
# Impact of Government Policies on Private R&D Investment in Agricultural Biotechnology: Evidence from China

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***Abstract:***

*This study evaluates the impact of Chinese government policies on private R&D investment in biotechnology. We apply survey data from 160 major agribusinesses to analyze the effects of various factors on firm R&D activities. Our findings provide evidence of inducement effects of government policy on firms' R&D investment. Significant drivers of Chinese agribusiness firms' decisions to invest in biotechnology R&D are public R&D subsidies, owning patents by firms, selling biotechnology products, and expectations of positive profit from commercialization of biotechnology crops. Firms' collaboration with universities has no significant impact. Government R&D subsidies also significantly increase firms' biotechnology R&D investment spending.*

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**Abstract** This study evaluates the impact of Chinese government policies on private R&D investment in biotechnology. We apply survey data from 160 major agribusinesses to analyze the effects of various factors on firm R&D activities. Our findings provide evidence of inducement effects of government policy on firms' R&D investment. Significant drivers of Chinese agribusiness firms' decisions to invest in biotechnology R&D are public R&D subsidies, owning patents by firms, selling biotechnology products, and expectations of positive profit from commercialization of biotechnology crops. Firms' collaboration with universities has no significant impact. Government R&D subsidies also significantly increase firms' biotechnology R&D investment spending.

**Keywords:** Agricultural biotechnology, China, Policies, Private R&D investment

## 1. Introduction

Government policies can exert great influence on private firms' investment behavior through shaping the ways or the environment in which firms operate (González and Pazó 2008; Wang, Chen, and Huang, 2014). Policies, such as tax levies, provision of public R&D subsidies, enforcement of laws, and regulation of competition, are often employed by the government to influence firms' investment decisions (Pastor and Veronesi 2012). Hu et al. (2011) studied Chinese private firms' agricultural R&D investment and concluded that the policy for agribusiness privatization and public R&D subsidies significantly increased Chinese private firms' agricultural R&D investment. With the advent of further significant challenges in agriculture, the Chinese government regards biotechnology as an important tool to boost agricultural productivity and has invested significantly in biotechnology R&D (Huang et al. 2002). The government has also put in place a series of policies to encourage private firms to conduct biotechnology research, such as providing incentives for government research institutes to collaborate with the private sector, subsidizing private research, and strengthening intellectual property rights (IPR), with the aim that Chinese agribusiness firms become the core of biotechnology research (Science and Technology Department of Zhejiang Province 2006).

China has been particularly wary of foreign control of its agricultural sector. To avoid dependence on foreign companies and help the transition of the Chinese economy to a science-based economy, the government has been attempting to build a globally competitive biotechnology industry for decades. As President Xi Jinping stated at the Central Conference on Rural Work in December 2013, the government encourages Chinese firms to boldly undertake research and innovation to the "commanding heights in biotechnology" while not allowing foreign companies to dominate the genetically modified (GM) product market (USDA 2015). The Chinese government also protects local biotechnology firms from competing with multinational corporations (MNCs) by not approving any GM traits for cultivation from MNCs since the approval of Bt cotton in 1997 and prohibiting foreign companies from investing in biotechnology in China.

The Chinese government has promised domestic firms that it will protect them from foreign competitions for 5 years in the cultivation of GM crops. As the large Chinese seed and biotechnology firm Origin Agritech said in its Annual Report in 2012 (Origin 2012):

if GM seed products were to be approved by the government on a broader scale and begin to gain widespread acceptance in the market, large international biotechnology companies could likely become more serious competitors. However, they may continue to face numerous obstacles in competing with us in China. Foreign companies are currently prohibited from developing or producing genetically modified plant seeds, breeding livestock and poultry, or producing aquatic seed. As a result, we believe we will continue to be in a strong competitive position in the genetically modified segment of the seed market when it becomes meaningful and legally permissible to do so.

Despite these policies and investments, only six Chinese GM products were judged sufficiently competitive to be approved for production in China: Bt cotton and GM tomatoes in 1997, virus-resistant papaya and disease-resistant pepper in 2006, and Bt rice and high phytase maize in 2009 (safety certificates of GM rice and maize were extended in 2014, but still have not been commercialized). Unlike the rest of the world, none of these products was developed by private research programs. Some GM traits that provide insect resistance for maize have been developed by Chinese private companies and government institutes and might be commercialized in the next 3 or 4 years. The purchase of Syngenta by ChemChina was finalized in 2017, which means that the Chinese government will own 60% of a globally competitive biotechnology company and China will require a healthy, competitive innovation ecosystem. Thus, Chinese biotechnology firms will not only be essential to help Chinese farmers obtain access to the new technology they need, but also will play a great role in agricultural biotechnology research.

Therefore, it is of great importance to understand the impact of government policies on private firms' R&D investment in biotechnology, which might assist China's policymakers to evaluate the effect of government policies, and further improve the management of biotechnology R&D. In the following Section 2, we review the literature on agricultural biotechnology R&D investment and policies in China. Section 3 presents the data collection and econometric model. Section 4 presents the empirical results. Finally, Section 5 concludes with policy implications based on the findings.

## 2. Background

### 2.1 Agricultural biotechnology R&D investment

China's agricultural biotechnology research started in the early 1980s following the start of two significantly important programs established by the government. The 863 Program, established in March 1986, stimulated the development of advanced technologies in a wide range of fields, including biotechnology (MOST 1986). The second program, the National Basic Research and Development Program ("973") was established in March 1997, and committed more than US$ 238 million to life sciences and biotechnology from 1996 to 2000 (Cao 2012). To improve international competitiveness in biotechnology, China significantly increased R&D investments since the mid-1980s (Huang et al. 2002; Liu and Cao 2014). The National GM Variety Development Special Program funded in 2008 is budgeted to allocate US$ 3.5 billion to biotechnology R&D in 2008–2020 (Hu et al. 2012; Huang et al. 2012; USDA 2012). The total government budget for all types of biotechnology in the Twelfth Five-Year Plan period (2011–2015) was approximately ¥ 2 trillion (US$ 308.5 billion) (Gilmour, Dang, and Wang 2015).

The Chinese government funds almost all plant biotechnology research while R&D

investment in agricultural biotechnology by the private sector is very limited and highly regulated. 2003 data show that less than 5% of agricultural biotechnology R&D investment in China was from the private sector (Huang et al. 2005). Since foreign companies are allowed to operate only as joint ventures in the seed industry (Pray and Fuglie 2015), their role in biotechnology research is limited (Hu et al. 2012; Huang et al. 2002). A report from the US Department of Agriculture (USDA) shows that foreign investment in biotechnology in China was shifted to the “banned” category from the “restricted” category in 2011 (USDA 2014).

**2.2 Agricultural biotechnology policy in China**

While investment in China’s biotechnology is overwhelmingly from government sources, the Chinese government recognizes the private sector’s role in biotechnology innovation and supports the private sector (Huang et al. 2005). Reformers in the late 1990s started to press for a more modern, less government-dominated research system and implemented policies to encourage the private sector to conduct research. In 2000, the government passed a new seed law that for the first time defined a role for the private sector. The law states that any entrepreneur with access to the required minimum amount of capital and facilities can sell seeds. Following the implementation of this law, private firms began to appear in the seed biotechnology industry. Some large Chinese seed companies, such as Origin Agritech and Dabeinong, have established biotechnology laboratories. In addition, a few multinational seed and biotechnology companies have conducted applied biotechnology research in China. For example, Monsanto collaborated with Delta & Pineland as well as research institutes of the government sector on breeding and testing BT cotton varieties in the 1990s, but the companies abandoned this research after 2000 as a result of low profits due to lack of effective enforcement of patents and trademarks (Pray et al. 2011).

In recent years, both local and central governments have been undertaking great efforts to create a favorable policy environment for agribusiness firms to engage in agricultural biotechnology innovation and industrialization. For example, the Science and Technology Department of Zhejiang Province issued a special program of agricultural biotechnology in 2006 (Science and Technology Department of Zhejiang Province 2006). It states that the government will nurture and support a number of agricultural technology firms, and develop them into the core of agricultural biotechnology R&D by encouraging agribusiness firms to apply for technology patents, reinforcing the protection of IPR in agricultural biotechnology, and providing preferential policies for promoting the use of biotechnology to transform traditional, high-tech agricultural enterprises. The State Council released the National Plan for Development of the Modern Crop Seed Industry (2012–2020) in 2012, claiming that the central government would support powerful seed enterprises to create a batch of new GM breakthrough varieties with outstanding-target traits as well as excellent comprehensive traits. The Ministry of Agriculture (MOA) issued a document in 2014 to guide key seed companies to participate in the implementation of a major program for new varieties of GM crops and to undertake biological breeding capacity-building.

At the start of 2017, the MOA issued the Thirteenth Five-Year Agricultural Science and Technology Development Plan, stating that the government will promote enterprises to become the core of technological innovation, R&D investment, and commercialization. To achieve this, the government will take a variety of measures. For example, it will use financial assistance and indirect investment to invest in major industrial technological innovation, and support enterprises to make their own decisions. In addition, the government will encourage enterprises to set up their own R&D institutions, and technology promotion departments to build joint R&D centers. Moreover, the government will provide preferential policies for corporate R&D cost plus deduction and enhance capital market support for agricultural technological innovation, such as guiding venture capital to participate in the establishment of an agricultural science and technology innovation fund. All the abovementioned policies reveal that the Chinese government has been trying to build a mechanism in the agricultural market in which agribusiness firms could be the core of technological innovation and R&D investment.

In terms of biosafety management and commercialization of GM crops in China, the government has established a set of biotechnology policies to manage genetically modified organism research, testing, production, processing, marketing, imports, and exports. Although a series of GM crops has received biosafety certificates for production and importing, only GM cotton and papaya have been grown commercially in China. In addition, GM crops or products imported from foreign countries can be used only as raw material for food processing rather than commercial cultivation. Executives and owners of major Chinese seed and biotechnology firms have expressed concern that if the Chinese government continues not to approve commercial cultivation of any new crops, it could cause significant earnings losses for firms and dampen their enthusiasm to invest in biotechnology research (Personal communication with four Chinese big biotechnology and seed firms in Beijing and Shenzhen, November 2016).

In summary, the Chinese government has enacted a variety of policies to encourage private agribusiness firms to conduct biotechnology R&D and become the core of R&D. On the other hand, the government remains very cautious of commercial cultivation of new GM crops in China, which might in turn dampen firms' incentives to undertake investment in biotechnology R&D.

## 3. Data and model

### 3.1 Data

To explore the effect of public R&D support and biotechnology policy on private R&D investment in agricultural biotechnology, we assessed the investment activities of agribusiness firms in the food, feed, chemical, and seed industries in China. Surveys of 160 agribusiness firms in China were conducted between November 2013 and June 2014 through face-to-face interviews, mail, and email. Since the commercialization of GM crops might use new GM seeds to replace conventional seeds, reduce the usage of herbicide, and increase sales of glyphosate, seed and chemical firms are big players in the agricultural biotechnology industry. Food and feed firms might be involved in employing GM products as raw material, which are often not as expensive as traditional products, such as soybean (Bett, Ouma, and De Groote 2010), and thus, these firms are also stakeholders of biotechnology. In order to interview the firms that are very influential in the food, feed, chemical, and seed industries, we contacted the MOA, industry associations, and local governments to help us conduct the surveys.

A survey of the top 70 seed firms in China, whose market share in China is around 30%, was conducted with the help of the MOA in April 2014. Fifty of these seed firms responded to our survey between April and September 2014. The Pesticide Industry Association emailed the questionnaires to 50 key chemical firms in China in November 2013. Unfortunately, only eight big chemical firms responded. Then, we attended a workshop for Environmentally Friendly Pesticide Processing Technology and Production Equipment in Shanghai in April 2014, which most big chemical enterprises attended. There we interviewed 45 chemical firms. Among the total 53 chemical firms that responded, 17 chemical firms rank in the top 100 chemical firms in China and 8 firms are listed on Chinese stock markets.

Due to the difficulty of choosing representative food firms that play an important role in the food industry, firms engaged in the grain and oil business became the focus of our study. An official working in the State Administration of Grain in China assisted us to attend a grain and oil conference in November 2013 attended by around 170 large grain and oil firms, and 40 grain and oil firms responded to our questionnaire. Some respondents are very large grain and oil firms in China, such as COFCO, the largest import–export grain and oil food producer in China, and Jilin Grain Group Co., Ltd., a top 10 grain and oil company. Regarding the survey of feed firms, we attempted to contact the feed association to interview large feed firms. Unfortunately, it did not work out without the help of any government department. Finally, with the help of the Agriculture Department of Zhejiang Province, 17 medium-sized feed firms in Zhejiang responded to our survey in January 2013.

The survey questionnaire consists of two parts: (1) questions about firm information, such as ownership, size, product structure, R&D investment, and R&D personnel; and (2) questions regarding firms' expectations of profit change from GM crops and biotechnology products.

### 3.2 Descriptive evidence

Most of the respondents are private firms (72.5%), followed by state-owned firms (16.2%), joint ventures (6.9%), and wholly foreign-owned firms (4.4%). None is a major foreign biotechnology company. These firms are located in 23 different provinces/ regions in China, with almost half concentrated in four provinces: Shandong (16.9%), Zhejiang (10.6%), Beijing (9.4%), and Jiangsu (8.1%). The sales revenue of the160 firms in 2013 was ¥ 2.01 billion ($US 303 million) on average[1]. Their average registered capital was ¥ 114.8 million ($US 17.3 million) and they had on average 922 employees.

Nearly half of these surveyed firms sell products relevant to GM technology[2] (n = 70, 18 for food, 9 for feed, 21 for chemical, and 22 for seed firms). Among the 70 firms that sell biotechnology products (bio-products), sales derived from bio-products in 23 firms account for more than 50% of the firm's entire sales.

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1 The seed firms did not provide the sales data. The average sales data of 70 major seed firms, including the 50 sample seed firms, was provided by the MOA. The average sales here are calculated based on the sales of these 70 major firms.

2 The respondents for the food, feed, and chemical firms were asked to report whether they sell biotechnology products, but no such question was surveyed for seed firms. Therefore, we checked all the surveyed seed firms' official websites to find out whether they sell cotton seeds because, among all major GM crops, only cotton is approved for widespread commercial cultivation in China and almost 97% of cotton seeds sold in China are GM organisms. Thus, we assume that a seed firm sells biotechnology products if it sells cotton seeds.

We surveyed firms' expectations of profit change from the commercialization of eight GM crops, including Bt cotton, soybean, corn, and rice as well as herbicide-tolerant (HT) cotton, soybean, corn, and rice (1=gain; 2=loss; 3=no change; 4=not sure)[3]. The results show that firms' profit expectations vary across industries: 49 firms expected to gain profit, 28 expected a loss, and 45 expected no change. Most food and feed firms claimed they would either benefit or have no change in profits from the adoption of GM crops. On the other hand, nearly 60% of chemical firms and 40% of seed firms either stated they would suffer a loss or were not sure how their firm profits would change. None of the feed firms expected an earnings loss from the adoption of GM crops.

As shown in Table 1, a significant proportion of the respondents, especially chemical and seed firms, undertook biotechnology research investment, received R&D subsidies from the government, and collaborated in research with public universities/institutes. Overall, 28% (n=45) engaged in agricultural biotechnology research, of which 44% (n=22) were seed firms, 32% (n=17) chemical firms, 18% (n=3) feed firms, and 8% (n=3) food firms. Only chemical and seed industries reported expenditure on biotechnology R&D investment, of ￥5.6 million ($US 0.84 million) and ￥28.5 million ($US 4.3 million), respectively. The

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[3] We defined the profit expectation as follows: if the manager answered "gain" ("lose") for at least one product type and "no change" for the remaining product types, we coded that a firm would gain (lose). If a firm reported to gain from the GM adoption of one product, but to lose from other crops, we coded it as a "mixed" profit expectation. If a firm's profits did not change from the adoption of all GM crops, it was coded as "no change" for the profit expectation. Firms that chose "not sure" for their profit expectation were coded as "not sure."

average annual R&D investment in the past 3 years for the 73 firms was ¥ 21.8 million ($US 3.3 million). Seed firms had the highest average investment, followed by chemical firms. In addition, 23 firms (8 chemical firms and 15 seed firms) received government subsidies for R&D. A total of 66 firms had collaborative projects with public universities and/or institutes, including 24 chemical firms, 36 seed firms, and 6 food firms. More than 70% of chemical firms and 92% of seed firms either had their own patents or jointly owned patents with public universities or other companies.

### 3.3 Econometric model

David, Hall, and Toole (2000) provide a conceptual framework to measure the impacts of various types of government research and technology policies on private research. The authors state that a firm's R&D investment decision is modeled as the interplay between the demand for innovations in their potential market area, appropriability, technology policies, and the technological opportunities for innovation. Following the concepts in David, Hall, and Toole (2000), we provide a generic specification of a firm's decision of biotechnology investment, *IB*, as follows:

$$(1) \quad IB = g(DEM, APP, POL, TOP, \boldsymbol{X})$$

where *DEM* represents the factors characterizing the demand for innovation in a firm's potential market area or line of business; *APP* represents conditions that affect the appropriability of innovation benefits; *POL* is a measure of policies that affect the private cost of R&D projects (e.g., tax treatment of that class of investment, R&D subsidies, and cost-sharing of government procurement agencies); *TOP* is a vector of factors reflecting a firm's technological opportunities to generate innovations (e.g., innovations by other firms in the industry or advances in science and technology); **X** includes other variables that might influence the firm's biotechnology investment decision or control variables, such as firm characteristics.

To make the analysis empirically tractable, we parameterize firms' investment decisions as $f(DEM, APP, POL, TOP, \mathbf{X}; \beta)$, where $\beta$ is a vector of parameters capturing the effects of all the abovementioned factors $(DEM, APP, POL, TOP, \mathbf{X})$ on $IB$. Equation (1) is written as

$$\text{(2)} \qquad \mathrm{IB} = f(DEM, APP, POL, TOP, \mathbf{X}; \beta) + \varepsilon$$

where $\varepsilon$ is an error term and $\beta$ the parameters to be estimated.

One challenge in estimating Equation (2) is to measure the biotechnology research variable denoted by *IB* appropriately. Research investment in a controversial new technology is viewed as a trade secret by a large proportion of private firms in China, which makes it difficult to collect investment data. We obtained biotechnology R&D investment only from chemical and seed firms. To utilize the survey data fully, we investigate both the impact of government policies on the probability of firms undertaking biotechnology R&D and the effect on firms' expenditure on biotechnology R&D.

On the one hand, the respondents were asked to answer the following question: "Does your firm have an R&D center? If your firm has an R&D center, does the R&D center engage in any biotechnology research?" Based on each respondent's answer, we assign 1 to *IB* if a firm engages in any biotechnology research and 0 otherwise. Following Greene (2003), the probability of having or not having biotechnology research can be written as follows:

$$\text{(3a)} \quad \mathrm{Prob}\,(IB = 1|\mathrm{Y}) = \mathrm{F}(\mathrm{Y}; \beta)$$

$$\text{(3b)} \quad \mathrm{Prob}\,(IB = 0|\mathrm{Y}) = 1 - \mathrm{F}(\mathrm{Y}; \beta) \quad ,$$

respectively, where $F$ is a cumulative standard normal distribution function and $Y$ is a vector of variables influencing the probability of whether a firm invests in biotechnology R&D, including $DEM$, $APP$, $POL$, $TOP$, and $X$. Thus, the Probit model is employed to examine the determinants of whether a firm engages in biotechnology R&D. The reduced-form equation is

$$(4) \quad \text{IB} = \boldsymbol{\beta_0} + \boldsymbol{\beta_1} DEM + \boldsymbol{\beta_2} APP + \boldsymbol{\beta_3} POL + \boldsymbol{\beta_4} TOP + \boldsymbol{\beta_5} X$$

The demand variables in *DEM* consist of firms' expectations of profit change from commercialization of GM crops in China. The following dummy variables are included in the estimation: gain, lose, not sure, and mixed (gain and lose) while "no change" is used as the base. We expect that firms with a positive profit expectation would be more likely to engage in agricultural biotechnology investment.

The appropriability factors denoted by *APP* include a dummy variable measuring whether a firm possesses any patent and a variable measuring firm size (number of employees). We expect that firms with patents and large firms are more likely to invest in R&D, because larger firms typically conduct more research than do smaller firms owing to economics of scale and economies of scope in research (Schumpeter 1942). Furthermore, large firms in China have more bargaining power to lobby the government for more research subsidies and favorable policies, such as tax benefits.

Whether a firm received research subsides from the government is included to reflect the technology policy denoted by *POL*. Private firms that obtain direct or indirect R&D subsidies from the government are expected to be more likely to engage in R&D activities (David, Hall, and Toole 2000).

Four variables were incorporated to reflect the technological opportunity denoted by *TOP*. First, the adaptive experience in selling bio-products might influence a firm's investment decision on biotechnology R&D because the firm has benefited from the new technology and might want to retain its competitive edge by undertaking biotechnology research. Therefore, we incorporate a dummy variable indicating whether a firm is selling a biotechnology product. Second, collaboration with research institutes or universities can reflect firms' technological opportunity. If a firm undertakes such collaboration in research, it might obtain access to more new ideas or technology, produce more technologies, and thereby be more willing to invest in biotechnology R&D. Third, a dummy variable representing state-owned firms is included, as state-owned enterprises are often more likely to have political and economic resources as well as human capital to engage in their own biotechnology R&D programs. Last but not least, firms' average R&D investment (including all GM and non-GM R&D projects) in the past 3 years was incorporated. Other variables measuring firm characteristics, including firm age and firm industries, are included as control variables.

On the other hand, we asked each respondent to provide firms' specific research projects to derive firms' investment spending in biotechnology R&D based on their research projects. We employed the ordinary least squares (OLS) to capture the impact of different factors on firms' biotechnology R&D investment spending[4]. The biotechnology R&D investment

[4] Since only chemical and seed firms provided a specific research project, we used only the OLS model to examine the impact of public R&D support and biotech policies on chemical and seed firms' investment in biotechnology R&D.

equation is

$$(5)\ BE = \boldsymbol{\beta}_0 + \boldsymbol{\beta}_1 DEM + \boldsymbol{\beta}_2 APP + \boldsymbol{\beta}_3 POL + \boldsymbol{\beta}_4 TOP' + \boldsymbol{\beta}_5 X$$

where $BE$ is the dependent variable, firms' biotechnology R&D investment, and $DEM$, $APP$, $POL$, and $X$ are vectors that are the same in Eq. (4). $TOP'$ is almost the same as $TOP$ except that firms' average R&D investment (including all GM and non-GM R&D projects) in the past 3 years were included in $TOP$, but not in $TOP'$, owing to the endogeneity between firms' average R&D investment and R&D investment in biotechnology.

**4. Results**

We estimated Eq. (4) with the Probit model to examine the impact of government policies on firms' decision of whether to undertake biotechnology R&D, and we estimated Eq. (5) with the OLS model to investigate the effect of the policies on how much firms spent on biotechnology R&D. We used the unique survey data set of 160 agribusiness firms in the food, feed, chemical, and seed industries. We are aware of the potential endogeneity problem of the two variables, government R&D subsidies and firms' collaboration with universities/institutes. Unfortunately, we do not have good instruments to control endogeneity. However, we checked robustness by running regressions with and without the government R&D subsidies dummy, as well as with and without the collaboration with universities/institutes, and the results are robust.

The Probit estimation results and corresponding marginal effects are summarized in Table 2. As we expected, firms with a positive profit expectation from commercialization of GM crops are more likely to undertake biotechnology R&D investment. Surprisingly, firms that expect a profit gain from some GM crops but an earnings loss from others, namely, firms expecting mixed profit change, have higher probability of investing in biotechnology research than do firms that expect no profit change. The surveyed results show that seven of the eight firms with such mixed profit expectations are chemical firms. These chemical firms sell products that complement GM traits, such as the herbicide glyphosate, and substitutes for GM traits, such as anti-Lepidoptera insecticides. Thus, these firms could earn profits from some GM products, like glyphosate, but lose profit from insecticides if GM crops are adopted. Therefore, these firms might strategize to gain more and lose less by investing in biotechnology research. No statistical difference is found in the probability of investing in biotechnology R&D between firms expecting an earnings loss and those expecting no profit change as well as between firms that are unsure about the profit change and those expecting no profit change. Thus, both earnings loss and profit uncertainty curb agricultural biotechnology R&D investment.

Firms with patents can increase the likelihood of engaging in biotechnology R&D by 28 percentage points compared to firms without patents. This finding supports the importance of patents and the corresponding exclusive market power in biotechnology investment. The Chinese government needs to strengthen the patent law and intellectual property system further to stimulate more private investment in agricultural biotechnology. On the other hand, different from our expectation, firm size measured by the number of employees does not significantly influence firms' decision to undertake biotechnology research.

Government subsidy of R&D has a significant and positive impact on biotechnology R&D investment while collaboration with research institutes/universities has a positive but insignificant impact on firms' decision to invest. This result implies that government policies, especially R&D subsidies, could stimulate private firms to invest in biotechnology R&D. According to the survey data, one-third (n = 15) of firms that engaged in biotechnology research received government grants for R&D and nearly 70% of these firms collaborated with universities. Therefore, the government could facilitate the collaboration among firms, public universities, and government research institutes, which could indirectly bring potential research support to firms. Then the government subsidy of firm R&D would directly stimulate firms to invest in biotechnology R&D.

As expected, firms that sell GM products are significantly more likely to invest in biotechnology R&D. There is no statistical difference in terms of the likelihood of biotechnology investment between state-owned firms and the private-sector counterparts. The other technological opportunity variable, R&D investment in the past 3 years, does not have a significant impact on a firm’s likelihood of conducting biotechnology research. This finding suggests that the policy of commercializing new GM crops might attract more private firms to sell GM products and further encourage these firms to undertake biotechnology research. In addition, firm characteristics, including firm age and industry, have no significant influence on firms’ decisions on biotechnology investment.

Table 3 reports the estimation results of impact of government policies on biotechnology R&D investment expenditure from the OLS estimation. The results show that only government R&D subsidies and firm size significantly increase firms’ expenditure on R&D investment in biotechnology. On the other hand, firms’ expectation of profit change from commercialization of GM crops, firms owning patents, collaborating with research institutes/universities, and selling biotech products have no significant impact on firms’ investment spending in biotechnology research. This result indicates that government R&D subsidies not only encourage more private firms to undertake biotechnology R&D, but also increase the research expenditure of those firms that have been engaged in biotechnology R&D.

## 4. Conclusion and policy implications

The failure of past investments in research and policies to develop commercial private biotechnology innovations in China suggests that it is time to re-examine these policies. This study undertakes this research by examining the relationship between government policies and biotechnology research by agribusiness firms in China, using a unique survey dataset of 160 Chinese agribusiness firms in the food, feed, chemical, and seed industries. The results provide support for the likelihood of a number of policies to induce private R&D investment in biotechnology.

Our analysis shows that companies that expect to profit from commercialization of GM crops are more likely to invest in biotechnology R&D, as are firms with experience selling biotechnology products, such as GM cotton or food or feed products made from GM crops. The most basic policy change required is the approval of new GM traits for cultivation and GM traits for consumption. If the government could approve more GM crops or take less time to approve them, firms would be more likely to conduct biotechnology research, because the probability that they can market their GM products is higher and the cost of moving the product through the regulatory process is lower. Second, government programs can educate people about the actual benefits and risks of biotechnology and increase the effectiveness of its food safety system, which could ease peoples' concerns about new GM foods. Then more firm managers would expect increased demand for biotechnology products. Thus, if government programs could induce more firms to expect increased demand, more firms would conduct biotechnology research.

More importantly, policies to reduce the cost of biotechnology research (government R&D subsidies) not only significantly influence firms' decision to undertake biotechnology research, but also increase firms' R&D expenditure on biotechnology. This supports earlier research by Hu et al. (2011). Therefore, the government could use government R&D subsidies to induce more private firms to invest in biotechnology.

The results show that firms with their own patents have higher probability of investing in biotechnology R&D, which implies that stronger IPR appear to stimulate more private firms to undertake biotechnology research. The patent system in China is in place and is gradually growing more effective, but major problems remain with the enforcement of patents.

All the results of this analysis indicate that the government has a number of policy tools to encourage the development of the Chinese biotechnology industry. The history of the last 30 years and evidence from this study shows that the Chinese biotechnology industry will not develop unless Chinese firms are allowed to market GM products that they have developed through their research. The Chinese government seems to have recognized the problems by promising to allow cultivation of GM maize and GM soybean products in the next 5 years (State Council 2016) and by financing ChemChina to buy Syngenta. Once new GM products are allowed, patents are strengthened, Syngenta starts conducting biotechnology research and introducing biotechnology products, and consumers become more comfortable with GM products, Chinese agricultural and food companies have a good chance of being successful in China and perhaps globally. They could build on the Chinese government's massive investments in biotechnology research as well as advances in medical biotechnology in China and elsewhere to conduct successful research and develop new products for the future.

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**Table 1 Research and development by firms (no. of firms)**

| Category | Total | Food | Feed | Chemical | Seed |
|---|---|---|---|---|---|
| Firms engaging in biotech research | 45 | 3 | 3 | 17 | 22 |
| Biotech investments (million RMB)[a] | 17.8 | | | 5.6 | 28.5 |
| Firms receiving R&D subsidies from | 23 | 0 | 0 | 8 | 15 |
| Firms collaborating with university/ institute on R&D | 66 | 6 | 0 | 24 | 36 |
| Average annual R&D investment in the past 3 years (million RMB) | 11.3 (21.8) [b] | 0.2 (1.8) [b] | 0 | 10.4 (22.8) [b] | 24.9 (24.9) [b] |
| Firms with patents | 101 | 14 | 3 | 38 | 46 |
| Total number of firms | 160 | 40 | 17 | 53 | 50 |

**Source: Calculated by the authors based on the survey in 2013–2014**

[a] Only chemical and seed industries reported biotech R&D investment.

[b] Figures in parentheses are average annual R&D investment for the firms that reported investment budgets.

**Table 2 Estimates of impact of policies on whether private firms invest in biotechnology research in China**

| Category | Variables | Dependent variable: whether firms invest in biotech R&D | | | | | |
|---|---|---|---|---|---|---|---|
| | | Estimated coefficients | | | Marginal effects | | |
| *Expected demand* | Gain | 0.68* (0.37) | 0.71** (0.37) | 0.70** (0.37) | 0.14* [0.07] | 0.15** [0.08] | 0.15** [0.07] |
| | Loss | 0.25 (0.44) | 0.17 (0.44) | 0.33 (0.43) | 0.05 [0.09] | 0.04 [0.09] | 0.07 [0.09] |
| | Not sure | -0.09 (0.45) | -0.11 (0.43) | -0.08 (0.44) | -0.02 [0.09] | -0.02 [0.09] | -0.02 [0.09] |
| | Mixed | 1.93*** (0.79) | 1.81** (0.76) | 1.89*** (0.77) | 0.40*** [0.15] | 0.39*** [0.16] | 0.39*** [0.15] |
| *Appropriability* | Having patents | 1.35*** (0.45) | 1.34*** (0.45) | 1.43*** (0.44) | 0.28*** [0.09] | 0.29*** [0.09] | 0.29*** [0.08] |
| | No. of employees | 0.26 (1.04) | 0.36 (1.06) | 0.33 (0.99) | 0.05 [0.21] | 0.08 [0.23] | 0.07 [0.20] |
| *Policies* | Receiving R&D subsidies from the | 0.88** (0.38) | | 0.94*** (0.37) | 0.18*** [0.07] | | 0.19*** [0.07] |
| *Tech. opportunity* | Selling biotech product | 0.69*** (0.27) | 0.70*** (0.27) | 0.72*** (0.27) | 0.14*** [0.05] | 0.15*** [0.05] | 0.15*** [0.05] |
| | Cooperation with universities/institutes | 0.35 (0.32) | 0.46 (0.32) | | 0.07 [0.07] | 0.10 [0.07] | |
| | Average annual R&D investment | 0.01 (0.01) | 0.01 (0.01) | 0.01 (0.01) | 0.01 [0.01] | 0.01 [0.01] | 0.01 [0.01] |
| | State-owned | 0.27 (0.42) | 0.12 (0.42) | 0.31 (0.41) | 0.06 [0.09] | 0.03 [0.09] | 0.06 [0.08] |
| *Control variables* | Food firm | -0.57 (0.53) | -0.77 (0.52) | -0.62 (0.52) | -0.12 [0.11] | -0.17 [0.11] | -0.13 [0.11] |
| | Feed firm | 0.52 (0.59) | 0.33 (0.57) | 0.43 (0.58) | 0.11 [0.12] | 0.07 [0.12] | 0.09 [0.12] |
| | Seed firm | -0.20 (0.37) | -0.16 (0.36) | -0.14 (0.36) | -0.04 [0.08] | -0.04 [0.08] | -0.03 [0.07] |
| | Firm age | -0.02 (0.02) | -0.02 (0.02) | -0.02 (0.02) | -0.01 [0.01] | -0.01 [0.01] | -0.01 [0.01] |
| | Constant | -2.30*** (0.62) | -2.19*** (0.61) | -2.29*** (0.62) | | | |
| | Observations | 160 | 160 | 160 | | | |
| | Pseudo $R^2$ | 0.37 | 0.34 | 0.37 | | | |

***, **, and * represent 1%, 5%, and 10% statistical significance, respectively.

Figures in parentheses are standard errors and those in brackets are standard errors of marginal effects.

**Table 3 Estimates of impact of policies on firms' investment in biotechnology research in China**

| | | Dependent variable: firms' investment in biotech R&D | | |
|---|---|---|---|---|
| Category | Variables | Estimated coefficients | | |
| *Expected demand* | Gain | 697.4 (571.8) | 739.0 (576.4) | 659.6 (558.0) |
| | Loss | 267.6 (572.5) | 204.2 (576.4) | 218.5 (551.3) |
| | Not sure | 222.6 (511.2) | 147.8 (513.8) | 194.9 (502.2) |
| | Mixed | 150.5 (766.9) | 121.4 (773.7) | 126.8 (759.9) |
| *Appropriability* | Having patents | 228.4 (489.8) | 205.2 (494.1) | 195.0 (447.5) |
| | No. of employees | 6680.3*** (1308.6) | 6772.6*** (1319.3) | 6641.2 (1297.1) |
| *Policies* | Receiving R&D subsidies from the | 718.0* (379.1) | | 700.1* (434.2) |
| *Tech. opportunity* | Selling biotech product | 520.5 (379.1) | 530.4 (382.5) | 501.2 (372.9) |
| | Cooperation with universities/institutes | -136.7 (403.5) | -57.7 (404.1) | |
| | State-owned | 492.9 (553.0) | 381.8 (553.9) | 472.3 (547.0) |
| *Control variables* | Seed firm | 303.9 (427.8) | 404.0 (427.3) | 285.2 (618.5) |
| | Firm age | 2.2 (24.9) | 8.8 (24.8) | 2.2 (24.8) |
| | Constant | -1284.7*** (621.7) | -1274.5*** (627.3) | -1279.7** (618.5) |
| | Observations | 103 | 103 | 103 |
| | R-squared | 0.4 | 0.4 | 0.4 |

***, **, and * represent 1%, 5%, and 10% statistical significance, respectively.

Figures in parentheses are standard errors.

## Appendix A

**Table A.1 Summary statistics**

| Categories | Variable | Mean/ Percentage | Standard deviation |
|---|---|---|---|
| ***Dependent variable*** | Biotech investment (with bio-research=1) | 0.28 | 0.45 |
| | biotech investment (RMB10,000) (only seed and chemical industries) | 586.28 | 2110.95 |
| ***Expected demand*** | Profit expectation (base: no change) | | |
| | Gain | 0.31 | 0.46 |
| | Loss | 0.18 | 0.38 |
| | Mixed (loss+gain) | 0.05 | 0.22 |
| | Not sure | 0.18 | 0.39 |
| ***Appropriability*** | Having patents | 0.63 | 0.48 |
| | Firm size measured by the no. of employees | 921 | 317 |
| ***Policies*** | Receiving R&D subsidies from the government | 0.14 | 0.35 |
| ***Tech. opportunity*** | Annual average R&D investment (million RMB) in the past 3 years | 11.26 | 35.85 |
| | Collaboration with universities/institutes | 0.41 | 0.49 |
| | Ownership: state-owned=1; other=0 | 0.16 | 0.37 |
| | Selling bio-products | 0.44 | 0.50 |
| | Industry (base= chemical) | | |
| | Food | 0.25 | 0.43 |
| | Feed | 0.11 | 0.31 |
| | Seed | 0.31 | 0.46 |