China Agricultural Economic Review

Economic impacts of commercializing insect-resistant GM maize in China

Wei Xie, Tariq Ali, Qi Cui, Jikun Huang,

Economic impacts of commercializing insect-resistant GM maize in China

Wei Xie, Tariq Ali, Qi Cui and Jikun Huang
China Center for Agricultural Policy, School of Advanced Agricultural Sciences, Peking University, Beijing, China

Received 27 June 2017
Revised 4 July 2017
Accepted 11 July 2017

Abstract

Purpose – The purpose of this paper is to examine the potential economic impacts of China's insect-resistant GM maize and provide new evidence for decision making concerning its commercialization.
Design/methodology/approach – This study uses data drawn from the production trials of insect-resistant GM maize and expert interviews to determine the impacts of commercializing GM maize at farm level under three scenarios with varying severity of insect pest attacks in maize production. Economic impacts are simulated using a modified Global Trade Analysis Project model.
Findings – In farm terms, insect-resistant GM maize increases crop yield and reduces both pesticide and labor inputs. In national terms, China can increase its GDP by USD8.6 billion and maize self-sufficiency by about 2 percent given normal insect pest attacks if China commercializes GM maize. Additional beneficiaries include consumers and the livestock industry. Non-maize crops can also benefit from land saving through GM maize commercialization. Chemical is a sector with the decrease in its output because demand for pesticides will fall.
Originality/value – Although China has announced a roadmap for commercializing GM crops for use as feed and in processing after nearly two decades of producing GM cotton, no clear timetable for producing GM maize as feed has been established due to several concerns, including the potential for economic gains from GM maize. This study is the first to assess the economic impacts of commercializing China's GM maize. The findings should have significant policy implications for the development and commercialization of GM crops in general and GM maize in particular.

Keywords China, Commercialization, Economic impacts, GM maize, Insect-resistant

Paper type Research paper

1. Introduction

While the global area under genetically modified (GM) crops has increased significantly over the past two decades, no expansion of GM crop area has occurred in China in recent decades (ISAAA, 2016). Indeed, China has not approved any major field GM crop for production since insect-resistant GM cotton was commercialized in 1997[1]. On the other hand, the government has heavily invested in research and development (R&D) in GM technologies (Huang *et al.*, 2005, 2012; Hu *et al.*, 2012). For example, China launched a grand GM program, the National GM Variety Development Special Program (GMSP), in 2008 to support R&D in GM crops and animals with a planned budget of USD3.8 billion between 2008 and 2020 (Huang *et al.*, 2012). China is now ahead of most developing countries in R&D in GM technology.

However, despite its advantage in the R&D of GM technology, China's GM crop commercialization has slowed down after 2009, right after the Ministry of Agriculture issued production safety certificates to *Bacillus thuringiensis* (*Bt*) rice and GM phytase maize[2]. The approval of these new GM crops, particularly *Bt* rice, has led to extensive debates on the pros and cons of GM technology (Pang *et al.*, 2016). Supporters of GM technology view it as an important tool for boosting agricultural productivity, increasing the competitiveness of

This research was supported by grants from the National GM Variety Development Special Program (2016ZX08015-001), National Natural Science Foundation of China (71333013 and 71503243), Chinese Academy of Sciences (Y02015004), and Tsinghua University (CIRS2016-03).

China Agricultural Economic Review
Vol. 9 No. 3, 2017
pp. 340-354

1756-137X
DOI 10.1108/CAER-06-2017-0126

agriculture and thus China's food security. Opponents are wary of the biosafety of GM crops particularly that of GM crops used for food consumption (Ye and Li, 2014). There are also concerns about the impact of GM technology on China's agricultural trade (Huang and Yang, 2014). Despite growing support for the use of GM technology for commercial production among scientific communities (National Academies of Science, Engineering and Medicine, 2016), the public perception that GM crops are unsafe for food consumption has increased sharply in China since 2010 (Huang and Peng, 2015). The rising public concerns about GM technology have influenced the country's position on commercializing new GM crops. Consequently, neither *Bt* rice nor phytase maize were approved for commercial production after they were issued production safety certificates in 2009.

Interestingly, while the government is reluctant to allow GM maize and soybean production in China, the country has been a main importer of GM maize and soybean. In 2016, for example, China exported only miniscule quantities of maize (about 4,000 tons) and soybean (0.13 million tons or Mt), but maize and soybean imports (both are GM crops) have reached 3.2 Mt and 83.9 Mt, respectively (UN Comtrade, 2017). Prohibiting GM maize and soybean production within China while allowing the consumption of imported GM maize (mainly used for feed) and soybean (mainly used for processing) has raised questions about the costs of not commercializing China's own GM maize and soybean.

After a careful analysis of the tradeoffs between the potential benefits of GM technology and public concerns about the safety of GM food, a compromised roadmap for commercializing GM crops was announced in 2014. For major field crops, rather than moving the production of GM crops from the current non-food crop (e.g. *Bt* cotton) to crops directly used as food, the commercialization of GM crops will follow a three-step roadmap: non-food crops, crops indirectly used as food (e.g. maize and soybean), and crops directly used as food (e.g. rice and wheat) (Ministry of Agriculture, 2014). Although this roadmap for commercializing GM crops was announced three years ago and public resistance to GM maize is much lower than is that to GM rice, no clear timetable for producing GM maize for feed use and industrial processing has yet been established in China. Our interviews with officials and scientists revealed that the current hesitation to commercialize GM maize is mainly due to three concerns: about whether China's own GM maize technology will be viable and competitive; about the potential economic gains from GM maize; and about whether China needs to commercialize GM maize now given the current huge maize stock held by the government[3]. All three questions are directly or indirectly related to the potential economic impacts of GM maize technology.

This study seeks to answer the questions raised above, focusing on the economic impacts of a major GM maize technology: insect-resistant GM maize. We first examine the potential impacts of insect-resistant GM maize at the farm level, and then use a modified Global Trade Analysis Project (GTAP) model to assess the national impacts of GM maize. The results show that China can gain significantly by commercializing insect-resistant GM maize ("GM maize" hereafter). The overall economy could gain USD4-14 billion in 2025 if China commercializes the technology by 2019. Meanwhile, the commercialization of GM maize will increase the maize self-sufficiency rate by about 1-3 percent. Other major beneficiaries include consumers, due to the lower meat price; the livestock industry, due to the cheaper feed and higher meat demand; and other crops, due to the lower land prices. However, the chemical sector's production will decline due to GM maize commercialization. These findings have important policy implications for the development and commercialization of GM crops in general and of GM maize in particular in China.

The rest of this paper is organized as follows. Section 2 briefly explains the supply and demand for maize in China since 1990 and future challenges, followed by a description of the current development of GM maize technology, with a focus on insect-resistant varieties. Section 3 describes the study's methodology and scenarios, including the study's overall approach, scenarios on GM maize's impact, and the GTAP model used to simulate the economic impacts. Section 4 explains the impacts of GM maize on the overall economy, the maize sector, and other major sectors. The final section concludes the study and outlines several policy implications.

2. China's maize economy and GM maize technology

2.1 The maize economy

Maize has experienced the fastest growth among cereal crops in China. The average annual growth rate of maize production reached 3.4 percent from 1990 to 2016, which was much higher than that of rice (1.1 percent) and wheat (0.4 percent) over the same period (National Bureau of Statistics of China (NBSC), 2016). Two-thirds of the maize production increase came from maize area expansion, and the other one third came from its yield increase. In contrast to rice and wheat, the sown areas of which have gradually decreased, maize area grew at an average annual rate of 2.0 percent from 1990 to 2009, and its growth rate accelerated to 3.4 percent from 2009 to 2015 at the expense of competing crops after China implemented the maize Temperate Reserve Policy (TRP; Huang and Yang, 2017). Between 2009 and 2015, annual maize production growth reached 5.4 percent. Indeed, maize has become the largest crop in China since 2007, and its area had expanded to 38.1 million hectares by 2015. Maize yield has also grown steadily, with an average annual growth rate of 1.1 percent from 1990 to 2015, which is lower than that of wheat (2.1 percent) but higher than that of rice (0.7 percent) over the same period. By 2015, maize yield had reached 5.9 tons per hectare. Although the current maize yield in China is higher than the global average (5.6 tons/ha in 2015), it is still much lower than the yields in major maize-exporting countries, such as those in the US (10.7 tons/ha), Canada (9.4 tons/ha), and Australia (7.5 tons/ha) in 2014 (FAO, 2017).

Accompanying the fast growth of maize production from 1990 to 2015 was the even faster growth of maize demand in China, but growth in demand and production differed widely before and after 2009. Data on the maize supply and utilization balance sheet developed by the China Center for Agricultural Policy (China Center for Agricultural Policy, 2017) show that total demand for maize rose from 79.5 Mt in 1990 to 173.8 Mt in 2009 and 192.7 Mt in 2015, at an average annual growth rate of 3.6 percent between 1990 and 2015, which fell from 4.2 percent between 1990 and 2009 to 1.7 percent between 2009 and 2015. This recent decline in the growth of maize demand was due mainly to the TRP, which raised maize prices and therefore slowed growth in demand for feed and industrial uses (Huang and Yang, 2017). Since maize used as feed increased from 51.1 Mt in 1990 to 115.9 Mt in 2009 (accounting for 69 percent of the increase in maize demand) from 1990 to 2009, it has remained largely unchanged thereafter. To meet the growing demand for meat driven by the rapid growth in incomes and urbanization, China's meat imports have been increasing since 2009.

Because growth in the demand for maize exceeded production growth in the 1990s and 2000s, maize exports gradually declined, and China shifted from a net exporter to a net importer in 2010 (National Bureau of Statistics of China, 2011). In fact, annual maize exports exceeded 10 Mt and reached a historic high level in 2003 (16.4 Mt) but then fell significantly thereafter, and China has been a net importer of maize since 2009. It is interesting to note that, while rising incomes and urbanization once caused China to import maize, China has been a net maize importer since 2010, a period when maize production growth was higher than its demand growth. This seemingly contradictory phenomenon is explained by the increasing price gap between domestic and international markets resulting from the maize TRP. Due to a domestic oversupply of maize and rising imports, China held more than 200 Mt of maize stocks in 2016. Imports of maize substitutes (e.g. dry distilled grains (DDGs), barley, sorghum, cassava) have also increased substantially in China (Huang and Yang, 2017; Hejazi and Marchant, 2017).

In June 2016, the Chinese government announced maize market reform intended to reshape maize production and demand. This reform, called *Jiabu Fenli* in Chinese, is designed to separate income support from pricing policy and to allow maize prices to be determined by the market. Within a year, maize prices fell sharply to their levels before the 2008 maize TRP, and the wide difference between domestic and import prices has been narrowing since early 2017. Due to this price decline, maize production decreased by 2.6 percent in 2016 and is projected to decline further by nearly 3 percent in 2017 (MOA, 2017). The lower price of maize has stimulated both feed demand to increase livestock production and maize demand for industrial processing. The growth of maize demand is expected to return to its level before 2009, and maize production could decline along with the lower maize prices, as China has decided to clear its excessive maize stocks by around 2020.

After 2020, China is likely to move into a maize deficit era given the increasing imports (Lv, 2013; Norse *et al.*, 2014). After the excessive maize stocks are eliminated, the pressure to increase maize imports will grow as the projected demand growth will exceed the domestic production growth during the 2020s (China Agricultural Academy of Sciences, 2017). However, whether maize imports will increase significantly after 2020 depends on China's maize trade policy. Maize imports have been managed under Tariff Rate Quota (TRQ) since China joined the World Trade Organization in 2001. Under this TRQ scheme, the maize import tariff is only 1 percent for imports within the import quota (7.2 Mt); if imports exceed this quota, China can decide whether to impose the 65 percent import tariff. However, the trade-off between importing maize or meat is the deciding factor in imposing this higher TRQ tariff. While imposing the above-quota import tariff can protect domestic maize production, it can hurt livestock production and increases meat imports due to the higher domestic maize and feed prices. Given the importance of the national meat market, China may follow the cotton import policy, i.e., to facilitate the development of downstream cotton industries (e.g. textile and garment industries), China has never imposed the above-quota import tariff (50 percent) on cotton imports that exceed its import quota. Of course, to have more effective options for increasing maize production and reducing imports in the long run, China will have to increase productivity significantly through technology innovations.

2.2 GM maize technology

Chinese maize R&D has generated most of the technologies used by farmers. The first single cross hybrid maize was commercially released in 1966. Maize farmers in China have used more than 200 major hybrid varieties each year since the late 1990s, this number reaching 932 in 2014 (Ministry of Agriculture (MOA), 1982-2014, 2015)[4]. Currently, the most popular varieties among farmers are Zhengdan-958 and Xianyu-335, accounting for 8.7 percent and 6.7 percent of the total maize sown area, respectively, in 2014 (MOA, 1982-2014, 2015).

China's GM maize research began in the late 1980s and was significantly enhanced by the national GM Special Program (GMSP) launched in 2008. The GMSP is directed toward five major crops (rice, wheat, maize, cotton and soybean) and three livestock sectors (pig, cattle and sheep). In addition to the phytase maize that was given the safety certificate for production in 2009, several new GM maize varieties have also been under environmental release or production field trial stages. These include GM maize with insect resistance, with both insect and herbicide resistance, with herbicide resistance, and with drought resistance.

This study examines insect-resistant GM maize because this technology is almost ready for production. Several insect-resistant GM maize events have reached the production trial stage, and others have applied for a safety certificate to enable production. These include the C0030.3.5 with Cry1Ab and CP4 genes and resistance to both insect and herbicide, the Double Resistance 12-5 with fusion genes of Cry1Ab and Cry2Aj and gene of G10evo and resistance to both insects and herbicide, the insect-resistant IE09S034 with the Cry1Ie gene, and the GH5112E-117C with G2-aroA and *Bt* Cry1Ah genes and resistance to both insects and herbicide. C0030.3.5, developed by Dabeinong Company, passed production trials in 2012/13, and a production safety certificate was applied in 2015. Double Resistance 12-5, developed by Zhejiang University and Hangzhou Ruifeng Biotech Company, completed its production trials in 2014, and a production safety certificate was applied for in 2016. Both the IE09S034 developed by the Chinese Academy of Agricultural Sciences and the GH5112E-117C developed by Beijing Aoruijin Company have also completed their production trials and are now ready for production safety certificate applications.

The promising new strains of the four abovementioned events via backcross have been developed for widely adopted maize varieties such as Zhengdan-985, Liangyu-88, Danyu-605 and Zhongdan-909, etc. Field experiments on these new strains show that they can significantly reduce pesticide inputs and raise maize yields in all experimental stations. Details on these field performances for pesticide use, labor input, and crop yield are presented in section 3.3.

3. Methodology and scenarios

Assessing the economic impacts of GM maize requires examining the primary impacts of GM maize at the farm level and its adoption trend over time. Below, these data are used to formulate a set of scenarios for GM maize commercialization and to evaluate the economic impacts of GM maize based on a modified GTAP model.

3.1 GM maize impacts at farm level and production scenarios

This study estimates the most likely impacts of insect-resistant GM maize at the farm level if GM maize varieties were adopted by farmers using the following three sets of data. The first data set reflects the performance of GM maize in the field trials. These production trials show that they can effectively control the corn borer and other insect pests and thus increase maize yield by 6-11 percent at the experiment stations in a normal year in various provinces across China. The GM maize also can save labor time expended for pesticide application and farm management. The second data set comes from interviews with scientists working on both GM and non-GM technologies. These interviews gleaned scientists' views on the performance of GM maize during the production trial stage and on the potential impacts of GM maize at the farm level if they were adopted by farmers. These data sets enable a measurement of the impacts of GM maize in a normal year of insect pest occurrence at the farm level (see column 2, Table I). The third data set reflects the severity of insect pests encountered in maize production in China. Generally, maize yield loss from insect pest attacks ranges from under 5 percent to more than 20 percent. Logically, the more severe the insect pest attacks, the greater the benefits of GM maize production.

To estimate the impacts of insect-resistant GM maize at farm level, a control group is selected. Here, Zhengdan-958, the most widely adopted non-GM maize variety in China, is used for the study. For simplicity, the study normalizes each value of changes in yield, pesticide use, labor use, and seed price for GM maize by the corresponding value of each of the above

Table I. Performance of GM maize, compared with Zhengdan-958 (value = 1)

	GM maize performance indicators by severity of insect pests		
	Light	Normal	Severe
Yield	1.033	1.065	1.098
Pesticide use	0.80	0.40	0.20
Labor use	0.98	0.95	0.92
Seed price	1.75	1.75	1.75

Source: Authors' estimates

performance indicators for Zhengdan-958. Thus, each of the above performance indicators for Zhengdan-958 is equal to 1. The study then calculates each of these indicators for GM maize. The results are presented in Table I. In a normal insect pest attack year (see column 2), insect-resistant GM maize can increase yield by 6.5 percent at the farm level compared with Zhengdan-958. This yield increase is less than the one reported in the field trials, but it reflects the difference between the field trials conducted by scientists and actual production achieved at the farm level. Regarding pesticide application, the study uses the conservative estimate of a 60 percent reduction rate, which is less than that often obtained in the field trials (80-95 percent). The more effective control of insect pests with GM maize is associated with the time spent on pesticide application and field management, which can save 5 percent of the total labor use in maize production. The adoption of GM maize will increase the price of maize seeds; however, better seed is often associated with higher prices, and it is assumed that the price of GM maize seeds will be 75 percent higher than the seed price of Zhengdan-958.

After identifying the impacts of GM maize in a normal insect pest year (or "normal"), the study formulates two more alternative scenarios with less and more severe insect pest problems: the "light insect pest attack year" (or "light") and the "severe insect pest attack year" (or "severe"), respectively. Based on historical data on the severity of insect pests and yield loss in China relative to a normal year, it is assumed that the impact on maize yield will be an increase (decrease) of 50 percent in the severe year (light year). A similar scale of impacts is applied to pesticide use and labor input (see Table I).

To estimate the economic impacts of insect-resistant GM maize, the study also needs to anticipate the path and speed at which farmers will adopt GM maize. Based on the current development of GM maize (discussed in the preceding section), it is assumed that insect-resistant GM maize will be approved for commercialization in 2019. Then, a GM maize adoption speed and path are assumed that are similar to those for GM cotton in China (Huang *et al.*, 2004; Qiao *et al.*, 2017). Thus, after two or three years of a slow spread of GM maize varieties due to the time needed to generate them, adoption will be significantly accelerated. By 2025, except for the maize used as food (which accounts for less than 5 percent of total maize production), 95 percent of maize production will have fully adopted the insect-resistant GM maize varieties.

3.2 GTAP model and analyses

Given the impacts of GM maize at the farm level (see Table I) and its adoption rate of 95 percent in 2025, the study estimates the average impacts of GM maize on the inputs and output of maize production per hectare. The study uses these average impacts as shocks in the GTAP model to simulate the economy given the commercialization of GM maize in 2025 for three alternative years with different insect pest attack severity levels (light, normal, and severe). Then, the impacts of GM maize are estimated by comparing between the economy with and without GM maize commercialization.

3.2.1 GTAP model and baseline database to 2025. The GTAP model is a well-known multi-country, multi-sector computable general equilibrium model (Hertel, 1997) based on the assumptions that producers minimize their production costs and consumers maximize their utility, subject to certain common constraints. Supplies and demands of all commodities clear by adjusting prices in perfectly competitive markets. Representative consumers of each country or region are modeled as having a non-homothetic Constant Difference of Elasticity demand function. On the production side, firms combine intermediate inputs and primary factors (e.g. land, labor, capital) to produce commodities with constant-return-to-scale technology. Intermediate inputs are composites of domestic and foreign components, with the foreign component differentiated according to region of origin (i.e. the Armington assumption).

This study uses the latest version of the GTAP database (version 9), with reference year 2011. Maize and soybean, two of China's most important agricultural imports, are not presented in the original GTAP database separately. As a starting point for the simulations, we split the original sectors containing maize ("grains") and soybeans ("oil seeds") by using production, consumption and trade shares from FAO and UN Comtrade based on Horridge's splitting method (Horridge, 2005). At the same time, we pay close attention to regional (China+11 regions) and sectoral aggregation, by keeping the maximum detailed disaggregation of the data. On the sectoral aggregation, see Table AII.

The comparative static model is used to generate the baseline projection for 2011–2025. The baseline database is constructed by recursively updating the database such that given GDP targets are met through given exogenous estimates of factor endowments – skilled labor, unskilled labor, capital, natural resources, and population. The procedure and the exogenous macro assumptions are discussed in detail in Hertel (1997) and Walmsley *et al.* (2006).

The baseline projection also includes the implementation and/or continuation of current trade policies in the coming decade. The updated baseline incorporates new data for the China's economy, especially the input-output relationship for maize, soybeans, rice, and wheat. China's trade in agricultural and industrial commodities is also updated using the latest data from FAO and National Bureau of Statistics of China, including the significant changes in the trade in maize, soybean and livestock from 2011 to 2015 (FAO, 2017; NBSC, 2016). The study also incorporates improved econometric estimates for income elasticities for livestock products, maize, rice and wheat (Huang *et al.*, 2004).

3.2.2 Alternative maize policies. One of two policies may be implemented for maize imports. As discussed in Section 2, although maize import is under TRQ policy, China is unlikely to impose above-quota tariffs (65 percent) on imports of maize that exceed the import quota (7.2 Mt) if it wishes to protect its domestic meat supply. Therefore, this study focuses on the impacts of GM maize in a scenario whereby China does not implement its maize TRQ policy (i.e. without a TRQ policy). In this scenario, China liberalizes its maize trade to facilitate the domestic production of livestock to meet the nation's growing demand for meat. This scenario is called the "baseline scenario without TRQ policy."

However, China could apply its maize TRQ policy. This scenario is called the "baseline scenario with TRQ policy." The major differences between the two scenarios concerning economic impacts occur between the maize and livestock sectors. Therefore, this analysis focuses on a comparison of the impacts on the maize and livestock sectors (i.e. pork and poultry) between the scenarios with and without a TRQ policy, though the overall economic impact is briefly discussed.

The key projection results for the maize and meat sectors are summarized here (detailed results of the baseline scenario without TRQ policy are presented in the Appendix). In the baseline scenario without TRQ policy, maize output is projected to increase by only 4 percent from 2015 to 2025, but imports will reach 20 Mt. On the other hand, China is projected to achieve near full self-sufficiency in pork and poultry. In the baseline scenario with TRQ policy, however, higher maize prices will stimulate maize production due to the above-quota tariff. While maize production will increase, livestock production will decrease due to the TRQ policy. These results are discussed in section 4.5.

4. Economic impacts of GM maize

This section presents the results concerning the economic impacts of commercializing GM maize on macroeconomic indicators, the maize economy, and other agricultural commodities under three alternative scenarios. First, the impacts under the baseline scenario without TRQ policies are discussed in Tables II-V. Then, the impacts under the baseline scenario with TRQ policy are discussed, focusing on the maize and livestock sectors (Table VI).

Table II. Impacts of GM maize on the macro economy in 2025

	Impacts by severity of insect pests		
	Light	Normal	Severe
Real GDP (%)	0.03	0.05	0.08
Real GDP (billion USD)	4.13	8.58	13.72
Factor prices (%)			
Land	−0.81	−1.90	−2.41
Unskilled labor	0.03	0.08	0.11
Skilled labor	0.04	0.12	0.18
Capital	0.04	0.12	0.17
Aggregate agricultural trade balance (million USD)	632	1,236	1,933

Note: The basis for comparison is the baseline scenario without TRQ policy
Source: Authors' estimations

Table III. Impacts of GM maize on the maize economy in 2025

	Baseline results (in level)	Impacts by severity of insect pests		
		Light	Normal	Severe
Percent change				
Price		−3.93	−8.33	−12.32
Output		2.39	5.03	7.70
Yield		3.09	6.18	9.26
Area		−0.59	−0.94	−1.25
Import		−11.31	−19.81	−33.23
Export		10.17	17.62	30.39
Quantity change				
Output (1,000 tons)	234,590	5,607	11,802	18,066
Yield (tons/ha)	6.50	0.20	0.40	0.60
Area (1,000 Ha)	36,200	−214	−340	−452
Import (1,000 tons)	19,890	−2,250	−3,940	−6,609
Export (1,000 tons)	10	1	2	3

Note: The basis for comparison is the baseline scenario without TRQ policy
Source: Authors' estimations

Table IV. Impacts of GM maize on the production of other agricultural commodities in 2025

	Impacts on production (%) by severity of insect pests		
Sector	Light	Normal	Severe
Rice	0.01	0.02	0.01
Wheat	0.01	0.02	0.09
Other cereals	0.20	0.39	0.56
Vegetables and fruits	0.04	0.06	0.09
Soybean	0.02	0.01	0.06
Other oilseed	0.02	0.03	0.03
Sugar	0.05	0.09	0.12
Cotton	0.04	0.05	0.06
Other crops	0.06	0.08	0.09
Pork and poultry	0.11	0.23	0.35

Note: The basis for comparison is the baseline scenario without TRQ policy
Source: Authors' estimations

4.1 *Impacts on the macro economy*

The commercialization of GM maize will have significantly positive effects on China's economy. Due to the increased production of maize and commodities in other sectors, China's GDP grows by USD8.58 billion (or 0.05 percent of GDP in 2025) under normal insect pest attack years (see column 2, Table II). Even under the light pest attack years, GDP still increases by USD4.13 billion (0.03 percent). Under severe pest attack years, the annual GDP increase is as high as USD13.72 billion (0.08 percent; see column 3, Table II).

The impact on factor prices varies among different factors. The prices of sluggish factors (land) fall and those of mobile factors (labor and capital) increase in comparison to baseline scenario. A high yield of GM maize will release the land endowments, but it cannot be easily reallocated to other crops due to its sluggish nature, resulting in an oversupply and a price decline in land. The demand for labor and capital increases due to expansion in other sectors, especially in the livestock and processed food sectors. This higher demand causes the prices of labor and capital to increase.

The adoption of GM maize will improve the trade balance of the agriculture sector. Due to the increased domestic production in the maize and livestock sectors and the lower prices of these commodities, their exports will increase and imports will decrease. With the

Table V. Impacts of GM maize on stakeholders along the value chain in 2025

	Impacts by severity of insect pests		
	Light	Normal	Severe
Gain in consumers welfare (billion USD)	3.19	6.20	9.34
Output gain for pork and poultry industry (billion USD)	0.79	1.67	2.53
Output loss for pesticide industry (billion USD)	−0.06	−0.15	−0.22

Source: Authors' estimations

Table VI. Comparison of GM maize's impacts under scenarios with and without TRQ policy in 2025

	Baseline results (in level)		Impacts in severe pest attack	
	With TRQ	Without TRQ	With TRQ	Without TRQ
Real GDP (%)			0.09	0.08
Aggregate agricultural trade balance (million USD)	−112,107	−123,525	1808	1933
Gain in consumer welfare (billion USD)			10.10	9.34
Maize				
Production (%)			8.1	7.7
Import (%)			0.0	−33.2
Export (%)			17.0	30.4
Production (1,000 tons)	238,820	234,590	19,344	18,063
Import (1,000 tons)	7,200	19,890	0	−6,610
Export (1,000 tons)	6	10	1	3
Self-sufficiency rate (%)	97.1	92.2	0.21	2.82
Pork and poultry				
Production (%)			1.1	0.4
Import (%)			−18.3	−8.9
Export (%)			5.0	3.4
Production (1,000 tons)	75,596	78,270	832	274
Import (1,000 tons)	4,090	1,550	−747	−138
Export (1,000 tons)	638	720	32	25
Self-sufficiency rate (%)	95.6	99.0	1.00	0.21

Source: Authors' estimations

movements of labor, capital, and a part of the land to other agricultural sectors, production in other agricultural sectors will also increase and prices will decrease, resulting in a net increase in exports in other agriculture sectors. All these factors will cause an increase of USD632 to 1933 million in the aggregate trade balance across the whole agricultural economy (see Table II).

4.2 Impacts on the maize sector

GM maize affects the maize economy through increased yield and saved pesticide and labor costs against increased seed costs. The new technology increases maize output and lowers maize price (see Table III). Due to its inherently higher yield, GM maize will save land area (see row 4, Table III), which will allow the production of other crops to increase (as discussed later). The expansion in production and reduction in the price of maize will lower imports and increase exports (see Table III). Under the normal year scenario, for example, an increase of 6.18 percent in maize yield will increase its production by 5.03 percent and decrease its price by 8.33 percent (see top half of Table III). Due to the higher domestic output, imports will fall significantly by 19.8 percent and exports will increase by 17.6 percent.

These trends become clearer when we convert the percentage changes into quantity changes (see bottom half of Table III). Under normal year scenario, for example, a 0.4 tons/ha increase in yield would increase output by 11.8 Mt. The gap between yield improvement and output expansion is visible in the reduction of 0.34 million ha in maize area. Furthermore, imports will fall by 3.94 Mt, equivalent to 1.68 percent of the production under baseline. The absolute effects of GM maize adoption on maize exports from China are marginal. The effects increase in magnitude as we move from the low pest severity to the high pest severity scenario, signifying the important role of GM technology, which is most effective amid severe pest attacks on maize crop.

4.3 Impact on the rest of the agricultural sector

The rest of China's agricultural sector will expand either due to the availability of extra production factors freed up by GM maize or to the lower price of maize used as feed stock (see Table IV). The changes in these sectors depend on whether they compete with maize, use maize as input, or use the freed-up resources most efficiently. Therefore, the production of other crops will expand (through the use of extra land), and livestock will expand due to lower maize prices, as maize is one of the two most important feeds (along with soybean). Pork and poultry gain the most, as they are the main users of maize in their production processes. The lower domestic price of maize will increase pork and poultry production rates from 0.11 percent in the light year to 0.35 percent in the severe pest attack year. Other cereals (e.g. barley, millet) that use resources (land and labor) similar to those used for maize will expand by the highest margin among all the agricultural sectors (0.2 percent under light year and 0.56 percent under the severe pest attack year).

4.4 Impact on stakeholders along maize value chain

Except for those in the chemical sector, all stakeholders along the maize value chain will gain from GM maize technology. Due to the improved supply of agricultural products and lower prices, consumers in China will experience significant welfare gains under all scenarios (see Table V), ranging from USD3.19 billion under the light insect pest attack years to USD9.34 billion under the severe insect pest attack years. Pork and poultry sectors using maize as feed are also major beneficiaries: their output will increase from USD0.79 billion during low pest attack year to USD2.53 billion during severe pest attack year.

The chemical sector is a major loser from GM maize commercialization (see last row, Table V). Obviously, with the adoption of insect-resistant GM maize, pesticide use will be significantly reduced. During normal insect pest attack years, annual pesticide output may be reduced by USD150 million. During severe years, the annual output reduction may reach USD220 million. However, the lower pesticide use may be seen as an environmental benefit and a positive effect on human and livestock health.

4.5 Impacts under maize TRQ policy

We also modeled the impacts of GM maize in the situation where China decides to implement TRQ on maize imports. Under the baseline scenario with TRQ implementation, maize imports will be limited to the import quota level (7.2 Mt), and the maize self-sufficiency rate will be at the high level of 97.1 percent in 2025. However, the livestock (pork and poultry) sector will be negatively affected, as the sector will have to use the more expensive maize grown in China. Pork and poultry production will decrease by about 3.4 percent, from about 78.3 thousand tons to 75.5 thousand tons in 2025 (see Table VI). Meanwhile, their imports will increase, causing the self-sufficiency rate to fall from 99.0 to 95.6 percent.

Table VI compares the impacts of GM maize on the maize and livestock sectors for years with severe insect pest attacks. As maize price in the domestic market will increase under the TRQ policy (due to reduced imports), a yield improvement of 9.26 percent will result in an 8.1 percent increase in output (compared to 7.7 percent under the scenario without TRQ policy). Maize imports will not change due to GM maize commercialization, as they will be limited to the import quota. The combined effects of the increased domestic output and zero change in imports will result in a smaller (0.21 percent) increase in China's maize self-sufficiency.

For the pork and poultry sectors, the increase in output will be higher (1.1 percent vs 0.4 percent) and imports will decrease more steeply (−18.3 percent vs −8.9 percent) than under the scenario without TRQ policy because GM maize can increase (reduce) maize production (maize prices) more significantly under the TRQ policy, further stimulating domestic livestock production. China's livestock self-sufficiency will improve by 1.00 percent under the TRQ policy but only by 0.21 percent under the scenario without TRQ policy. These results indicate that, although GM maize technology is adopted mainly due to its ability to fight pest attacks, it can also help ease demand pressure in the maize and livestock sectors.

The slightly higher impact of GM maize on domestic maize production under the TRQ policy will also result in a marginal increase in real GDP compared with the scenario without TRQ policy (0.091 vs 0.080; see Table VI). As no decrease in maize imports occurs under the TRQ policy, the total agricultural trade balance (exports minus imports) will increase slightly as well. Overall consumer welfare will increase from USD9.34 billion in the scenario without TRQ policy to USD10.1 billion in that with TRQ policy.

5. Concluding remarks and policy implications

Despite the rapid growth in its maize production, China shifted from a net exporter to a net imported in 2010, and its maize imports are projected to grow. The recent oversupply of maize was due mainly to the government's market intervention (TRP), which raised the domestic price but also accumulated huge stocks. Given its phased-out policy intervention and policy of destocking maize since 2016, China is likely to rebalance its maize production and demand in the coming years and may run into deficits again after 2020. According to the baseline projection of this study, under the scenario where above-quota tariffs are not imposed, maize imports increase to nearly 20 Mt to satisfy the increasing demand from livestock expansion. If China follows a maize TRQ policy, it will be highly self-sufficient in maize, but livestock imports (mainly pork and poultry) will increase, with the self-sufficiency rate of pork and poultry decreasing from 99 percent in 2015 to 95.6 percent in 2025.

This paper examines the economic impacts of insect-resistant GM maize at the macro and sectoral levels, as well as for stakeholders along the maize supply chain. The results suggest that the development of GM maize technology in China has been impressive. Several GM maize varieties are ready for production pending approval for commercial uses. The current oversupply of maize stock will soon vanish, and China will need new technologies with which to increase maize productivity. This study shows that the economic gains from GM maize are substantial. If China decides to commercialize insect-resistant GM maize, the annual increase in maize production from GM maize will range from 5.6 Mt (2.4 percent) to 18.1 Mt (7.7 percent) by 2025 if no maize TRQ policy is imposed. If a TRQ policy is imposed, a slightly higher gain could be obtained. The increased maize production would not only improve China's maize self-sufficiency but would also facilitate livestock production and reduce meat imports.

The GM maize would also increase the productions of all other crops and benefit all stakeholders along the maize supply chain, except for the pesticide industry. Even under the no-TRQ policy scenario, GM maize would conserve cultivated land by a range of 214-452 thousand hectares (see Table III), allowing other crops to expand their production. Meanwhile, the saved labor time required for maize production due to GM maize technology could be used for other production, increasing the overall net exports in the agricultural sector. Among stakeholders, consumers are the biggest beneficiaries: they would gain USD3.19-9.34 in total welfare from GM maize. Maize processing and livestock sectors would also gain from GM maize through expanded production. Of course, the pesticide sector would suffer output losses because of reduced pesticide use in maize production, which is not bad news given the environmental and health benefits (e.g. avoiding food safety issues from the intensive use of pesticides).

The results of this study have important policy implications. First, the returns on investment in GM technology are extremely high if the technology is commercialized in a timely manner. The annual economic gains from commercializing GM maize are far greater than the planned total budget for the entire GMSP (USD3.8 billion) from 2008 to 2020. Second, although China has made a roadmap for commercializing GM crops used as feed and processing, there is no clear timetable for producing GM maize as feed in the country. The results of this study suggest that a one year delay in commercializing insect-resistant GM maize will incur income losses in the range of USD4.13-13.72 billion. These are the opportunity costs of not making decision for one year. Third, although the consumers are the biggest beneficiary, they are not aware of this and indeed most of them are against or at least not favor of GM technologies (Huang and Peng, 2015). Providing them with accurate information about the economic impacts on different stakeholders is critically important for obtaining public support for GM technology.

Notes

1. Although China previously approved the production releases of color-altered petunias (1997), virus-resistant tomatoes (1998) and sweet peppers (1998), none of them has been commercially produced. The others that have been approved for commercial production include the insect-resistant poplar (2005) and virus-resistant papaya (2006), the area of the former was about 540 hectares and that of the latter reached 8550 hectares in 2016 (ISAAA, 2016).
2. After the first period (2009-2014) of the production safety certificates for *Bt* rice and GM phytase maize were expired, they were renewed in 2014 for the following five years (2014-2019).
3. China is believed to have more than 200 million tons of maize stocks held by the government at the end of 2016 due to the Temperate Reserve Program implemented from 2008 to 2015 (Zhao and Zhong, 2016; Huang and Yang, 2017).
4. A variety is considered "major" when its area exceeds 6670 ha in one year.

References

China Agricultural Academy of Sciences (2017), *China Agricultural Outlook (2016-2025)*, China Agricultural Science and Technology Press, Beijing (in Chinese).

China Center for Agricultural Policy (2017), *Baseline Projection of CAPSiM Model to 2025*, Peking University, Beijing.

FAO (2017), "Maize yield data", available at: www.fao.org/faostat/en/ (accessed June 2017).

Hejazi, M. and Marchant, M.A. (2017), "China's evolving agricultural support policies", *Choice*, Vol. 32 No. 2, pp. 1-7.

Hertel, T.W. (Ed.) (1997), *Global Trade Analysis: Modeling and Applications*, Cambridge University Press, New York, NY.

Horridge, M. (2005), *SplitCom – Programs to Disaggregate a GTAP Sector*, Centre of Policy Studies, Monash University, Melbourne, available at: www.monash.edu.au/policy/SplitCom.htm

Hu, R., Cai, J., Huang, J. and Wang, X. (2012), "Silos hamstring Chinese plant biotech sector", *Nature Biotechnology*, Vol. 30 No. 8, pp. 749-750.

Huang, J. and Yang, G. (2017), "Understanding recent challenges and new food policy in China", *Global Food Security*, Vol. 12, pp. 119-126.

Huang, J. and Yang, J. (2014), "Trade and economic implications of low level presence and asynchronous authorizations of agricultural biotech crops in China", *World Food Policy Journal*, Vol. 1 No. 2, pp. 30-47.

Huang, J. and Peng, B. (2015), "Consumers' perceptions on GM food safety in urban China", *Journal of Integrative Agriculture*, Vol. 14 No. 11, pp. 2391-2400.

Huang, J., Hu, R., Cai, J. and Wang, X. (2012), "Human research capacity in Chinese agbiotech", *Nature Biotechnology*, Vol. 30 No. 10, pp. 1007-1008.

Huang, J., Hu, R., Rozelle, S. and Pray, C. (2005), "Insect-resistant GM rice in farmers' fields: assessing productivity and health effects in China", *Science*, Vol. 308 No. 5722, pp. 688-690.

Huang, J., Hu, R., van Meijl, H. and van Tongeren, F. (2004), "Biotechnology boosts to crop productivity in China: trade and welfare implications", *Journal of Development Economics*, Vol. 75 No. 1, pp. 27-54.

ISAAA (2016), *Global Status of Commercialized Biotech/GM Crops: 2016*, Brief No. 52, ISAAA, Ithaca, NY.

Lv, X. (2013), "Review of mid-and long-term predictions of China's grain security", *China Agricultural Economic Review*, Vol. 5 No. 4, pp. 567-582.

Ministry of Agriculture (MOA) (1982-2014, 2015), "Compilation of varietal areas for major crops".

Ministry of Agriculture (2014), "GM crop commercializing roadmap: fiber-feed-food", available at: http://politics.people.com.cn/n/2014/1206/c1001-26158566.html (accessed June 2017).

Ministry of Agriculture (2017), "Agriculture outlook report 2017", Ministry of Agriculture, Beijing.

National Academies of Science, Engineering and Medicine (2016), *Genetically Engineered Crops: Experiences and Prospects*, National Academies Press , Washington, DC, available at: www.nap.edu/catalog/23395/genetically-engineered-crops-experiences-and-prospects (accessed June 2017).

National Bureau of Statistics of China (2011), *China Statistical Year Book 2011*, China Statistics Press, Beijing.

National Bureau of Statistics of China (NBSC) (2016), *China Statistical Year Book 2016*, China Statistics Press, Beijing.

Norse, D., Lu, Y. and Huang, J. (2014), *China's Food Security: Is it a National, Regional or Global Issue?* Vol. 120, Palgrave Macmillan, Basingstoke, pp. 251-302.

Pang, J., Ma, C., Feng, Y. and Hu, R. (2016), "Biosafety of genetically modified crops: scientific evidence", *China Biotechnology*, Vol. 36 No. 1, pp. 122-138.

Qiao, F., Huang, J. and Wang, X. (2017), "Fifteen years of bt cotton in China: results from household surveys", *World Development*, Vol. 98, pp. 351-359.

UN Comtrade (2017), "DESA/UNSD, United Nations Comtrade database", available at: http://comtrade.un.org/ (accessed May 2017).

Walmsley, T.L., Dimaranan, B.V. and McDougall (2006), "A baseline scenario for the dynamic GTAP model", *Dynamic Modeling and Applications for Global Economic Analysis*, p. 136.

Ye, J. and Li, H. (2014), "Review and thoughts on GM technology", *Journal of Agrotechnical Economics*, Vol. 1, pp. 11-21 (in Chinese).

Zhao, C. and Zhong, Y. (2016), "The challenges and solutions of corn overstocking in China", *Research of Agricultural Modernization*, Vol. 37 No. 5, pp. 824-830.

Further reading

Wang, X., Huang, J., Zhang, L. and Rozelle, S. (2011), "The rise of migration and the fall of self-employment in rural China's labor market", *China Economic Review*, Vol. 22 No. 4, pp. 573-584.

Appendix

Here we summarize major results on agricultural production and demand projection with specific focus on maize. Detailed results for the baseline projection of each commodity can be found in Table AI. For production, the changing trends differ among products. Maize output is projected to increase by only about 4 percent from 2015 to 2025 (see Table AI), which is significantly less than the increase of more than 60 percent from 2005 to 2015 (NBSC, 2016). The substantial decline in maize production growth in the coming decade is due primarily to the decrease in maize prices resulting from the destocking of the huge maize stocks held by the government. For the same reason and further affected by the falling demand, rice and wheat production is projected to decrease slightly. The production of other food products such as soybean, vegetables, fruits, edible oil crops, and livestock will increase along with their increasing demand.

For food and feed demand and imports, all other sectors except for rice and wheat are projected to increase in the coming decade (see Table AI). The projected maize demand will reach 254.5 Mt by 2025, and imports will be about 20 Mt. The rapid rise in maize imports is due mainly to the rapid expansion of domestic livestock production and the study's assumption that the above-quota tariff rate of 65 percent will not be imposed on imports exceeding the import quota (7.2 Mt). The other significant increase in both demand and imports is that in soybean crop. With the growing imports of both maize and soybean as feed, despite the large increase in meat demand, China is projected to achieve near self-sufficiency in pork and poultry by 2025.

In addition to the baseline scenario, the study also projected a scenario where China imposes an above-quota tariff rate (65 percent) for maize imports exceeding 7.2 Mt (i.e. the baseline scenario with TRQ policy). Here, maize imports are projected to remain under 7.2 Mt because the projected maize prices in China will not exceed those of imported maize by more than 65 percent. While the higher maize price will stimulate maize production due to the above-quota tariff, the livestock sector will be hurt by the higher feed price as maize is the main feed used in China.

	2015			2025		
	Production	Export	Import	Production	Export	Import
Rice	145,772	287	3,377	135,460	344	2,820
Wheat	130,247	122	3,007	116,692	177	2,074
Maize	225,000	11	4,730	234,590	10	19,890
Other cereals	13,090	583	21,432	12,220	707	17,661
Vegetable and fruit	562,705	13,186	3,461	644,302	18,251	3,626
Soybean	10,800	134	81,694	11,338	111	98,556
Other oilseed	8,863	21	1,458	9,184	21	1,447
Sugar	15,211	75	4,846	12,839	39	9,285
Cotton	5,605	30	1,759	5,215	29	1,831
Pork and poultry	63,812	681	1,188	78,270	720	1,550

Source: Authors' estimations

Table AI. Production and trade (thousand tons) of major agricultural commodities in 2015 and projections for 2025

Aggregated sector	Original sector
Rice	Paddy rice, processed rice
Wheat	Wheat
Maize	Maize
Other grains	Other grains
Vegetable, fruit	Vegetable, fruit
Soybean	Soybean
Other oilseeds	Other oilseed crops
Sugar, sugar cane	Sugar, sugar cane
Plant based fibers (cotton)	Plant based fibers (cotton)
Other crops	Other crops
Beef, mutton	Beef, mutton
Chicken, pork	Chicken, pork
Milk	Raw milk, dairy products
Wool	Wool
Vegetable oils and fats	Vegetable oils and fats
Beverages and tobacco products	Beverages and tobacco products
Food products nec	Food products nec
Fisheries	Fisheries
Minerals nec	Minerals nec
Coal	Coal
Oil	Crude oil
Gas	Gas
Forestry	Forestry
Textile leather	Textile, wearing apparel, leather
Mineral products	Mineral products nec
Light manufacturing	Wood products, paper products, publishing, motor vehicles and parts, transport equipment nec
Chemical, rubber, plastic products	Chemical, rubber, plastic products
Petroleum, coal products	Petroleum, coal products
Ferrous metals	Ferrous metals
Non-ferrous metals	Non-ferrous metals
Mineral products	Mineral products nec
Heavy manufacturing	Electronic equipment, Machinery and equipment nec
Electricity	Electricity
Gas manufacture, distribution	Gas manufacture, distribution
Utility and construction	Water, construction,
Trade and communication	Trade, communication,
Other transport	Transport nec
Water transport	Water transport
Air transport	Air transport

Table AII.
Sectoral concordance

Corresponding author
Jikun Huang can be contacted at: jkhuang.ccap@pku.edu.cn

This article has been cited by:

1. HuangJikun, Jikun Huang, WangXiaobing, Xiaobing Wang, DangHugh, Hugh Dang. 2017. Impacts of and attitudes toward GM technology in China: challenges, policy and research implications. *China Agricultural Economic Review* **9**:3, 334-339. [Citation] [Full Text] [PDF]