

# Impact of government science and technology policies with a focus on biotechnology research on commercial agricultural innovation in China

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## Abstract

**Purpose** – The Chinese Government has used a number of policies to encourage commercial agribusiness firms to do more innovation. These include public sector agricultural research and development (R&D), public sector biotechnology research and innovation, subsidies for commercial research, encouraging foreign firms to invest in China as minority shareholders in joint ventures, and allowing commercial companies to raise money on the stock market. The purpose of this paper is to assess whether these policies were effective in stimulating innovations by commercial firms in China.

**Design/methodology/approach** – This study estimates the impact of public biotech research and other policies by employing an econometric model of patenting by commercial firms. It uses a unique data set collected from commercial agribusiness firms for the years 2001, 2004, 2005, and 2006. Addition data were collected from public research institutes and universities and patent data from the Derwent Innovations Index database. It employs four count data models for the empirical analysis.

**Findings** – This study finds a positive impact of public biotechnology (measured by the number of biotech patents of government research institutes and public universities) on commercial innovation measured by the number of patents granted to the commercial firms. As expected the firm's research expenditure and having their own R&D center (as opposed to contracting R&D or no R&D investment at all) have a positive and statistically significant effect on the number of patents granted. The impacts of public R&D investment spending have no statistically significant effect on commercial innovation. Multi-national firms and publicly traded firms have fewer patents than their counterparts suggesting that policies to encourage multi-nationals and financing through stock markets had no impact on innovation.

**Originality/value** – This study is one of the first studies to untangle the relationship between government policies and innovation by commercial agricultural research output and public R&D investment and biotechnology. The main findings suggest that simply increasing research money to public research does not increase commercial innovations, but moving resources to the development patentable biotech does improve commercial research productivity. The results also suggest that policies to increase commercial research will also increase innovation. These could include strengthening the legal framework and institutional resources for public institutes to the protection and enforcement of intellectual properties.

**Keywords** Agricultural biotechnology, Agricultural research output, Count data analysis, Public and private R&D, Research and development investment

**Paper type** Research paper

## 1. Introduction

Research and development (R&D) investment is considered as a driving force of technological advances and economic development (Prodan, 2005). Extensive economic research indicates that the growth in agricultural productivity is largely due to research and

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innovations that significantly increase crop and livestock yields (Balcombe *et al.*, 2005; Salim and Islam, 2010; Alene, 2010; Block, 2010; Andersen, 2015; Huffman and Evenson, 2008; Alston *et al.*, 2009; Wang *et al.*, 2012). In recent years more studies have focused on the size and impact of research by private firms and the technology that they develop and spread (Fuglie *et al.*, 2012; Piesse and Thirtle, 2010). In 2000, the global spending on agricultural R&D totaled \$36 billion and about 36 percent of which was invested by the private sector. The share of public and private agricultural R&D investment was strikingly different between developed and developing countries – private agricultural R&D investment accounted for 93 percent in developed countries, but only 6 percent in developing countries (Pardey *et al.*, 2006). On the other hand, private agricultural R&D investment has been increasing in both developed and developing countries in the last decade. Yet, the rising importance of private R&D investment does not necessarily diminish the role of public R&D investment as the majority of empirical studies show complementarities between public and private agricultural R&D (Pray and Fuglie, 2015).

The lack of private agricultural R&D investments in developing countries is mainly due to weak intellectual property rights, government control of agricultural input markets, and limited foreign direct investment (Pray and Fuglie, 2002). The private sector plays an increasingly important role, especially in plant breeding, livestock and food processing research and innovation (Fuglie and Toole, 2014; Fuglie *et al.*, 2011). Public and private agricultural R&D can potentially affect research output differently due to their distinct focuses. Public R&D investments mainly focus on basic and applied research, while private R&D largely focuses on applied and development research to develop commercial technology that improves agricultural productivity.

The Chinese Government has used a number of policies to encourage commercial[1] agribusiness firms to do more research and innovation. These policies include public sector agricultural R&D, public sector biotechnology research and innovation, subsidies for commercial research, encouraging foreign firms to invest in China as minority shareholders in joint ventures with Chinese firms and allowing commercial companies to raise money on the stock market. The purpose of this study is to assess whether these policies were effective in stimulating innovations by commercial firms in China.

## 2. Past studies on the determinants of research and innovation by private firms

The literature is sparse in investigating both public and private R&D investment and public and private research output (Fuglie *et al.*, 2012). Public and private agricultural R&D can potentially affect research output differently due to their different focuses. Public R&D investments mainly focus on basic and applied research, while private R&D largely focuses on applied and development to develop commercial technology which raises agricultural productivity. In particular, the private sector plays an increasingly important role producing innovations (Fuglie and Toole, 2014; Fuglie *et al.*, 2011). The analysis on private research output should incorporate both public and private R&D investment, especially when government funding, including public R&D investment, is an increasingly scarce resource in times of financial crisis and economic austerity (Becker, 2015).

Public R&D research capability and output can influence private R&D output through inducing more private sector research. Early economic analysis on agricultural technology showed a pattern of complementarity between public research development and the spread of new technology by private seed companies in the USA (Griliches, 1957). More recently, Wang *et al.* (2009) find that public US R&D lead to more private R&D. Tokgoz (2006) finds that public basic life sciences research induces more private agricultural R&D but there is no significant relationship between public applied life sciences research and private agricultural research. Hu *et al.* (2011) find similar results in China. Basic and applied research stimulate public research while development research crowds out private agricultural research.

Pray and Nagarajan (2013) show that public agricultural R&D is positively correlated with private agricultural R&D in the seed and biotechnology industry in India.

Private research output and innovation can be measured as the number of patents a firm applied for or was granted (Griliches, 1994; Prodan, 2005) and productivity as the number of patents per unit of the R&D investment (Lanjouw and Schankerman, 2002). de Rassenfosse and de la Potterie (2009) claim that research efforts lead to inventions and inventions lead to patents. Han and Lee (2007) find a positive association between R&D investments and the number of patents per employee in Korea. Government investments and policies play an important role in innovation. Jaffe (1989) finds a positive effect of university research on the number of patents granted to American firms. Branstetter and Sakakibara (2000) find that the Japanese Government sponsored R&D investment increases the number of patents. Since it in general takes two to nine years for a patent to be granted after its application is submitted (Kondo, 1999), some studies use the number of patent applications to measure research productivity of R&D investments (de Rassenfosse and de la Potterie, 2009).

Only a few studies attempted to estimate the impact of public research on agribusiness innovation. Toole and King (2011) find that public agricultural research performed in universities stimulates agricultural patenting by agricultural chemical firms in the USA. Shi and Pray (2012) analyze Chinese pesticide patent data from 1986 to 2005. They find some evidence that the presence of a public sector research institute in the region positively influences total pesticide patenting. They separate patenting by commercial firms from patenting by individuals and research institutes. Patenting by commercial firms is stimulated by patenting by public sector research institutes and patents on active ingredients of foreign firms but patenting of formulations by these foreign firms has a negative impact.

### 3. Methodology

Based on previous literature we hypothesize that the research output of commercial agribusiness firms, measured by the number of patents granted, is affected by private R&D investments, R&D investments of public research institutions, government subsidies for research, public R&D outcomes, measured by the number of agricultural biotech patents, the quality of firms' research staff, and firms' attributes such as ownership, basic and sales and development revenue. Public R&D investment is divided into the investment focusing on applied R&D research. Public R&D investment and number of agricultural biotechnology patents are separated by sector and province and take the average value of three years (2003-2006). The commercial R&D investment variables and government subsidies for commercial research take the average value of three years at the firm level. Whether a firm has an in-house R&D center is also incorporated. The human capital of R&D activities measured by the total number of research staff without a PhD degree and the total number of research staff that hold a PhD degree are incorporated separately in the model. We also control for the difference by region and industry. Three main hypotheses will be empirically tested:

- H1.* Commercial R&D investment and having an own in-house R&D center increase the number of patents granted to the firms.
- H2.* Public R&D investment on basic and applied research and government subsidies for research have a positive impact, while public R&D investment on development has a negative impact on the number of patents granted to the firms.
- H3.* Public R&D research innovation measured by the number of agricultural biotechnology patents stimulates commercial research and increases the number of patents granted to the firms.

The findings in Hu *et al.* (2011) inspired us to distinguish two types of public R&D investment. They find that public R&D investments in basic and basic-applied research

increase private R&D, but public R&D investments in development research decrease private R&D investment. The same analogy can also be applied to the effect of public R&D investments on patent granted to agricultural firms (*H2*). *H3* highlights the influence of knowledge spill-over from the public sector to the private sector. Such spill-over effect is confirmed in Shi and Pray (2012). They find patents by government chemical research institutes lead to more patents by the private sector.

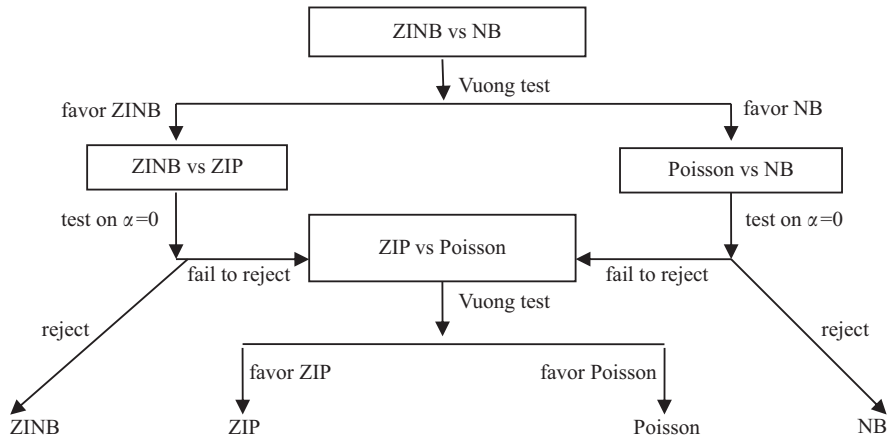
The literature suggests that the classical linear model is inadequate in modeling discrete count data such as patents because the predicted probabilities may be above unity (Blundell *et al.*, 1995). We employ count data modeling approaches to investigate the effects of both public agricultural R&D investments and research output as well as commercial R&D investment on the number of patents granted to commercial agricultural firms. Appendix 1 presents the four most popular count data models, namely, Poisson, negative binomial (NB), zero-inflated Poisson (ZIP), and zero-inflated NB (ZINB) (Cameron and Trivedi, 2013). Poisson model assumes that variance equals to its mean, which can lead to inefficient estimates if over-dispersion is present in the count data. Over-dispersion can be caused by either unobserved heterogeneity among individuals or excess zeros for the dependent variable. When unobserved heterogeneity is a concern, a NB model has been suggested and it adds an error term to the conditional mean of the Poisson distribution. Both Poisson and NB models do not account for excess zeros and thus can produce biased estimates. Excess zeros can be a concern in this study because more than 68 percent of the observations have no patent at all (see Table I). Zero-inflated regression models, such as ZIP and ZINB models, are warranted to address the issue of having excess zeros. Both ZIP and ZINB include a logit (or probit) regression for zero inflation, followed by the Poisson estimation for ZIP or the negative binomial estimation for ZINB. Based on statistical tests on the null hypothesis  $\alpha = 0$  for over-dispersion for nested models (Poisson vs NB as well as ZINB vs ZIP) and the Vuong test for non-nested models (ZINB vs NB as well as ZIP vs Poisson), we can choose the most suitable one among these four count data models.

As shown in Figure 1, if the Vuong test favors the ZINB model over the NB model, then a statistical test on  $\alpha = 0$  is conducted to contrast ZINB vs ZIP. If  $\alpha = 0$  is rejected, ZINB is the most appropriate specification, and both individual heterogeneity and excess zeros contribute to the over-dispersion. Otherwise, the ZIP model is compared to the Poisson model by using the Vuong test. If ZIP is the most appropriate specification, then only excessive zeros account for over-dispersion. Otherwise no over-dispersion is present and Poisson is favored. On the other hand, if the Vuong test favors the NB model, then we will test if the heterogeneity parameter  $\alpha$  is significantly different from zero to contrast NB vs Poisson. A rejection of  $\alpha = 0$  suggests that the NB model is most appropriate specification and heterogeneity accounts for over-dispersion. Otherwise, the Poisson and ZIP are compared.

No. of patents	No. of firms	% of firms	By patent type	No. of patents	% of patents
0	919	68.53	Product	421	38.20
1	156	11.63	Process	552	50.09
2	103	7.68	Packaging & Marketing	129	11.71
3	58	4.33	Total	1,102	100
4	35	2.61			
5	19	1.42			
6+	51	3.80			
Total	1,341	100			

Source: Calculated by the author based on the CCAP survey 2007

**Table I.**  
Distribution of the  
number of patents  
granted to agricultural  
firms



**Figure 1.** Procedure to choose an appropriate model among the Poisson, NB, ZIP and ZINB models

**Source:** Modified based on Figure 1 at Elbakidze and Jin (2015)

STATA 14 is used to estimate the four models. For each of the four count data estimations, we included the fixed effects of industry and economic regions. To further control for unobservable factors at the province level, we also assume that the variance-covariance of the error term is clustered by province. That is, we assume that the error terms for firms in the same province are correlated, but they are not correlated with firms in other provinces.

#### 4. Data and variable construction

Except agricultural biotechnology patents in the public research institutes that were collected from the Derwent Innovations Index, the firm level data set used for this study come from a nation-wide mail survey of agribusiness firms in 29 provinces (Hebei and Tibet are not included) in China. The survey was initiated by the Ministry of Agriculture and implemented by Center for Chinese Agricultural Policy in 2007. In each province, the local government distributed the mail survey questionnaire and collected surveys from each firm. Several measures were used to improve the accuracy of the self-reported data. First, a questionnaire manual defining each question in detail was provided to the surveyed firms along with the survey. Second, researchers collaborated with local governments to control data quality and improve response rate by calling firms regularly (see the details at Hu *et al.*, 2011). Firms surveyed included all agricultural companies supervised by the Chinese agricultural administration system except those fully owned by foreign companies and firms supervised by non-agricultural administration systems. The latter includes some agricultural inputs firms under different ministries (e.g. fertilizer, insecticide, and agricultural machinery). We excluded ten observations in the machinery, pesticide, or fertilizer industries that were overseen by the Ministry of Agriculture, we have 1,355 firm-year pairs.

The survey collected information of agricultural R&D investments, government subsidies for agricultural research, human resources, technology transfer, and sales revenues, and R&D research centers/divisions for the years 2000, 2004, 2005, and 2006. Firm-level attributes were also collected, including information on the year the firm was established, ownership structure, and industry coverage. The key variable of the interest is the reported total number of patents granted to each firm by 2006. As shown in Table I, more than two-thirds did not have any patents granted ( $n = 927$ ) and the majority of firms have either one or two patents. More than half were process patents, followed by new product patents (38 percent), and the least for packaging and marketing patents (12 percent).

Table II provides the summary statistics of the key variables. Except the number of patents, the other variables take the annual average in 2000, 2004, 2005, and 2006. All the monetary values are deflated by consumer price index of 2006. Commercial R&D investments are the sum of own investments, contract research funded by firm, and money they received from other firms. Commercial agricultural R&D investment more than doubled – increasing from 0.74 million yuan in 2000 to 1.61 million Yuan in 2006. About half of the firms had an in-house R&D center, less than 1 percent have R&D investments through contracts, and approximately 13-14 percent had both an in-house R&D investment center and R&D contracts. The government subsidy to firms for commercial R&D increased from 0.048 million yuan in 2000 to 0.123 million yuan in 2006. Since the patent counts were reported as the total number of patents granted to each firm by 2006, we use the three-year average (2004-2006) of the covariates in the count data analysis.

The public agricultural R&D investment in China is reflected by the research budgets of public agricultural research organizations which was obtained from the Ministry of Science and Technology (Hu *et al.*, 2011). The fiscal budget allocation consists of government funds allocated to public research organizations for institutional support such as salaries,

Variable	2000	2004	2005	2006
No. of observations	497	1,052	1,228	1,341
Total private R&D investment (million yuan)	0.74 (2.71)	1.06 (3.61)	1.25 (3.89)	1.61 (4.59)
Patent granted to commercial firms (count data)	0.96 (1.66)	0.88 (1.58)	0.82 (1.53)	0.80 (1.52)
Public R&D investment for basic and applied research (million yuan)	45.73 (67.44)	59.10 (77.49)	74.07 (92.36)	83.14 (103.96)
Public R&D investment for development research (million yuan)	110.17 (170.41)	257.09 (340.48)	299.96 (386.70)	335.43 (430.62)
Government subsidy for commercial R&D (million yuan)	0.048 (0.36)	0.099 (0.72)	0.114 (0.780)	0.123 (0.601)
Public biotech patent counts	0.262 (0.63)	1.617 (3.3)	1.822 (4.65)	1.924 (4.715)
Sale revenues (million yuan)	72.45 (238.64)	102.74 (427.28)	114.20 (499.59)	128.14 (594.85)
Firm age (years)	7.53 (8.86)	7.20 (7.37)	7.33 (7.16)	7.79 (7.08)
Ratio of R&D staff having a PhD degree (%)	0.13 (0.69)	0.18 (0.84)	0.24 (1.04)	0.34 (1.31)
Public listed company (yes = 1)	0.02 (0.15)	0.02 (0.14)	0.02 (0.13)	0.02 (0.13)
<i>Ownership</i>				
Private	0.61 (0.49)	0.70 (0.46)	0.72 (0.45)	0.73 (0.44)
State	0.16 (0.37)	0.11 (0.31)	0.09 (0.29)	0.09 (0.29)
Foreign	0.002 (0.04)	0.009 (0.03)	0.002 (0.05)	0.002 (0.05)
Collectively owned	0.13 (0.33)	0.12 (0.32)	0.11 (0.31)	0.11 (0.31)
Other	0.09 (0.51)	0.06 (0.43)	0.06 (0.42)	0.06 (0.42)
<i>Sector</i>				
Crops	0.25 (0.44)	0.26 (0.44)	0.27 (0.45)	0.27 (0.44)
Livestock	0.25 (0.44)	0.24 (0.43)	0.24 (0.43)	0.25 (0.43)
Fishery	0.07 (0.25)	0.07 (0.25)	0.07 (0.25)	0.06 (0.24)
Food processing	0.42 (0.50)	0.43 (0.50)	0.43 (0.50)	0.42 (0.49)
<i>R&amp;D division</i>				
In-house R&D	0.54 (0.50)	0.52 (0.50)	0.50 (0.50)	0.50 (0.50)
Contracting out R&D	0.06 (0.24)	0.08 (0.26)	0.07 (0.27)	0.08 (0.27)
In-house and contract R&D	0.14 (0.34)	0.14 (0.34)	0.14 (0.34)	0.13 (0.34)
No R&D	0.26 (0.44)	0.27 (0.44)	0.28 (0.45)	0.29 (0.45)

**Note:** Numbers in the parentheses are standard errors

**Table II.**  
Summary statistics  
of key variables

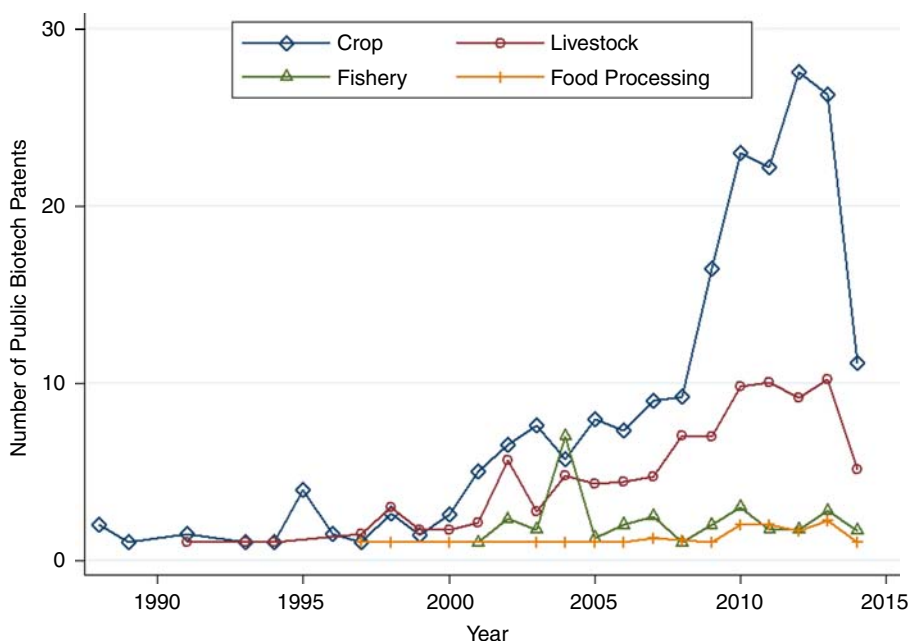
operating and maintenance of labs and experiment stations, and competitive grants for the variable costs of research projects. Commercial income is revenue earned through commercial activities conducted by research organizations. Some of these funds pay for the expenses of commercial operations while some support research; however, no data are available to indicate how much funding from commercial operations goes to research. Since 2000, the total budget for agricultural research in China has increased by more than 10 percent a year, driven by an almost 15 percent annual rate of growth in government contributions (Hu *et al.*, 2011). We calculate the three-year average public R&D investment (2004-2006) by province and industry sector (crop, livestock, food processing, and fishery) and disaggregate into those invested in applied research and experimental development (Public-R) and those invested in basic research (Public-D). According to the Frascati Manual (OECD, 2002), "Basic research is experimental or theoretical work undertaken primarily to acquire new knowledge of the underlying foundations of phenomena and observable facts, without any particular application or use in view" (p. 77). "Applied research is original investigation undertaken in order to acquire new knowledge. It is, however, directed primarily towards a specific practical aim or objective" (OECD, 2002, p. 77). "Experimental development is systematic work, drawing on knowledge gained from research and practical experience, which is directed to producing new materials, products and devices; to installing new processes, systems and services; or to improving substantially those already produced or installed" (OECD, 2002, p. 77). Thus, the focus of Public-R and Public-D investments differs. They are expected to affect research productivity differently. Despite of its significant growth, commercial agricultural R&D investment is still much less than public R&D investment.

Agricultural biotechnology patents granted to the public research institutes during 1985-2013 were collected from the Derwent Innovations Index. Among all the 200 colleges/universities and public research institutes that engaged in the National Genetically Modified Variety Development Special Program in China, the agricultural biotechnology patent data cover 160 colleges/universities and public research institutes in China. As shown in Table II, on an average, a public research institute own less than two biotechnology patents in all four industries during 2004-2006. As shown in Figure 2, crop industry has the largest number of biotechnology patents, followed by livestock industry. Crop industry experienced the fastest growth in biotechnology patents in most recent years. To be matched with the public R&D investment, we also take the three-year average by province and industry during 2004-2006 for the public biotechnology patents. After merging the public biotechnology patent data with the main survey data, the sample size decreased from 1,355 firm-year pairs to 1,341 pairs. These 1,341 firm-year pairs are classified into four industries: crop, livestock, food processing, and fishery.

We also compare some important factors between firms with and without patents granted. As shown in Table III, firms with patents have a higher sales revenue, more research staff, especially those with a PhD degree, than firms without patents. They also have greater government subsidies for research as well as higher public and commercial agricultural R&D investments as well as the number of agricultural biotech patents hold by public research institutes.

## 5. Estimation results

Among all the four count data models, we conclude that the ZINB model is a more appropriate specification than Poisson, NB, or ZIP models. More specifically, as shown in Table IV, the Vuong test (Vuong-statistic = 4.99 and  $p$ -value = 0.00) suggests that the ZINB model fits the data better than the NB model, and the likelihood ratio test of  $\alpha = 0$  indicates that the ZINB model outperforms the ZIP model ( $p$ -value = 0.00). This conclusion is also reinforced by the finding that, relative to the other pooled models, ZINB has the highest ratio of correct predictions among the four models (42.13 percent).



**Figure 2.** Number of agricultural biotechnology patents received by 160 public research institutes, colleges and universities

**Source:** Compiled by the authors based on the patent data extracted from Derwent Innovations Index

	Firms with no patent 919	Firms with at least one patent 422
Number of observations		
Average patent count for commercial firms	0	2.55
Sales revenue (1,000,000 yuan)	73.35	154.85
Private R&D investment (1,000,000 yuan)	0.63	2.26
Research staff without a PhD degree	5.51	21.50
Research staff with PhD degree	0.11	0.41
Government subsidies for private research (1,000,000 yuan)	52.71	198.25
Public R&D investment for basic and applied research (1,000,000 yuan)	78.64	92.93
Public R&D investment for development research (1,000,000 yuan)	318.16	373.02
Average agri-biotech patent count for public institutes	4.05	6.62

**Source:** Calculated by the author based on the CCAP Survey 2007

**Table III.** Comparison of key variables of firms with and without patents

The marginal effects of each contributing variable are summarized in Table IV based on the regression results in Table AI. The results in Table IV show, first, that commercial R&D investment and having its own R&D research center have a statistically significant and positive impact on the number of patents granted to the firms. This finding supports *H1*, and it is also consistent with the previous research (Griliches, 1984; Jaffe, 1989; Kondo, 1999; Han and Lee, 2007; de Rassenfosse, 2009). The impact of the in-house R&D research center is positive because most firms would not contract out research to develop new patentable products due to the fear that the contacted firm might get the patent first.



Variable	Poisson	NB	ZIP	ZINB
Private R&D investment (million yuan)	0.021*** (0.000)	0.025*** (0.001)	0.035*** (0.001)	0.058* (0.003)
Public R&D investment for basic and applied research (million yuan)	0.0003 (0.003)	0.0004 (0.003)	0.0004 (0.003)	0.0004 (0.0004)
Public R&D investment for development research (million yuan)	-0.0001 (0.0001)	-0.0000 (0.0001)	-0.0000 (0.0001)	-0.0001 (0.0001)
Government subsidy for commercial R&D (million yuan)	0.0000 (0.0000)	0.0000 (0.0000)	0.0000 (0.0000)	-0.002 (0.007)
Public biotech patent count	0.003 (0.003)	0.009 (0.006)	0.014*** (0.004)	0.015*** (0.005)
<i>R&amp;D division (base = own R&amp;D center)</i>				
Contracting out R&D	-0.418*** (0.075)	-0.403*** (0.076)	-0.451*** (0.093)	-0.462*** (0.096)
Having own R&D center and contract out R&D	0.135** (0.071)	0.157** (0.075)	0.209** (0.052)	0.224** (0.010)
No R&D	0.018 (0.112)	-0.782*** (0.466)	-0.835*** (0.052)	-0.846*** (0.053)
Sale revenues (million yuan)	-0.0000 (0.0000)	-0.0000 (0.0000)	-0.0000 (0.0000)	-0.0000 (0.0000)
Firm age (years)	0.002 (0.004)	0.002 (0.004)	0.001 (0.005)	0.001 (0.006)
Non PhD R&D staff	0.002 (0.018)	0.001 (0.031)	0.005** (0.004)	0.007 (0.012)
PhD R&D staff	0.012 (0.019)	0.030 (0.031)	0.020 (0.042)	0.022 (0.057)
Publicly traded firms	-0.244** (0.126)	-0.314** (0.110)	-0.464*** (0.132)	-0.484*** (0.174)
<i>Ownership (base = state-owned)</i>				
Private	-0.106 (0.095)	-0.087 (0.092)	-0.084 (0.112)	-0.085 (0.117)
Foreign participation	-0.374** (0.193)	-0.268 (0.343)	-0.387* (0.242)	-0.411* (0.250)
Collectively owned	-0.001 (0.082)	-0.010 (0.098)	0.031 (0.106)	0.013 (0.102)
Other	0.018 (0.118)	0.140 (0.098)	0.155 (0.159)	0.156 (0.168)
Sector fixed effects	X	X	X	X
Region fixed effects	X	X	X	X
Overall prediction accuracy	41.68%	42.02%	42.05%	42.13%
Vuong test	ZIP vs Poisson: $Z = 9.93$ ( $p$ -value = 0.00)		ZINB vs NB: $Z = 4.99$ ( $p$ -value = 0.00)	
$\alpha$ test	NB vs Poisson: $\alpha = 1.97$ ( $p$ -value = 0.00)		ZINB vs ZIP: $\alpha = 0.03$ ( $p$ -value = 0.00)	

**Table IV.** Marginal effects on patents based on the four count data models

**Notes:** Numbers in the parentheses are standard deviations of the coefficients. The variance-covariance matrix of the error term is assumed to be cluster by province to capture the dependence of the error terms for firms in the same province, but the error term is independent for firms in the different provinces. The symbol, X, denotes that the fixed effects of sector and regions are incorporated to control for, but we do not report the results to save space. \*, \*\*, \*\*\* Significant at 10, 5 and 1 percent level, respectively

The second finding states that public R&D investment on basic and applied research has a positive impact, but public R&D investment on development research has a negative effect. These effects are not, however, statistically significant. The signs of the co-efficient are consistent with studies in China (Hu *et al.*, 2011) and the USA. Tokgoz (2006) finds that public basic and applied research can induce private research and applied and development research crowds out private research. Government subsidies for commercial research also have a positive impact on the number of patents granted but are not statistically significant. These findings partially support *H2*. This is also consistent with some of the previous literature. For example, Görg and Strobl (2007) find that in Ireland small grants in the form of government R&D subsidies increase commercial R&D spending, but too large a grant may crowd out commercial financing of R&D.

Public R&D research output measured by agricultural biotechnology patents is found to have a significant and positive effect on the number of patents granted to commercial firms. This result is consistent with the idea that it is basic government research not development research that influences private firms. Biotech patents are the result of basic and applied research not from development research. Biotech patents are particularly relevant to the firms in our sample which are either plant, livestock, or food firms and they are in the machinery or pesticide industries. The result is also consistent with evidence from India (Pray and Nagarajan, 2013) that the introduction of biotechnology stimulated total private research not just other biotech research. These findings support *H3*. This study suggests that public R&D research output is more likely to be efficient in stimulating commercial research output than public R&D research expenditures as public R&D investment could crowd out private research. These results are also consistent with the Shi and Pray (2012) results. They find that public pesticide patenting stimulated patenting by commercial firms commercial firms are granted significantly fewer patents than state-owned firms in China. There are two possible reasons for this finding. First, most of foreign firms have joint ventures with Chinese commercial firms or state-owned firms, in which the Chinese firm has the majority of shares. Among 1,355 survey firms, only 2 percent were foreign firms. They may not bring in their newest technology because they fear their partner could use the technology without their permission. Another reason that foreign-owned firms may not apply for patents in China is because of inadequate intellectual property laws enforcement. The firms that raise money on Chinese stock exchanges (publicly listed companies) are also found to have fewer patents than their counterparts. State-owned firms do have an advantage in patenting over private, cooperative, and foreign firms (which all have negative signs) but only the foreign firms have significantly less patenting than state-owned firms.

## 6. Conclusions and policy implications

The public sector dominates agriculture research in China but commercial agribusiness is starting to play an important role on technology innovation after the policy reforms in 2000. The government has attempted to stimulate the growth of commercial agribusiness innovation. This study is the first study that has attempted to measure the impacts of several types of government intervention on agribusiness innovation. Using survey data from 1,341 firms across 29 provinces in the year of 2000, 2004, 2005, and 2006 in China, this study analyzes the impact of investment of various types of public R&D and subsidies, public biotechnology innovation, and policies on foreign investment and allowing firms to raise money on Chinese stock exchanges on commercial innovation.

Several policies of the Chinese Government seem to have stimulated patenting by Chinese agribusiness firms. The regression analysis confirmed that research expenditure by private firms is productive in creating innovations especially if the money is spent in its own research center rather than on a contract research. Regarding policy variables, public biotech research that results in patents has a major impact on firms' patenting while the level of public expenditures does not. The policies to encourage multi-national firms to enter joint ventures appear to have had a negative impact on patenting. Allowing firms to issue shares on local stock market also seems to have had a negative impact on patents. The evidence suggests that the money raised does not go into research and innovation.

This study offers several policy implications. The main findings suggest that shifting resources to the development of biotechnology is an effective way for the Chinese Government to improve commercial innovations. Our findings do not support simply increasing the public research investment will induce commercial innovation. The results also suggest that policies to increase commercial research will also increase innovation.

These could include strengthening the legal framework and institutional resources for public institutes to the protection and enforcement of intellectual properties which stimulated private research in India (Pray and Nagarajan, 2014) and elsewhere. However, encouraging agribusiness firms to be listed on the stock market or encouraging foreign firms without allowing them to control their joint ventures appears to be counterproductive for commercial innovation.

#### Note

1. We use “commercial” instead of “private” because some firms have both private and public ownership.

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**Appendix 1. A brief review of four count data models**

In a basic Poisson regression model with a logarithm link function, the number of events  $y$  for individual  $i$  has a Poisson distribution with a conditional mean  $\lambda_i$  depending on individual  $i$ 's characteristics,  $x_i$ :

$$\lambda_i(x_i) = E(y_i|x_i) = \exp(x_i\beta), \tag{A1}$$

where  $\beta$  is a vector of unknown coefficients associated with the covariate vector  $x_i$ . For convenience of notation, we drop  $x_i$  in  $\lambda_i(x_i)$  and use  $\lambda_i$  below. The probability density function of  $y$  given  $x$  is:

$$f(y_i|x_i) = \frac{\exp(-\lambda_i)\lambda_i^{y_i}}{y_i!}. \tag{A2}$$

The NB model adds an error term,  $\varepsilon$ , to the conditional mean of the Poisson distribution to model the unobserved heterogeneity:

$$E(y_i|x_i) = \exp(x_i\beta + \varepsilon_i). \tag{A3}$$

where  $\exp(\varepsilon_i)$  is normally assumed to follow a  $\gamma$  distribution with mean one and variance  $\alpha$ . The probability density function of  $y$  given  $x$  now becomes:

$$f(y_i|x_i) = \frac{\Gamma(y_i + 1/\alpha)}{y_i! \Gamma(1/\alpha)} \left( \frac{1}{1 + \alpha\lambda_i} \right)^{1/\alpha} \left( \frac{\lambda_i}{1/\alpha + \lambda_i} \right)^{y_i}. \tag{A4}$$

The conditional mean and variance of  $y_i$  under the NB model are:

$$E(y_i|x_i) = \lambda_i \text{ and} \tag{A5}$$

$$\text{VAR}(y_i|x_i) = \lambda_i(1 + \alpha\lambda_i). \tag{A6}$$

where  $\alpha$  is the variance of  $\gamma$  distribution and indicates the degree of over-dispersion. As  $\alpha$  becomes larger, the distribution will be more dispersed. As  $\alpha$  gets close to zero, the NB model converges to the Poisson model. The Poisson and NB models are nested, and a statistical rejection of the null hypothesis of  $\alpha = 0$  will favor NB over Poisson specification.

Lambert (1992) first introduced ZIP model as:

$$\begin{aligned} y_i = 0 & \quad \text{with probability } \pi_i \\ y_i \sim \text{Poisson}(\lambda_i) & \quad \text{with probability } 1 - \pi_i (y_i = 0, 1, 2, \dots) \end{aligned} \quad (A7)$$

The probability of having an extra zero which is not subject to the Poisson distribution,  $\pi_i$ , is assumed to have a logit function (A7). The unobserved probability  $\pi_i$  is generated as a logistic or probit function of observable covariates to ensure non-negativity. The choice between logit and probit is usually unimportant since the two functions are similar and usually give very similar results:

$$\pi_i = \frac{\exp(z_i\gamma)}{1 + \exp(z_i\gamma)}, \quad (A8)$$

where  $z_i$  is a vector of observable covariates and  $\gamma$  is a vector of coefficients associated with  $z_i$ . The mean and variance of  $y_i$  in the ZIP model are:

$$E(y_i | x_i) = (1 - \pi_i)\lambda_i \quad \text{and} \quad (A9)$$

$$\text{VAR}(y_i | x_i) = \lambda_i(1 - \pi_i)(1 + \lambda_i\pi_i). \quad (A10)$$

Equations (A9) and (A10) show that  $(\pi_i)/(1 - \pi_i)$  indicates the degree of over-dispersion. As  $\pi_i$  approaches zero, the ZIP model converges into the Poisson model.

Similarly, to account for individual heterogeneity and excess zeros simultaneously, ZINB model with a logit link function is used. The mean and variance of  $y_i$  under the ZINB model are:

$$E(y_i | x_i) = (1 - \pi_i)\lambda_i \quad \text{and} \quad (A11)$$

$$\text{VAR}(y_i | x_i) = \lambda_i(1 - \pi_i)(1 + \lambda_i(\pi_i + \alpha)). \quad (A12)$$

Equations (A11) and (A12) show that  $(\pi_i + \alpha)/(1 - \pi_i)$  reflects the degree of over-dispersion in the ZINB models, which accounts for over-dispersion from both zero inflation and unobservable heterogeneity.

The Poisson and ZIP models are not nested, and neither are the NB and ZINB models. Vuong (1989) proposed a likelihood ratio test for non-nested models, and (Greene, 1994) adapted the technique for the cases of ZIP vs Poisson, and ZINB vs NB models. The test statistic is:

$$Z = \frac{\sqrt{N\bar{m}}}{s_m}, \quad (11)$$

where  $\bar{m}$  and  $s_m$  are the mean and standard deviation of  $m_i$  and  $N$  is the number of observations.  $m_i$  is defined as  $m_i = \ln(\hat{p}_1(y_i | x_i) / \hat{p}_2(y_i | x_i))$  where  $\hat{p}_1(y_i | x_i)$  and  $\hat{p}_2(y_i | x_i)$  are the predicted probabilities from the competing models. Asymptotically,  $Z$  has a standard normal distribution, with large positive values ( $> 1.96$ ) favoring the zero-inflated model and with large negative values ( $< -1.96$ ) favoring the non-zero inflated model at a 5 percent significance level.

**Table A1.**  
Estimation results  
of the four count  
data models

Variable	Poisson	NB	Inflated	ZIP	ZIP	Inflated	ZINB	ZINB
Private R&D investment (million yuan)	0.040*** (0.000)	0.045** (0.000)	0.064* (0.030)	0.016* (0.000)	0.016* (0.000)	0.114* (0.084)	0.009 (0.011)	0.009 (0.011)
Public R&D investment for applied research (million yuan)	0.0006 (0.0004)	0.0007 (0.000)	0.0007 (0.0007)	0.0011* (0.0005)	0.0011* (0.0005)	0.0007 (0.0012)	0.0011 (0.0006)	0.0011 (0.0006)
Public R&D investment for basic research (million yuan)	-0.0001 (0.0001)	-0.0002 (0.0001)	-0.0002 (0.0002)	-0.0003* (0.0001)	-0.0003* (0.0001)	-0.0002 (0.0003)	-0.0003 (0.0002)	-0.0003 (0.0002)
Government subsidy (million yuan)	0.0001 (0.0003)	0.0000 (0.000)	0.0000 (0.000)	0.0000 (0.000)	0.0000 (0.000)	0.0000 (0.000)	0.0000 (0.000)	0.0000 (0.000)
Public biotech patent counts	0.005 (0.010)	0.017 (0.010)	-0.040** (0.010)	-0.003 (0.010)	-0.003 (0.010)	-0.046** (0.020)	-0.002 (0.010)	-0.002 (0.010)
<i>R&amp;D division (base = own R&amp;D)</i>								
Contracting out R&D	-1.181*** (0.270)	-1.148*** (0.280)	0.149 (0.570)	-1.022*** (0.280)	-1.022*** (0.280)	0.027 (0.690)	-1.068*** (0.290)	-1.068*** (0.290)
Having both R&D center and contracting out R&D	0.225 (0.120)	0.263* (0.120)	-0.602** (0.210)	-0.052 (0.080)	-0.052 (0.080)	-0.728* (0.330)	-0.052 (0.100)	-0.052 (0.100)
No R&D	-1.875*** (0.130)	-1.863*** (0.130)	1.629*** (0.290)	-0.695** (0.220)	-0.695** (0.220)	1.507** (0.480)	-0.819** (0.290)	-0.819** (0.290)
Sale revenues (million yuan)	0.0000 (0.000)	0.0000 (0.000)	0.0000 (0.000)	0.0000 (0.000)	0.0000 (0.000)	0.0000 (0.000)	0.0000 (0.000)	0.0000 (0.000)
Firm age (years)	0.004 (0.010)	0.004 (0.010)	-0.006 (0.010)	-0.002 (0.000)	-0.002 (0.000)	-0.008 (0.010)	-0.004 (0.010)	-0.004 (0.010)
Non PhD R&D staff	0.0004 (0.034)	0.001 (0.006)	-0.013 (-0.010)	0.0002 (0.001)	0.0002 (0.0005)	-0.019 (-0.030)	0.0004 (0.0006)	0.0004 (0.0006)
PhD R&D staff	0.023 (0.030)	0.056 (0.060)	-0.045 (0.110)	0.004 (0.050)	0.004 (0.050)	-0.059 (0.160)	0.002 (0.060)	0.002 (0.060)
Publicly traded firms	-0.577 (0.400)	-0.850 (0.470)	1.604 (0.830)	-0.086 (0.250)	-0.086 (0.250)	1.854 (1.010)	0.043 (0.210)	0.043 (0.210)
<i>Ownership (base = state owned)</i>								
Private	-0.185 (0.160)	-0.155 (0.160)	-0.287 (0.270)	-0.322* (0.130)	-0.322* (0.130)	-0.434 (0.360)	-0.386 (0.200)	-0.386 (0.200)
Foreign participation	-1.130 (1.080)	-0.681 (1.260)	-2.859 (1.610)	-1.934 (1.120)	-1.934 (1.120)	-2.735* (1.090)	-1.780 (1.190)	-1.780 (1.190)
Collectively owned	-0.002 (0.150)	-0.019 (0.180)	-0.388 (0.280)	-0.186 (0.160)	-0.186 (0.160)	-0.529 (0.380)	-0.252 (0.210)	-0.252 (0.210)
Other	0.032 (0.210)	0.234 (0.220)	-0.298 (0.260)	0.044 (0.240)	0.044 (0.240)	-0.370 (0.400)	0.025 (0.310)	0.025 (0.310)
Constant	2.983 (2.680)	3.503 (2.870)	4.870 (4.010)	7.152** (2.730)	7.152** (2.730)	5.235 (5.740)	7.102* (3.480)	7.102* (3.480)
Sector fixed effects	X	X	X	X	X	X	X	X
Region fixed effects	X	X	X	X	X	X	X	X
No. of observations	1,341	1,341	1,341	1,341	1,341	1,341	1,341	1,341

**Notes:** Numbers in the parentheses are standard deviation of the coefficients. The variance-covariance for the error term is cluster by provinces to reflect the dependence of the error terms for the firms in the same provinces but they are independent for the firms in different provinces. The fixed effects of sector and regions are incorporated to control for, but we do not report the results to save space. \*, \*\*, \*\*\*, \*\*\*\*: Significant at 10, 5 and 1 percent level, respectively