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Risk analysis of GM crop technology in China: modeling and governance

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Abstract

This paper aims at analyzing risks management of genetically modified (GM) crop technology in China, including risk classification, risk generating mechanisms and its governance. Firstly, we seek to create a three-dimensional model capable of assessing the risks of GM crop technologies. Based on this model, the risks of GM crop technologies can be divided into eight types, depending on the high or low risks levels associated with social hazard, technology uncertainty and economic harm. China's GM technology is currently located in the high risk zone of this model, particularly in the market of GM soybean. In order to tackle this risk, the article introduces the Actor-Network Theory (ANT) as a useful tool to explore its risk assessment and governance. Lastly, we suggest the Chinese government needs to construct an efficient governance mechanism which should be able to balance actors' interests and reduce or avoid risks induced by GM crop technologies.

INTRODUCTION

The development of the world's agriculture has so far experienced two green revolutions. The first started in the 1940s and was aimed at changing the seeds while the second is the agricultural technology revolution focused on GM crop technology which appears to be dominating the 21st century. However, the discourses of opponents to GM crop technology in scientific and public communities are extending over a whole range from environmentalists (Lövei and Arpaia, 2005), social economists (Hubbard, 2009), health workers (Domingo, 2007; Then and Potthof, 2009) to ethicists (Jensen and Sandoe, 2002). Many of these critical discourses focus on the uncertainty of GM technology and its potential risk on human being and environment (Levidow *et al.*, 2005; Myhr and Traavik, 2003).

In fact the development of GM crop technology faces a dilemma. On the one hand it is aimed at delivering economic, social and environmental benefits, but on the other hand it may be threatening to the ecology, human health and social security. According to the dilemma towards GM crop technology, there are two hot research topics: the discussion of its potential or/and actual risks and the approaches of its risk management. From public attitudes' perspective, it is examined public policy attitudes towards GM technology (Paarlberg, 2000). But the reactions of public to GM food vary widely, including positive and negative cognition as well as positive and negative affect (feelings) (Siegrist, 2000; Cook, Kerr and Moore 2002; Liver *et al.*, 2005; Sjöberg, 2008). These different kinds of attitudes towards GM food may have different risk impact on social and economic system. Certainly, the various attitudes also lead to different actions in practice. The companies and authorizations by decision-makers suppose GM technology to be commercialized for its absence of health risks or nutritional equivalence serve (Huang *et al.*, 2005), while the environmental non-governmental organizations (NGOs) oppose it. Recently, the commercialization of GM crops has been a focus of attention in relation to consumers' information rights, property rights problems and ethical questions, which is related to the integrity of research and the objectivity of scientists (Diels, 2011). GM crop technology itself is indeed uncertain at different levels: technical uncertainty, epistemological uncertainty, (e.g., limited knowledge concerning properties of the GM production in question), and methodological uncertainty (Myhr and Traavik, 2003). Maybe the scientific uncertainty concerning the GM plant utilization impedes consensus on terminology from value differences between proponents and opponents of GM crop technology (Clark and Lehman, 2001; Costa-Font *et al.*, 2008).

In this context, there are a lot of measures proposed to GM risks governance. Freestone and Hey (1996) provide the Precautionary Principle (PP) to manage scientific uncertainty. Now the PP has been accepted by many national governments as a basis for policymaking, and it has also become important principle in international environmental laws and international treaties (EU, 2000). But in the view of opponents, the PP represents a non--scientific attitude that causes trade hindrance (Adler, 2000), and inhibits technology development as well as economic benefits (Miller and Conko, 2000). As a result, Rogers (2001) argues the risk associated with GM crop technology is divided into high, medium and low levels of uncertainties. The risk governance concerning high uncertainty should take preventive strategy while the latter two levels should apply PP strategy, such as increasing transparency or collecting more information. Furthermore, Cockburn (2002) applies a comparative approach to analyze the safety between the GM products and traditional crops. It is also argued GM food risk event is presented to the public as a new hazard occurring in a crisis context (Frewer *et al.*, 2002). Consequently, they apply social amplification of risk framework, which is proposed to explain why risk events with minor physical consequences often elicit strong public concern and produce extraordinarily server social impacts (Kasperson et al., 1988), to explain the potential impact on risk perceptions of GM food risk event. From label management perspective, it is suggested GM-food labels on bidding behavior of participants in an experimental auction (Huffman et al., 2003, 2007), while Rousu *et al.* (2004) develop a methodology to value the contribution of third-party information in a setting with conflicted information. Recently, the risk governance of GM food is enhanced by the application of science and technology studies, and Actor-Network Theory (ANT) in particular (Bryn and Janice 2002; Bled 2010). In their research, however, ANT is only used as a tool to analyze the ethical problem or environmental negotiation of GM technology. As a matter of fact, ANT is a useful theory framework to explore the GM technological choice and its risk governance.

Based on above literature review, research on the risk governance of GM crop technology includes not only micro-management, but also analysis from the perspectives of different disciplines. However, little research has conducted studies on the risks management associated with GM crop technology through constructing assessment models or frameworks. In particularly, it sorely lacks of multi-level perspective to analyse the GM uncertainties. In this study, we attempt to explore the risks governance of GM crop technology by establishing an innovative model of three dimensions for risk management with multi-level viewpoint. The three-dimensional model can analyze social risk, technology risk and economic risk at the same time. In order to address the practical reality of GM food risk in China, particularly in the market of China's GM soybean, we have also applied the actor-network theory to explore its risk governance. In this study, the GM risk governance has been an active area of research and the contribution is the establishment of an innovative three--dimensional model and actor-network theory application.

THEORY AND MODELING

The GM crop technology refers to the recombinant DNA technology which can transfer external DNA from one crop to another and hence achieve a new technology with new characteristics. This technology has advantages of decreasing the usage of chemicals and fertilizers and at the same time increasing the agricultural production (Zhang *et al.*, 2002). However, according to Rønning *et al.* (2003), there are many potential risks associated with GM crop technology, including unexpected concentrations and repetitive sequences of the exogenous genes. In spite of different risks (including social risk, technology risk and economic risk), we use the degree of risk as a whole to depute its risk in this research, which is related with three dimensions: social hazard, technology uncertainty and economic harm. First, despite continue development of GM crop technology, the risks caused by the uncertainties are also gradually socialized every day. Hence, the researchers must consider the level of social hazard (including actual and psychological hazard) and public response during their R&D and promotion of the GM crop technology. Second, according to Roger's (2001) *Harm = f(Hazard)* model, the harm brought by the GM technology risks is definite (i.e. the risk is constant), but the functional relationship is indefinite. In other words, GM technologies themselves are indeed uncertain at different level (e.g. with low or high uncertainty), which may cause the technology risk. Third, if the economic value cannot compensate for the damage inflicted on human health, resources, environment and social security, society should have enough reason to reject this type of technology (James *et al.*, 2003). Therefore, the GM technology risks are also linked to economic benefits or harm and generally the higher of economic harm from the GM technology the higher of its risks.

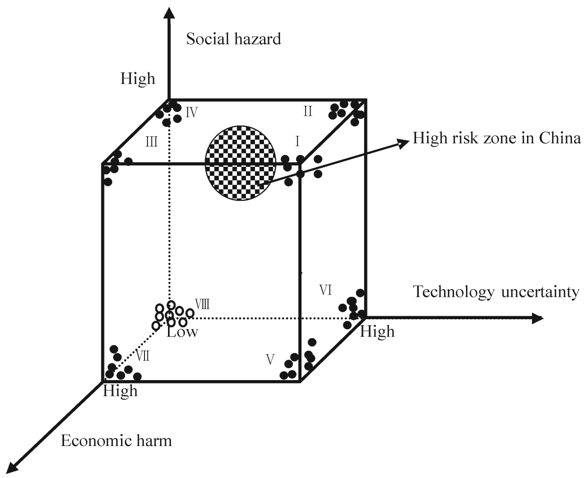

Figure 1. *Three dimensional-model of GM crop technology risk.*

The three dimensions, social hazard, technology uncertainty and economic harm, is used to assess the risk associated with GM crop technology (see Figure 1). Social hazard can be actual and/or perceived and is linked to implications related to human health, resources, environment and social stability during marketization. For instance, the GM plants may result in unmanageable weeding and then produce serious bad impacts on the ecosystems, including animals, fungi and bacteria. If people eats the GM food, it may cause detrimental effects on human being health (Domingo, 2007; Then and Potthof, 2009). If the problem of environment and human health is indeed serious, the social hazard will be obviously high and produce big risk. If the social hazard is under human control, it shows the social risk of GM crop is not big problem. Here, we propose that this dimension is the most important factor for the whole GM crop technology risk in the model. Technology uncertainty is related with these issues such as technology content, scale, range/sphere of influence, patenting and other research conditions. Generally, higher uncertainty is expected to bring higher risks and vice versa.

The third dimension represents the economic harm on GM crop technology. There are two kinds of economic harms or costs caused by investment in GM technology, including enterprise and social or environmental costs. We assume the economic revenues received from GM crops in time t to be TR_t, CC_t deputes the enterprise cost, CU_t deputes environmental and social cost that is unknown with a probability of P_t, the discount factor is $D_t=1/(1+r)^t$, where r is the social rate of time preference. Then the economic profits of GM crop technology can be represented by: $\Sigma D_t(TR_t-CC_t-P_t \times CU_t)$. The public decision-making about GM crop technology depends on a positive value of the profit (James *et al.*, 2003). Those countries who own low or none of economic profits from the development of GM technology will do not take positive policy to support it. The economic harm is taken into the model as the third dimension to reflect GM crop technology risk. These three dimensions with different fit in high or low level can be demonstrate the risk degree of GM crop technology (see Figure 1 and Table 1). Notablely, it is potentially assumed that the social hazard, technology uncertainty and economic harm are dependent each other in the three-dimensional model. If the three dimensions are correlated with each other, it may lead to the boundaries of eight types of GM technology risks blurred.

There are 8 types of risks (Table 1). First, the social hazards (SH) of GM crop technology are characterized by broad deep and irreversible, which means that this dimension plays a decisive role in the model. In other words, if the social hazard is higher the degree of risk is bigger regardless of other two dimensions. Second, the technology uncertainty (TU) of GM crop can create risks manifested through social and environmental hazard, which plays the second important role in deciding the degree of risk. The GM technology economic harm (EH) does not cause environmental harm directly but can also play a strong coordinating role in the risk degree. For example, an „SH high TU high" situation can create two types of risks, namely „SH high TU high EH high" and „SH high TU high EH low" where the latter has a lower risk than the former, because the risk is always positively associated with economic harm. The 8 categories can be arranged in the following descending sequence according to the risk degree: $R_I>R_{II}>R_{III}>R_{IV}>R_V>R_{VI}>R_{VII}>R_{VIII}$ (R stands for the level of risk).

TABLE 1

Types of GM crop technology risks.

Risk I	Risk II
SH high TU high EH high	SH high TU high EH low
Risk III	Risk IV
SH high TU low EH high	SH high TU low EH low
Risk V	Risk VI
SH low TU high EH high	SH low TU high EH low
Risk VII	Risk VIII
SH low TU low EH high	SH low TU low EH low

Note: SH-social hazard, TH-technical uncertainty, EH-economic harm

CHINA'S GM CROP TECHNOLOGY RISK IN THREE-DIMENSIONAL MODEL

Risk analysis on the whole

Since the GM tomatoes were firstly commercialized in US in 1994, the global commercialized plantation areas of GM crops have been on the stable rise (see Figure 2) with mainly four types of crops: soybean (90mln ha or 77% of global production), corn (158mln ha or 26%), cotton (33mln ha or 49%) and canola (31mln ha or 21%) (ISAAA, 2009). Although China delays the plantation of GM crops, its current development is very fast. By 2008, there are seven kinds of domestic GM corps approved for commercial production and 22 kinds of foreign GM crops approved for import. Currently a small amount of home-grown GM tomatoes are planted in Hubei and Guangdong provinces, however the frutescens capsicums are limited to Liaoning province (Xu *et al.*, 2009). Recently, although the plantation of Bt cottons grows rapidly at an average rate of 70 percent a year (see Figure 3), about 70% GM seeds are provided by Monsanto. Although the GM cottons are mainly used as a raw material for textiles, many farmers in Hebei province of China also have started to extract cooking oil from the seed (Xu *et al.*, 2009). If these GM plants contain any risk material, this would lead to unexpected consequences, such as social risk, technology risk and even economic risk, for which the republic is unprepared. In the three-dimensional model, we argue that China's GM crops technology is at the high risk of high social hazard, high technology uncertainty and high economic harm (see Figure 1).

From a higher social hazard perspective, once GM food becomes daily supply, it would be fatal if there is one risky case happing such as cross-species infection, pathogen drug-resistant or food toxicity. On the other hand, the awareness about this issue is very weak in China (Huang *et al.*, 2006). The low awareness level not only causes weak self-defense and social supervision power but also provides opportunities for international biological companies to control China's GM food. Most importantly, with its large size irreversible social hazard can be produced if GM technology is promoted in China without relevant governance and control. Examples include the allergic reaction to Brazil's soybeans in 1996 and 1998, the StarLink corn incident when soybeans were polluted by GM corn followed by the American Monarch butterfly incident in 1999, the 2001 Mexican corn gene pollution and the 2002 English experiment that caused the GM food DNA to remain in human bodies (Jia, 2004).

The US attitude remains positive towards the technology maturity, but the EU does not support GM technology. The technological levels are various between different countries. This is because their different GM policies reflect their public resistance to the technology and are amplified in the public debate (Miller *et al.*, 2008). More specially, there are four stages of research in developed countries: closed greenhouse, semi-closed greenhouse, isolated and fully opened experimental field plots, and every step has special requirements. However, in China, research institutes conduct GM research in the laboratories most of which do not have closed or semi-closed conditions and some do not even have the basic conditions for such research (Zhou and Cui, 2006). In addition, GM technology itself is uncertain all over the world. GM technologies may cause unintended non-target effects. Non-target effects include the influence on and interactions with all organisms in the environment, including direct or indirect effects. Direct effects concern ecotoxic effects on other organisms, for instance larval feeding on insect-resistant plants (Obrycki *et al.*, 2001), or effects on soil organisms (Saxena and Stotzky, 2000). Indirect effects are like consumer health, contamination of wild gene pools, or alterations in ecological relationships.

The expansion of GM areas shows the fast marketization of GM seeds. However, what is of concern is the concentration of seeds within a handful of companies. In 2006 Monsanto, Pioneer Company, Syngenta and Bayer accounted for 41% of the total global seed sales (Chen, 2010). The highly concentrated market of GM seeds enhances the dependence of Chinese farmers and the global agricultural system on multinational firms. This has not only reduced the diversity of agricultural biological resources, but also intensifies the system risks for agriculture, including market power, limiting R&D and biological risks (Harhoff *et al.*, 2001). Also, although China has certain global competitiveness in biotechnology, the GM technology intellectual rights are still far behind developed countries. The monopoly of patent technology has not only delivered low economic benefits from GM technology, but has exposed the country's traditional agriculture to serious challenges.

Based on the three-dimensional model, the risk of China's GM crop development is high. The following

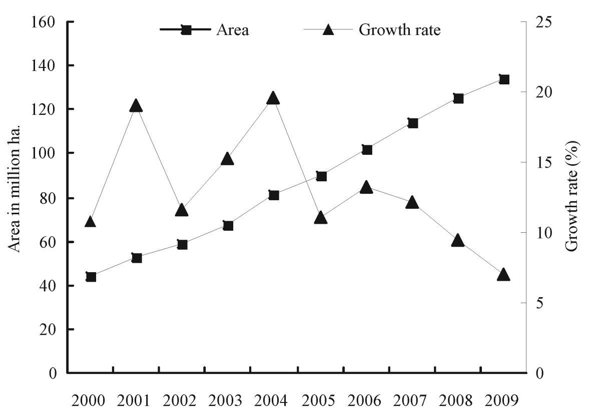

Figure 2. *The development of world GM crops.*
Source: James *et al.* (2003) and ISAAA (2009).

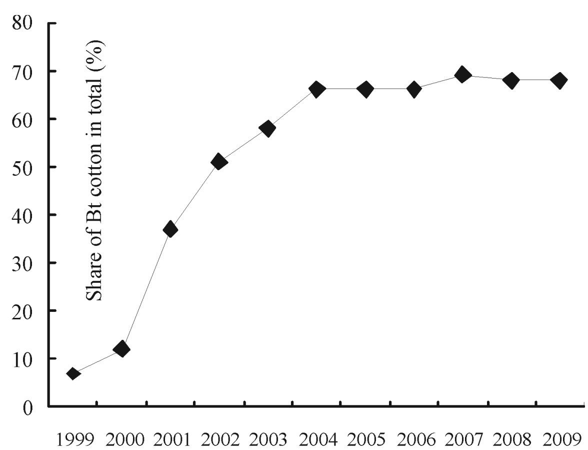

Figure 3. *The development of Bt cotton in China*.
Source: James *et al.* (2003) and ISAAA (2009).

TABLE 2

Types of GM technology issues disclosed by national news reports (2010.1.1-2010.12.31).

Subject	Number of reports	Share of total (%)
Recent progress of GM technology	9	8.4
Debate of GM cotton	7	6.5
Debate of staple foods	11	10.3
Debate of GM soybean	24	22.4
Attitudes toward GM crops	26	24.3
Consumer interest of GM crops	5	4.7
Laws and regulations on GM crops	4	3.7
Risk governance on GM crops	11	10.3
Others	10	9.3
Total	107	100

example of China's soybean market is able to reflect the potential social hazard and economic harm of China's GM crops more clearly.

The case of GM soybean market

According to Jiang (2012), the issues on GM technology are classified into 9 types (see Table 2) through analyzing 107 samples selected from 1821 pieces of news and articles from more than Chinese 500 newspapers in 2010. As it is illustrated in Table 2, the issues on foreign GM soybean risk account 22.4 %, which ranks the second in all issues. These results show that the risk of GM soybean is an important issue. Hence we take China's soybean as a good example to demonstrate the potential social and economic risks resulting from international GM soybean trade.

TABLE 3

Volume change of China's soybean export and import between 1990 and 2007.

Year	Export	Import	Net export	Year	Export	Import	Net export
1990	91.0	0.1	90.9	1999	20.4	431.9	–411.5
1991	106.5	0.1	106.4	2000	21.1	1041.9	–1020.8
1992	84.5	12.1	72.4	2001	24.8	1394.0	–1369.2
1993	34.5	9.9	24.6	2002	27.6	1131.5	–1103.9
1994	92.7	5.2	87.5	2003	26.7	2074.1	–2047.4
1995	42.7	29.4	13.3	2004	33.4	2023.0	–1989.6
1996	19.2	110.8	–91.6	2005	39.6	2659.0	–2619.4
1997	18.6	287.6	–269.0	2006	37.9	2827.0	–2789.1
1998	17.0	319.3	–302.3	2007	45.6	3082.0	–3036.4

Notes: The unit is 10 thousand tons.

Source: Ministry of Commerce of the People's Republic of China (1991–2008) and Ministry of Agriculture of the People's Republic

In China the import of soybean increases rapidly from only 1000 tons in 1990 to 30.8 million tons in 2007, while the export has a slight decrease from 910 kilotons in 1999 to 456 kilotons in 2007 (see Table 3). There have been three fast rising stages of net import on China's soybean since 1990. During the first stage in 1996, China's soybean market was just open for international markets, and its import firstly exceeded the export. From then on, the import of soybean has always been much greater than the export. In 2001 with China's accession to WTO, the single low tariffs of soybean was set as 3%, which induced the import to enter into the second fast increasing stage. While in 2003 China's soybean import stepped into the third increasing stage with the growth rate of 83%. In particular in 2002, the public announcement of temporary measures on genetically modified food by China's Ministry of Agriculture suggests that foreign companies can export GM products to China with their temporary certificates. This policy facilitated the third quickly increasing stage of China's soybean import, and also provided a significantly potential risk for China's GM crops. For example, between 2001 and 2008, China imported 200mln tons of soybeans, however 70% of them contain GM ingredients which are the major source for cooking oil (Xu *et al.*, 2009). If GM soybeans are harmful for human health, they may also create serious social problems.

In addition, China is the largest import country in the international GM soybean market. However, the import of China's soybean is basically from several regular multinational companies. For example, three countries, including the United States, Brazil and Argentina, have monopolized about 99 % of China's GM soybean imports (see Table 4), resulting in the pricing war in the market of cooking oil supply chain which completely depends on these three countries. In fact, the multinational corporations have taken many measures to manipulate China's soybean market. For instance, in 2004 they came to an agreement to control the soybean future trading price of Chicago, leading to the rapidly increasing cost of China's domestic soybean processing companies. In that year about 50 % of China's soybean processing companies went bankrupt due to that agreement which caused the direct economic loss of 8 billion yuan (Deng, 2010).

Meanwhile the GM soybean import also changes the trade patterns of China's agricultural products from surpluses to deficits (see Table 5). China's soybean production has decreased from 13.5 million tons in 1995 to 12.73 million tons in 2007, while the self-sufficiency ratio of soybean has dropped from 101% to 29.5%. The dependence of China soybean production has significantly negative effect on China's self-sufficiency ratio of grain on the whole, which decreases from 98.5% in 1995 to 95.7% in 2007.

In summary, both the whole risk analysis and the GM soybean risk analysis demonstrate that the risk of GM crops in China is high. Particularly, the whole risk is correlated with high social hazard, high technology un-

TABLE 4

Source structure of China's soybean imports (1995-2007).

Year	1995	1996	2000	2001	2002	2003	2005	2007
Total import	29.4	110.8	1041.9	1393.8	1131.5	2074	2659	3082.1
America	14.4	86.0	541.4	572.6	461.9	829.3	1104.8	1157.1
Brazil	0.7	5.3	212	316	390.9	647	795.2	1058.3
Argentina	9.4	11.8	278.4	502.0	277.5	596.4	739.6	827.8
Others	4.9	7.7	10.1	3.2	1.2	1.3	19.4	38.9
Share of import (%)	100	100	100	100	100	100	100	100
America	48.98	77.62	51.96	41.08	40.82	39.99	41.55	37.54
Brazil	2.38	4.78	20.34	22.67	34.55	31.2	29.91	34.34
Argentina	31.97	10.65	26.72	36.02	24.52	28.76	27.81	26.86
Others	16.67	6.95	0.97	0.23	0.11	0.06	0.73	1.26

Notes: The unit of import is 10 thousand tons and the data for 2006 is missing.
Source: Ministry of Commerce of the People's Republic of China (1991-2008) and Ministry of Agriculture of the People's Republic of China (1991–2008).

TABLE 5

Impacts of soybean trade on China's farm products trade.

Year	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007
Volume of soybean trade	8.6	9.5	23.3	28.9	25.6	55.1	71.2	79.5	76.4	116.7
Export	0.6	0.6	0.6	0.8	0.8	0.9	1.4	1.7	1.5	2.0
Import	8.0	8.9	22.7	28.1	24.8	54.2	69.8	77.8	74.9	114.7
Balance of Trade	–7.4	–8.3	–22.1	–27.3	–24	–53.3	–68.4	–76.1	–73.4	–112.7
Volume of farm produce trade	221.3	216.3	268.2	279.0	305.8	403.6	514.2	558.3	634.8	781.0
Export	138.1	134.7	156.2	160.7	181.4	214.3	233.9	271.8	314	370.1
Import	83.2	81.6	112	118.3	124.4	189.3	280.3	286.5	320.8	410.9
Balance of Trade	54.9	53.1	44.2	42.4	57.0	25.0	–46.4	–14.7	–6.8	–40.8

Notes: The unit of import is 100 million in US dollar.
Source: Ministry of Agriculture of the People's Republic of China (2008) and Ministry of Commerce of the People's Republic of China (199–2008).

certainty and high economic harm in the three-dimensional model. However the position of China's GM crops technology risk in the three dimensions is the outcome from the game played by all actors in the fields of interests. In order to deal with the high risk of China's GM crop technology in the model, this study applies the actor-networks theory to explore its risk governance mechanisms.

RISK GOVERNANCE OF GM CROP TECHNOLOGY WITH ACTOR-NETWORKS

Actor-Networks Theory is first proposed by French sociological scholars to analyze the technology development among different actors interactions in the 1980s (Latour, 1987; Callon *et al.* 1986). It is a brand new basic model of scientific activities during which actors attempt to establish a long chain of allies through Concatenation of Translation to form a seamless web constructed with sciences, technologies, economies, nature and societies. Among these chains, sponsors are always attempting to realize their hub position as Obligatory Passage Point (OPP). There are generally four steps during the Concatenation of Translation between actors: Problematization, interessement, enrollment and mobilization. Therefore scientific research became an effective power during the competition between alliances while the development of technology is the result of the power. In brief, actor networks can reduce the risks in the society while providing a platform for constructing the knowledge.

Actor-network and OPP analysis

The risk management of GM crop technology, to a large extent, can be explored through the supervision of actor networks. According to the actor-networks theory, GM technology development is no longer to be regarded as a mutual fragmented process between the natural non-human actors and social human actors. Non-human actors translate their own benefits to the whole GM

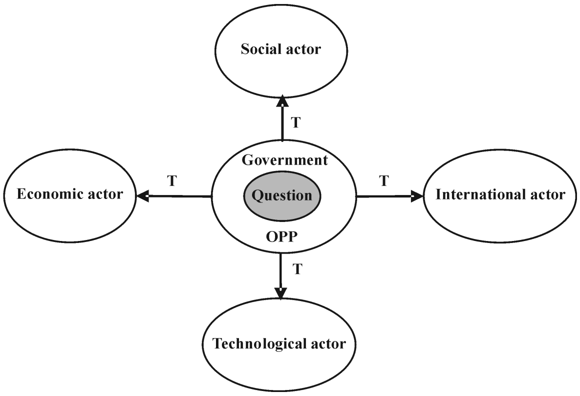

Figure 4. *Risk governance of GM crop technology in actor. network.*

networks through Concatenation of Translation to undertake the GM technology in the actor-networks (Callon *et al.*, 1986; Wang *et al.*, 2009, Hong et al., 2010). The risk governance structure of GM crop, especially for China GM soybean, within the three-dimensional model involves governments, enterprises, R&D, international actors, the public and many other stakeholders. A complex actor-network can be formed by these stakeholders (see Figure 4) with actors including government actors, economic actors, technology actors, social actors and international actors. In figure 4, the government actors are located in the center of the network, where represents the Concatenation of Translation process of the OPP and the central circle shows the encountered problems during the risks management.

From the perspective of the OPP (i.e. Chinese government), it includes state food and drug supervision bureaus, ministry of science and technology, agricultural department, health department, national environmental protection bureau, ministry of commerce, education department and intellectual property bureau etc. Through formulating proper evaluation documents of GM technology development, government regulators will achieve their concatenation of translation in their 'actor-network' and activate various actors of China's GM technology risk governance while achieving their strategic position of the OPP to incorporate other actors into the dynamic and heterogeneous network governance to achieve the risks management of GM technology under the three-dimensional model. The key of GM risk management from the perspective of actor-network is how the government actors, who are in the OPP, achieve the balance of interest between the GM actors during the translation process and then change the risks pattern in the three-dimensional model. For instance Chinese government can change the patter of current China GM crop risk from type I to type II by lowering the economic risk in the three-dimensional model. The risk also can be changed from type I to type III by increasing R&D investment on GM technology to decrease its technology uncertainty.

From the perspective of the technology actors, they need to receive financial support from government and enterprise actors, but on the other hand they should promote the degree of GM technology maturity to ensure the safety of GM food. For example, a technological actor was formed by the Chinese Academy of Agricultural Sciences, the Chinese Academy of Social Sciences and the GM technology R&D institutes of several universities to jointly manage risks. After the GM crops are approved to be allowed in the market, economic actors (such as farmers, manufacturers, distributers and retailers) start to plant, produce and sell GM products. Driven by opportunism, the first purpose of the economic actors is to benefit as much as possible from the process of environmental release of the technology for commercialization. However, these self-driven interests are exposed to pressures from consumers, social media and government regulatory authorities and are constrained by environmental management costs. The social actors mainly composed of consumers, social media and environmental NGOs are the direct GM crops and risks monitors. They are able to effectively monitor the GM technology risks, but firstly they need to properly understand the characteristics of the lifecycle of GM technology and the level of social hazard, technology uncertainty and economic harm in its different stages. Finally, the main international actors, such as the World Trade Organization (WTO), World Bank and biological multinational companies will also greatly influence the risks management. For example, WTO is responsible for the international trade coordination for GM foods; however the biological multinational companies to a great extent have been controlling the intellectual property system of Chinese GM seeds.

Concatenation of Translation analysis

Through the analysis of the actors in Chinese GM crop technology risks management as well as the examination of the OPP, it can be inferred that the evolution of actor-networks has its own regularity and convertibility of the government actors' OPP. During the evolution of the actor- networks of the dynamic and heterogeneous GM crop technology, Chinese government actors will translate imbalanced interests of risks management to balanced common interests of all actors and form a complex network of risks management. These networks include not only governmental, social, technological, economic and international actors (as shown in Figure 4) but also the sub-networks associated within all actors.

Figure 4 shows that in the Chinese GM actor-network the core of management with the OPP is to achieve a balance of network benefits through the process of Concatenation of Translation, which can be divided into 4 stages:

(1) In the stage of Problematization, every actor is involved by the OPP to work out how to effectively control the GM crop technology risks triggered by high social hazard, high-technology uncertainty and high economic harm. These risks will not be naturally controlled and they need the participation and cooperation among all actors. However whether actors can volun-

tarily participate in risk governance depends on how they estimate any benefits and risks. When the risk management costs for GM technology are greater than the benefits, the actors tend to give up their management plans which could result in an unstable actor-network.

(2) In order to manage the risks successfully, Chinese government actors should achieve the network stability and solidification through the interessement step of the Concatenation Translation of benefit rights process. Throughout the process of formation, development, stability and solidification, the network of a particular actor depends on how the key point strengthens other actors' role and status during the process of problematization in order to establish a new alliance system while breaking their potential competitive alliances on GM technology.

(3) The enrollment of stakeholders involves public support for the GM technology. During the process of interessement, in response to public opposition against GM foods due to lack, insufficient or negative information about safety, Chinese government's role is to react to public concerns and social awareness. A strict GM auditing system can make scientific research more socially responsible in laboratories and relate to the broader interests within society. This can further improve the certainty of the technology in order to lower the risk probability or reject the development of the GM technology. In consideration to economic actors and the opportunism of multinational companies, Chinese government should emphasize environmental management and the indirect benefit transformation costs to achieve effective risk management alliances, particularly on GM soybean international market.

(4) The mobilization stage will depend on the outcomes from the previous three stages and will respond both to any scientific evidence and broader social attitudes towards GM crop technology.

International biological and biotechnology multinational companies can be unscrupulous in inputting products with GM ingredients on the Chinese market. They also control China's GM seeds and related patents which will influence badly the translation of international actors' benefits to Chinese actors' benefits. Chinese government actors should enhance the publicity and education in GM technology while improving the GM legislation and strengthening the communication and cooperation between actors. On the other hand, the government actors must emphasize the risks management costs (or environmental costs) of the economic actors during any production of GM food. The government also needs to increase R&D capabilities and direct technology actors in the development of GM crop technology in order to protect China's independent intellectual rights and reduce the monopoly of GM crops and seeds by international multinational companies. In fact, only the government actors can address the obstacles and problems with a technology that is still at an early stage of development. Finally, the government, under the mobilization process, will become the voice for social, economic, technological and international actors and ultimately be responsible for risks management.

CONCLUSION

The GM crop technology is a very controversial issue. While many parts of the world are strongly objecting and banning its use, others are leaving its fields and markets unprotected and open to be controlled by ambitious profit-seeking and powerful multinational companies. Which way a country will go depends on policy makers and the legislation they approve. This is, however, not a simple process. The analysis in this paper showed that there are different types and levels of risk associated with the GM technology as well as different actors influencing the developments in the field. China is currently located in the high-risk zone of the developed three-dimensional model, where the high risk associated with the potential high social hazard, high technology uncertainty and high economic harm shows the urgency for better governance.

The Chinese Government needs to have a policy system in place that will allow to properly balance the opportunities and risks associated with the GM crop technology. Is it a wise option to completely give up GM R&D research? What the actors embedded by interests in this issue need to do is know how to improve the ability of risks management. There is a big gap between China's GM technology level and the world's most advanced achievements. There is also the threat from international actors to prevent China's GM independent. China needs the R&D capabilities not to be left behind in the global food race.

However, it is important for the Chinese government to have a system in place that optimizes and promotes the balance of risks/benefits from GM crops. System supply and optimization are effective solutions for the negative externalities of GM technology. This includes a risk assessment system for GM crop technology, GM products R&D approval system, environmental impacts assessment system, a comprehensive reporting system for tracking and monitoring GM agricultural production, processing, operation, import and export activities, text and graphics identification management system. Improvement in the management system and security measures will help achieve a balanced network of benefits to maximize the control of GM technology risks.

Finally, it is vital for the Chinese government to strengthen the communication and cooperation between beneficial bodies and to achieve the actors' networked comprehensive management. They are essential for the government to translate the management benefits of GM technology risks into the self-interests of each actor. Cooperation is necessary within the networks of main bodies of actors and each actor should be treated as having an international background, hence there is a need to have international communication and cooperation. In addition, each actor in China should learn the lessons from the industrialization of the American GM food production and should mirror the European Union's integrity and risk management of food security in order to achieve the required risks management during the network evolution.

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