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Privatization, Public R&D Policy, and Private R&D Investment in China's Agriculture

Ruifa Hu, Qin Liang, Carl Pray, Jikun Huang, and Yanhong Jin

Private R&D is a major source of innovation and productivity growth in agriculture worldwide. This paper examines trends and determinants of agricultural R&D in China. Results show that while the public sector monopolized agricultural research until recently, private agricultural R&D has grown rapidly since 2000, driven largely by agribusiness privatization. Public-sector R&D investments in basic research also encouraged private R&D research, but public investments in technology development crowded out private R&D investment. China's private R&D investment would grow more rapidly if the government shifted public resources from technology development to basic research.

Key words: Agriculture, China, Private R&D, Privatization, Public R&D

Introduction

In OECD countries, private-sector research and development (R&D) is a major source of innovation and productivity growth; private companies now conduct half of all agricultural R&D (Pardey, Beintema, and Dehmer, 2006) and account for much of the increase in crop and livestock productivity in the United States (Huffman and Evenson, 2006) and elsewhere. Studies in India have shown that the private sector in developing countries can also play a key role in agricultural innovation and productivity growth, even though private research in developing countries is currently limited (Evenson, Pray, and Rosegrant, 1999; Ramaswami, Pray, and Kelly, 1979).

The public sector is the primary provider of agricultural R&D in developing countries as well as the major source of new agricultural technology. The most recent data on government investments in R&D show a divergence among different countries and regions of the world. A few large and rapidly-growing countries–China, Brazil, and India–are making major investments in agricultural R&D, while public agricultural R&D is stagnant or declining in much of the rest of the world (Beintema and Stads, 2010).

Many countries appear to rely on the private sector to play a greater role in generating and transferring agricultural technology as government participation declines. This increase in reliance on the private sector often requires commensurate improvements in intellectual property rights, business incubation, and tax incentives to encourage R&D investments . Unfortunately, little data exist to test the nature of the relationship between public and private research expenditures and determine the best policies forstimulating private research. This article uses a unique data set on

Ruifa Hu is at the School of Management and Economics, Beijing Institute of Technology and the Center for Chinese Agricultural Policy, Chinese Academy of Sciences. Qin Liang is at the Center for Chinese Agricultural Policy and the Graduate School of the Chinese Academy of Sciences. Carl Pray and Yanhong Jin are at the School of Environmental and Biological Sciences, Rutgers University. Jikun Huang is at the Center for Chinese Agricultural Policy, Chinese Academy of Sciences.

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agricultural R&D expenditures by private firms to test the impact of public sector agricultural R&D and incentive programs on private sector R&D expenditures.

Past studies of private research in China have argued that private-sector R&D in developing countries is constrained by weak intellectual property rights (IPR), government control of agricultural input markets, and policies limiting foreign investment in agriculture (Pray and Fuglie, 2002; Pray, 2002). More recent studies suggest that public sector research may be crowding out private R&D. One study reported that China's public agricultural research system (PARS) conducts most of the applied research from which commercial firms could earn profits (Huang, Hu, and Rozelle, 2003). Further, in recent interviews, executives and owners of major Chinese seed and biotechnology companies stated that public-sector plant breeding research dominates and limits growth in the private sector, despite recent increases in private-sector R&D (Personal communication with five Chinese-owned firms in Beijing, August 2009).

In the 1990s, the Chinese government recognized the potential value of private investments in agricultural research and innovation and implemented several policies to encourage private R&D. These policies included reforming China's public R&D system, increasing public R&D investment, liberalizing agricultural input markets, and encouraging private R&D through measures such as government financing of private R&D, tax incentives, and strengthening intellectual property rights.

This paper examines investments in private agricultural research and development (R&D) in China by examining three questions:

1. Have investments in private agricultural R&D increased in China?
2. Have recent policy changes, particularly public R&D investments and input market liberalization, induced more private R&D investment?
3. What are the implications for future research policy in China?

Changes in Agricultural Research Policies and Institutions in China

In the last 40 years, China has outpaced other developing countries in investments in and the expansion of agricultural research personnel and research expenditures (Fan and Pardey, 1997). However, agricultural research in China remains institutionally and geographically fragmented (Fan and Pardey, 1997). In the late 1980s and early 1990s, the Chinese government gradually allowed the private sector to play a major role in agricultural input and output markets, but most research remained the province of the public sector (Huang, Hu, and Rozelle, 2003).

Since the mid-1990s, Chinese leaders have encouraged and supported private R&D investment by implementing three types of policies. The first provided incentives to public research institutes to increase basic research and privatized some public research institutes that conducted applied research. This shift in public research focus to basic research aimed at stimulating private-sector innovation. The second liberalized input markets and enacted specific laws allowing the private sector to conduct research. The third strengthened IPRs and provided specific subsidies and tax incentives for private companies conducting R&D.

Reforms in China's agricultural research system have occurred in two distinct phases. In the first phase, from the mid 1980s to early 1990s, policies were meant to increase funding for and improve efficiency of public agricultural R&D with the ultimate goal of maintaining and enhancing competitiveness in the agricultural sector. In addition, these reforms were intended to accelerate technology transfer from the public research system to technology users such as farmers (Huang et al., 2000; Huang, Hu, and Rozelle, 2003; Koo, Pardey, and Qian, 2007). Specific policies were also implemented to shift the mechanism of research funding from centralized institutional distribution to a less well-funded competitive grants system and to encourage institutes to make up the difference by commercializing their research products (Huang et al., 2000; Huang, Hu, and Rozelle, 2003; Koo, Pardey, and Qian, 2007). However, Huang et al. (2000); Huang, Hu, and Rozelle (2003) reported that funding gains generated from commercial activities did not offset declines in government research support. Income generated from commercial activities also declined after the early 1990s.

The second phase of reforms, in the late 1990s, was designed to encourage and stimulate private research in China's agricultural research system. In particular, public institutes, especially those conducting applied research and with technologies sufficiently profitable to pay research costs, were encouraged to commercialize their research or technologies (Koo, Pardey, and Qian, 2007). The private sector was also encouraged to take on a greater role in applied research. In this phase, various private research institutes emerged, including commercial firms owned by public research institutes and other government agencies, agribusiness firms owned by other government agencies, and companies privately held by individuals or listed on stock markets.[1]

However, public research institutes still formed the backbone of China's agricultural research system. For example, institutes focusing on applied and basic research with a strong public goods nature (such as those analyzing genomes of important crops and breeding new varieties of self-pollinated crops) were maintained in the public "research innovation base" (Huang, Hu, and Rozelle, 2003). By the end of 2002, the Ministry of Agriculture (MOA) oversaw sixty-six agricultural research institutes in the three Academies (Chinese Academy of Agricultural Science, CAAS; Chinese Academy of Fishery Sciences, CAFS, and Chinese Academy of Tropical Agricultural Science, CATAS). Among these agricultural research institutes, approximately half (thirty-three institutes) were maintained as public research institutes, twenty-two were commercialized, four were merged with universities, and eleven reformed as quasi-public institutes. In addition, each province and many lower-level governmental bodies supported agricultural research academies. Many provinces reformed their agricultural research academies in a manner similar to the reforms in the MOA institutes, but others did not. As a result, the sample of private firms used in this study includes firms that were once part of government research institutes.

One thing is clear: public applied and basic research budgets have grown dramatically since the second reform phase. Table 1 reports the research budgets of public agricultural research organizations. The fiscal allocation consists of government funds allocated to public research organizations for institutional support such as salaries, 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. From 1995 to 2000, total budgets for agricultural research in real terms grew by only 1.3%, largely because revenue from commercial activities declined. However, public-sector funding began to accelerate during this period. Since 2000, in real terms, total budgets for agricultural research have increased by more than 10% a year, driven by an almost 15% annual rate of growth in government contributions.

Official data provide mixed signals on whether the latest set of reforms actually focused public research on the production of public goods rather than technology development. The decline in commercial income obtained by public institutes since 1995, shown in table 1, suggests that some applied research and commercial activities may have been spun off to the private sector. Table 2 reports project-based research funding, which excludes non-project based budgets (e.g., salaries, regular operation costs, costs of constructing research facilities, and institutional support), divided into research and development expenditure.[2] This is the only data available which disaggregates government R&D into these two categories; we designate these categories as public research (Public-

[1] In this paper we include all these types of companies as private sector. because even the government-owned enterprises included here operate as private companies with little interference from their government owners. In this paper–as in China–commercial and private and commercialized and privatized are used as synonyms.

[2] Research project based funding data are from all government agricultural research institutes (about 1100) supervised by the Ministry of Agriculture at national, provincial, and prefecture levels. Funding for research projects is classified as basic research, basic-applied research, experiment and development, application of research and experiment outcome, sciences and technology service, and production activities.

Table 1. Total Income for Public Agricultural Research in China in 1991-2006 (Billion Yuan)

Year	Current price			At 2006 constant price		
	Total	Fiscal allocation	Commercial income	Total	Fiscal allocation	Commercial income
1991	2.85	1.80	1.05	6.47	4.08	2.39
1992	3.66	2.10	1.56	7.90	4.53	3.37
1993	4.16	2.23	1.92	8.25	4.44	3.81
1994	5.27	2.95	2.32	9.02	5.05	3.97
1995	5.89	3.26	2.64	8.06	4.45	3.61
1996	6.41	3.54	2.87	7.50	4.14	3.36
1997	6.15	4.10	2.05	6.62	4.42	2.20
1998	6.85	4.40	2.45	7.15	4.59	2.56
1999	7.51	4.85	2.67	7.89	5.09	2.80
2000	7.90	5.32	2.58	8.41	5.66	2.75
2001	8.18	5.72	2.46	8.63	6.04	2.60
2002	10.50	7.72	2.78	11.01	8.09	2.92
2003	11.81	8.81	3.00	12.50	9.33	3.18
2004	11.65	9.34	2.31	12.23	9.80	2.42
2005	13.12	10.92	2.21	13.33	11.09	2.24
2006	15.47	12.83	2.65	15.47	12.83	2.65
Annual growth rate[a]						
1991-1995	19.9	16.4	25.0	5.9	2.9	10.4
1995-2000	6.0	10.4	-0.4	1.3	5.5	-4.9
2000-2006	11.6	15.9	-1.2	10.5	14.8	-2.1
1991-2006	10.3	13.4	3.4	44.6	7.6	-1.9

Notes: [a] Annual growth rates are estimated by regression methods based on data from the Ministry of Science and Technology (MOST, various issues), which includes agricultural research conducted in public research institutes and universities. The deflator used to calculate the real values is Consumer Price Index (CPI) published by National Bureau of Statistics of China (NBSC) (2007).

R) and public development (Public-D), which we believe reflects the allocation of scientists and R&D capital resources.[3] Both agricultural Public-R and Public-D grew rapidly after the mid 1990s. However, in contrast to the government's declared objective, Public-R expanded in the 1990s and then declined when the second phase of agricultural research reforms began in late 1990s. Although Public-R began to recover in 2001, by 2006 it was still only 18% of total agricultural R&D investment (column 4, table 2).

The second major set of policy changes that may have encouraged private-sector R&D involved the privatization of agricultural input markets and the food industry. Commercial enterprises were allowed to enter the livestock, fisheries, crop, and food industries in the late 1980s, during the first

[3] Public-R includes basic and basic-applied researches and Public-D includes all other projects. The distinction between Public-R and Public-D differs from the classification by the Frascati Manual (). The Frascati Manual classifies R&D research activities into three categories, basic research, applied research and experimental research. "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" (Organisation for Economic Co-operation and Development (OECD), 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" (Organisation for Economic Co-operation and Development (OECD), p. 78). "Experimental development is systematic work, drawing on knowledge gained from research and practical experience, that 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" (Organisation for Economic Co-operation and Development (OECD), p. 79). To a great extent, the public-R represents both basic and applied research in the Frascati Manual; and the public-D is similar as experimental development defined in the Frascati Manual.

Table 2. Project Based Funding of Public Agricultural Research Institutes under MOA System in 1991-2006 (Billion Yuan)

Year	Current price			Share of Public-R	At 2006 constant price		
	Total	Public-R	Public-D		Total	Public-R	Public-D
1991	0.26	0.03	0.23	13	0.55	0.07	0.49
1992	0.30	0.05	0.25	16	0.58	0.09	0.49
1993	0.31	0.04	0.26	13	0.53	0.07	0.45
1994	0.33	0.07	0.27	20	0.46	0.09	0.37
1995	0.37	0.08	0.30	20	0.44	0.09	0.35
1996	0.41	0.11	0.30	27	0.45	0.12	0.33
1997	0.50	0.14	0.36	28	0.54	0.15	0.39
1998	0.71	0.22	0.49	32	0.76	0.24	0.53
1999	0.71	0.19	0.52	26	0.77	0.20	0.57
2000	1.05	0.15	0.91	14	1.14	0.16	0.98
2001	1.06	0.17	0.90	16	1.15	0.18	0.96
2002	1.43	0.24	1.19	17	1.55	0.26	1.30
2003	1.49	0.28	1.21	19	1.60	0.30	1.30
2004	1.79	0.33	1.45	18	1.85	0.34	1.50
2005	2.13	0.36	1.77	17	2.16	0.36	1.80
2006	2.40	0.44	1.96	18	2.40	0.44	1.96
Annual growth rate[a]							
1991-1995	8.5	23.1	5.9		-6.6	6.0	-8.8
1995-2000	22.8	16.8	23.9		21.2	15.3	22.3
2000-2006	15.7	20.1	14.8		14.0	18.4	13.2
1991-2006	17.3	17.8	17.2		12.5	12.9	12.4

Notes: [a] Annual growth rates are estimated by regression methods based on unpublished reports by the Ministry of Agriculture (MOA), which record annual income, expenditure, research capacity of each agricultural research institute under MOA. The deflator used to calculate the real values is Consumer Price Index (CPI) published by National Bureau of Statistics of China (NBSC) (2007).

phase of the agricultural research system reforms. However, markets were introduced gradually and differed from industry to industry and province to province. In addition, as discussed above, institutions such as public research institutes were encouraged to support themselves in the late 1980s and 1990s through commercial activities. Only after the mid 1990s did the commercial activities of those research institutes decline (table 1).

Seed was one of the last markets that private firms were allowed to enter. In 2000, the government passed the first seed law to legally define a role for the private sector. The law stipulates that any entrepreneur with access to the required capital and facilities could sell seed. This legislation ended monopoly protections for county, prefectural, and provincial seed companies. All firms–private, quasi-commercialized state-owned enterprises (SOEs), and traditional SOEs–were allowed to apply for permits to sell seed in any jurisdiction. Measures were also enacted that allowed some firms to operate in any province in the country and to certify seed at the provincial level, entitling them to sell seed in any county in the province.

In addition to the reform of the public agricultural research system and food industry privatization, several policies were introduced to encourage additional private R&D. The government strengthened the intellectual property rights (IPR) system, provided subsidies for research, and reduced taxes on companies investing in agricultural R&D. China passed its first patent law in 1983 and began accepting patent applications in 1985. Gradually, industry coverage expanded and enforcement was strengthened. In recent years, specialized courts focusing on intellectual property cases expanded to new regions of the country and were provided with more resources and training. These courts now hear many more cases, and, as a result, case law governing patent disputes has developed.

The public agricultural sector also uses patent law to protect technology. For example, the Chinese Academy of Agricultural Sciences (CAAS) has patents that protect its Bt genes (Fang et al., 2001). However, it is unclear how successful these efforts to protect and then license public sector innovations have been.

In 1997, China passed and implemented its first Plant Variety Protection Act. Legislators developed a legal framework based on International Union for the Protection of New Varieties of Plants (UPOV) guidelines. After officially promulgating the law, China began accepting applications for plant variety protection certificates (PVPCs) in 1999. The legislation appears to have stimulated public research institutes and private firms to increase investments in plant breeding (Hu et al., 2006).

Interviews by the authors with Chinese and multinational private seed and biotech firms in 2004 and 2009 indicated that, while they would like enforcement of both patents and PVPCs to be strengthened, the current system is sufficiently effective to justify investing in applications for PVPCs and patents. This is a substantial change from the 1990s, when those firms did not apply for patents or PVPCs.

Major policies to promote private investment in R&D began after 1999. The State Council released a policy document in 1999 outlining policy guidelines to promote China's technology innovation. Several policies to encourage companies to invest in R&D were included (Chinese Central Committee of Communist Party of China and the State Countil, 1999). For example, the government eliminated the business tax (usually 3% to 5%) on income generated from the sale of a firm's technology or services related to the technology and provided subsidized loans through state banks to firms generating new technologies. Following the guidelines of the 1999 State Council document, the Ministry of Finance and State Administration of Taxation developed an implementation plan in late 1999 and 2000 to allow tax deductions on revenues for funds that any agency provides for R&D in research institutes and universities (Ministry of Finance (MOF), 1999).

Another policy permits companies to apply to the government for research grants. The National Economic and Trade Committee (NETC) initiated this policy in 2000 to encourage mid- and small-sized firms to invest in R&D. The NETC asked each level of local government to support the development of mid- and small-sized firms by establishing risk investment foundations that would directly invest in commercial firms' R&D and technology commercialization efforts. The policy also eliminated sales taxes for three years for sales of technology developed through firms' technology improvement projects (National Economic and Trade Commission (NETC), 2000).

Trends and Characteristics of Private Agricultural R&D

We use a unique R&D data set created by surveying more than 1000 private agribusinesses in China to examine the characteristics of private agricultural R&D. No comparable data set has been constructed for any other developing country. The data allow us to conduct an econometric analysis of the impacts of public policies and investments on private agribusiness R&D, focusing on the extent to which public research stimulates or hinders private R&D.

The data used in this study are derived from the first nation-wide mail survey of private agribusiness research organizations in China. Coordinated by the Ministry of Agriculture, the survey was implemented by the Center for Chinese Agricultural Policy (CCAP) in 2007 and covered all 31 provinces in China. 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).

The questionnaire collected detailed information on firms' R&D investments, human resources, technology transfer, and sales revenues for the years 2000, 2004, 2005 and 2006. Firm-level data were also gathered, including information on the year the firm was established, ownership characteristics, and industry coverage.

In each province, the local government distributed the mail survey questionnaire and collected completed surveys from each firm. Several measures were used to improve the accuracy of the self-reported data. First, a detailed 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. In the first round of the survey, 24 of 31 provinces sent back questionnaires from 1293 agricultural companies. Among provinces returning questionnaires there was an overall response rate of 54%. Of the non-responding firms (46%) in these provinces, 5% were randomly selected for phone interviews. None of the non-responders had any R&D activities. Third, in the remaining 7 provinces, we randomly selected 10% (or 66) of all agricultural companies and interviewed them by mail; the response rate was 100% of 66 firms. In estimating total private R&D investment, we assume zero investment from non-responding firms. Finally, to check data quality we also randomly selected 5% of the responding firms (1293+66) and conducted an additional phone-survey. We concluded that the survey data were quite reliable.[4]

We collected data on private agricultural R&D investment to obtain firms' expenditures on R&D activities from their own resources and funding received from government sources, including government-sponsored contract research. This makes it possible to identify the total amount of private firm research (private plus public funding spent by the firms) and the amount of research funded solely by private firms. Since we are primarily concerned with research funded by each private firm, most of the data reported and the data used as the dependent variable in the regression analysis below is research funded by private firms. We also present the total amount of R&D conducted by private firms in table 3. Firms are classified into five industry categories: crops (seed, tea, silkworm, mulberry, vegetable, and fruit); livestock (pork, cattle, poultry, and veterinary); fishery; food processing (milk, grain, vegetables, fruit, meat, and other food products); and other (54 firms in machinery, fertilizer, and pesticide industries).[5]

Data used in estimating the models were from 1,305 firms (1293 + 66 - 54) providing a total of 4,021 observations over four years. In 2006, each firm employed an average of 326 people, had average sales revenues of 132 million yuan (approximately $16.5 million), and made average R&D investments of 1.66 million yuan ($0.21 million).

Survey results indicated that private agricultural R&D investment grew rapidly from 2000 (table 3). Measured in 2006 prices, total real investment agricultural R&D performed by private firms increased from 840 million yuan ($101 million) in 2000 to 3,504 million yuan ($438 millions) in 2006, at an average annual growth rate of 26.9% (table 3). Most R&D investment came from firms' own funding (column 2, table 3), though the government also provided some co-funding for private R&D (see the last column of table 3). In-house R&D funding increased from 721 million yuan ($87 million) in 2000 to 2,988 million yuan ($375 million) in 2006 (column 3, table 3). Over the same period, outsourced contract R&D investment increased from 29 million yuan ($3.5 million) to 264 million yuan ($3 million) (column 4, table 3). R&D growth rates were 26.8% for in-house investments and 44.4% for outsourced investments.

[4] In the follow up phone survey, we asked each of the selected firms (67) the following questions: 1) Did your firm have R&D expenditures in 2006? 2) If yes, how much was spent on R&D activities in 2006? 3) What were the major R&D activities in 2006? The same questions were then repeated in 2004. We compared the data received from the phone survey with the data collected by the mail survey. We found that the answers for questions 1 and 3 were the same in both surveys, there was no statistical difference in the mean of R&D expenditure (question 2), and none of 67 (above you say you interviewed 66 firms?) firms interviewed reported R&D expenditures that differed by more than 10%.

[5] Although these 54 firms are supervised by the agricultural administration system, they account for only a small portion of overall industries in machinery, fertilizer, and pesticide. We include these 54 firms when calculating total private investment, but they were excluded in regression analysis.

Table 3. Private R&D Investment in China, 2000-2006

Year	Total Investment	Private Firm Investment in R&D			Firm's R&D Funding from Government
		Total	In own Firm	Contract Out	
2000	840	750	721	29	90
2004	2,169	1,849	1,747	103	319
2005	2,684	2,435	2,270	165	249
2006	3,504	3,252	2,988	264	252
Annual growth rates (%)					
2000-2006	26.9	27.7	26.8	44.4	18.7

Notes: Prices are for million yuan in 2006 prices. Investment in nominal values was deflated by consumer price index based on 2006. This table is based on a national mail survey coordinated by MOA and implemented by CCAP in 2007.

Figure 1 presents the distribution of private R&D investment each year. In 2000, nearly half of private firms had no R&D investment at all, but over time more firms began investing in R&D activities. The percentage of firms with no R&D declined from 43.60% in 2000 to 28.81% in 2006. Average private R&D investments among all firms sampled increased from 0.82 million yuan in 2000 ($0.10 million) to 1.66 million yuan ($0.20 million) in 2006. Average investment among firms that made any investments increased from 1.54 million yuan ($0.19 million) in 2000 to 2.34 million yuan ($0.30 million). Figure 1 also suggests that private R&D investment is highly skewed, with a small number of firms accounting for most private R&D investment. Private agricultural R&D investment in China is heavily focused on the agricultural processing industry. In 2006, the processing industry accounted for more than 40% of total investment, followed by livestock and veterinary industries with around 30% in total (Figure 2), crop research with less than 20%, and fisheries with about 10%.[6]

Several types of firms carry out what is classified as private research in China. Table 4 shows the types of firms, their frequency in the sample, sizes (employees and sale revenues), and research focus. More than 1000 firms are fully privately owned; these firms are relatively small, with fewer than 300 employees, and their research intensity averages about 1.2% of sales revenue. One hundred and three firms are still state-owned but operate as private or commercial firms with little government intervention. These are the smallest Chinese firms with the lowest research intensity, perhaps because they depend most heavily on technology from government research institutes and on government funding for in-house research. Some firms are classified as private co-operatives; others are joint ventures between Chinese and international companies. There are only 73 joint venture firms, but these firms are the largest in terms of size (almost 600 employees) and have the lowest research intensities. A few firms, 23 in the sample, have listed stock on one of China's stock exchanges. These are very big firms with lower than average research intensity.

Table 5 provides summary statistics of firm characteristics. These firms were relatively young–the average age was seven years in 2006. Average sales revenues per firm were about 132 million yuan ($1.57 million) and exhibited large standard deviations. The bottom half of table 5 compares firms with no R&D investment to those with at least some R&D investment. There is no significant difference in terms of firm ages and ownership structures. However, average sales revenues for firms with positive R&D investments were almost triple those of firms not investing in R&D activities (147.35 vs. 52.52 million yuan). Few private agricultural firms were publically traded in 2000, and

[6] In making international comparisons it is important to note that some sectors of agricultural research such as pesticide and some agricultural machinery research is not counted here because these types of firms are not supervised by China's agricultural administration system. If they were included, they would increase the share of crop-related research.

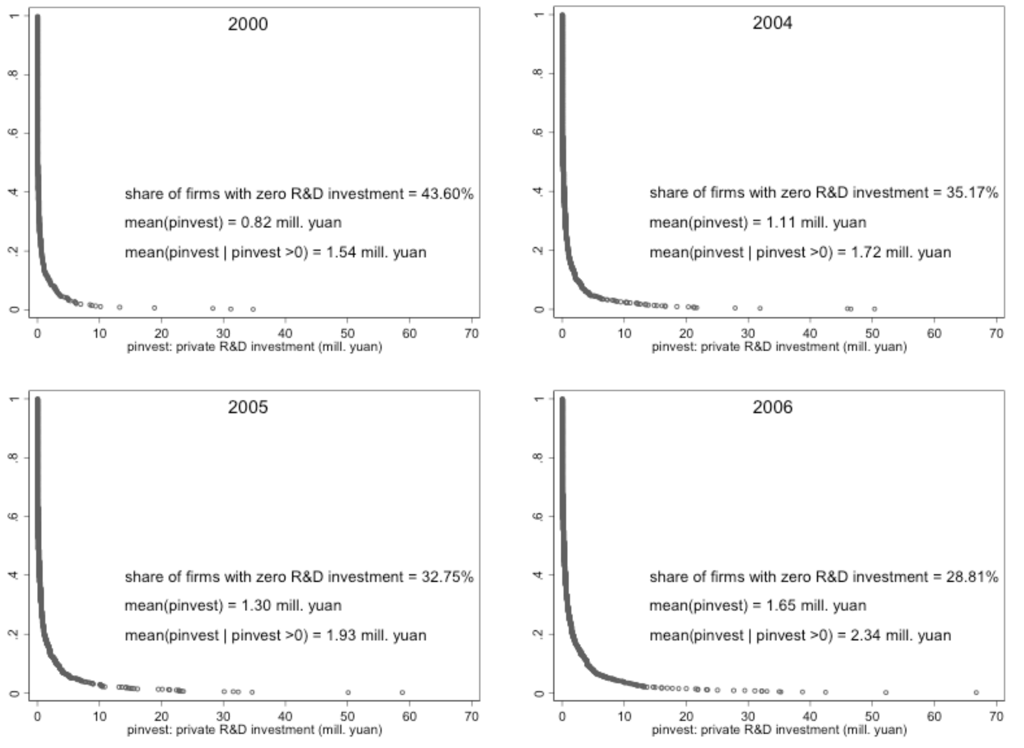

Figure 1. Distribution of Private R&D Investment by Year

only 10 of these firms were included in the sample. The number increased to 21 in 2004 and 23 in 2006. Publically traded firms are more likely to invest in R&D research activities (69 out of 73 total observations of publicly trade firms have R&D investment in table 5). On average, publicly traded agricultural firms had R&D investments more than ten times greater than their counterparts (10.4 million yuan vs. 1.14 million yuan; i.e., $1.26 million vs. $0.01 million).

We hypothesize that privatization plays an important role in R&D investment. However, it is not easy to measure privatization. We consider two measures. First, the total number of private firms investing in R&D reflects the growth of privatization. Between 2000 and 2006, the total number of such firms more than doubled, increasing from 505 to 1355 (table 5). Second, even a privately owned firm may be a joint venture with the state, foreign governments, or other non-private partners. Thus, we collected information on ownership structures in the mail survey. We divided a unit's ownership structure into percentages held by purely private, state, foreign, and other parties. Table 5 suggests that average state-owned shares declined from 18.6% in 2000 to 11.0% in 2006, while purely private shares increased from 68.1% in 2000 to 79.1% in 2006.

Figure 3 shows that during 2000-2006, the distribution of private agricultural firms hardly changed. In 2006 private agricultural firms were predominant in the food-processing industry (43.1%), with smaller shares in the crop industry (28.1%), livestock and veterinary industries (21.8%), and the fishery industry (7.1%).

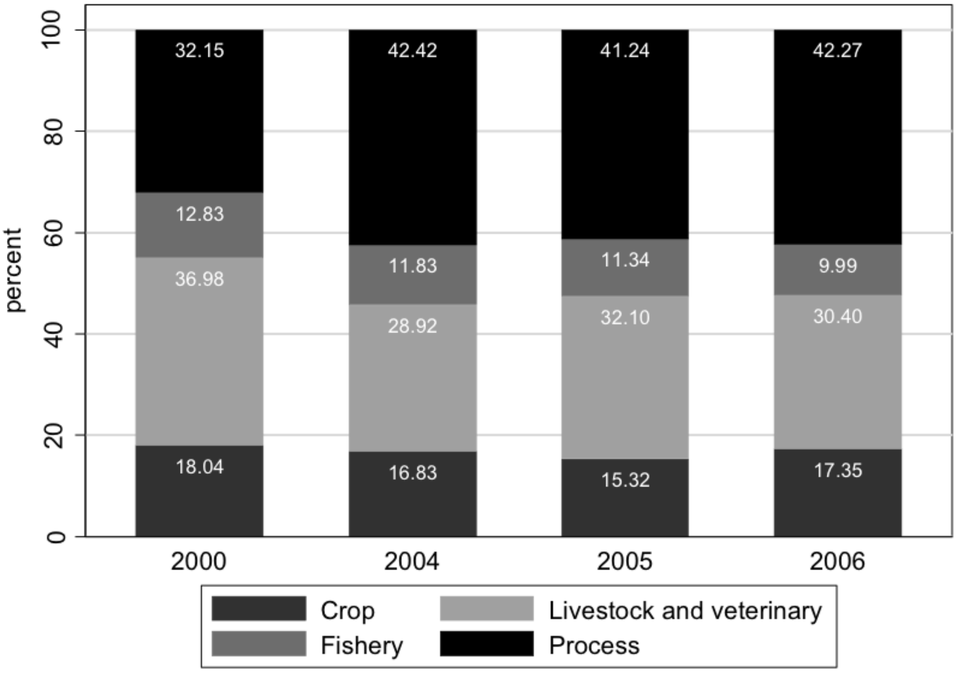

Figure 2. Proportion of Private Agricultural R&D Investment in China

Modeling Private R&D Investment

What explains this rapid rise in private research expenditure? Generally, private firms' agricultural R&D are modeled as investments they make to increase profits. Expected returns to research investment will improve in the presence of sizable expected demand for research products, the strength of exclusion mechanisms such as patents which allow the firm to appropriate part of the benefits from the new product or process, and a favorable business environment that permits profitable innovations. The profitability of private research also depends on technological opportunities and research costs (David, Hall, and Toole, 2000).

The transformation of the Chinese system to a market economy has provided larger markets for private innovations as the government has withdrawn from agricultural input markets. Markets for agricultural inputs and food products have grown with increased demand for food products. Appropriability has improved with the development and enforcement of intellectual property rights legislation. Technological opportunities have grown as government research in more basic research has grown.

A major justification for public R&D is that it should provide positive spillovers of knowledge that private firms can use to develop profitable technologies through their own applied research. Public agricultural development research produces commercial products that compete with private-sector products, likely reducing private firms' willingness to invest in R&D. Thus, more agricultural Public-D is likely to decrease private agricultural R&D investment, and more agricultural Public-R is likely to increase private agricultural R&D investment (Pray, Fuglie, and Johnson). These hypotheses are supported by empirical studies using U.S. data on seed industry research (Fuglie and Walker, 2001).

Table 4. Firms' R&D Investment and Characteristics in 2006

	Number of firms	Staff per firm	Sales revenue (million yuan) per firm
By ownership:			
Fully state owned	103	253	114
Fully private owned	1,013	296	112
Joint equity coop	116	494	231
Joint venture	73	590	2,677
By listed company in the stock market:			
Listed company	23	2,214	1,431
Non-Listed company	1,282	292	108
Total	1,305	326	132

	Firms' R&D investment		Government direct R&D investment to firm	
	(Thousand yuan)	% of sale revenue	(Thousand yuan)	% of firm R&D
By ownership:				
Fully state owned	858	0.8	158	18.4
Fully private owned	1,365	1.2	80	5.9
Joint equity coop	3,549	1.5	428	12.1
Joint venture	3,851	0.1	242	6.3
By listed company in the stock market:				
Listed company	12,592	0.9	706	5.6
Non-Listed company	1,462	1.3	116	7.9
Total	1,658	1.3	126	7.6

Notes: Based on a national mail survey coordinated by MOA and implemented by CCAP in 2007.

We hypothesize that firm-level private agricultural R&D investment, denoted by *PARDI*, is affected by the three types of major policies discussed above and other factors, with the following specification:

(1) $$PARDI_{it} = \mathrm{f}(Privatization_{it}; Public-R_t, Public-D_t; Support_{it}; X_{it}, Z),$$

where the supply variables are defined as follows:

1. Privatization: Four variables capture privatization and liberalization of China's agricultural input industry: number of private agricultural firms at the national level; two ownership variables (share of private and foreign ownership vs. the SOE) at the firm level; and a dummy variable reflecting whether a firm is publically traded or not. The number of private agricultural firms represents the trend of agricultural market liberalization. Ownership variables directly measure privatization.

2. Public-R and Public-D: Public R is lagged public investments on basic and basic-applied research in plant, livestock, fisheries, or food science. Public D is lagged public investment on development research project in the four areas of science. The optimal lag length is determined based on information criteria.

Table 5. Summary Statistics of Key Independent Variables

Variable	2000	2004	2005	2006
No. of observations	484	1,032	1,200	1,305
No. of agricultural firms	505	1,064	1,239	1,355
No. of publicly traded firms	10	21	22	23
Public R&D (1,000,000 yuan)	128	268	352	372
	(182)	(350)	(461)	(471)
Public-R (1,000,000 yuan)	49	61	76	85
	(694)	(79)	(94)	(106)
Public-D (1,000,000 yuan)	118	267	309	345
	(175)	(348)	(393)	(438)
Government funding for private R&D research	53	104	118	126
(1,000 yuan)	(391)	(749)	(798)	(609)
Firm age (years)	5.12	6.04	6.33	6.90
	(3.56)	(3.87)	(3.99)	(4.09)
Sale revenues (1,000,000 yuan)	81	108	119	131
	(245)	(446)	(512)	(603)
Ownership				
Private share (%)	68.07	76.34	78.41	79.08
	(44.54)	(40.31)	(39.02)	(38.64)
State participation (%)	18.64	12.88	11.58	11.00
	(37.35)	(31.83)	(30.43)	(29.71)
Foreign participation (%)	4.41	3.61	3.51	3.41
	(17.79)	(15.72)	(15.55)	(15.44)

Comparison between firms with zero or positive R&D investment

	With zero investment	**With a positive investment**
	(n = 1,343)	(n = 2,678)
Sale revenue	52.52 (196.40)	147.35 (600.64)
Age	5.75 (3.74)	6.57 (4.06)
Ownership		
Private share (%)	12.81 (32.21)	12.45 (31.22)
State participation (%)	75.64 (41.19)	77.45 (39.49)
Foreign participation (%)	4.02 (16.84)	3.41 (15.32)
No. of publicly traded firms	9	67

Notes: Values above parentheses are means and inside parentheses are standard deviations.

3. Policy support: Because data on various policy supports are not available (e.g., IPR, tax incentive, subsidized loans, and others) for private R&D investment, we include, the amount of funding received from the government for private R&D at the firm level as an additional variable.

4. The vector **X** represents all the firm's key characteristics, including firm size as measured by sales and age of firms; sales revenues represent each firm's ability to invest in agricultural R&D.

5. Vector **Z** represents industry and province dummy variables.

Among the total 4021 usable observations, approximately 33% (1343 observations) had no R&D investments. A Tobit model is used to control for the high frequency of zero R&D investment.

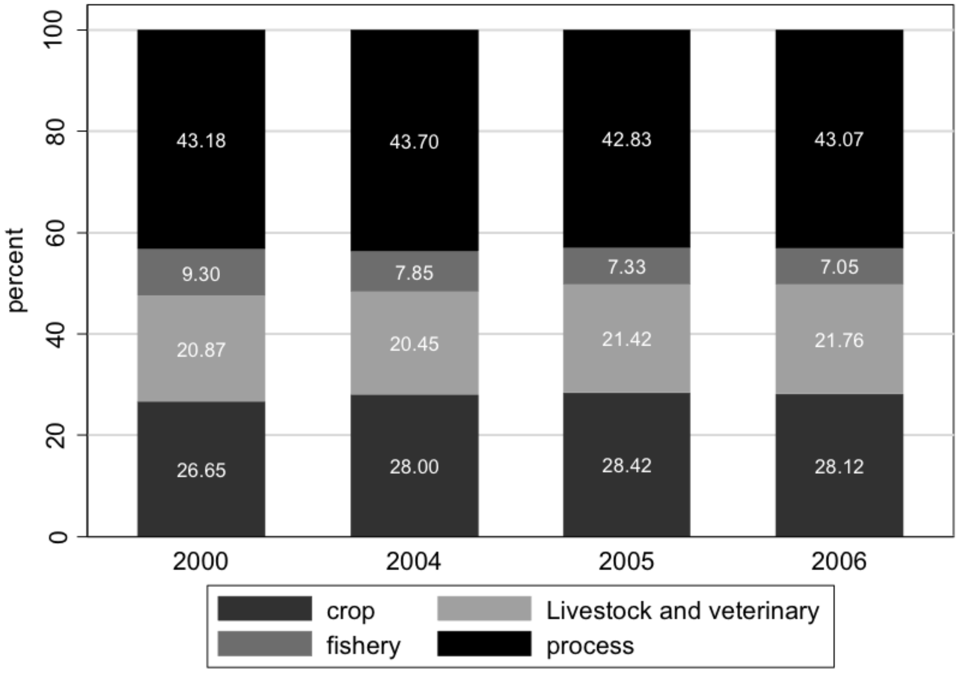

Figure 3. Industry Distribution in Private Sample Firms by Year

Before presenting the detailed discussion of estimation results, we report some test results on model specifications.

Testing for the Presence of Individual Heterogeneity

Panel estimators are similar to pooled estimators in the absence of individual heterogeneity. The absence of individual heterogeneity is statistically equivalent to $H_0 : \omega_\mu^2 = 0$ (Wooldridge, 2002, p. 264). A likelihood ratio test for $H_0 : \omega_\mu^2 = 0$ rejects the null hypotheses at the 1% significance level (see the last part of table 6). Thus, a RE-Tobit estimator is more appropriate than a Tobit estimator for our pooled data.

Testing for the Optimal Lag Length of Public R&D Investment Stock

R&D expenditures are highly correlated from year to year; for example, the correlation coefficients for Public-R, Public-D, and total public R&D investment separately from year to year in the five year time span in our data exceed 0.9. Given such high correlations among years, it is "unlikely that one can estimate the separate contribution with any precision" in the context of the linkage between public R&D investment and change in productivity (p. 106 Griliches, 1979). Several analyses that examined the relationship between public research and private R&D using U.S. and European data use fairly short lags of 1 to 3 years, but some studies of the relationship between basic public sector research and private research reported that lags of 6 to 8 years fit best (David, Hall and Toole 2000). The only empirical study of the relationship between public and private agricultural research that we

Table 6. Estimation Results of Four Firm Random-Effects Tobit Models

	Model 1	Model 2	Model 3	Model 4
Privatization:				
No. of private agricultural firms	1.842*** (0.279)	1.799*** (0.279)	1.793*** (0.278)	1.748*** (0.277)
Private share (compared w/ State)	3.415 (3.22)	3.483 (3.22)	3.792 (3.18)	3.871 (3.18)
Foreign share (compared w/ State)	0.212 (7.75)	0.325 (7.76)	0.785 (7.66)	0.916 (7.66)
Publicly traded company	7,446*** (856.7)	7,443*** (857.1)	7,336*** (847.0)	7,330*** (847.2)
Public R&D investment lagged 3 years:				
of the total R&D	−0.001*** (0.000)		−0.001*** (0.000)	
of public-R		0.017*** (0.005)		0.018*** (0.005)
of public-D		−0.004*** (0.001)		−0.004*** (0.001)
Government funding for private R&D			0.302*** (0.09)	0.310*** (0.09)
Firm age	165.5*** (29.39)	168.2*** (29.42)	165.4*** (29.05)	168.1*** (29.06)
Firm's sale revenues	0.003*** (0.000)	0.003*** (0.000)	0.003*** (0.000)	0.003*** (0.000)
Industry of the firm (compared w/ crop)				
Livestock and veterinary	−546.4 (554.9)	381.8 (602.3)	−558.9 (552.9)	394.2 (600.6)
Fishery	−1,214* (675.0)	71.6 (750.6)	−1,239* (671.0)	81.5 (747.3)
Process	−1,975*** (593.2)	−560.0 (694.0)	−1,982*** (591.9)	−529.9 (693.4)
sigma_u	3,612*** (97.0)	3,616*** (97.0)	3,562*** (96.9)	3,565*** (96.8)
sigma_e	2,041*** (32.7)	2,033*** (32.6)	2,046*** (32.9)	2,038*** (32.7)
No. of observations (firm-year pairs)	4,021	4,021	4,021	4,021
AIC	51,658	51,645	51,649	51,635
BIC	51,916	51,909	51,913	51,906
Test for sigma_u = 0 ($\chi^2(1)$)	1,389	1,391	1,352	1,355
p-value	0.00	0.00	0.00	0.00
Value of AIC (Akaike Information Criterion) of test for the optimal lag length				
r = 1	51,659	51,656	51,650	51,647
r = 2	51,659	51,646	51,650	51,636
r = 3	**51,658**	**51,644**	**51,648**	**51,634**
r = 4	51,659	51,646	51,649	51,638
r = 5	51,658	51,641	51,649	51,631

Notes: The single, double, and triple asterisks (*, **, ***) represent 10%, 5%, and 1% significance levels, respectively. The province dummy variables are included in the model estimation but not reported.

are aware of was conducted by (Fuglie and Walker, 2001). Because of the nature of their data, they use a 10-year lag for estimating the effects of public research on private research.

In this paper, we consider lags of 1 to 5 years for both Public R and Public D and checked for the robustness of different lags. We find that choosing different lag lengths made no difference in the results. However, a lag of three years results in the lowest values for the Akaike information criterion and Bayesian information criterion (see table 6). Thus, estimation results for models with a three year lag are reported.

Table 6 summarizes estimation results of the four models. The first two models do not include research funds received by private firms from the government for their R&D activities as an explanatory variable. Several privatization variables had the expected positive impacts on firms' investments in agricultural R&D. Others did not have any impact. The coefficient on number of firms is positive and statistically significant. Whether a firm is listed on one of China's stock exchanges also has a statistically significant positive impact on its R&D investment. The percentage of government participation in ownership, percentage foreign participation, and purely private ownership do not have a statistically significant impact on private R&D. This could be because private shares predominate and there is little difference over time (see table 5).

As expected, firms with larger sales invest more heavily in research than smaller firms, and older firms spend more resources on research than younger firms.

Econometric estimates of the impact of public R&D investment on private research are of particular interest from a policy perspective. The coefficients of total public R&D investments are negative and significant in both models 1 and 3. This indicates that although public agricultural R&D investment increased 14.8% annually between 2000 and 2006, it did not promote increases in private-sector R&D, but seemingly restrains increases in private agricultural R&D. However, the negative, significant impact is very small. Separating Public-R from Public-D provides a clearer picture of what is going on. The coefficient of the Public-R variable is positive and statistically significant indicating that government public research investment provides ideas, concepts, and pre-commercial technologies that firms can use to produce proprietary technologies. The result provides evidence of the positive impacts of public investment on private agricultural R&D investment. This is consistent with our hypothesis that, if the government invests more in basic and basic-applied research, the private sector will increase its R&D investments. The coefficients for the Public-D variable are negative and statistically significant in all model specifications. The implication is that when agricultural Public-D increases, crowd out private R&D investments. This is consistent with the hypothesis that government investments in development research constrain private R&D investment growth. A similar result was also reported for the US seed industry (Fuglie and Walker, 2001).

Government funding for research conducted by private firms appears to have a large, positive impact on private-sector investments in research. This at times has partly been driven by a policy requiring private agricultural firms to match part of the government funds with their own R&D funds. However, because information is lacking on specific matching requirements in different industries, provinces and research projects, we cannot determine whether government funding of private research induces more private R&D investment than is required by the match.

Industry dummy variables do not have consistent results across model specifications. Only food processing has a consistently negative coefficient that is also significant in specifications 2 and 4. While not reported in table 6, the estimated results indicate that agricultural private R&D investment differs significantly among regions and provinces. More detailed province-level information is needed to further analyze regional differences in agricultural private R&D investment.

Conclusions and Policy Implications

This paper documents rapid growth in China in private-sector R&D since 2000. In 2006, private R&D investment (3.25 billion yuan) was about 17% of total agricultural R&D (18.97 billion yuan), a major increase over the 2000 number of 0.75 billion yuan and even smaller numbers that reported by Pray (2002) in the 1990s.

Econometric evidence suggests that agribusiness privatization since the late 1990s was an important determinant for the rise of private agricultural R&D, resulting in rapid growth in the number and size of private agricultural firms and increasing the private sector's ability to invest in agricultural R&D. Now that most agricultural input industries have been privatized, it seems likely that privatization will not be a major source of growth for private R&D in the future.

We also find that whether public R&D investments displace or stimulate private R&D investments depends on the nature of those. In particular, 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. In China, most public R&D investment focuses on technology development. Basic and applied research is a small proportion of total public R&D investment, accounting for less than 20% in 2006. Thus, the overall impact of public R&D investment has been to restrain private R&D investment in China. Government funding provided directly to private firms for research does increase investment by firms in private R&D. These findings indicate that if the government wants to encourage private firms to increase their agricultural R&D investments, the government should reduce its investments in development research, particularly in fields where technology can be protected easily with intellectual property rights. Instead, these funds should be invested in basic and basic-applied research or in directly funding R&D conducted by private firms.

The findings in this paper also provide lessons for other countries. Private sector R&D in countries that are spending less on public R&D is not likely to increase unless these countries shift their government investments in research from technology development to applied and basic research, and, like China, have a rapidly growing agricultural input industry. The findings also suggest that government subsidies for private research expenditure can stimulate private research, but not in a substantial manner. For countries like Brazil and India, which are rapidly increasing their government research expenditure, the evidence from China provides a cautionary note: rapid expansion of technology development spending could crowd out private sector R&D. If the goal of the governments of these countries is to increase private R&D at the same time as they are increasing public R&D, then they should be investing resources in applied and basic agricultural R&D.

The Chinese government uses several programs to stimulate private R&D. Future research should consider the impacts of various tax incentives and of strengthened intellectual property rights on private-sector R&D.

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