output	0.7	0.4	0.2	0.1	0
Exports	0.9	0.6	0.3	0.1	0
Imports	– 0.3	– 0.2	– 0.1	0	0
Trade balance (million USD)	1067	670	341	155	– 41

Source: model simulations.

savings due to its yield increasing, labor saving and pesticides saving impact. If the adoption will take place according to the assumed scenario the supply price of rice will be 12% lower in 2010. Almost 8%-points can be contributed to the yield increasing impact of GM rice, 4.4% to the labor saving impact, and 0.9% to pesticides saving (Table 5). The higher seed price increases the supply price with 1.1%. Despite the sharp decrease in price the output response is only 1.4%. This is due to the low income and price elasticities of domestic demand. People do not demand much more rice if the price decreases or their income increases. The increase in exports is very high (67%), but the impact on output is limited since only a small portion (1.2%) of production is exported.

5.2.2. Macro impact

The commercialization of both GM crops has substantial welfare effects. Table 6 separates aggregate macro effects into the Bt cotton and GM rice components. The adoption of Bt cotton enhances welfare in China by 1097 million USD in 2010. (equivalent variation,

Table 5
Impacts on rice sector of adopting GM rice (percent change, relative to situation without GM products in 2010)

	Total impact Bt cotton and GM rice	Total impact GM rice	Yield increasing	Labor saving	Pesticide saving	Higher seed price
Rice						
Supply price	– 12.0	– 12.1	– 7.8	– 4.4	– 0.9	1.1
Output	1.4	1.4	0.9	0.6	0.1	– 0.1
Dom demand	1.1	1.1	0.7	0.4	0.1	– 0.1
Exports	66.9	66.2	43.5	24.1	5.2	– 5.8
Imports	– 23.2	– 23.4	– 15.3	– 8.4	– 1.8	2.1
Change rice trade balance (million USD)	173.2	175.1	113.8	63.1	13.7	–15.5

Source: model simulations

Table 6
Macro impact of adopting Bt cotton and GM rice (a)

	Bt cotton	GM rice	Total
Welfare (EV, million USD)	1097	4155	5249
Welfare relative to value added in cotton sector (%)	14.6		
Welfare relative to value added in rice sector (%)		15.2	
Percent changes (%)			
Factor prices			
Land	– 0.2	– 2.1	– 2.4
Unskilled labor	0.2	0.1	0.3
Skilled labor	0.3	0.4	0.7
Capital	0.3	0.4	0.7
Real exchange rate change (%)	0.2	0.1	0.3
Change aggregate trade balance, (million USD)	– 671	– 1223	– 1894

Source: model simulations.
(a) Numbers do not exactly add up to the 'Total' column because of small interaction effects.

EV). The adoption of GM rice enhances welfare in China by 4155 million USD (Table 6). The impact is therefore four times larger than in the case of Bt cotton, which is explained by the larger size of the rice sector in 2010 (EV in terms of sectoral value added is for both sectors about 15%). This implies that with the same productivity gains more resources are saved in the rice sector.

The impact on factor prices varies across factors. Land is a 'sluggish' production factor that is not easily reallocated between alternative uses. Hence we allow for land rent differentials across crops. Land prices decline because factor demand is lower due to the yield increasing effect of the GM technology. At the same time, the output expansion falls short of the yield increase, and consequently less land is demanded in the aggregate.

Labor and capital are perfectly mobile across domestic sectors. Although the demand for labor decreases in both crops, the aggregate demand for labor increases. In the cotton case the additional labor demand originates mainly from the unskilled labor intensive textiles sector. Due to the positive technical change impact the real exchange rate[8] improves in both experiments, and this leads to a deterioration of the trade balance.

5.2.3. Impact on other sectors

The two major price effects of adopting GM rice are the lower price of rice itself and the lower land price. Sectors that use rice or land intensively will therefore achieve the biggest cost gains and can lower their prices and expand output. Land intensive sectors such as wheat, coarse grains, cotton and other crops can use the extra land that is not necessary anymore to produce the demanded quantity of rice. Animal products (mainly pork and poultry) output will grow because they use land and can use the cheaper coarse grains. Especially the other food sector (mainly food processing) can lower its price because the rice they use as inputs has become much cheaper. This generates an output growth in the other foods sector, which in turn leads to more intermediate demand for its inputs such as wheat and other crops.

[8] The real exchange rate is defined as the ratio of the regional factor price index relative to a global factor price index. The global factor price index is taken to be the *numeraire* of the model.

Although not apparent from Table 7, it should be noted that the effects of GM adoption differ in one important aspect between the two crops. Not only is rice a much larger sector than cotton in terms of its contribution to agricultural output and employment, we also observe completely different demand side effects. Consumers demand not much more rice if price is lower or income higher. This means that consumer can spend their increased income and money they save on buying rice on other products. These income effects increase the demand for many other sectors. Such indirect demand effects are not much observed for Bt cotton.

5.2.4. Impact in different periods

Table 8 shows the impact of adopting Bt cotton and GM rice over time. The incremental contribution of adoption within three periods is given. The first two columns show the impact of past adoption that is already achieved in 2001. In 2001 the welfare gain due to the adoption of Bt cotton is more than one third of the total welfare gain of Bt cotton realized by 2010. The additional gains from adopting Bt cotton in the other two periods slow down, as most farmers that potentially adopt have already switched to the new varieties. For GM rice all the benefits have still to come. Between 2001 and 2005, as adoption of GM rice starts to pick up, about one third of the welfare gains in 2010 are realized. In the period 2005–2010 the adoption rate increase from 40% to 95% and China is expected to arrive at the steep part of the adoption curve and a large part of the potential gains will be realized. Fig. 1 shows the cumulative land productivity gains obtained endogenously from the simulations. Land productivity is defined here as the ratio of output to land use. Fig. 1 displays the change of this ratio, cumulated over the simulation period.

Table 7
Impacts of adoption of Bt cotton and GM rice on other sectors in 2010 (percentage change relative to situation without GM products)

	Supply price	Output quantity	Consumer demand	Exports (fob)	Imports (cif)
Rice	− 12.0	1.4	1.1	66.2	− 23.2
Wheat	− 0.3	0.7	0.1	1.1	− 0.2
Coarse grains	− 0.4	0.6	0.8	0.9	0
Oilseeds	− 0.1	0.6	0.2	0	0.4
Sugar	− 0.1	0.5	0.4	0.3	0.3
Cotton	− 11.4	5.1	7.2	61.9	− 17.4
Other crops	− 0.3	0.7	0.3	0.6	0.4
Cattle	− 0.3	0.5	0.4	0.9	0
Other animal products	− 0.4	0.5	0.4	1.6	− 0.4
Milk	− 0.3	0.5	0.4	0.8	0
Fish	− 0.6	0.6	0.6	1.4	− 1
Other food	− 1.2	1.5	0.8	4.4	− 2.1
Extract	0.1	0.0	0.5	− 0.3	0
Textiles-leather	− 0.2	0.6	0.6	0.7	− 0.1
Labor intensive Manufacturing	0.2	− 0.2	0.5	− 1.7	1
Capital intensive Manufacturing	0.2	− 0.2	0.5	− 1	0.6
Services	0.3	0.3	0.4	− 1	0.9

Source: model simulations.

Table 8
Impact in different periods: adoption of Bt cotton and GM rice (incremental contribution of adoption within a period in percent changes)

	Past impact (before 2001)		2001–2005		2005–2010	
	GM rice	Bt cotton	GM rice	Bt cotton	GM rice	Bt cotton
Rice						
Supply price	0	0.1	– 5.1	0.1	– 8.6	0
Output volume	0	0	0.7	0	1.2	0
Export volume	0	– 0.3	23.6	– 0.3	37.9	– 0.2
Trade balance (mil. USD)	0	– 1	74	– 1	139	– 1
Cotton						
Supply price	0	– 5.3	– 0.2	– 4.8	– 0.3	– 3.6
Output volume	0	2.0	0	2.1	0.1	1.7
Export volume	0	24.4	0.7	19.4	1.1	13.3
Trade balance (mil. USD)	0	88	3	96	9	99
Macro						
Welfare (mil. USD)	0	410	1474	381	2697	314

Source: model simulations.

Again, the S-shaped curvature for Bt cotton and GM rice indicates that the productivity gains will level off in the future. This pattern is well known from the ‘green revolution’ that dramatically improved rice yields in the 1970s. The productivity growth is not perpetual.

5.2.5. Trade impact on other regions

Although China witnesses rising exports and/or reduced imports as a consequence of rapid GM adoption, the patterns of global trade in both the textiles and garments and the rice sectors are not affected very much. Table 9 presents the changes in the regional trade balance relative to the ‘no-GM’ case in 2010. The impact is negligible on major rice importers such as Africa and some rice deficit developing countries in Asia. Major rice

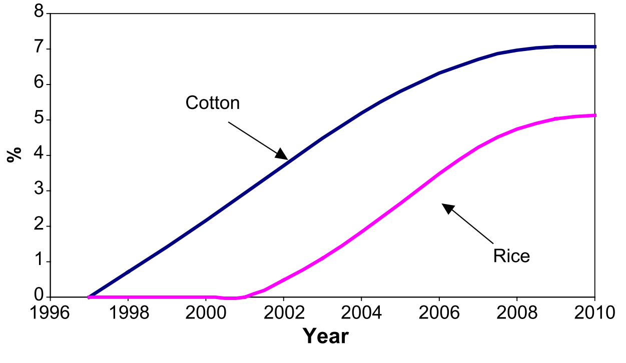

Fig. 1. Simulated land productivity growth rates over time. The graph is obtained from a Spline interpolation of simulated ratios of output growth over land use in 1997, 2000, 2005 and 2010.

Table 9
Impact of adoption of Bt cotton and GM rice in China on the commodity trade balance in various regions (year 2010, comparison against situation without GM crops)

	Rice		Cotton		Textiles	
	(million USD)	%	(million USD)	%	(million USD)	%
China	173	62	408	43	756	1
HongKong	1	0	1	− 1	− 25	− 2
Taiwan	− 1	− 12	2	1	− 73	− 1
JapKor	− 6	− 2	6	1	− 124	− 10
SEA	− 68	− 14	7	0	− 100	− 1
OthAsia	− 26	− 2	− 12	− 19	− 59	0
AusNzl	− 5	− 3	− 51	− 5	− 4	0
NAFTA	− 21	− 4	− 203	− 8	− 137	0
SAM	− 10	− 7	− 6	− 1	− 50	− 1
EU	− 11	− 2	1	0	− 270	− 1
CEEC	− 2	− 2	0	0	− 20	− 1
ROW	− 23	− 1	− 132	− 4	− 67	1

Details of country groups are provided in Appendix Table A.

exporters in South-East Asia (i.e., Thailand, Vietnam and Burma) may witness a drop in net export revenues. The Chinese biotechnology research strategy has in the first place concentrated on crops that are of great importance to rural livelihoods, and not on those that are important in terms of export earnings. Rice exports from China represent only a small share in international rice trade.

There is an immediate negative impact on other major cotton exporters, most notably India and Pakistan, which are part of our OthAsia region. The cost savings and yield increases from Bt cotton translate into lower production cost for the Chinese textiles and garments industry, but these cost reductions are not of such orders of magnitude that other garments producers (e.g., India and Bangladesh) are affected very much. The phasing out of the multifibre agreement by 2005 is of greater importance for global textiles and garments trade than Bt cotton commercialization in China.[9]

5.2.6. Robustness of results: sensitivity analysis on productivity shocks

In this section we conduct a systematic sensitivity analysis (SSA) on the productivity parameters, given the uncertainty in the magnitude of the GMO impacts on input usage and yields and given the uncertainty with regard to the adoption rates. In Section 3.1 we have argued that the maximum technically feasible adoption of the GM technology may not be realized. As a starting point for the SSA, we have taken a more conservative projection of the adoption rates of Bt cotton, which are obtained from estimating a logistic equation for each region.[10] The estimates that are based on historical adoption data do not take fully into

[9] The phase out of export quota under the ATC is included in our baseline. Chinese textile and garments exports are simulated to grow by 20% between 2001 and 2005 as a result of the ATC. In Other Asia (including India and Bangladesh) the growth is 35%.

[10] The estimated equation is $f(x)=(a)/(1+b\cdot e^{-c\cdot x})$. Where x denotes time. The estimated adoption rates asymptotically approach the value a. The estimation provide a rather good fit to the data, with more than 90% of the variance explained by the equation, in spite of the limited number of observations.

account that the benefits of GM technologies over non-GM technologies increase over time and are therefore lower than those reported in Table 3. According to the logistic model 56% of the area would be Bt cotton by 2010, rather than the 92%, which is believed to be technically feasible given increased benefits of GM technologies. For rice, the same procedure has been followed, albeit that we do not have historical observations available. Here, we have also reduced the mean adoption rate in 2010 to 56%. The simulation results of the previous estimates, as described in Section 5.2.2, and a scenario where the adoption rates are 56% for both cotton and rice are given in Table 10. The average effects vary almost linearly with the adoption rates. The lowering of adoption rates by about 40% compared to the optimistic scenario of Table 3, results also in a reduction of values of key variables by about 40% (compare the first two columns called "Total impact").

Next, we performed an SSA to test the robustness of our results with regard to the productivity shocks due to uncertainty in GM impacts and adoption rates. The SSA procedure follows Arndt (1996), and uses a Gaussian quadrature. A main advantage of the SSA is that it produces estimates of means and standard deviations of model, while requiring only a limited number of model runs. This approach views the adoption rates as random variables with associated distributions.

We assume that the productivity shocks fall within a band of plus and minus 60% of the mean and the distribution is assumed to be triangular around the mean. Table 10 shows that the standard deviation around the mean values is generally low, and the SSA results

Table 10
Results of sensitivity analysis: adoption of Bt cotton and GM rice

	Adoption rates: Cotton: 92%; Rice: 95 %	Adoption rates: Cotton: 56%; Rice: 56%		
	Total impact	Total impact	SSA Mean[a]	SSA Standard deviation[a]
Cotton				
Supply price	– 10.9	– 7.2	– 7.3	1.2
Output	4.9	3.2	3.2	0.5
Exports	58	35	34.9	6.7
Imports	– 16.6	– 11.1	– 11.2	1.8
Trade balance	389	260	261	43
Rice				
Supply price	– 12	– 7.5	– 7.5	1.3
Output	1.4	0.8	0.8	0.2
Exports	66.9	36.6	36.5	7.6
Imports	– 23.2	– 14.7	– 14.9	2.6
Trade balance	173	101	101	19.5
EV	5249	3280	3289	939
EV/sectoral value added[b]	15.1	9.4	9.5	2.7

Source: model simulations.

[a] Systematic sensitivity analyses in 56% scenario around cotton and rice productivity shocks (vary 60%, triangular distribution).

[b] EV (equivalent variation measured in million USD) as a percentage of sectoral value added from rice and cotton sector (measured in million USD).

are very encouraging as regards the robustness of the simulation estimates. For example, if we subtract two times the standard deviation from the mean EV estimate, we still observe a positive macro economic welfare gain, of 1.4 billion USD in 2010.

5.3. Assessment: benefits of GM adoption

In the discussion above we have referred to the equivalent variation (EV) concept to provide a summary indicator of the potential economy-wide benefits of GM adoption. Of course, the conventional EV measure of welfare changes does not take into account other important aspects of human well-being. The welfare measurement is based on a comparison of utility derived from consumption with and without the simulated changes. The utility function[11] does not account for intrinsic, positive or negative, utility that might be attached to the introduction of new crop varieties.

Another clear benefit of Bt cotton adoption is the reduced application of insecticides. According to Huang et al. (2000) pesticide poisoning affected between 30,000 to more than 70,000 persons in farming each year in China in the past decade. On average China had about 500 deaths due to pesticide poisoning every year, and the number has increased significantly since the late 1980s and reached 741 in 1995.

Bt cotton has an enormous potential to reduce the health risks of insecticide use. According to Pray et al. (2002) Bt cotton has significantly reduced the number of farmers who are poisoned each year. Based on surveys these authors show that 22%–29% of the non-Bt cotton farmers reported poisonings in 1999 and 2000, while only 5–7% of the Bt cotton farmers reported poisonings.[12] Self-reported ailments are only the tip of the iceberg. Both visible acute health impairments and invisible chronic health diseases of rice farmers are closely linked with the extent of their exposure to pesticides (Hunbag et al., 2000).

The estimated macro-economic welfare gains of adoption far outweigh the biotech research expenditure in China. The optimistic scenario, with high adoption rates, results in an annual income gain of roughly 5 billion USD in 2010, while the lower range estimate with lower adoption rates still delivers 3 billion USD. These gains are recurring annually and may be compared to R&D expenditures reported in Huang and Wang (2003). They estimate biotech research expenditures in 2000 at about 40 million USD. The accumulated expenditure between 1986 and 2000 amount to about 450 million USD (in real 2000 prices). The implied social rates of return to research are certainly very high.

On the other hand a number of limitations should be borne in mind when interpreting the results. Issues of biosafety, environmental effects, and food safety are not entering our analysis. All these factors should be considered next to the economic assessment in order to arrive at a societal evaluation of GM technology.

5.4. GMO trade ban on GM rice

The question addressed in this section is whether it is still worthwhile for China to commercialize GM rice if consumer concerns in the enlarged EU, Japan, Korea and South

[11] In the GTAP model, the utility function is of the Constant Differecences of Elasticities (CDE) form.

[12] Farmers asked if they had headache, nausea, skin pain, or digestive problems when they applied pesticides.

Table 11
Impacts of GM import ban on China and other regions (comparison against situation without GM crops in 2010)

	Adopt Bt cotton and GM rice	GM trade ban
China		
Rice exports (% change)	67	5
Rice output (% change)	1.4	0.9
Change rice trade balance (million USD)	173	19
Welfare (million USD)	5249	5229
Other regions		
Japan & Korea welfare (million USD)	298	212
South East Asia welfare (million USD)	13	− 33
EU-27 welfare (million USD)	− 7	− 52

Source: model simulations.

East Asia lead to a ban on GM food products. Technically, this is modeled as a non-tariff-barrier against Chinese rice imports that reduces these countries' imports of Chinese rice to zero.

Under this scenario exports of GM rice from China decline substantially. Whereas an increase of rice exports volume of 67% was projected when both GM rice and Bt cotton are adopted, the trade ban results in a drop to just 5% above the baseline result for 2010 (Table 11). This follows immediately from the export shares in the baseline situation in 2010 (without all the biotech shocks), which amount to 21%, 8% and 9% for South East Asia, Japan–Korea and the EU27 (enlarged EU with 27 counties), respectively. Rice output is also declining, by 0.5% points (1.4–0.9% = 0.5%, Table 11). The drop is limited, because the share of exports in production is only 1.2%.

Table 11 also shows the welfare effects for the banning countries. The welfare impact is negative but not substantial in these countries. The three banning regions together forego 177 million USD. Again it should be stressed that our welfare measure does not include the (dis-) utility of having GM varieties. In the banning scenario this means that we are not taking into account the possible positive utility in the banning countries derived from not having the GM rice on the market.[13] Our method, in fact, does exactly the opposite. It counts the unavailability of GM rice as a negative contribution to welfare, as consumers' choices are more limited under the banning scenario. If we subtract this negative effect from the welfare loss of the banning countries, they still forego about 90 million USD. This results mainly from negative allocation effects because the banning of imports stimulates domestic production in the heavily protected rice sector.

Is it still worthwhile for China to invest in GM rice if other countries ban GM rice imports from China? The aggregate welfare measure against which the trade ban impact can be evaluated indicates that the export ban does not significantly change the benefits of adopting GM rice in China. Although output growth in the rice sector is somewhat dampened, the overall negative effect on China is small. The largest adoption gains are

[13] Some empirical evidence can be derived from willingness to pay studies that estimate the price premium for non-GM varieties. For example Lin (2002) estimates that Japanese consumers were willing to pay a price premium of up to 30% for non-GM soybeans in 2000.

realized within China itself. As far as rice is concerned, the negative attitude towards GM food products in some high-income countries is of little concern to China.

5.5. Labeling

In this scenario, China requires labeling of soybean imports from NAFTA and South America. In January 2002 the Chinese Ministry of Agriculture has announced three new regulations on the biosafety management, trade and labeling of GM farm products that took effect after March 20, 2002. These regulations require importers of genetically modified agricultural products to apply for official safety verification approval from China's Ministry of Agriculture. Since China is a large market for US soybean exports, buying more than $1 billion worth in 2001, it is not surprising that US producers have accused Beijing of using the new rules to hinder imports and protect Chinese soybean growers. After 2-month intensive negotiation between China and US, recently an interim deal was reached under which China will temporarily waive its regulations and has agreed to recognize US assurances that its soybeans are safe for human consumption. The other main sources of soybean imports into China are countries that also have embraced the benefits of herbicide tolerant (Round-Up Ready) GM soybeans: Argentina and Brazil.

However, labeling is not only introduced for imports. Domestic produce has to be labeled as well.[14] The simulation experiment in this section provides an assessment of the economic effects if indeed China is to label its own GM food crops, given that it exercises labeling requirements for imported soybeans. In our case, this means that China has to implement a labeling for GM rice only, as there is no GM soybean production within China.

We do not model separate production–consumption chains for GM and non-GM varieties. One consequence of this simplification is that we are unable to quantify any (positive or negative) price premium that GM varieties might achieve on the Chinese market. Our analysis is based on a rather straightforward assumption on labeling costs for both imported and domestic GM crops.

Labeling involves more than just attaching some information to the product. A complete system is needed to separate GM from non-GM products. This leads to an externality for non-GM farmers and processors, as they have to make sure that their product is actually GM-free. The incidence of labeling cost falls more on conventional farmers than on GM adopters. Costs of separation are due to changed agricultural practices (e.g. more space between fields, etc.), monitoring and measurement (e.g. instituting a system for Hazard Analysis at Critical Control Points, HACCP), insurance, identity preservation in processing and transport. There exist some estimates of the cost of segregation for oilseeds, corn and potatoes. Such estimates for the European Union (European Commission, 2002), Canada (KPMG, 2000) and the USA (Economic Research Service, 2001; Lin, 2002) show that on average segregation may raise unit cost by as much as 28% for oilseeds and 22% for corn. These estimates appear to be rather high, and it is questionable whether it is realistic to assume that this high cost will have to be incurred in the Chinese situation. Using the corn estimates as a reference, we arrive at a rough

[14] Hence, the Chinese labeling requirements are in accordance with the GATT principle of national treatment, as enshrined in article 3 of the GATT.

approximation of extra cost that have to be incurred by non-GM rice producers, and we assume that total production costs will increase by 3 percent through labeling.[15,16] This is modeled as an increase in the cost of services required for rice production. Labeling of imported GM soybeans is modeled as an increase in the ‘‘transport/handling’’ margin between FOB and CIF for soybean exports from NAFTA and Southern America (SAM) to China. We assume that these handling costs will increase so much that the total import costs (CIF price from NAFTA or SAM to China) will increase with 5%. The size of the import cost increase is of course debatable. Existing studies on this issue have focused on the additional cost to insure that GM and non-GM products are not adventitiously mingled in the hold of ocean ships. This is not relevant in the Chinese case, as all US and SAM soybeans for the Chinese market are in fact GM varieties. However, the labeling requirement does undoubtedly lead to additional bureaucracy, which acts similar to a tariff in its effect on trade volumes (although no tariff revenue is involved). Indeed, the short run effects after the introduction of the new labeling requirements in 2002 have resulted in a considerable drop of US soy exports to China.

The assumed cost increases are obviously a rough estimates, and the actual cost for the Chinese rice producers and for international suppliers of soybeans may be higher or lower. In the absence of better information, this assumption will be sufficient to illustrate the effects of labeling, and to give a sense of the order of magnitude of macro-economic effects.

Table 12 shows the economic costs of labeling both imported soybeans and domestic rice. The domestic supply price of rice increases relative to the previous experiment, but still a price decline of almost 10% relative to the baseline is projected. The higher domestic supply price leads to fewer exports, less output, and more rice imports. The labeling of imported soybeans increases the equilibrium price of imported soybeans from NAFTA and South America with 7.1% and 6.2%, respectively, resulting in a considerable drop of soybean exports from these regions. Total Chinese soybean imports decline with 6% because soybeans from NAFTA and SAM cover 77% of all Chinese soybean imports.

Labeling is costly. Measured in terms of equivalent variation, and bearing in mind that we do not include any positive utility effects that might exist when consumers have access to improved product information, the welfare loss to China is about 1.3 billion USD. However, even when a trade ban and labeling are occurring together, we still observe a very positive welfare impact of adopting GM crops (almost 4 billion USD).

This experiment highlights an important trade-off that China is facing. Labeling of imported soybeans raises the domestic price of soybeans, and benefits Chinese soybean farmers, who will see a shift towards domestic demand, and are able to increase output at higher prices. This also has an adverse effect on the users of imported soybeans in the livestock sector. However, domestic labeling of GM foods also raises the price of domestic rice, and this affects rice consumers. Hence, labeling improves the competitive position of domestic (non-GM) soybean farmers, as they become cheaper relative to

[15] If we have 40% GM rice farmers in 2005, then $60 \times 22\% = 13.2\%$ is the average cost increase for the whole rice sector. In 2010, with an assumed adoption of 95%, this would become $5 \times 22\% = 1.1\%$.

[16] To make it even more complicated: In practice, the separation cost is not constant. As more adoption takes place it becomes harder and more costly for the non-adopters to assure a GM free product.

Table 12
Impacts of labeling in 2010 (percent change relative to baseline)

	Bt cotton & GM rice adoption with GM rice trade ban	Labeling soybean imports and domestic rice
Rice		
China		
Supply price	− 12.1	− 9.3
Output volume	1.4	0.6
Export volume	5.3	− 7.2
Import volume	− 23.7	− 18.5
Trade balance (million USD)	19	− 14
Soybean		
NAFTA		
Import price China (cif)	0.0	7.1
Export volume to China	0.4	− 14.1
South America		
Import price China (cif)	0.0	6.2
Export volume to China	0.4	− 10.7
China		
Supply price	− 0.1	0.3
Output volume	0.7	2.7
Export volume	0.1	− 1.5
Import volume	0.4	− 6.1
Trade balance (million USD)	− 13	58
Welfare (million USD)	5229	3953
EV/sectoral value added[a]	15.0	11.4

Source: model simulations.

[a] EV (equivalent variation measured in million USD) as a percentage of sectoral value added from rice and cotton sector (measured in million USD).

imports, but it hurts rice consumers, as well as users of imported soybeans in the livestock industry.[17]

6. Conclusions

China is developing the largest public plant biotechnology capacity outside of North America. The international debate on GM technologies has its influence on Chinese policy making and on agricultural industry. Adoption of Bt cotton has been proceeding at a rapid pace in recent years. The largest part of the potential productivity gains from Bt cotton will be realized already by 2005, thereafter the productivity growth is slowing down. In contrast, GM rice is not yet available to farmers on a commercial basis, and our estimates indicate that large productivity gains are yet to be realized between 2005 and 2010.

[17] Our experiments considered only a unilateral GM labeling by China. As a consequence some soybean trade is diverted towards EU markets, which does not adopt labeling in our scenario. If this alternative outlet for US and South American soybeans does not exist, the price effects on imported soybeans would be smaller.

This paper uses productivity estimates for GMOs that are based on empirical micro-level data for the cotton sector and tentative experimental data for the rice sector in China. Biotechnology leads to crop specific factor biased technical change, and the results show that the distinction between yield and production factors effects is important. Factor markets for labor and land will witness different effects, depending on the type of biotechnology being adopted. The scarce land resources can be utilized more effectively with land-saving technologies. Even though labor is relatively abundant in China, the adoption of somewhat labor-saving GM crops does not necessarily lead to falling wages. This is especially the case in Bt cotton. Here, the expansion of the cotton sector itself, together with rising labor demand from the unskilled labor intensive textiles sector more than compensate for the savings in labor inputs obtained by adopting the GM crop. The use of empirical estimates that give a better indication of the magnitudes of the productivity impact of GMOs is certainly very important.

The economic gains from GMO adoption are substantial. In the most optimistic scenario, where China commercializes both Bt cotton and GM rice, the welfare gains amount to an additional annual income of about 5 billion US$ in 2010. This amounts to about 3.5 USD per person. This is not a small amount in a country, where according to the World Bank 18% of the population had to survive with less than 1$ per day in 1998.[18] If actual adoption rates are lower, we still observe an income gain of 3 billion USD in 2010. Given the importance of rice for agricultural production, employment and food budget shares, the gains from GM rice adoption are orders of magnitude larger than the Bt cotton gains. The estimated macro economic welfare gains far outweigh the public biotechnology research expenditures.

The effects of GM adoption differ in one important aspect between the two crops. Not only is rice a much larger sector than cotton in terms of its contribution to agricultural output and employment, we also observe completely different demand side effects. Given the generally low price and income elasticities for rice, consumers demand not much more rice if price is lower or income higher. Consequently, consumers can spend their increased income and money they save on buying the cheaper GM rice on other products. These income effects increase the demand for many other sectors. Such indirect demand effects are not much observed for Bt cotton. On the other hand, Bt cotton is clearly associated with positive health effects and with positive income effects at the farm level. Bt cotton also generates forward linkage effects on the domestic textiles industry, which serves a large export market and generates foreign exchange earnings.

Although the productivity gains for China are significant and translate to rising exports or reducing imports, the patterns of global trade in both the textiles and garments and the rice sectors are not affected very much. The impact is negligible on major rice importers such as Africa and some rice deficit developing countries in Asia, but major rice exporters (i.e., Thailand, Vietnam and Burma) may experience a drop in net export revenues. The Chinese biotechnology research strategy has in the first place concentrated on crops that are of great importance to rural livelihoods, and not on

[18] World Development Indicators. (World Bank, 2000) International poverty line of 1$ (PPP adjusted) in 1998.

those that are important in terms of export earnings. Rice exports from China represent only a small share in international rice trade. There is an immediate impact on the export revenues of major cotton exporters, most notably India and Pakistan. The cost savings and yield increases from Bt cotton translate into lower production cost for the Chinese textiles and garments industry, but these cost reductions are not of such orders of magnitude that other garments producers (e.g., India and Bangladesh) are affected very much. The phasing out of the multifibre agreement by 2005 is of greater importance for global textiles and garments trade than Bt cotton commercialization in China.

Our results indicate that trade restrictions do not significantly lower the gains from biotechnology research in China. A trade ban on GM rice (food crop) has only a minor effect since the portion of rice exported is very small. The effects of unilateral labeling of soybean imports are larger and it has clear distributional impacts. Our experiments highlight an important trade-off that China is facing. If China wants to label GM products, this raises the domestic price of soybeans, and benefits Chinese soybean farmers. However, domestic labeling also raises the price of domestic GM rice, and this affects rice consumers. Our findings suggest that it would be economically advantageous for China to continue the promotion of its GM biotechnology, including commercializing its GM food crops. The economy-wide benefits associated with more productive crops outweigh R&D expenditures by a wide margin.

Our findings also suggest that most gains occur inside China, and can be achieved independently from biotech-unfriendly polices adopted in some industrialized countries. This stands in contrast to the findings of Anderson and Yao (2001), who argue that the effects of GM adoption depend to a considerable extent on the trade policy stance taken in high-income countries opposed to GMOs.

This paper offers an economic analysis of some of the issues surrounding rapid adoption of biotechnology in China. Despite being based on the comprehensive general equilibrium model and an associated global database, a number of limitations should be borne in mind when interpreting the results. First of all, in this paper no utility is attached to improved product information. We are therefore unable to quantify the possible positive effects that labeling may have on consumer's welfare. We are also unable to provide estimates of the price premium that may occur due to preference shifts, because we do not consider the separation of GM and non-GM supply chains. While we have concentrated on trade policy issues relating to primary products, more complicated issues may arise with respect to trade in processed foods.

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Appendix A

Tables A, A1, A2, A3

Table A
Regional and sector aggregations

	Description	Original GTAP v5 sector
Regional aggregation		
China	Mainland, China	Mainland, China
Hong Kong	Hong Kong, China	Hong Kong, China
Taiwan	Taiwan, China	Taiwan, China
JapKor	Japan and Korea	Japan, Korea
SEA	South East Asia	Indonesia, Vietnam, Malaysia, Philippines, Thailand, Singapore
OthAsia	Other Asia	Bangladesh, India, Sri Lanka, rest of south Asia
AusNzl	Australia and New Zealand	Australia, New Zealand
NAFTA	North American free trade area	Canada, United States, Mexico
SAM	South and Central America	Central America, Caribbean, Colombia, Peru, Venezuela, rest of Andean Pact, Argentina, Brazil, Chile, Uruguay, rest of South America
EU15	European Union	Austria, Belgium, Denmark, Finland, France, Germany, United Kingdom, Greece, Ireland, Italy, Luxembourg, Netherlands, Portugal, Spain, Sweden
CEEC	Central European Associates	Hungary, Pollen, rest of CEEC
ROW	Rest of World	Switzerland, rest of EFTA, Turkey, rest of Middle East, Morocco, rest of North Africa, Malawi, Mozambique, Tanzania, Zambia, Zimbabwe, Other Southern Africa, Uganda, rest of Sub-Saharan Africa, Former Soviet Union, Botswana, rest of SACU, rest of world
Sector aggregation		
Rice	Rice, paddy and processed	Paddy rice, processed rice
Wheat	Wheat	Wheat
Cgrains	Coarse grains	Cereals grains nec
Oilseeds	Oilseeds and vegetable oils	Oilseeds, vegetable oils and fats
Sugar	Sugar raw and processed	Sugar cane, sugar beet, Sugar
Pfb	Plant based fibers	Plant based fibers
Othcrop	Horticulture and other crops	Vegetables fruit nuts, crops-nec
Ctl	Cattle and red meat	Cattle, sheep, goats, horses and their meats
Oap	Pig & poultry-white meat, wool	Animal products nec, wool, silk-worm cocoons, meat products nec
Milk	Raw milk and dairy products	Raw milk, dairy products
Fish	Fish	Fish
Ofood	Food products nec	Food products nec, beverages & tobacco products
Extract	Natural resources and extract	Forestry, coal, oil, gas, minerals nec
Texlea	Textiles and leather	Textiles, wearing apparel, leather products
Labintman	Labor intensive Manfact	Wood and paper products, publishing, metal products, motor vehicles and parts, transport equipment nec
Capintman	Capital intensive manufact	Petroleum, coal products, chemical rubber plastic prods, mineral products nec, ferrous metals, metals nec, electronic equipment, machinery and equipment nec, manufactures nec

(continued on next page)

Table A (*continued*)

	Description	Original GTAP v5 sector
Sector aggregation		
Svces	Services and activities NES	Electricity, gas manufacture, distribution, water, construction, trade, transport nec, sea transport, air transport, communication, financial services nec, insurance, business services nec, recreation and other, pub-admin/defence/health/educat, dwellings

ANNEX: Baseline.

Table A1
Key assumptions for baseline 2001–2010 (Annual growth rates)

	Real GDP	Land	UnSkLab	SkLab	Capital	NatRes	Population
China	7.1	0	1.2	3.8	8.9	0.7	0.7
HonKong	5.4	0	– 0.2	4.0	5.3	0.7	0.2
Taiwan	5.8	0	0.7	1.0	6.5	0.7	0.7
JapKor	2.5	0	– 0.4	0.0	2.0	0.7	0.3
SEA	5.6	0	1.4	5.1	3.8	0.7	1.4
OthAsia	5.0	0	2.0	5.1	5.2	0.7	1.6
AusNzl	3.4	0	1.0	0.7	3.4	0.7	0.8
NAFTA	2.7	0	1.2	1.1	3.5	0.7	1.0
SAM	4.4	0	1.4	5.0	3.1	0.7	1.4
EU	2.6	0	– 0.1	– 0.1	2.5	0.7	0.0
CEEC	4.7	0	0.1	0.3	3.6	0.7	0.2
ROW	4.3	0	2.3	3.0	2.5	0.7	2.0

Table A2
Values of key variables in 2010 (million USD)

	Production	Exports	Imports	Trade balance
Rice	37,218	288	– 172	116
Other cereals	40,989	537	– 1272	– 736
Oilseeds	12,987	52	– 3847	– 3795
Sugar	2952	42	– 443	– 401
Cotton	10,967	24	– 2642	– 2618
Other crops	104,492	3726	– 180	3546
Livestock	98,662	893	– 2005	– 1112
Processed food	105,401	19,760	– 2932	16,828
Extract	179,586	1513	– 40,045	– 38,531
Textiles/Leather	387,398	150,447	– 36,979	113,468
Labor-intensive manufacturing	309,051	49,099	– 22,163	26,936
Capital-intensive manufacturing	1,152,114	178,653	– 189,021	– 10,368
Services	1,281,471	39,655	– 30,499	9155

Table A3
Value of income elasticities in 2010 in China

	Adjusted	standard GTAP
Rice	0.1	0.4
Wheat	0.1	0.4
Coarse grains	0.3	0.4
Oilseeds	0.4	0.9
Sugar	0.6	0.9
Cotton	0.6	0.9
Other crops	0.6	0.9
Cattle	0.6	1.1
Other animal products	0.4	1.1
Milk	0.8	0.8
Fish	0.9	0.9
Other food	0.9	0.9
Extract	1.2	1.2
Textiles-leather	1	1
Labor intensive manufacturing	1.2	1.1
Capital intensive manufacturing	1.2	1.3
Services	1.3	1.1

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