Cost of Delay of Bt Rice Approval in China

Picture source: http://www.ricewisdom.org/

Yan Jin

March 2016

Cost of Delay of Bt Rice Approval in China

Yan Jin

Registration number 911223400100

Supervisors

Justus Wesseler

Qianqian Shao

A thesis submitted in partial fulfilment of the degree of Master of Science at Wageningen University and Research Centre, The Netherlands

30-03-2016

Wageningen, the Netherlands

Thesis code number: AEP-80433

Wageningen Univerisity and Research Centre

Agricultural Economics and Rural Policy Group

Abstract

This research aims to show the opportunity of Bt rice by analyzing the cost of delay (COD) in approval of its commercialization from 2009 to 2015. We used the economic surplus model developed by Alston *et al*. (1998) to calculate the COD resulting from the differences between net present values from the year 2009 and 2015. We made the sensitivity analysis on proportionate input cost change, supply elasticity, maximum adoption rate and commercialization date to see how they affect the COD. The study shows that delaying the commercialization of Bt rice is costly. The COD in China from 2009 to 2015 was up to 27.52 billion US dollars under the discount rate of 3% and 25.49 billion US dollars under the discount rate of 5%. The sensitivity analyses show that the impact of supply elasticity is limited. The maximum adoption rate and the commercialization date of Bt rice have a much bigger impact on the COD. The proportionate input cost change has the biggest impact. Chinese rice farmers lose 361 million US dollars annually on their health. Based on these results, the adoption of Bt rice is beneficial to China. The paper provides results about how much China lose each year due to the delay for the decision-makers to weigh the pros and cons on the road of biotechnology.

Keywords: Bt rice, commercialization, opportunity, public acceptance

Acknowledgement

I would like to thank my two thesis supervisors, Professor Justus Wesseler and Qianqian Shao for their patient guidance. Special thanks also go to Professor Ruifa Hu who gave me access to their unpublished data. I would like to show gratitude to my family for their support and love. At the end, I would like to thank China Scholarship Council for sponsoring my master study in Wageningen University.

Table of Contents

1. Introduction

Rice is a staple food for Chinese people. In China, due to the development of the industry and the increasing degradation of arable land, the land for cultivating rice has its limits. There were 95.7 million hectares of rice land in 1990 but decreased to 30.3 million hectares in 2014 (National Bureau of Statistics of China (NBSC), 2014). The arable land per person was 0.11 hectare in 1990 but decreased to 0.08 hectare in 2014, which is below the world average of 0.2 (World Bank (DB), 2014). Based on the trend of growing population, the United States Census Bureau estimates that the Chinese population will increase to 1.4 billion around 2026. So how to increase yield in limited arable land to be self-sufficient in rice production is important for China. Under such circumstances, Chinese scientists try to cultivate new rice varieties to solve the problem. Bt rice is the rice genetically modified with insecticidal genes from bacillus thuringiensis with the advantages of increasing yield, reducing the use of pesticides and generating environmental benefits (Huang *et al.*, 2005). There are three phases of bio-safety procedures required in China, namely field trials, environmental release trials and pre-production trials. The pre-production trials are large-scale trials in experiment stations and farmer fields. China spent 20 years researching its thermal stability, digestibility, toxicity, allergy of Cry proteins produced by Bt rice and comparisons of nutrient composition (Li *et al.*, 2015). On October 22, 2009, China's Ministry of Agriculture (CMOA) in Hubei Province issued two Bt rice lines (Cry1Ab/Ac Huahui No. 1 and Cry1Ab/Ac Bt Shanyou 63) bio-safety certificates (Chen *et al.*, 2011). It means they are as safe as non-Bt rice and ready for commercialization. However, there is no commercialization until now.

The reasons for its delay are largely due to low public acceptance in China (Chen *et al.*, 2014). Farmers have concerns about the potential Bt rice market that more cultivation will not generate high profits to them. A nationwide survey about the knowledge on Bt rice in 2010 shows that although almost half of the consumers know little about it, they think it has negative effects on human health and the environment (Qu *et al.*, 2011). Bt rice is a controversial issue in China. Some think it is beneficial economically and environmentally while others consider more about its uncertainties and potential risk. Therefore, the government is hesitated to let China step forward as the first country in the world to commercialize it. Delaying the commercialization of Bt rice might generate losses because of its great potential economic, environmental and health benefits.

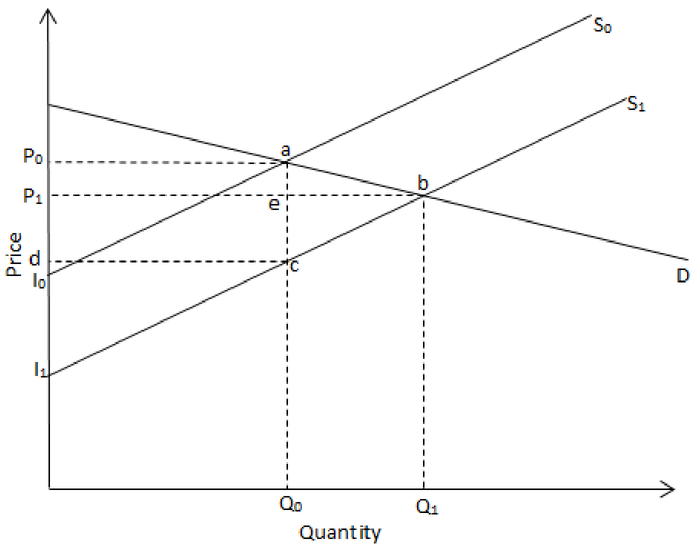
Chinese rice farmers intensively apply more chemical pesticides than farmers in almost any other country (Huang *et al*., 2000). The study shows that the use of pesticides can decrease by 80% after adopting Bt rice (Huang *et al.* 2005). Bt rice farmers also reduce their labour use (Rozelle *et al.*, 2005). Bt rice can increase rice yields by more than 60% in comparison with conventional rice when no pesticides are used (Wang *et al.*, 2010). The simultaneous rises in output and reductions of inputs contribute to the absolute rises in productivity, which is about 15% higher (Rozelle *et al.*, 2005). It is safer to aquatic ecosystem (Li *et al*., 2014). Farmers' adverse health effects also significantly decreased (Huang *et al.*, 2005).

The economic surplus model was developed by Alston *et al*. (1998) and used by Krishna and Qaim (2007) to estimate the welfare and distribution effects among eggplant farmers and consumers in India. In Philippines, Bayer (2007) used the model to calculate the regulatory cost of Bt rice, PRSV papaya, tomato and eggplant. Francisco (2006) used it to evaluate the potential impacts of adopting Bt eggplant on yield, cost and profitability. Mamaril (2005) focused on the cost and benefit of MVR tomato in his study. Wesseler and Zilberman, (2014) calculated the COD of golden rice in India under uncertainty and irreversibility. Due to the fact that the Bt rice is not only profitable to farmers but also beneficial to the environment, the delay of its commercialization might result in large opportunity costs (Raybould *et. al.*, 2010). Although Bt rice is important to China, the literature about its economic impact is limited and there is no research about its COD. The objective of this research is to calculate the COD in approval of Bt rice from 2009 to 2015. The contribution of the research is to provide results about how much China loses each year due to the delay for the decision-makers to weigh the pros and cons on the road of biotechnology.

The rest of the paper is organized as follows. Section 2 introduces the economic surplus model of closed-economy. Data, data sources, model parameterization and the results of the base model are discussed in section 3. Section 4 is the sensitivity analysis about the proportionate input cost change, elasticity of supply, maximum adoption rate and commercialization date of Bt rice. Finally, the conclusion drawn from the research is given in section 5.

2. The model

We want to know how the welfare of farmers, consumers and the government change when the input costs decrease and rice yields increase after the adoption of Bt rice. China is a self-sufficient country of rice production with low export. So in this case, the economic surplus model of a closed-economy is suitable to calculate COD. We assume linear demand and supply function and there is perfect information in the market about Bt rice and conventional rice. We assume rice farmers are homogeneous and they would like to and are able to adopt Bt rice. There are no externality effects from the adoption of Bt rice. Other commodity prices are assumed to be constant.



Source: Alston *et al.* (1998, pp. 209)

Figure 1. Surplus distribution in the basic model

Initial supply (S_0): $Q_s = \alpha + \beta P$

Supply (S_1): $Q_s = \alpha + \beta(P+k) = (\alpha + \beta k) + \beta P$

Demand (D): $Q_d=m-nP$

where α and m are intercept of initial supply and demand function; β and n are the slope of initial supply and demand function. In Figure 1, the initial equilibrium is at point *a*. After adopting Bt rice, the supply function shift outwards to S_1, where k is the shift down of the supply due to the cost saving of adopting Bt rice. The new equilibrium is at point *b*. The change of consumer surplus (ΔCS_t) is area P_0abP_1, change of producer surplus (ΔPS_t) is area P_1bcd. The change of total supply (ΔTS_t) is area abI_0I_1 due to the parallel shift of supply. Based on Alston *et al*. (1998), the function of the change of consumer surplus in closed economy model is as follows (calculation see appendix):

$$\Delta CS_t=P_t Z_t Q_t (1+0.5 Z_t\eta) \tag{1}$$

where P_t and Q_t represent the equilibrium price and quantity of Bt rice at the time of t. The quantity equals to the pre-research equilibrium quantity, which is a constant and equal to the base quantity in 2009 times the maximum adoption rate in the pre-production trial. Similar as the quantity, price is a constant and equal to the equilibrium price in domestic rice market in China in 2009. Z_t is the change in price due to the supply shift. ε is the absolute value of the price elasticity of supply. η is the absolute value of the price elasticity of demand. Similarly, the function of the change of producer surplus in closed economy model is as follows:

$$\Delta PS_t=P_t Q_t (K_t-Z_t) (1+0.5Z_t\eta) \tag{2}$$

where K_t is the vertical shift of supply curve in the year t due to the adoption of new technology which can be up or down. The change of total surplus in closed economy model is as follows:

$$\Delta TS_t=\Delta CS_t +\Delta PS_t \tag{3}$$

Since the bio-safety certificates of Bt has been issued in 2009 which means this technology is successful, we assume there is no further research cost any more after 2009. So *Net benefit* $=\Delta TS_t=\Delta CS_t +\Delta PS_t$

We use NPV_{2009} to denote the net present value of Bt rice in 2009 and use NVP_{2015} to denote the net present value of Bt rice in 2015. Therefore, the way we calculate the COD in approval of Bt rice in China from 2009 to 2015 is:

$$COD=NPV_{2009}-NPV_{2015} \tag{4}$$

3. Data and model parameterization

3.1 Data and data source

The information and data used in this research are from both primary and secondary sources. The primary data is maximum adoption rate and input cost change in pre-production trial. They are provided by Hu, who participated in the pre-production trial. Input cost change includes pesticide cost, labour cost, seed cost, fertilizer cost and other costs. The proportionate input cost change is calculated based on them.

All the secondary data used in this research result from the literature about its pre-production trial. Higher yields require more fertilizer use. However, the data shows that when Bt rice yields increase, its fertilizer use decreases (Huang *et al*. 2008), which is interesting to mention. This is because the rice genetically transferred into Bt rice is an old breed developed in 1980s while the conventional rice used as comparison is a newly-developed rice breed and thus it has higher yields. The supply elasticity and the demand elasticity are estimated by Bayer *et. al.* (2010). Price in this research is the average domestic market price of rice in 2009. The base quantity in this research is the maximum adoption rate times the total supply of rice in China in 2009. The price and quantity are from the official website of NBSC. The exchange rate between yuan and US dollar is based on the average exchange rate of the year from official website of the People's Bank of China in 2009.

3.2 Model parameterization

Since the bio-safety certificates of Bt rice have already been issued in 2009, we define the probability of success as 1, which means it has already been successful in reality. For the same reason, there was no further research cost after 2009. The maximum adoption rate in pre-production trial in China is 55%. The parameters of the base model include a price of 442 US dollars/ton based on the average domestic market price of rice in 2009 and a quantity of 195.1 million ton based on the domestic supply of rice in China in 2009 times the maximum adoption rate of 55%, which equals to 1.07 million ton. In the research, we discuss the discount rate of 3% and 5% to estimate the stream of benefits and costs from 2009 to 2015. 3% is based on the risk-free rate of China bond market in 2009 while 5% is based on the calculation of Kula (2004) for evaluating agricultural projects. Depreciation factor of technology is used from paper about similar Bt products for estimation; in this case, the Bt product is Bt eggplants (Bayer, 2007). It decreases 5% each year starting from the ninth year until 65%. So in sixteen years, the depreciation factor of technology for Bt rice will maintain at the level of 65%. Targeted pests might get resistance to Bt rice so the assumption of depreciation factor of technology is reasonable.

Table I. Parameterization

Parameter	Description (2009)	Values and unit	Source
P	price of Bt rice	442 US dollars/ton	Fujian Provincial Price Bureau (2009)
Q	quantity of Bt rice	107306650 ton	NBSC (2009)
$E(Y)$	proportionate yield change	0.04 ton/ha	Huang *et al.* (2008)
$E(C)$	proportionate change in input cost per ton	0 US dollars/ha	interview with experts
r	discount rate	discuss at 5% and 10%	Bayer *et al.* (2010)
ε	supply elasticity	0.95	Bayer *et al.* (2010)
η	demand elasticity	-0.3	Bayer *et al.* (2010)
$1\text{-}\delta$	depreciation factor of technology	starting from the 9th year, drop 5% each year till 65%	Bayer (2007)
A	adoption rate	55%	interview with experts
α	constant of integration	2.3026	calculation

β	nature rate of diffusion	3.1513	calculation

Notes: **The unit for calculating the COD in this research is yuan. Exchange rate: 1 US dollar= 6.8311 yuan**

Source**: People's Bank of China (PBC), 2009 (http://www.pbc.gov.cn/).**

3.3 Base model results

Based on the economic surplus model, the results of the calculation for net present value (NPV) and COD are huge. Under the discount rate of 3%, the COD is 27.52 billion US dollars and China lost 4.42 billion US dollars annually from 2009 to 2015. Under the discount rate of 5%, the COD is 25.49 billion US dollars and China lost 4.40 billion US dollars annually in the past seven years. Although the Chinese government has invested billions of US dollars into Bt rice in the past 20 years, there is no return due to the delay. China could have lost more because we do not take the benefits of rice consumers and environment benefits into account.

Table II. Results of base model

Discount rate	NPV_{2009} (billion US dollars)	NPV_{2015} (billion US dollars)	COD (billion US dollars)
3%	152.12	148.78	27.52
5%	94.62	92.65	25.49

Table III. Results of annual COD

i	3%	i	5%
n	7	n	7
CRF	0.1605	CRF	0.1728
Annual COD (billion US dollars)	4.42	Annual COD (billion US dollars)	4.40

Notes*:* Capital Recovery Factor (CRF)=[i(1+i)^n]/[(1+i)^n-1]

3.4 Distribution of different provinces

The study uses the rice quantity of 30 provinces in China in 2009 (excluding Qinghai Province whose data is not available) to see how the distribution of welfare loss of different provinces. Hunan Province, Jiangxi Province and Jiangsu Province are the three provinces that have the most welfare loss because there were more rice yields in these three provinces in 2009. These three provinces will benefit the most once the commercialization of Bt rice is permitted. 32.2% of the total surplus will go to the farmers and consumers there.

To be more detail, for consumer surplus, Hunan Province, Jiangxi Province and Jiangsu Province lost 3.77 billion US dollars, 2.78 billion US dollars and 2.63 billion US dollars for delaying the commercialization of Bt rice from 2009 to 2015. For producer surplus, Hunan Province, Jiangxi Province and Jiangsu Province lost 1.19 billion US dollars, 878.89 million US dollars and 831.39 million US dollars for delaying the commercialization of Bt rice from 2009 to 2015. Total surplus can up to 4.95 billion US dollars, 3.66 billion US dollars and 3.46 billion US dollars for these three provinces. In Figure 2 below, more information about the welfare loss are provided for other provinces in China.

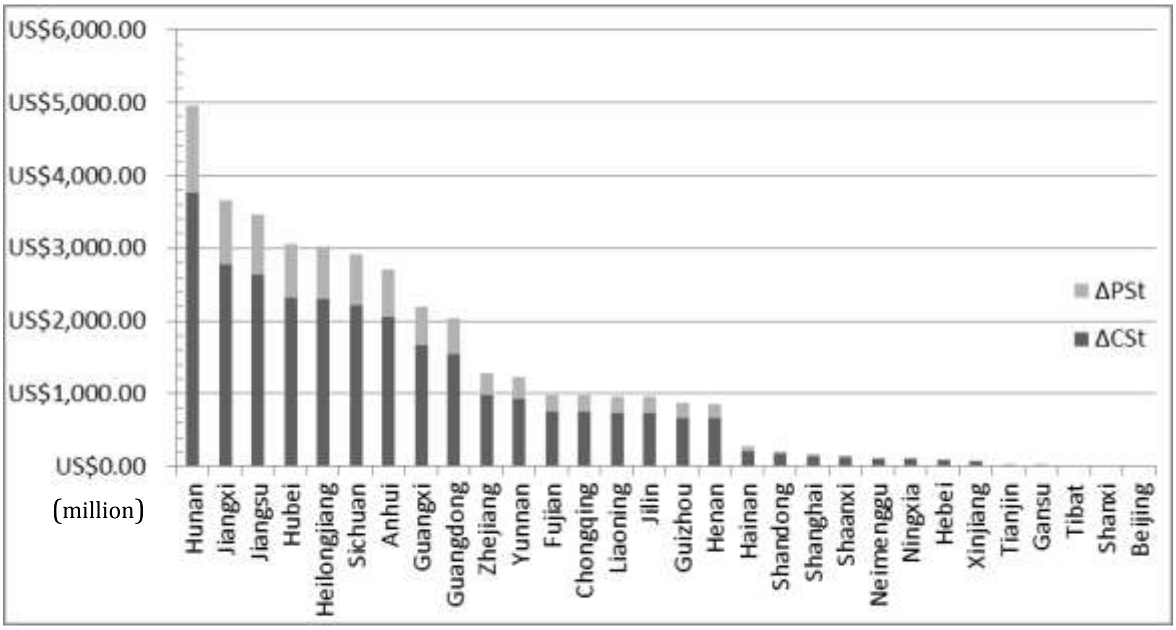


Figure 2. Distribution of consumer surplus and producer surplus in different provinces

4. Model sensitivity analyses

4.1 Effect of the proportionate input cost change

Proportionate input cost change in this case is the proportionate change in variable input costs per hectare to achieve the expected yield change (Alston *et. al.*1998). It includes pesticide cost, labour cost, seed cost, fertilizer cost and other costs. Based on the data from Hu, the seed cost slightly increases when adopting Bt rice while other costs decrease dramatically, especially the labour cost and pesticide cost. The total cost of production decreases by more than 20% after adopting Bt rice. Proportionate input cost change plays an important role in the economic surplus model, so it is necessary to discuss different values to see how the proportionate input cost change affects the COD in approval of the commercialization of Bt rice.

The proportionate input cost change of Bt rice is -0.21 in base model and changed from -0.20 to -0.28 in the sensitivity analysis. The results show that it affects COD greatly since 1% change in proportionate input cost change can increase the COD by more than 1 billion US dollars under both discount rate of 3% and 5%. If the proportionate input cost change of Bt rice increases to -0.28 the same as the amount of Bt cotton (Huang *et. al*, 2002), the COD can be up to 34.79 billion US dollars under the discount rate of 3% and 32.22 billion US dollars under the discount rate of 5%. This is because when the absolute value of proportionate input cost change increases, the net cost change increases, so that the proportional supply shift of the supply function and thus the change in price due to the proportional supply shift increases accordingly. The result is that the consumer surplus and total surplus increases, leading to bigger NPVs.

Table IV. Results of the sensitivity analysis for the proportionate input cost change

Proportionate input cost change	COD (3%) (billion US dollars)	COD (5%) (billion US dollars)
-0.20	25.95	24.03
-0.21	27.05	25.05
-0.22	28.15	26.07
-0.23	29.25	27.09
-0.28	34.79	32.22

4.2 Effect of the supply elasticity

Supply elasticity is a measure used in economics to show the responsiveness of the quantity supplied of a good or service to a change in its price (Png, 1999). In this case, it shows how sensitive the supply of Bt rice reacts to its price change. The reason for choosing supply elasticity instead of demand elasticity is that it has a greater effect than varying the demand elasticity on the projected benefits (Bayer, 2007).

The supply elasticity for the Bt rice was assumed to be 0.95 based on the data from the paper by Bayer *et. al.* (2010). Because rice is inelastic products, the sensitivity analysis varies the supply elasticity from 0.30 to 1.00 to see how it affects the COD. The results show that when the supply elasticity decreases, the COD increases; and vice versa.

This is because when the supply elasticity increases, the net cost change decreases due to the fact that the gross cost change decreases, so that the proportional supply shift and thus the change in price due to the proportional supply shift decreases accordingly. The result is that the consumer surplus and total surplus decreases, leading to the lower NPVs.

There are some reasons that can lead supply elasticity to increase. If the resource is easy to get or the technology is not time-consuming to adopt, the supply elasticity will be bigger. In the case of Bt rice, farmers are able to change to grow the Bt rice instead of the conventional rice on the same land, so the land is accessible. The price of Bt rice is not significantly higher than the conventional rice, so the investment is low. Bt rice can reduce labour spreading the chemical pesticides, so there is no extra increase of labour or even decrease. Bt rice is also not time-consuming to adopt since in pre-production trial, it only takes three years to reach the maximum adoption rate of 55%.

From Table V, we can see that if the supply elasticity increases by 1 %, the COD will decrease by around 40 million US dollars. Since we do not know exactly what the supply elasticity of the Bt rice in China is, it is necessary and important for us to discuss different levels of supply elasticity in order to see the effect of this parameter.

Table V. Results of the sensitivity analysis for the supply elasticity

Supply elasticity	COD (3%) (billion US dollars)	COD (5%) (billion US dollars)
0.30	36.64	33.93
0.60	29.97	27.76
0.94	27.56	25.53
0.95 (base)	27.52	25.49
0.96	27.47	25.44
1.00	27.31	25.29

4.3 Effect of the maximum adoption rate

The maximum adoption we use in this research is 55% which is based on the data from Hu, who involved in the pre-production trial of Bt rice. Normally, it takes time for farmers to adopt new technology and the adoption rate for the first year is low, so we assume the adoption rate for the first year is 5%. The pre-production trial executed for three years from 2002 to 2004, so it took three years for the adoption rate to rise from the starting point 5% to the maximum point 55%. We use two points (t=0, A_t=5%; t=2, A_t=55%) to identify the α and β in the adoption function. We follow Wesseler and Zilberman (2014) to use the logistic function as adoption function:

$$A_t = \rho max/[1 + exp(-\alpha - \beta t)] \quad (5)$$

where ρmax represents the long-term upper limit on adoption of Bt rice in China, parameter α represents constant of integration and parameter β represents the nature rate of diffusion measuring the rate at which adoption A_t increases with time t. When we vary the maximum adoption rate, the adoption rate for the first year maintains at 5% while the adoption rate in the second year changes accordingly. Maintaining other parameters to be the same, the sensitivity analysis varies the maximum adoption rate to see how it affects the COD in approval of Bt rice in China.

The maximum adoption rate might still be able to increase through years because the pre-production trial only lasted for three years. If changing the maximum adoption rate can increase the COD to a certain level, the maximum adoption rate actually affects the benefit a lot. Since we already know that increasing public acceptance is an important way for increasing the adoption rate, more information should be provided to the public in later years to reduce the asymmetric information among the farmers and consumers about Bt rice. When the maximum adoption rate is changed in sensitivity analysis, we can see different results of COD both under the 3% and 5% discount rate as the Table VI below shows.

Table VI. Results of the sensitivity analysis for the maximum adoption rate

Maximum adoption rate	COD (3%) (billion US dollars)	COD (5%) (billion US dollars)
50%	25.03	23.19
55% (base)	27.52	25.49
60%	29.99	27.78
65%	32.48	30.08
80%	39.99	37.02

The COD increases when the maximum adoption rate increases. This phenomenon is reasonable because the Bt rice is beneficial and profitable. The more that the Bt rice are adopted, the more benefits and profits they can bring to the farmers, consumers and the government, which leads to the more potential COD if their commercialization is delayed. From Table VI, we can see that when the maximum adoption rate increases by 5%, the COD will increase by over 2 billion US dollars under the discount rate of both 3% and 5%. If the maximum adoption rate can reach 80%, there will be a gain of 39.99 billion US dollars under the discount rate of 3% and a gain of 37.02

billion US dollars under the discount rate of 5% in comparison to the current maximum adoption rate of 55%. Based on this result, we can conclude that if farmers want to cultivate more Bt rice due to the reduction of asymmetric information, the maximum adoption rate will increase and thus increase their benefits.

4.4 Effect of the commercialization date of Bt rice

It has been seven years since Bt rice was ready for commercialization. The total COD and annual COD we have known and now we can also calculate how much it costs for a one-year delay and how much it gains for a one-year earlier adoption. The two-year case is similar. Maintaining other parameters to be the same, the sensitivity analysis varies the commercialization date of Bt rice to see how it affects the COD in approval of Bt rice in China. We discuss different possibilities for the commercialization date of Bt rice. Gain 1 year (2014), gain 2 years (2013), lag 1 year (2016) and lag 2 years (2017) are discussed based on the economic surplus model in order to get the different NPVs for calculating the COD. A lag of one or two years is easily conceivable while the gain of one or two years is no longer possible, which we just calculate for comparison.

The commercialization date of Bt rice in China has a great influence on the COD. Based on the data we get from the sensitivity analysis, we can conclude that the later the commercialization date of Bt rice in China, not only the COD will increase, but also it will increase with a positive acceleration due to the discount rate.

For example, with the discount rate of 3%, the COD for 2013 is 24.29 billion US dollars; the COD for 2014 is 25.88 billion US dollars. The different between the commercialization in 2013 and 2014 is 1.59 billion US dollars. The COD for 2016 is 29.21 billion US dollars and for 2017 is 30.94 billion US dollars. The difference between the commercialization in 2015 and 2016 is 1.69 billion US dollars while the difference between the commercialization in 2016 and 2017 is 1.73 billion US dollars. It is continuously increasing with a positive acceleration. The Table VII below shows the results in detail.

Table VII. Results of the sensitivity for the commercialization date of Bt rice in China

Commercialization date	COD (3%) (billion US dollars)	COD (5%) (billion US dollars)
2013	24.29	22.92
2014	25.88	24.17
2015 (base)	27.52	25.49
2016	29.21	26.86
2017	30.94	28.31

5. Health benefit of Bt rice farmers in China

The recent study shows the adoption of Bt rice can improve farmers' health due to low exposure to the pesticides (Huang *et al.*, 2015). This section will quantify the health benefits of Bt rice farmers to show how much they can benefit individually on average from adopting Bt rice. Huang *et. al.* (2000) calculated that the sample mean value for health cost per rice farmer due to the pesticide use in China, which equals to 3.33 US dollars per year (PBC, 2016). The total area for cultivating rice in China in 2009 was 2962692 ha while the average cultivation area per rice farmer was 0.15 ha (NBSC, 2009), so we estimate there are 197 million rice farmers in China in 2009.

Health benefit = health benefit per farmer × number of farmers × adoption rate [1]

Based on the calculation, our estimation about the health benefit for Chinese farmers adopting Bt rice since 2009 is 361 million US dollars per year. We multiple the number of rice farmers with the maximum adoption rate 55% which we got from the pre-production trial, namely 108.35 million rice farmers in China benefiting from adopting Bt rice. The health benefit of 361 million US dollars per year can be considered conservative estimation because the health effect of consumers is not taken into account. However, the health benefit of Bt rice farmers could decrease every year because the number of farmers in China is continuously decreasing (Yang, 2013). This is due to the phenomenon that more farmers prefer to migrate to big cities. In addition, proper usage of pesticides due to increasing awareness about the pesticide effect on health will also decrease the health benefit (Bourguet and Guillemaud, 2016).

6. Conclusion

The bio-safety certificates for Bt rice were issued and renewed on October 22, 2009 and December 11, 2014. The commercialization of Bt rice in China has not been permitted till now. The delay can lead to huge opportunity cost. This study uses the economic surplus model to evaluate the economic impact of the Chinese GMO regulatory process on the change of consumer surplus, producer surplus, total surplus, NPVs and the result of the COD in approval of Bt rice in China from 2009 to 2015. All the data used for calculation are based on the literature and Hu, who directly involved in the pre-production trial. The estimated base model of the closed economy for the Bt rice results in the COD up to 27.52 billion US dollars under the discount rate of 3% and 25.49 billion US dollars under the discount rate of 5%. Sensitivity analyses were then carried out in which the proportionate input cost change, supply elasticity, the maximum adoption rate and the commercialization date of Bt rice were varied separately in order to show the impact of the welfare of such changes. The results show that the impact of supply elasticity is limited. The maximum adoption rate and the commercialization date of Bt rice have a much bigger impact on the COD. The proportionate input cost change has the biggest impact. Health benefits of adopting Bt rice by Chinese rice farmers are huge due to huge number of rice farmers. This research does not include the quantification of environmental benefits, because the environmental benefits due to the reduction of pesticide use are still largely unknown (Wabbi and Taylor, 2008), so the actual COD could have been even larger. Should China decide to permit the commercialization of Bt rice? From a standpoint of cost and benefit based on the research, it cannot be denied that the adoption of Bt rice will be economically beneficial to China. Since the low public acceptance of Bt rice is the major reason for the delay in China, the asymmetric information should be reduced and public cognition of the safety and benefit of Bt rice should be improved.

---

[1] Health benefit = health benefit per farmer × number of farmers × adoption rate =3.33×197×55% =361 million US dollars per year

References

Alston, J.M., Norton, G.W. and Pardey, P.G. (1998), *Science and Scarcity*, CAB International, New York, NY.

Biotechnology Research Institute (BRI), 2000, "The progress of transgenic cotton", working paper, Chinese Academy of Agricultural Sciences, Beijing, 2000.

Bayer, J. C., (2007), "Biotechnologies in the Philippines: the cost of regulation", available at: https://theses.lib.vt.edu/theses/available/etd-06082007-105019/unrestricted/JBayerThesis.pdf (accessed 29 February 2016).

Bayer, J.C., Norton, G.W. and Falck-Zepeda, J.B. (2010), "Cost of compliance with biotechnology regulation in the Philippines: implications for developing countries", *AgBioForum*, Vol. 13(1), pp. 53-62.

Bourguet, D. and Guillemaud, T. (2016), "The hidden and external costs of pesticide use", Sappa, J., *Sustatinable Agriculture Reviews*, Springer International Publishing AG Switzerland, Dijon, France, pp. 55-60.

Chen, M., Shelton, A. and Ye G.Y. (2011), "Insect-resistant genetically modified rice in China: from research to commercialization", *Annual Review of Entomology*, Vol. 56, pp. 81–101.

Chen, X., Yang, C. and Jia, H. (2014), "Issues confronting GMO crops in China", *Journal of Huazhong Agricultural University*, Vol. 33, pp. 118–210.

Francisco, S.R. (2006), "Ex-ante impact assessment of fruit and shoot borer resistant eggplant in the Philippines", *Philippine Journal of Crop Science*, Vol. 32 No. 2, pp. 3-14.

Fujian Provincial Price Bureau (2009), available at: http://www.fjjg.gov.cn (accessed 17 March 2016).

Huang, J., Qiao, F., Zhang, L., and Rozelle, S. (2000), "Farm pesticide, rice production, and human health", *Economic and Environmental Program for Southeast Asia (EEPSEA)*, IDRC, Singapore.

Huang, J., Rozelle, S., Pray, C. and Wang, Q. (2002), "Plant biotechnology in China", *Science*, Vol. 295, pp. 674–677.

Huang,J., Hu, R.., Rozelle, S. and Pray, C. (2005), "Insect-resistant GM rice in farmers' fields: assessing productivity and health effects in China", *Scienc*e, Vol. 308, pp. 688-690.

Huang, J., Hu, R., Rozelle, S. and Pray, C. (2008), "Genetically modified rice, yields, and pesticides: assessing farm-level productivity effects in China", *Economic Development and Cultural Change*, Vol. 56, pp. 241-263.

Huang, J., Hu, R., Qiao, F., Yin, Y., Liu, H. and Huang, Z. (2015), "Impact of insect-resistant GM rice on pesticide use and farmers' health in China", *Science China*. Vol.58 No.5, 466–471.

Krishna, V.V. and Qaim, M. (2007), "Potential impacts of Bt eggplant on economic surplus and farmers' health in India", paper presented at 2007 AAEA, WAEA & CAES Joint Annual Meeting, 29 July- 1 Agugst, Portland, Oregon, available at: http://ageconsearch.umn.edu/bitstream/9909/1/sp07kr02.pdf (accessed 16 March 16, 2016).

Kula, M., (2004), "Estimation of a social rate of interest for India", *Journal of Agricultural Economics*, Vol 55, pp. 91-99.

Li, G., Wang, Y., Liu, B. and Zhang, G. (2014), "Transgenic Bacillus thuringiensis (Bt) Rice is safer to aquatic ecosystems than its non-transgenic counterpart. *PLoS ONE*, Vol 9 (8).

Li, Y., Hallerman, E., Liu, Q., Wu, K. and Peng, Y. (2015), "The development and status of Bt rice in China", *Plant Biotechnology Journal*, Vol. 14(3).

Mamaril, C.B. (2005). *Multiple virus resistant tomato: an ex-ante evaluation of the potential impact of adopting MVR tomato in the Philippines*, ISAAA, Los Baños, the Philippines.

MOA (Ministry of Agriculture) (2005), *Agricultural Yearbook of China, 2005*. China's Agricultural Press, Beijing.

National Bureau of Statistics of China, available at: http://data.stats.gov.cn/index.htm (accessed 10 March 2016).

People's Bank of China, available at: http://www.pbc.gov.cn/ (accessed 10 March 2016)

Png, I. (1999), *Managerial Economics*, Blackwell Publishers, New Jersey.

Qu, Y., Chen, Y., Hou, Y., Huang, K. and Kang, D. (2011), "Survey analysis of the cognition of GMO risk and safety among Chinese public", *Journal China Agricultural University,* Vol.16, pp. 1–10.

Raybould, A. and Quemada, H. (2010), "Bt crops and food security in developing countries: realised benefits, sustainable use and lowering barriers to adoption", *Springer Science, Food Sec*, Vol 2, pp. 247–259.

Rozelle, S., Huang, J., and Hu, R. (2005), "Genetically modified rice in China: effect on farmers— in China and California", *Giannini Foundation of Agricultural Economics*, Vol. 9 No.1, pp. 2-6.

Statista, available at: http://www.statista.com/ (accessed 20 March 2016).

United States Census Bureau, available at: http://www.census.gov/ (accessed 20 March 2016).

Wabbi. J.B. and Taylor, D.B. (2008), "Health and environmental benefits of reduced pesticide use in Uganda: an experimental economics analysis", paper presented at joint annual meeting of American Agricultural Economics Association and the American Council on Consumer Interests, July 27-29, 2008, Orlando Florida, available at: http://ageconsearch.umn.edu/bitstream/6441/2/469143.pdf (accessed 29 February 2016).

Wang, Y., Zhang, G., Du, J., Liu, B. and Wang, M. (2010), "Influence of transgenic hybrid rice expressing a fused gene derived from cry1Ab and cry1Ac on primary insect pests and rice yield", *Crop Protection*, Vol.29, pp. 128–133.

Wesseler, J. and Zilberman, D. (2014), "The economic power of the golden rice opposition", *Environmental and Development Economics*, Vol. 19 No. 6, pp.724-742.

World Bank, available at: http://data.worldbank.org/ (accessed 20 March 2016).

Yang, Z. (2013), "Demographic changes in China's farmers: the future of farming in China", *Asian Social Science*, Vol. 9 No. 7, pp. 1911-2016.

Appendix

Calculation of equation (1), (2), (3) and (4)

This section based on the economic surplus model by Alston *et al* (1998). We denote K_t as the proportional supply shift in year t relative to the initial equilibrium price. $(P_1\text{-}P_0)$ is the research-induced change in price and $-(P_1\text{-}P_0)/P_0$ is the absolute value of the relative change in price. We denote Z_t as proportionate decrease in price in year t.

We can see from Figure 2 that:

$k=(P_0\text{-}d)$

$K=k/P_0=(P_0\text{-}d)/P_0.$

When $Q_s=Q_d=Q$

$$P_t=(m\text{-}\ \alpha\text{-}\beta k)/(\ \beta+n)$$

When $k=KP_0$

$$P_1=(n\text{-}\ \alpha\text{-}\beta KP_0)/(\ \beta+n)$$

$$(P_1\text{-}P_0)=\ \text{-}\beta KP_0/(\beta+n)$$

$-(P_1\text{-}P_0)/P_0=\beta K/(\beta+n)=K\ \varepsilon/(\varepsilon+\eta)=Z$ (multiplying through the numerator and denominator by P_0/Q_0 to convert the slopes to elasticities)

$\Delta CS=P_0abP_1=P_0aeP_1+abe=(P_0\text{-}P_1)Q_0+0.5(P_0\text{-}P_1)(Q_1\text{-}Q_0)$

Since $Z=-(P_1\text{-}P_0)/P_0$

$$(Q_1\text{-}Q_0)/Q_0=Z\eta$$

So $\Delta CS=P_0Q_0Z(1+0.5Z\eta)$

$\Delta PS=P_1bI_1\text{-}P_0aI_0=P_1bcd=P_1ecd+bce=(P_1\text{-}d)Q_0+0.5(P_1\text{-}d)(Q_1\text{-}Q_0)$

Rewrite to $(P_1\text{-}d)Q_0[1+0.5(Q_1\text{-}Q_0)/Q_0]$

We define $(P_1\text{-}d)=(P_0\text{-}d)\text{-}(P_0\text{-}P_1)=KP_0\text{-}ZP_0.$

So $\Delta PS=P_0Q_0(K\text{-}Z)\ (1+0.5Z\eta)$

$\Delta TS=\Delta CS+\Delta PS$

$$=P_0Q_0Z(1+0.5Z\eta)\ \ +P_0Q_0(K\text{-}Z)\ (1+0.5Z\eta)$$

$$=KP_0Q_0\ (1+0.5Z\eta)$$

In sum, we can summarize the consumer surplus, producer surplus and total surplus in the year t as equation (1), (2) and (3).

We denote $\varphi=E(Y)/\varepsilon$ as the gross proportionate reduction in marginal cost per ton of output. We denote $\omega=E(C)/(1+E(Y))$ as the proportionate input cost change per ton of output. We denote $\theta=\varphi-\omega=E(Y)/\varepsilon\ \text{-}\ E(C)/(1+E(Y))$ as the net proportionate change in cost per ton of output. $K_t=\theta A_t(1\text{-}\delta)$ is the proportional supply shift in year t where $(1\text{-}\delta)$ is the depreciation factor of technology.

$K=[E(Y)/\varepsilon-E(C)/(1+E(Y))]*\rho max/[1+exp(-\alpha-\beta t)]*(1\text{-}\delta)$

$Z_t=K\varepsilon/(\varepsilon+\eta)$

We substitute K and Z_t into equation (1), (2) and (3), and we can get:

ΔTS_t =*Net benefit* = $[E(Y)/\varepsilon\text{-}\mathrm{E(C)}/(1+\mathrm{E(Y)})]*[\rho\max/[1+\exp(\text{-}\alpha\text{-}\beta t)]*(1\text{-}\boldsymbol{\delta})\ P_t\ Q_t\ (1+0.5\ K\varepsilon/(\varepsilon+\eta)\eta)$

Finally, we can use *net benefit* to calculate the NPV and COD in equation (4).