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Biotechnology Boosts to Crop Productivity in China And its Impact on Global*

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Abstract

China is developing the largest public plant biotechnology capacity outside of North America. The list of GM technologies in trials, including rice, cotton, tomato, wheat, potatoes and peanuts, is impressive. At the same time there is an active debate on whether China should continue to promote its GM biotechnology and when China should commercialize its GM food crops. Answers to these questions are of critical importance for policy makers and industry. This paper provides an economy-wide assessment of these issues and analyses the impact of adopting GM crops on production, trade and welfare of China and the rest of world under various scenarios.

A main feature of this paper is that productivity impacts of GMOs are based on empirical micro-level data for the cotton and on field trial data for rice in China. Biotechnology leads to crop specific factor biased technical change, and our scenarios take this important aspect fully into account. A second feature is the thorough improvement of the database of the Global Trade Analysis Project (GTAP) model that incorporates the most updated information (up to 2001) on the Chinese economy and detailed information on factor shares of inputs by each agricultural commodity. Third, the representation of inter-sectoral and of bilateral trade linkages between world regions in the GTAP model allows us to study a wide range of trade implications. Furthermore, a baseline for the period 2002-2010 is constructed that includes China's WTO accession and the MFA phase, with Version 5 data of the GTAP model.

Our results indicate that the development of biotechnology has an important impact on China's production, trade and welfare. The gains from adoption Bt cotton and GM rice are substantial. In the most optimistic scenario, where China commercializes both Bt cotton and GM rice, the annual welfare gains amount to an additional income of about 5 billion US\$ by 2010. The estimated macro economic welfare gains far outweigh the public biotechnology research expenditures. For food crops we also investigate the possible impact of import restrictions pertaining to GM rice imposed by Japan, Korea, the EU and South East Asia and the impact of labeling of imported soybeans in the face of recently (March 2002) installed Chinese regulations. The results indicate that most gains occur inside China, the impact from trade restriction imposed by other countries is minimal. Labeling will significantly lower the welfare gain from GM food development. Policy makers should put less weight on the international dimension in making their decisions on biotechnology development.

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Biotechnology Boosts to Crop Productivity in China And Its Impact on Global Trade

I. Introduction

Biotechnology, one of the most promising and innovated technologies in this century, has spurred a worldwide debate since the technology uses genetic modification techniques. The debate has been going on for decades and has brought a significantly depressing impact on the supply of biotechnology. The debates discourage the incentive to invest in the new technology of both the public and the private sectors in many developed and developing countries. On the other hand, the demand for the technology keeps growing. The global area of GM crops increased from 1.7 million hectares in 1996 to 44.2 million hectares in 2000 and is expected to continue to grow by 10 percent in 2001 (James, 2002). The number of farmers planting GM crops in 2001 is expected to grow substantially from 3.5 million in 2000 to 5 million or more in 2001. Most GM crops are planted in USA, accounting for more than two-third of the global total 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 sown, after the USA, Argentina, and Canada (James, 2002). A recent study by Huang et al (2002a) shows that China is developing the largest plant biotechnology capacity outside of North America. The list of GM technologies in trials, including rice, cotton, tomato, wheat, potatoes and peanuts, is impressive. Although commercialization of major food crops has proceeded at a cautious pace in China, the government has considered biotechnology as one of the national priorities in technology development since the 1980s (SSTC, 1990; Huang, et. al., 2002a). The Chinese government views agricultural biotechnology as a tool to help China improve the nation's food security, raise agricultural productivity, increase farmer's income, foster sustainable development, and improve its competitive position in international agricultural markets (Huang, et al, 2001a). There were at least 3 million small farmers who adopted Bt cotton in 2000 in China and this number might increase to 5 million in 2001 (Huang, et al., 2002b).

China's agricultural biotechnology development is an interesting case and unique in many aspects. The public sector dominates the industry. The list of GM crops in trials differs from those being worked on in other countries where the technologies were dominated by the private sector (Huang et al, 2000a). The first commercial release of a GM crop in the world occurred in 1992 when transgenic tobacco varieties were first adopted by Chinese farmers.¹ GM varieties in cotton, tomato, sweet pepper, and petunias have been approved for commercialization in China since 1997. Cotton varieties with the *Bacillus thuringiensis* (Bt) gene to control bollworm have spread widely, and reached 1.48 million hectares in 2001 (Table 1). GM varieties in crops such as rice, maize, wheat, soybean, peanut and others are either in the research pipeline or are ready for commercialization (Chen, 2000; Li, 2000; Huang et 2001b).

On the other hand, there is a growing concern among policy makers regarding the impacts of the ongoing global debate over biotechnology on China's agricultural trade, biosafety,

¹ Chinese farmers have not been allowed to grow GM tobacco since 1995. This policy measure is a response to strong opposition from tobacco importers from the USA and other countries.

and the potential opposition derived from public concerns on the environmental and food safety of GM products. Under this situation, despite GM crops have continued to be generated in public research institutes and the number of imported GM crop varieties for field trial and environmental releases has been rising, the approval of GM crops, particular food crops, for commercialization has become more difficult since late 1998 (Huang et al., 2001a). This reflects the influence of the global debate on GM crops on Chinese policymakers, in particular restrictions on imports to EU countries and export from North America,. For example, earlier this year in January, the Ministry of Agriculture (MOA) 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 GM agricultural products to apply for official safety verification approval from China's MOA, leading US producers to accuse 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. China in effect will temporarily waive its regulations and has agreed to recognize US assurances that its soybeans are safe for human consumption.²

China, like many other developing countries, now faces a dilemma as to how to proceed on the further commercialization of GM crops. Several issues were raised by policy makers. Should China continue to promote its agricultural biotechnology and commercialize its GM food crops (i.e, rice and soybean)? How will the rest of the world, particular EU and other Eastern Asia, react to China's GMO's commercialization? What will be the impacts of alternative biotechnology development strategies (both in 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 agricultural industry.³

The overall goal of this paper is to access the likely answers to the above issues. To achieve this goal, the paper is organized as the follows. In the next section, a general review of agricultural biotechnology development in China is provided. Statistics presented are based on a primary survey of leading plant biotechnology research institutes and biotechnology policy process reported in Huang et al (2001a, 2001b, and 2002a). The impacts of Bt cotton adoption in China are presented in section III. All materials are from recent empirical studies on Bt cotton by the first two authors of this paper and their collaborators (Pray et al, 2001; Huang et al, 2001c and 2002c). The results from these studies and hypothesized results of GM rice commercialization will be used as a base for the later simulation analyses. The fourth section presents the model and scenarios that will be used in the impact assessments. The results on the impacts of alternative biotechnology development strategies are discussed in the fifth section. The final section provides concluding remarks and areas for policy actions.

² China imported about 14 million metric tons of soybeans from USA, Argentina and Brazil, most of them are RoundUp Ready Soybean in 2001. China is also the largest market for US soybean exports, buying more than \$1 billion worth in 2001.

³ Anderson and Yao (2001) recently investigated the potential economic effects of China's adoption of GMOs based on a hypothesized 5% gain in productivity with GMO adoption. The results show that the effects depend to a considerable extent on the trade policy stance taken in high-income countries opposed to GMO and to liberalization of China's trade in textiles and apparel.

II. Agricultural Biotechnology Development in China

An Overview

Biotechnology in China has had a long history. Several research institutes within CAAS (the Chinese Academy of Agricultural Sciences) and CAS (the Chinese Academy of Sciences) as well as in public universities, initiated their first agricultural biotechnology research programs in the early 1970s.⁴ The most significant progress in agricultural biotechnology was made after 1986 when China initiated a national high-tech program in March 1986 (so call “863” program). Since then agricultural biotechnology laboratories have been established in almost every agricultural academy and major universities. By the late 1990s, there were over 100 laboratories in China involved in transgenic plants research (Chen, 2000).

Bt cotton is one of the most often cited examples on the progress of agricultural biotechnology in China. Six Bt cotton varieties with resistance to bollworms generated by China’s public institutions and two Bt cotton varieties from Monsanto had been approved for commercialization in 1997-2000 (BRI, 2000a). Since the first Bt cotton variety was approved for commercialization in 1997, total area under Bt cotton reached nearly 1.5 million hectares in 2001, accounted for 31 percent of China’s cotton area (Table 1). In addition, other transgenic plants with resistance to insects, disease, herbicides or that 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 or diseases, wheat resistant to barley yellow dwarf virus, maize resistant to insects or with improved quality, soybeans resistant to herbicides, transgenic potato resistant to bacterial disease, and so on (Huang et al., 2002a).

Table 1. Bt cotton adoption in China

	1997	1998	1999	2000	2001
Cotton area (000 ha)	4491	4459	3726	4041	4733
Region I	1796	1784	1366	1655	2024
Region II	1123	1115	876	922	1147
Region III	1572	1561	1484	1464	1562
Bt cotton area (000 ha)	2	67	400	897	1480
Region I	2	60	368	801	1272
Region II	0	5	20	81	171
Region III	0	2	12	16	37
Bt cotton (%)	0	2	11	22	31
Region I	0	3	27	48	63
Region II	0	0	2	9	15
Region III	0	0	1	1	2

Note: Region I includes Hebei, Shangdong and Henan, regional II includes Anhui, Jiangsu and Hubei, and all rest of China are in region III.

Source: Huang et al., 2002b.

⁴ The research focus of biotechnology in the 1970s was cell engineering, tissue culture, and cell fusion. Research in cell and tissue culture covered crops including rice, wheat, maize, cotton, vegetable and others (KLCMCB, 1996). Several advanced rice varieties were generated through another culture in 1970s and 1980s.

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.

Research Priorities

Rice, wheat and maize are the three most important crops in China. Each accounts for about 20 percent of the total area planted. 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, has been a central goal of China's agricultural and food policy and has been incorporated into biotechnology research priority setting (Huang et al., 2001b).

Cotton also has been selected as one of top priority crops not only because of its importance due to area sown and its contributions to the textile industry and trade, but also because of the serious problems with the associated rapid increase in pesticide applications to control insects (i.e., bollworm and aphids). Per hectare pesticide expenditures in cotton productions in China increased considerably in the past decades, reaching RMB yuan 834 (approximately US \$ 100) in 1995. This amount is much higher than comparable expenditure in grain crops production but lower than in horticultural production (Huang et al, 2000). Cotton production alone consumed about US\$ 500 million annually in pesticides in recent years.

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). 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. Northern China is a major wheat and soybean production region that has significant implications to the nation's food security and trade.

Huang et al (2002a) show that there are over 120 different genes and more than 50 different plant varieties that have been used in plant genetic engineering in China since the middle 1980s. By 2000, there were 18 GM crops generated by Chinese public research institutes, four of them have been approved for commercialization (Bt cotton, tomatoes with resistance to insects or improved shelf-life, a petunia with altered flower color, and sweet pepper resistant to diseases).

GM Cotton and Rice

GM cotton and rice are two major GM crops and technologies that China has been one of leading countries in the world (Table 2). The Biotechnology Research Institute (BRI) of CAAS developed insect-resistant Bt cotton. The Bt gene's modification and plant vector construction technique was granted a patent in China in 1998. The Bt gene was introduced into major cotton varieties using the Chinese-developed pollen tube pathway (Guo and Cui, 1998 and 2000). Five transgenic, open-pollinated varieties and one transgenic hybrid Bt cotton variety had been registered with the new plant variety registration authorities by

2001. Bt cotton has been approved for commercialization in 9 provinces since 1997 (BRI, 2000a), the area planted to CAAS' Bt cotton is nearly equal to Monsanto Bt varieties (Huang et al., 2002b).

BRI of CAAS recently made the other breakthrough in plant disease resistance by developing cotton resistant to fungal diseases (Table 2). Glucanase, glucoxidase and chitinase 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, 2000a).

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 & 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: Huang, Wang, Zhang and Zepeda, 2001.

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 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 (Zai and Zhu, 1999; 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, the commercialization of various GM rice is ready. However, the commercializing GM rice production has not yet been approved as the policy makers' concern on the 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.

III. Impact of Bt Cotton in China: Factor Biased Technical Change

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 (2001c and 2002c) 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). 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, the significant reduction 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 percent fewer times and reduce pesticide expenditures by 82 percent (Huang et al. 2001c). Because the reduction on the farmers spraying pesticide time (from an average of 20 times during one crop season to 8 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 percent (based on author's survey in 1999, 2000 and 2001 in 5 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 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.

After controlling for all input differences and geographical location, Huang et al (2002c) 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 2 similar surveys conducted in 2000 (with additional Henan province) and in 2001 (with additional Anhui and Jiangsu provinces, cotton region II). However, new surveys in 2000-2001 also reveal that the extent of the impacts (pesticide and labor inputs and yield) decline with moving Bt cotton from the region I to region II (Huang et al., 2002b).

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

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

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 and impacts, 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.

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	5.82	8.30	5.80	3.00	-51	120	-5.1
2002	5.94	8.47	5.92	3.06	-53	120	-5.3
2005	6.30	8.98	6.28	3.25	-57	120	-5.7
2010	6.96	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	31	63	15	2			
2002	41	80	30	5			
2005	79	95	85	55			
2010	92	95	90	90			
GM rice							
2002	2						
2005	40						
2010	95						

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 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. The assumptions summarized in Table 3 will be used in later simulations.

There is a consensus that one cannot simply assume that the GM technologies imply a Hicks-neutral productivity boost, as in Anderson and Yao (2001). 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. The productivity impact of GM technologies in crops is typically factor-biased.⁶ That is, cost reductions on some of the

⁶ 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".

productions factor can be achieved in varying degrees. The yield increases through GM technology, for example, allow the same volume of output to be produced with less units of land. The ultimate effect on total land demand will, however, depend on the interaction of the substitution effect (less land relative to other factors) with the expansion effect, as the total output expansion may possibly be larger than the land savings per unit of output. Similarly, the labor savings obtained from less weeding and pesticide sprayings leads to a drop of labor demand at the same level of output. Conversely, more output can be produced with the same amount of labor. The combined effects of factor-biased technical change depend on the relative cost shares of production factors and on the substitution elasticities in the production function. In addition, the general equilibrium model used in the next sections takes also indirect feed back effects through the demand side into account. Increased demand through lower prices in the wake of cost savings will be important determinant of the sectoral expansion.

IV. Methodology and scenarios

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. 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 III. 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). 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 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.

The comparative static model has first been used to generate a so-called baseline projection for 2001-2010. In a second step, the impact of alternative biotechnology 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: 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 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 and 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 CCAP/CAPSIM econometric estimates for income elasticities for livestock products, rice and wheat. As the new estimates are lower than the original GTAP estimates. 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. The baseline is more fully documented in Van Meijl et al. (2002).

Scenarios

The baseline projection does not contain any assumptions on biotechnology developments. Four scenarios have been developed to assess the policy choices highlighted in the introductory section. The first scenario is designed to study the impact of Bt cotton adoption. During the period 2002-2010, the Chinese cotton sector is assumed to experience the factor biased productivity gains summarized in Table 3. We assume that these cost savings affect those farmers who have adopted the GM crop varieties. That is, we weigh the productivity and seed cost estimates by adoption rates to arrive at an average impact the cotton sector.

The second scenario adds the commercialization of GM rice during 2002-2010 to the adoption of Bt cotton. Again, we used the productivity estimates and adoption rates from Table 3. The third scenario focuses on a possible import ban on GM 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 crops have been commercialized.

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.

V. Economic impact assessment

The Impact 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 baseline projection for 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. Main sectoral effects of adopting Bt cotton (percent change, relative to baseline 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

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%. 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 $10.9\% \times 2.5\% = 0.27\%$ 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.

The Impact of Commercializing both Bt Cotton and GM Rice

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 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. 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 don't 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.

Table 5. Impacts on rice sector of adopting GM rice (percent change, relative to baseline in 2010)

	Total impact Bt cotton & GM rice	Total impact GM rice	Yield increa- sing	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

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, EV). This is equivalent to about USD 0.80 per person per year. The adoption of GM rice enhances welfare in China by 4155 million USD. The impact is therefore 4 times larger than in the case of Bt cotton, which is explained by the larger size of the rice sector in 2010. 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 improves in both experiments, and this leads to a deterioration of the trade balance.

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

	Bt cotton	GM rice	Total
Welfare (EV, million USD)	1097	4155	5249
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

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

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. Other 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) and to a lesser extent, the fish sector can lower their 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.

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 observed for Bt cotton.

Table 7. Impacts of adoption of Bt cotton and GM rice on other sectors in 2010 (percentage change relative to baseline)

	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

Impact in different periods

Table 8 shows the impact of adopting Bt corn and GM rice over time. The first two columns show the impact that is already achieved in the past (until 2001). The gains of Bt corn are already partly realized (26% of welfare over the total period) while GM rice is not yet adopted and hence there are zero welfare effect in the past. The gains from adopting Bt cotton follow an S-shaped adoption curve. The gains are highest in the period 2001-2005 (46% of the total welfare gain) and slow down in the period 2005-2010, as most farmers that potentially adopt have already switched to the new varieties. (25% of the total welfare gains are realized in the last period). For GM rice all the benefits have still to come. In 2001-2005 adoption starts and a minor part of the gains may be realized (35% of welfare gains total period). In 2005-2010 China is expected to arrive at the steep part of the adoption curve and a large part of the potential gains will be realized. Figure 1 shows the cumulative output gains obtained from the simulations. Again, the S-shaped curvature for Bt cotton 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.

Table 8. Impact in different periods: adoption of Bt cotton and GM rice (percent changes relative to baseline)

	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	-5.1	0.1	-8.6	0
Output volume	0	0	0.7	0	1.2	0
Export volume	0	-0.2	23.6	-0.4	37.9	-0.2
Trade balance (million USD)	0	-1	74	-1	139	-1
Cotton						
Supply price	0	-3.7	-0.2	-6.2	-0.3	-3.4
Output volume	0	1.4	0	2.8	0.1	1.6
Export volume	0	16.5	0.7	26.4	1.1	12.8
Trade balance (million USD)	0	62	3	127	9	95
Macro						
Welfare (million USD)	0	289	1474	511	2697	303

Source: model simulations

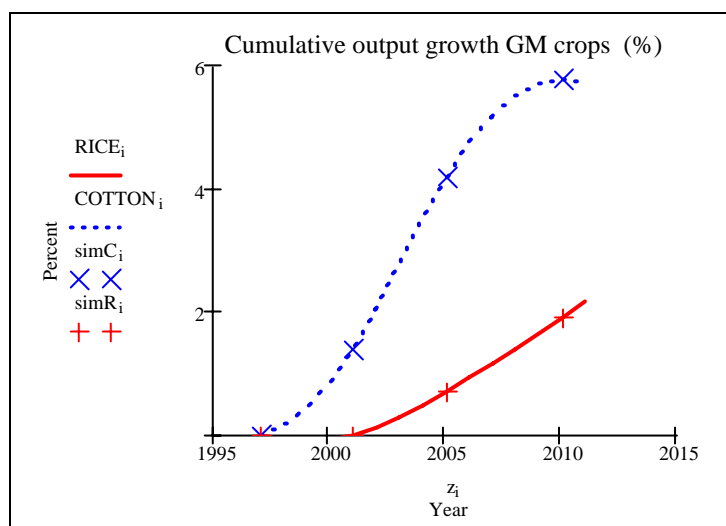


Figure 1: Simulated output growth rates over time

GMO Trade Ban on GM Rice

In this scenario China is engaged in producing both Bt cotton and GM rice. However, consumer concerns lead to a ban on GM food products. More specifically, the enlarged EU, Japan, Korea and South East Asia ban GM rice from China. Technically, this is

modeled as a taste shift against Chinese rice imports that reduces these countries' imports of Chinese rice to zero.

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% additional exports relative to the baseline result for 2010 (Table 9). 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 respectively South East Asia, Japan-Korea and the EU27 are respectively. Rice output is also declining, by 0.5 percent points.. The drop is limited, because the share of exports in production is only 1.2%. The rice trade balance deteriorates with 154 million USD and welfare in China decreases with 20 million USD.

Table 9. Impacts of GM import ban on China and other regions (comparison against baseline in 2010)

	<i>Adopt Bt cotton and GM rice</i>	<i>GM trade ban</i>
China		
Rice exports (% change)	66.9	5.3
Rice output (% change)	1.4	0.9
Change rice trade balance (million USD)	173.2	19
Welfare (million USD)	5249	5229
Other regions		
Japan & Korea		
Welfare (million USD)	298	212
- Terms of trade effect	132	130
- Taste effect	0	-38
- Allocative effects	111	65
South East Asia		
Welfare (million USD)	13	-33
- Terms of trade effect	-16	-3
- Taste effect	0	-33
- Allocative effects	13	-12
EU-27		
Welfare (million USD)	-7	-52
- Terms of trade effect	-79	-84
- Taste effect	0	-16
- Allocative effects	1	-15

Source: model simulations

Table 9 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. The negative welfare effect is due to a negative taste effect (some consumers cannot buy their favorite Chinese rice).⁷ Next to this, there is a negative

⁷ In these simulations we are not taking into account the possible positive taste impact by some consumers in these countries.

allocative effect because the banning of imports stimulates domestic production in the heavily protected rice sector. This results in misallocation of resources.

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 realised 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.

Labeling

In this scenario, China requires labeling of soybean imports from NAFTA and South America. While soybean imports will be subject to a very low tariff of only 3% as an outgrowth of the WTO accession agreement, there is a discussion about the implementation of a labeling system for soybean imports that distinguishes GM varieties. 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 the largest 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 which also have embraced the benefits of herbicide tolerant (Round-Up Ready) GM soybeans: Argentina and Brazil.

However, if a labeling system for imports is introduced, it is very likely that a labeling system for domestic produce has to be installed as well. This would follow from the GATT principle of national treatment, as enshrined in article 3 of the GATT⁸. It is at this stage not certain if and how the legal interpretation of the GATT articles will lead to the requirement for China to label its own GM crops. 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.

The labeling of GM rice in China is modeled as an increase in the cost of services required for rice production.⁹ We assume that total production costs will increase by 3 percent through labeling. Labeling of 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

⁸ Although treated slightly differently, the principle of national treatment also applies to services (GATS article 17) and intellectual property rights (TRIPS article 3). National treatment applies only once the product (or service or item of intellectual property right) has entered the national market.

⁹ The impact of GMO labeling on the domestic consumer preference is not modeled in this paper. We recognize that this impact might be substantial and could significantly reduce the benefits of GMOs to China.

with 5%. It should be noted that we assume here that only NAFTA and SAM labels their soybeans that are exported to China. Labeling by other countries, most notably the EU, is not included.

Table 10: Impacts of labeling in 2010 (percent change relative to baseline)

	<i>Bt cotton & GM rice adoption with GM rice trade ban</i>	<i>Labeling Soybean imports and domestic rice</i>
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
Soybeans		
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

Source: model simulations

Table 10 shows the 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 import price of soybeans from NAFTA and South America with 7.1% and 6.2%, respectively, resulting in a drop considerable 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 in terms of welfare. 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. If it wants to label US soybean imports, it may have to accept the obligation to install a labeling system and institutional structure domestically, in order to comply with the GATT principle of

national treatment. This raises the domestic price of soybeans, and benefits Chinese soybean farmers, who will see a shift towards cheaper domestic demand, and are able to increase output at higher prices. However, domestic labeling 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 US imports, but it hurts rice consumers.

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 NAFTA soybeans does not exist, the price effects on imported soybeans would be smaller.

VI. 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.

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 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 3.5US\$ 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 1998.¹⁰ 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.

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

¹⁰ World Development Indicators. International poverty line of 1\$ (PPP adjusted) in 1998.

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 as well as major rice exporters (i.e., Thailand, Vietnam and Burma). 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. The immediate impact is small on other 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 US soybean imports, it may have to accept the obligation to install a labeling system and institutional structure domestically, in order to comply with the GATT principle of national treatment. 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 suggested that China should continue to promote its GM biotechnology, including commercializing its GM food crops. Policy makers should put less weight on the international dimension in making their decisions on biotechnology development.

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