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Commercializing Agricultural Research and Fungible Government Investment: Lessons from China

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working paper

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Governments in developed, developing, and transitional countries around the world, facing tightening budgets and increasing global competition, have implemented a series of policy measures designed at reforming and improving the performance of public agencies and policy institutes. High on the priority list, given the increasing importance of research and development (R&D), reformers have targeted public research systems, including those for agriculture. Institutional innovations, such as moves from funding by block grants to competitive grants and decentralization of research planning and administration, have been attempted with the goal of increasing the output and productivity of research systems.

At the same time that the importance of research for food security and international competitive has been widely documented and recognized by policy makers, public research institutes throughout the world – particularly in developing and transitional countries - are facing stagnant or declining funding from traditional government sources (Alston, Pardey and Roseboom 1998). While reducing or holding constant government funding, research policy makers typically encourage institutes to seek more funds from private firms, industry groups, and commercializing the output of their research by either licensing patented technology or establishing firms to use the proprietary technology. For example, since the mid-eighties researchers in the United Kingdom and Australia have been encouraged to find non-traditional commercial funding sources (Thirtle, Piesse, and Smith 1997; Industry Commission, 1995). U.S. agricultural universities, which have been under similar pressures, obtain about 19 percent of their research funding from sales of products, private grants, contract research, royalties and gifts (Cooperative 1996).

Most governments are pushing commercialization as a supplement not a substitute for government funds. Governments do not announce that it has adopted commercialization for the expressed purpose of being able to escape its agricultural R&D responsibilities. While goals of almost all of these policy moves include increasing the efficiency of agricultural research and making scientists more responsive to society's needs, in a technology-dependent society, nearly all governments have continued to reiterate their commitments to increasing agricultural research and development.

Can the policy of commercialization of agricultural research really increase research funding and the resources available to agricultural sciences for R&D? What determines the success of the agricultural research institutes in generating commercial revenues? Will governments stick to their commitment to increase funding for agricultural research after they have adopted reforms committed to research commercialization?

Goals, Limitations, and Contributions

The goal of our paper is to provide answers to these questions for the special case of China, the world's largest developing and reforming country. The question that we want to answer is what has been the *net* impact of commercialization on research expenditures. We not only hope to provide information to China's government on the effectiveness of its moves to increase research funding through commercialization, we also want to draw more generalizable lessons for policy makers in all countries. China is a particularly appropriate for studying research commercialization, since it has arguably moved further in its efforts to commercialize its research system than any other country in the world (Rozelle, Pray, and Huang, 1997; Swinbanks and Maddox, 1995). Focusing on the case of China, of course, will force careful consideration of the applicability of the findings before advertising wholesale policy lessons. We will make an effort, however, to sort out which elements of China's research reforms are Sino-specific, and which elements are common to other developing and/or reforming countries.

To meet the broad goal, our paper has three more narrowly defined objectives. In the first part of the paper, we will describe the features of China's agricultural research system, the performance of the nation's R&D in recent years, and its efforts to reform research, especially emphasizing research commercialization "with Chinese characteristics." The research also will seek to understand the determinants of research investment behavior of both the traditional government sector and the newly commercialized R&D enterprises. After accounting for a number of elements that influence the level of research intensity, we will explicitly test the hypotheses that revenues generated from commercial research ventures do help supplement government research budgets but also allows officials to shirk their R&D duties and reduce government contributions to research.

Finally, we attempt to generate an estimate of the impact that commercial reforms have had on agricultural R&D in China in the 1990s.

Our investigation focuses on sub-national funding. In China the vast majority of the nation's R&D is funded by and carried out by the provinces and prefectures. This may limit lessons from our work somewhat, since with the exception of the US, almost no country has such a decentralized research system. As Lele (1998) argues, however, the move to decentralized research funding in agriculture around the world is an important trend. Thus, the findings from this study on the determinants of sub-national research spending , should be of interest to many countries.

We will also not attempt to answer all of the outstanding questions on commercialization and research. We are primarily concerned with the earnings by commercial enterprises that are owned and operated by government controlled research institutes. Their commercial activities include not only the development, production, and marketing of the output of their research, but also all business ventures run by research units. We ignore both agricultural research by private companies and contract research, both of which are almost absent in China (authors' survey). We are interested primarily in the impact of commercialization on government funding, ignoring in this paper the effect that it might have on research output or productivity (see Rozelle, Pray, and Huang, 1997 for an analysis of these issues).

In summary, our research has several distinctive contributions. Above all, this paper is the first empirical study in any country that examines the impact of commercialization-led research reform on government funding. We also try to understand the incentives and constraints faced by officials as they allocate scarce financial resources in a system characterized by a great deal of decentralization. Finally, in the context of China, this is the first rigorous empirical study of the determinants of research intensity, an issue identified in the World Bank's 1997 report on China's development in the 21st Century (World Bank 1997) as one of the most fundamental issues if the nation wants to meet its food security goals.

China's Research System: Organization, Performance, and Reform

China has one of the most comprehensive research systems in the world, including the largest number of agricultural scientists of any country in the developing world. Since the 1950s, China's researchers have successfully produced a steady flow of new varieties and other technologies (Stone, 1988). Farmers used semi-dwarf varieties developed in China several years before the release of Green Revolution technology elsewhere. China was the first country to develop and extend an F-1 variety of hybrid rice. Chinese-bred corn, wheat, and sweet potatoes technologies were comparable to the best varieties in the world in the pre-reform era (Stone, 1993). The focus of the work of much of China's research system was on developing higher yielding varieties and in breeding shorter season, photosensitive varieties that allowed for more intensive cultivation of the land, though in recent years institutes of animal husbandry and aquaculture have begun to flourish (Huang and Rozelle, 1996).

Many of the most famous research discoveries, such as hybrid rice, were made by scientists in provincial research centers. Most breakthroughs, everyday breeding and other scientific work were done by researchers at the subnational level. In 1978, the first year of the reforms, 85 percent of China's investment in agricultural research occurred at the subnational level (Table 1). Although in the early years of transition, the proportion contributed by the national government increased to 28 percent, reducing the proportion funded by provincial and prefectural governments to 72 percent, by 1990 the burden of subnational governments rose to 78 percent. By 1994, the national government's share had shrunk to 15 percent, a lowest level of the reform period (Table 1). The number of institutions, the size of staff, and number of research projects in the nation's agricultural research also show similarly high levels of decentralization (Table 2).

Research Performance and Funding Trends

China's research effort has succeeded by almost every indicator in many different sectors. Fan (1991) has demonstrated the positive effect of technology on the value of the output of the agriculture sector in the early reform era. More recent work has demonstrated that the contribution of research to the increase in yields and production of rice, wheat, maize, and cash crops exceeds that of any other factor in the early and late reform eras (Huang and Rozelle, 1996; Huang and Rozelle, 1997; Rozelle and Huang, 1997). Research on the rates of return of agricultural research spending also have generated estimated levels that range between 70 and 108 percent (Fan 1996), high for investments even in China's capital short economy.

Despite the contributions of research to the national food supply, farmer incomes, and efforts of leaders to meet the nation's food security goals, sectoral officials have had trouble maintaining access to enough fiscal resources to keep agricultural research investment from falling—although the direction of research investment is currently the subject of intense debate. Huang, Rozelle and Rosegrant (1995) find that real agricultural research expenditures decline from 1985 to 1991, their most recent data. Fan and Pardey (1995) report an increase of 20 percent between 1986-90 and 1991-93, however, they admittedly include in their revenue figures all research funds from government source and income from enterprises owned by research organizations (an issue that is the center of discussion in this paper). The actual direction of the trend and magnitude of the fall or rise in research funding depends heavily on both the choice of endpoints for the period of analysis and the definition of research resources—but given the sensitivity of the estimates to these factors, it is clear that resources directed at agricultural research have not risen much if at all.

Budget pressures, the nation's "urban first" mentality, and poor intellectual property rights, in part, account for the inability of China to maintain a robust and growing agricultural research system. Despite the rapid growth of the economy, China's record on tax collection has left governments at all levels, but especially the national government and poorer provinces, short of fiscal resources (Naughton, 1995). Faced with hard budget constraints, one response of budget managers has been to slash even well-functioning public services. Cuts to agriculture-oriented public agencies, may be even greater, given the well-known bias of policy makers against the rural sector and for urbanites (Putterman, 1992). Weak intellectual property rights, as typified by the lack of plant breeding rights before 1997, have exacerbated the problem, since agricultural research institutes have been unable or unwilling to make up funds by marketing their products or selling their technology (Rozelle, Pray, and Huang, 1997).

Research Reform: Open Doors, Competition, and Commercialization

Concerned about maintaining its traditional excellence in science and technology, especially

as the nation decided to join the rest of the world in the 1980s, China's leaders launched a series of reforms of the entire research system (Swinbanks and Maddox, 1995) as well as that in agriculture (World Bank, 1997). Research officials initially implemented their version of an Open Door Policy, encouraging exchanges of personnel, ideas, and research findings. Competitive grants programs also replaced formula budget allocations in an attempt to channel research resources to the more productive research teams who were working on issues of national priority. Most observers generally agree that these facets of research reform have improved science in China, in general, and in agriculture, in particular (Huang and Rozelle,1997)

China's officials also unleashed the forces of commercialization in the agricultural research sector to both encourage more focused, applied work and increase funding, although the form of commercial activities did not always end up as expected (Rozelle, Pray, and Huang, 1997). The initial policies hoped to spur licensing of breakthroughs, contract research between research institutes and firms, and the emergence of private research firms. Somewhat unexpectedly, (though given the state of intellectual property rights in China it may not be so surprising), almost all commercialization activity has occurred by research institutes starting their own companies, trying to directly capture the profits associated with their R&D products. For example, one plant pathologist in a Eastern China university started a firm to develop, manufacture, and market what has become one of the most popular pesticides in the region. According to the regulations, entrepreneurially oriented scientists and research staff can start businesses and use institute or university capital, equipment, land, and technologies, but in return part of the profits are suppose to flow back into institute accounts to subsidize research.

Not all commercial activity, however, has taken on the originally expected form and some scientists complain that the research side of the institute has not benefited as promised. In many cases, the new firms did not even consider exploiting the research products of the institute, instead opting to start businesses with no connections to their original mandates. Research staffs have opened travel agencies, trading companies, and real estate consultancy firms. In one of the most extreme examples, we visited a plant breeding institute in which the main source of its revenue came from its subsidiary's auto parts manufacturing profits.

Impact of Commercialization Reforms

The move to encourage commercial activity in the agricultural research sector has had a dramatic impact on the structure of aggregate research revenues and an uneven influence on the amount of resources available to institutes in different parts of the country. While the absolute amount of research institute revenues coming from government sources has increased in real terms slightly over time (albeit only from 580 million yuan to 605 million yuan, a rise of less than 0.5 percent annually), the government's share of total agricultural research income has fallen sharply, declining from 74 percent in 1986 to 50 percent in 1994 (Table 3, column 1). In the mean time, research institute income statements have risen sharply due to a more than tripling of income from commercial activities, rising from 151 million yuan in 1986 to 475 million yuan in 1994 (column 2). During the 8 year study period, the sharp real rise in commercial income boosted its proportion of total agricultural research income from 19 to 39 percent. Such a rapid evolution in research funding of a major global agricultural research system is not only unprecedented, the shift to reliance on commercial sources certainly puts China in a class by itself. Even in the US, a country known for its advocacy of private sector research, research organizations receive less than 20 percent of their resources from commercial sources.

Research reform also has affected different provinces differently in terms of the intensity of research investment by governments and ability to generate revenues through commercial channels. Province investment in agricultural research as a proportion of agricultural output (*government-sponsored investment intensity*) ranges widely in 1994 from more than 0.2 percent by provinces such as Beijing, Tianjin, Shanghai, Guangdong, and Shanxi to less than 0.1 percent by provinces such as Sichuan, Hunan, Hubei, and Anhui (Table 4, column 2). Growth rates in investment intensity also varies (columns 3).

The range in revenues earned from commercial sources show even greater heterogeneity. Earnings from commercial sources as a proportion of agricultural output range (*commercial intensity*) from more than 0.3 percent by provinces such as Beijing, Shanghai, Guangdong, and Jiangxi to less than 0.03 percent by provinces such as Guizhou, Gansu, and Qinghai (Table 4, column 5). Similar to government spending growth rates, growth rates in commercial intensity also differ among provinces (column 6).

Comparisons among the provinces regarding their levels of government- and commercial-supported research raise several issues about the impact of research reform. In many cases, although not all, the same provinces that have the higher levels of government-sponsored investment intensity also have higher earnings from commercial sources. Moreover, the provinces that have high total levels of research support tend to be the richest provinces and those with large urban populations. While such trends have obvious efficiency and welfare implications (such as, are investment resources being spent in a way consistent with a region's comparative advantage, or, are the rich getting richer and poor poorer?), they should not be surprising. Given both China's highly decentralized agricultural research system (discussed above) and the characteristics of its transitional economy—e.g., the nature of its fiscal system (Wong, Christine, Christopher Heady, and Wing Woo. 1995), the pace of growth in different regions of China (Rozelle, 1996), and its urban-first mentality (Putterman, 1992)—provinces with more means and greater incentives to support and earn agriculture research funds, from whatever source, may be the ones most able to maintain research levels.

In China's complex political economy, one with many pressures and rapidly evolving economic forces, it is difficult to tell the relationship between government investment and commercially generated income and the impact of commercialization agricultural research. The positive and significant correlation coefficient (0.247) measuring the co-movement of the different types of investments may mean that governments reward those research institutes that are successful enough to increase revenues, using their success in commercial ventures as indicators of their overall quality, and that China's commercialization policies have led to increased funding. The small size of the coefficient and the preponderance of factors that affect both government-sponsored research intensity and commercial research earnings suggests that a conclusion about the relationship between research funding sources should not be made too quickly. For example, it may be that government funding bodies reduce support to commercially successful systems, channeling scarce resources to other parts of the economy. The positive relationship between government and commercial intensity may be related to the robust economic growth which generates fiscal resources occurs in areas with large urban populations, providing both the resources for the local government to investment in research that it sees as important for supporting its urban constituency, and markets for the products commercial subsidiaries of research institutes.

A Model for Government-sponsored and Commercial Research Intensity

The discussion in the preceding section not only describes the trends of government research investment in a system increasingly dominated by commercialization, it also showed the complexity of the relationship between the types of research funding sources and the factors that affect them. To untangle such a great number of factors and isolate the interaction between commercial income sources and government investment, a model describing the political economy of research investment is needed. In this section, we construct such a model, accounting for factors that affect the government's ability and willingness to investment in its agricultural research system, including the impact of the presence of income sources from commercial sources has on the decision. Because of the simultaneity of the two types of investment decisions, a separate model of commercial research income is needed both for the analysis of government investment and to examine the determinants of commercial research funding by itself.

Empirical Model

Government-sponsored Agricultural Research Intensity

We assume provincial officials charged with research and development duties allocate their financial budget based on both economic and political considerations to maximize some complex objective function. It is assumed that leaders care about fostering rapid growth of agriculture as long as the use of investment funds do not affect alternative goals. Increasing food security, improving rural incomes, and fostering rapid growth are all part of a leaders duties in reform China (Huang, 1996).

To specify our model, which is aimed at explaining agricultural research investment at the provincial level, in general, and the impact of institute commercial earnings on total research spending, in particular, we will apply models of the political economy of research spending found in the literature to the institutional arrangements that our current and previous work in China has described in great detail. Following the recent research on research literature, we use research intensity, or government-sponsored research divided by the gross value of agricultural domestic product, as the dependent variable (although Jin, 1997, uses per capita provincial research spending and comes out with almost the same results). Based on number of works (cited below), we hypothesize that five types of variables should influence China's provincial research expenditures (summarized in top half of Table 5).

Sources of agricultural growth and demand factors. For leaders who care about stimulating agricultural growth in a country, the factors, like land and labor, that both constrain or increase productivity will affect the level of production-enhancing investment like agricultural research. Following Hayami and Ruttan's induced innovation theory (and Lin's 1991 version for China), we hypothesize that factor scarcity will encourage agricultural research officials to allocate funding to develop technologies to save on land. In China, more than 66 percent of research funding supports work on developing land-saving, high yielding varieties in crop breeding programs, compared to only 9 percent for labor saving mechanization research (MOA, 1994). The coefficient on the land to person ratio variable should be negative.

The expected signs on the irrigation, grain yield, and the size of the agricultural economy variables, however, are not as unambiguous, given multiple pressures acting on research due to these variables. For example, Evenson and David (1993) argue that more irrigation makes research results easier to spread, increases the return to research, and would likely lead to greater research investment. Frisvold and Lomax (1991), however, counter that public investment in land infrastructure can substitute for scientific research, and a nation with more investment in land infrastructure, such as irrigation, will invest less, predicting a negative coefficient. The same problem arises with the grain yield variable. We would expect a positive relationship between past grain yields and research outlays since these areas should have higher levels of rates of return, unless research investment is hitting decreasing marginal returns, in which case the predicted sign would be negative or zero.

The variable measuring the size of the agricultural economy also has pressures working both ways on research investment. In the same way that factor scarcity sets off the search for new technology to save on the scarce factor, demand for agricultural commodities will influence research spending. As demand for food rises, prices will increase, and according to Griliches (1957), will induce agricultural research officials and research administrators to increase their investment in research. If the size of the economy is a proxy for food demand, as gross domestic product rises, we would expect higher research investment. In contrast, as the size of the agricultural economy gets larger, the cost of research per unit of agricultural output falls (as shown by Byerlee and Traxler, 1996), and these economies would allow government officials to spend less for a set amount of research, ceteris paribus. Since the size of the economy, and demand effect, has been controlled for by the construction of the dependent variable, we would expect the variable to have a negative sign.

Research cost variables. Factors that affect research costs also will influence research investment. For example, despite moves by research officials to promote competitive grants, fiscal manager still have some obligation to allocate a minimal level of core funding based on the number of agricultural scientists. Although we would expect the relationship to become weaker over time, research investment from the government should rise with the size of the research staff. In addition to economies of scale effects captured represented by a variable measuring the size of the economy (discussed above), Huffman and Mironowski (1981) and Dinar (1991) have suggested another set of factors that affect the cost of doing research. When cropping patterns are concentrated in terms of the number of varieties (i..e., a region has only one or two main crops that account for most of sown area), there should be economies of scale for research, since adding any new crops to the agricultural research program will add fixed costs. The more concentrated a provinces cropping pattern is the lower the investment in research that is needed.

Budget constraints and political economy variables. The economics of research investment aside, governments invest or do not invest in agricultural research for many political reasons, increasing investment when doing so increases the popularity of the regime, and cutting back when alternative pressure groups have greater influence over the allocation of scarce resources. Before interest groups can pressure governments into investment decisions, treasuries need to have access to investable funds. Per capita government revenue reflects a province's ability to collect taxes, and in China can vary widely given the decentralized tax system and the reliance on enterprise sales and manufacturing taxes. All political pressures held equal, those provinces with greater fiscal resources can invest more in agricultural research..

After accounting for the ability to finance investment projects, high priority government policies may induce leaders who want to move up in the hierarchy to invest in projects that will aid producers in meeting targets. For example, the governor's responsibility system placed great emphasis on each provincial leader being able to provide sufficient food at reasonable prices to the residents of the province, especially those in cities (Watson, 1994). From this point of view, provincial leaders may strive for self-sufficiency and use agricultural research to help meet the goal, and the expected sign on a variable representing level of dependence on other provinces should be positive. On the other hand, those provinces with export potential may also increase research funding as a way of increasing marketed surplus and source of revenue for local farmers.

Pressure may also come from lower level constituencies. Hayami and Ruttan argue that US and Japanese governments provided high levels of investment for their countries' research systems because farmers pressured them to create the technologies that would increase farm productivity. Lin (1991) argues that this model also fits China—leaders respond with higher investment in areas with more farmers, all other things held constant. Berstein (1996), however, claims that the nature of China's politics are such that the interests of farmers hold little sway over leaders and that pressure from the urban population is more important. We included two variables in this model to measure the government's responsiveness to farmers or to urban populations in China, the ratio of agricultural spending to total government spending and the ratio of urban population to total population. A variable measuring the importance that provincial governments give to all types of science also may be a factor and can be included in the analysis as the ratio of science expenditures to total government expenditures.

Alternative research funding. Once other factors have been accounted for, an answer the key question in this paper, how does commercially-generated income by research institutes affect the propensity of governments to make their own investments in agricultural research. In short, this is a test of the fungibility of research funding. Do leaders in provinces and prefectures appropriate less money to research in regions with research institute-run firms that can earn more money? Or do subnational governments keep their commitments to agricultural research and continue to provide funding as promised? In some provinces officials even reported that they were adding staff and government funding to support those institutes which were earning the most money. Depending on the answer to this question, the sign of the coefficient of the commercial intensity variable in the government-sponsored research investment equation will be negative, zero, or positive.

Provincial leaders also may apply for funding from the World Bank for alternative sources of research funding to supplement, complement, or substitute for provincial government funding. World Bank funding in the 1960s and 1970s in 24 developing countries was a substitute for government investment (Evenson 1991) which suggests that a negative relationship is likely in China also. A correlation coefficient between government research intensity and the presence of a provincial-level World Bank project is negative and significant, leading one to predict on the basis of a simple descriptive statistic that the coefficient in the multi-variate equations also should be negative. A time trend proxies for changing government attitudes on funding agricultural research.

In summary, to test the impact of commercialization on government agricultural research investment, after controlling for sources of agricultural growth, the demand for agricultural technology, the cost of research, political factors, and international funding efforts, we can then isolate the relationship of government agricultural research intensity and commercial income. Examining the determinants of the government funding also will be of interest.

Model for Commercial Revenue Intensity

Because of the endogeneity of the commercial funding variable in the government research equation, a separate equation for commercial intensity is needed for use in building a two-stage least squares model. A well specified model is important to assure that the instrument used in the government-sponsored research equation is highly correlated with the commercial earnings and is properly identified. The normal Hausman-Wu tests of endogeneity and exclusivity were applied and the statistical test found that the uncorrected commercial earnings variable is endogenous, but that the instrument used only in the commercial earnings equation is exogenous to government-sponsored research equation. The results of the equation explaining commercial earnings by research institutes will be of interest themselves.

Commercial earnings in this study refer to income is derived from the sale of agricultural technology and non-agricultural goods and services and the leasing of land and buildings. In 1994, the money from non-agricultural commercial enterprises (so called "non-technical income") accounted for 67 percent of total earnings (MOA 1995), while income from technology related enterprises ("technical income") accounted for only 33 percent of income.

In explaining earnings from the commercial enterprises of research institutes, we will assume that they respond like private firms (see Table 5, bottom half of table). Commercial earnings will be a function of the market demand for its product (both those related to research output—measured by provincial Ag.GDP; and to the other products and services sold by the subsidiaries—measure by provincial GDP); the cost and probability developing and commercializing new technology (as measured by the size—the number of scientists--and quality—size of total research budget--of the province's research effort); and the ability of the institute to appropriate the gains from technology (as measured by the nature of the province's legal environment as proxied by the number of patents, and the share of the research system that is involved in livestock research, a part of China's research system that has been successful in generating commercial revenues). The World Bank funding variable also was included as was a time trend. While the direction of most of the signs of the coefficients in the commercial earnings equation are fairly straightforward, the sign of patents should be of interest, given its obvious policy implications. If a good legal and patent system matter, a positive sign on the patent variable should be positive and significant.

Data

Provincial level cross-section (25 provinces) and time series (1990 to1994) data are utilized in the analysis. Three metropolitan cities (Beijing, Tianjing and Shanghai) are excluded in the analysis because of their unique nature and Tibet is excluded because some data was missing. Data on government investment for agricultural research and commercial earnings of research institutes are from the *Statistical Material of Agricultural Sciences and Technology*, a statistical compendium compiled by China's Ministry of Agriculture (MOA) and made available to us for research purposes. The funds invested by the government refers mostly to the allocations made by provincial and prefectural leaders for support of their province's research institutes. A small part of the amount, however, does include the amount of funding hand down to the provinces from the central government (and as such does not reflect subnational leader decisions—but given its minimal size should not affect the results). The figures do not include research money that is allocated to the agricultural universities, colleges, or CAAS units located outside of Beijing. The number of research personnel is also obtained from the same source.

The rest of the data comes from standard published statistical sources. Cultivated land, irrigation area, grain yields, crop sown area, and the value of livestock data are obtained from *Chinese Agricultural Yearbooks*. The crops used to calculate the crop concentration value include rice, wheat, corn, soybean, potato (sweet potato and white), cotton, peanut, rapeseed, sorghum and others for cash crops Interprovincial grain flow data are from the *Chinese Domestic Trade Statistical Yearbooks* and the *Chinese Statistical Yearbooks.* The data for all the other variables were obtained from *Chinese Agricultural Yearbooks and Chinese Statistical Yearbooks.*

Results

Using two stage least squares (2SLS), the two equation, government-sponsored investment and commercial earnings system performs remarkably well. Table 6 presents two specifications of the model in column 1 and 2, differing only by the inclusion of a time trend variable in the second. The R-square coefficient for the main equation explaining agricultural research intensity is 0.76, and that for the commercial earnings equations is 0.40. Most importantly, the results are robust across alternative specifications (both those reported here in the paper's main text and appendices, and a number of others using different dependent variables--e.g., research investment per capita) and alternative estimators (e.g., OLS). In the rest of this section, we first describe the determinants of government-sponsored research investment and commercial earnings, establishing the validity of our results by showing their compatibility with our *a priori* expectations, and then examine our main question: do commercial earnings add to or subtract from government investment. Results of a decomposition analysis are included to shed light on the magnitudes of the different determining factors.

Government-sponsored Research Investment Equation

The signs and levels of significance of the coefficients of the variables included in the government-sponsored research investment equation to control for sources of agricultural growth, demand, the cost of research, and a variety of political factors also demonstrate the strength of the results, in most cases conforming to a priori expectations and findings by others in previous studies. For example, the negative sign on the variable representing land scarcity suggests that provincial research officials invest in agricultural research as a way to reduce the pressure on land in provinces with low levels of cultivated land per capita (Table 6, row 1). The negative relationship between investment and land confirms the results of Lin (1991) who showed that China's research establishment responds to scarce factors in its still partially planned economy in the same way that Hayami and Ruttan (1985) predicted researchers would react in market economies. A history of high yields in a region, however, does not affect government agricultural research funding, a result that may mean that diminishing marginal gains from research may be offsetting the comparative advantage of a region (row 3).

The method of funding research also affects the research investments of provincial officials. The positive sign on the coefficient of the variable measuring the number of agricultural officials most likely means the formula funding practices still exists; a large research staff apparently helps keep research intensity high (row 5). In the same way that Byerlee and Traxler (1996) found strong evidence of economies to scale in international breeding programs, the negative sign on the coefficient of the variable measuring the size of the agricultural economy may show that the lower costs of research in a larger system may allow officials to invest less, holding other factors constant (row 4). The results, however, do not provide evidence that China's agricultural research system enjoys economies of concentration (row 6).

The results associated with the political variables also capture a number of important elements that may help explain government agricultural research investment behavior. The highly significant positive coefficient of the fiscal solvency variable shows that it is the richer provinces, those most successful in their tax collection efforts, that allocate the most resources to productive public goods and services like agricultural research (Wong, Wu, and Heady, 1995, and Park et al., 1996—row 7). Given fiscal resources, important political constituencies may pull more resources into agricultural research both indirectly and directly. For example, when provinces with greater commitments to general R&D (for some reason--perhaps due to high demand from industrialists and/or pro-growth leaders) invest more in overall research, agricultural research intensity also rises (row 11). Likewise, high concentrations of urban population appear to increase the pressures on leaders to spend relatively more funds on agricultural research (row 9). This is a plausible result given China's traditional urban-first political mentality (Berstein, 1996) and a belief by political leaders that investments in research increase food supplies for urban consumers. This result is quite different from studies in more democratic countries which often have strong agricultural lobbies that press leaders for more investment in the agricultural sector (Huffman and Miranowski, 1981; Ackerman and Evenson, 1985). The level of food self-sufficiency does not appear to affect government-sponsored agricultural research intensity (row 8).

For those concerned about the effect of China's research reforms on the government's commitment to agricultural research funding, the sign on the commercial earnings variable should raise serious doubts about the effectiveness of the commercialization policy in boosting government research spending. The negative and significant sign on the coefficient of the commercial earnings variable means that as commercial subsidiaries of research institutes increase their revenues, all other factors held constant, government research officials reduce the level of intensity of investment in agricultural research (row 12). Thus, commercial earnings appear to be a substitute for government funds rather than a complement as the government had originally hoped. Of course, even given this rate of substitution, if all commercial revenue went to support agricultural research, research efforts might still gain. Rozelle, Pray, and Huang (1997) show, however, only a small proportion of commercial earnings ultimately enter the research section of an institute, at most 20 percent. If the findings of our current and past research are accurate, the commercialization part of China's research reforms have not met the government's stated goals of increasing resources for research.

The other alternative to government research funding–in China's case, the World Bank–also has a negative impact on government research intensity. This confirms our hypothesis based on

Evenson (1991) that international development bank funds that are allocated to research are fungible.

The positive coefficient on the year variable means that some factor is leading to a gradual rise in government research investment intensity. If all important other structural factors are controlled for, the positive effect may reflect a policy impact, arising from the government's declared intention to increase investment in research investment (Huang, 1996). The marginal significance of the variable, however, could mean this commitment is not very strong, or that there are other offsetting factors that the current model does not capture.

The Determinants of Commercial Earnings

The results of the commercial earnings equations also produced results that support most of our *a priori* expectations (Table 6, rows 16 to 23). The positive and significant coefficient on the GDP per capita variable suggests that higher demand in the economy for the output of commercial enterprises, including businesses run by research institutes, leads to higher commercial earnings (row 16). The positive sign on the coefficient of the variable by measuring the number of scientists shows that a larger research staff either pressures institutes to look for ways to support their large wage bill, or provides the labor necessary to set up while run a business concern and also increases earnings (row 18). The results also suggest that while patents and setting up firms in the livestock industry (where the gains from commercialization of the institute's technology are more capturable) raise commercial revenues (rows 21 and 22), when firms are well-funded by government budget allocation and have access to other funds, such as loans from the World Bank, commercial revenues fall (rows 19 and 20).

Decomposing the Growth of Government Research Investment and Commercial Earnings

To identify the *importance* of the individual factors (e.g., land scarcity or fiscal solvency) on changes in research investment, including the propensity of governments to invest less in research when institutes earn more commercial revenues, we decompose the growth of research investment over the sample period into its component parts (Table 7). To calculate the contribution of each factor to research intensity change (column 3), the elasticities (column 1) are multiplied by the change in the level of the factors from 1990 to 1994 (column 2). Dividing the contribution of each factor by the total change in research activity provides an estimate of the proportion of growth accounted for by each factor (column 4). To aid in the interpretation of the important determinants of agricultural research,we decompose the change of research investment both in terms of research intensity (Table 7) and total research expenditures (Table 8).

The decomposition results demonstrates the importance of commercialization policy in funding government agricultural research in China (Table 7). From 1990 to 1994, the government-sponsored research intensity was declining by 1.21 percent annually (bottom row). The results showed that the increase in commercial revenue intensity contributed most to the decline in government research intensity. If all the other factor had been held constant, this factor would have contributed four times the actual government research intensity decline (row 7). This implies that the commercialization of agricultural research institutes failed to meet government's goal of increasing government-sponsored research investment.

Other factors both compensate and reinforce the negative impact of commercialization on the government-sponsored research intensity. Per capita agricultural GDP also provides a large contribution (about 310 percent of total decline) to the decline of research intensity (row 2). This implies that the government funding has not kept up with the rapid expansion of agricultural GDP. The result also is consistent with other studies (Pardey, Roseboom and Anderson, 1991; Byerlee and Traxler, 1996) which show a tendency for the growth of public research intensity to lag behind the sector's growth rate. The other factor which leads to a large fall in government-sponsored research intensity is the decline in total number of agricultural scientists (row 3). The annual decline rate of 1.66 percent in the total number of agricultural scientists contributed 182.69 percent of the total decline in government-sponsored research intensity.

Many other factors offset the negative effects of these factors, making the decline in government research intensity lower than it would otherwise be. For example, rises in fiscal revenues and urbanization trends have contributed to the rise in research expenditures (rows 4 and 5). Surprisingly, the time trend is the most important factor to offset the fall in government sponsored research intensity (row 8). This may show that government's recent effort to emphasize those elements that improve agricultural productivity, ceteris paribus, has kept its commitment and meet its goal of increasing government-sponsored research intensity.

The results of the decomposition of *total* government-sponsored research funds (Table 8) are mostly consistent with the *intensity* decomposition results (Table 7). Commercial revenue also is the most important factor holding back agricultural research expenditure (Table 8, row 8). If it had not been for the rise in revenue from the commercial subsidiaries of the research institutes, research expenditures would have been 154.97 percent greater. The only material differences in the results from those of the research intensity decomposition are that per capita AgGDP leads to an increase in government-sponsored research funds while it leads to a decline in research intensity. Moreover, the time trend variable is insignificant in the total research funds model.

Policy Implications and Conclusions

Can the policy of commercialization of agricultural research really increase research funding and the resources available to agricultural sciences for R&D? What determines the success of the agricultural research institutes in generating commercial revenues? Will governments stick to their commitment to increase funding for agricultural research after they have adopted reforms committed to research commercialization? Our paper has attempted to answer these key questions on agricultural research. The answer to the effectiveness of commercialization to increase research funding depends on the goals of the research system and the context of the country's development.

China's Answers

In China's context it is clear that commercialization of agricultural research can raise substantial amounts of money. Research institutes have increased their commercial income by 12 percent annually for the period 1990 to 1994. The wealth of the province has a positive impact on commercial incomes while agricultural GDP had a negative impact. This result may suggest that institutes are making their money from non-agricultural rather than agricultural commercial activities.

Despite the government's explicit commitment to increase research to 1.5 percent of GDP from the current levels of less than 0.5 percent, the increases in commercial income have been accompanied by major declines in government contributions to agricultural research, everything else held constant. The elasticity in Table 7 (row 7, column 1) suggests that a 100 percent increase in commercial earnings intensity will lead to a 60 percent decline in government research intensity and those in Table 8 (row 8, column 1) suggest that a 100 percent increase in commercial earnings will reduce government funding by 30 percent. Since at most 20 percent of commercial earnings are actually used in the research laboratory, there is a net loss of 10 percent research funds each due to this transaction. Thus, provincial governments have reduced both research intensity and levels of research funding.

Fortunately for the research system and China's agricultural sector, other factors also affect the level of commercialization of agricultural research and the expansion of government funding and government research intensity. Researchers and farmers are responding to factor scarcities and supplying and demanding more research to relieve these constraints. Officials are responding to budget constraints, urban pressures, and other political pressures. An area's general commitment to investment in R&D leads to more agricultural research.

Lessons for Other Developing Countries

A number of other developing countries also have large decentralized research systems, for example, India, Brazil and Nigeria, and the officials from these countries may be able to learn lessons from China's experience. In larger countries, research systems also can expect to earn money from commercial enterprises. However, unlike China, they may have to face more competition from private firms (although this will not be so different from the competition that China's institutes face in the form of collective enterprises and the emerging private sector). Such competition could have both stimulating and limiting effect. On the one hand, it could induce research institute subsidiaries to do business more effectively. On the other, they may choose not to enter at all. Research institutes in countries with stronger intellectual property rights should be able to make more money from agricultural and other technology that they develop than in China's case.

The substitution effect of commercial earnings for government funding documented in China is a warning that policy makers should be aware of. In the United States, state legislatures have reduced state government contributions to some land grant universities by the amount of their earnings in royalties and other means. The substitution of World Bank funds for local government funding of research has been noted elsewhere (Evenson 1991). If the goal of commercialization is primarily the increase of total agricultural funding, policy makers should take note of the tendency for commercial funds to substitute for government investment.

Lessons for Transitional Economies

Declines in government funding have been particularly large in the Former Soviet Union and Eastern Europe (Pray and Anderson 1997). Our findings are useful lessons there also. They indicate that it is possible for research institutes to earn money in transitional economies. It is a way of keeping institutes alive. However, it is not likely to make up for the declines in government funding. Authorities are likely to further reduce government contributions to research if an institute is successful in earning money.

Policy change.

To break out of this circle of declining funding, research planners should consider a matching grant program that would match earnings from enterprises that are put back into research, instead of automatic reductions in funding in response to increased earnings by the institutes. This would give the research parts of the institutes more incentive to support the commercial enterprises. The implication for leaders of research institutes seems to be that they should put less emphasis on increasing their earnings since this just leads to reduced government funds. The fact that GDP is the main factor contributing to growth in development income and agricultural GDP and revenues contribute to growth in funding suggests that there also are possible income distribution problems ahead which central governments need to be aware when implementing this type of reform.

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Table 1. The Importance of Subnational Investment[a] (Province level and below) in China's Agricultural Research System, 1978 to 1995.

Year	National Level	Subnational Level
1978	15	85
1979	22	78
1980	23	77
1981	24	76
1982	22	78
1983	27	73
1984	28	72
1985	24	76
1986	19	81
1987	21	79
1988	19	81
1989	27	73
1990	22	78
1994[b]	23	77
1994[c]	15	85
1995[b]	22	78

[a] For years 1978 to 1990, figures are share of total agricultural research investment as reported in Huang et al., 1998).
[b] For years 1994 and 1995, figures are the share of total agricultural project money as reported in MOA, 1996.
[c] For the second 1994 number, figure is share of total revenues of research revenues as reported in STS, 1996. Some of revenues of subnational institutes may come from central budget expenditures.

Table 2. Number of Agricultural Research Institutes, Staff, and Total Research Expenditures by Different Level of Government in China,1994.

	Number of Institutes	Number of Staff and Workers	Total Research Expenditures (1000 yuan)[a]
Total	1146 (100)[b]	122,451 (100)	2,952,395 (100)
MOA	60 (5.)	13,588 (11)	368,716 (13)
Provincial	453 (40)	63,121 (52)	1,485,386 (50)
Prefectural	633 (55)	45,742 (37)	1,098,293 (37)

[a] Expenditures at the current year price
[b] Numbers in the parentheses are the percentage
(Sources: MOA, 1995)

Table 3. The Structure of Agricultural Research Investment in China, 1986 to 1994 (in million 1985 yuan).

	Government-sponsored Research Investment	Earnings from Commercial Activities by Research Institute Subsidiaries	Other Sources
1986	580.0 (73.7)[a]	150.6 (19.1)	56 (7)
1990	493.5 (60.0)	255.8 (31.1)	73 (9)
1994	604.9 (49.6)	475.0 (38.9)	140 (11)

[a] The figures in parentheses are the percentage in the total agricultural research income.
(Sources: MOA, 1987, 1991 and 1995)

Table 4. Provincial Government Agricultural Research Intensity and Proportion of Research Institute from Commercial Activities in China, 1990-1994.

	Government-sponsored Research			Commercial-generated Revenues		
Province	1990	1994	Percent Change 1990-94	1990	1994	Percent Change 1990-94
Beijing	0.389	0.294	-24.4	0.41	0.46	12.2
Tianjin	0.245	0.234	-4.5	0.14	0.34	142.9
Hebei	0.116	0.093	-19.8	0.03	0.04	33.3
Shanxi	0.215	0.274	27.4	0.05	0.06	20.0
Inner Mongolia	0.151	0.132	-12.6	0.02	0.01	-50.0
Liaoning	0.266	0.245	-7.9	0.12	0.13	8.3
Jilin	0.250	0.194	-22.4	0.16	0.12	-25.0
Heilongjiang	0.222	0.166	-25.2	0.07	0.11	57.1
Shanghai	0.404	0.593	46.8	0.18	0.48	166.7
Jiangsu	0.077	0.113	46.8	0.07	0.07	0.0
Zhejiang	0.098	0.107	9.2	0.04	0.03	-25.0
Anhui	0.036	0.047	30.6	0.2	0.03	-85.0
Fujian	0.137	0.106	-22.6	0.04	0.01	-75.0
Jiangxi	0.108	0.075	-30.6	0.15	0.37	146.7
Shandong	0.073	0.061	-16.4	0.04	0.04	0.0
Henan	0.054	0.056	3.7	0.02	0.07	250.0
Hubei	0.065	0.060	-7.7	0.09	0.08	-11.1
Hunan	0.074	0.065	-12.2	0.09	0.08	-11.1
Guangdong	0.108	0.214	98.1	0.19	0.35	84.2
Guangxi	0.112	0.115	2.7	0.08	0.10	25.0
Sichuan	0.091	0.082	-9.9	0.04	0.19	375
Guizhou	0.180	0.150	-16.7	0.03	0.03	0.0
Yunnan	0.148	0.266	79.7	0.08	0.11	37.5
Tibet	0.295	--		0.02	--	
Shaanxi	0.282	0.187	-33.7	0.04	0.03	-25.0
Gansu	0.302	0.257	-14.9	0.06	0.01	-83.3
Qinghai	0.483	0.336	-30.4	0.01	0.02	100
Ningxia	0.567	0.546	-3.7	0.08	0.20	150.0
Xingjiang	0.290	0.251	-13.4	0.05	0.08	60.0

Note: Intensity is investment by source divided by agricultural gross domestic product.
(Source: Author's calculations based on data from MOA, 1991 to 1995.)

Table 5. Definition of Variables in Government-sponsored Research Investment and Commercial Revenue Intensity Equations and Hypothesized Signs.

Independent Variable	Definition of Variable	Expected Sign
	Model of Government-sponsored Research Intensity	
	Dependent variable: government-sponsored research intensity	
Sources of Agricultural Growth		
Land scarcity	Cultivated land per capita	-
Irrigation potential	Potential irrigated land per capita	?
Yield potential	Grain yield growth rate in 1976-89	+
Demand for Ag. Technology		
Size of ag. Economy	Agricultural gross domestic product	-
Cost of Research		
Fixed costs of system	Number of Agricultural Scientists	+
Crop concentration	Sum of squared crop sown area proportions	-
Political variables		
Fiscal solvency	Total revenue of the province	+
Food dependency	Interprovincial net grain exports	?
Urban influence	Ratio of urban to total population	-
Agriculture influence	Ratio of agricultural to total government expenditure	+
Priority of R&D	Ratio of all science to total government expenditure	+
Alternative funding		
Development income	Earnings of research institute commercial activities	?
World Bank	Provincial Dummy =1, if province received World Bank funding for agricultural research	-
Time trend		+

Independent Variable	Definition of Variable	Expected Sign
	Model of Commercial Revenue Intensity	
	Dependent variable: Commercial earnings divided by Ag. GDP	
Market demand		
GDP	Gross Domestic Product	+
Ag. GDP	Agricultural Gross Domestic Product	+
Technology opportunities		
Amt. of technology	Number of agricultural scientists	+
Quality of technology	Government funds for agricultural research	+
World Bank	Dummy =1 if World Bank ag. research project	+
Appropriability variables		
IPR environment	Number of patents approved in the province	+
Commercializability	Ratio of value of livestock to Ag.GDP	+
Time trend		+

Table 6. Two Stage Least Square Estimates of Government-sponsored Research Intensity and Commercial Revenue Intensity.

	Without Trend	With Trend
Model of Government-Sponsored Research Intensity		
Dependent variable: government-sponsored research intensity		
Sources of Agricultural Growth		
Land scarcity	-0.093 (-2.31)**	-0.091 (-2.50)**
Irrigation potential	0.0014 (0.04)	-0.003 (-0.09)
Yield potential	-0.692 (-0.89)	-0.392 (-0.49)
Demand for Agricultural Technology		
Size of agricultural Economy	-0.588 (-4.44)***	-0.670 (-4.67)***
Cost of Research		
Fixed costs of system	1.905 (6.67)***	1.905 (7.48)***
Crop concentration	-0.092 (-0.85)	-0.031 (-0.26)
Political Variables		
Fiscal solvency	0.680 (3.69)***	0.746 (3.90)***
Food dependency	0.331 (0.65)	0.179 (0.36)
Urbanization	0.390 (2.35)**	0.378 (2.43)**
Agricultural sector influence	-0.661 (-1.64)	-0.514 (-1.34)
Priority of R&D	1.430 (3.83)***	1.298 (3.39)***
Alternative funding		
Commercial revenue intensity	-1.050 (-2.87)***	-1.095 (-3.39)***
World Bank	-0.039 (-2.30)**	-0.034 (-1.96)*
Time trend		
Year		0.0089 (1.72)*
Adjusted R-Squared	0.76	0.76
Model of Commercial Revenue Intensity		
Dependent variable: Commercial earnings divided by agricultural GDP		
Market Demand		
GDP	0.124 (4.35)***	0.130 (3.87)***
Agricultural GDP	-0.955 (-4.50)***	-0.993 (-4.36)***
Technology opportunities		
Amount of Technology	1.529 (6.49)***	1.573 (6.44)***
Quality of technology	-0.856 (-4.51)***	-0.893 (-4.48)***
World Bank	-0.026 (-1.72)*	-0.027 (-1.70)*
Appropriability variables		
IPR environment	0.029 (3.03)***	0.0287 (2.94)***
Commercializability	0.164 (1.30)	0.181 (1.30)
Time Trend		
Year		-0.0008 (-0.14)
Adjusted R-Squared	0.40	0.40

Notes: Numbers within parentheses are t-ratios.
***, **, and * refer to statistical significance at 1%, 5% and 10%, respectively

Table 7. Sources of Decline in Government-sponsored Research Intensity.

Factors	Elasticities[a]	Factor Growth Rate (percent per year)	Contribution of factors	
			Growth [b]	Percent[c]
Land scarcity	-0.51	-1.10	0.56	46.07
Size of agricultural economy	-1.05	3.57	-3.75	-309.92
Fixed costs of system	1.33	-1.66	-2.21	-182.69
Fiscal solvency	0.45	1.24	0.55	45.78
Urbanization	0.48	2.17	1.04	85.41
Priority of R&D	0.18	7.35	1.31	108.10
Commercial revenue intensity	-0.57	9.40	-5.33	-440.71
Year	97.14	0.05	4.88	403.10
Residue			1.75	144.86
Total			-1.21	100

Sources of Increase in Commercial Revenue Intensity.

Factors	Elasticities	Factor Growth Rate (percent per year)	Contribution of factors	
			Growth	Percent
GDP	1.62	12.02	19.51	207.58
AgGDP	-3.01	3.57	-10.74	-114.27
Amount of technology	2.13	-1.66	-3.52	-37.49
Quality of technology	-1.73	-1.21	2.09	22.21
Residual			2.07	21.97
Total			9.40	100

[a] Elasticities are calculated from coefficients reported in Table 6 and means of variables reported in Appendix 2.
[b] Growth contribution of each factor is calculated by multiplying factor growth rate (column 2) by elasticity (column 1).
[c] Percent of contribution of each factor is calculated by dividing the growth contribution of each factor by total growth rate.

Table 8. Sources of Increase in Government-sponsored Research Expenditure.

Factors	Elasticities[a]	Factor Growth Rate (percent per year)	Contribution of factors	
			Growth [b]	Percent[c]
Land scarcity	-0.45	-1.10	0.49	21.12
Irrigation Potential	0.14	0.05	0.007	0.31
Size of agricultural economy	0.53	3.57	1.90	81.49
Fixed costs of system	1.01	-1.66	-1.68	-71.96
Fiscal solvency	0.37	1.24	0.46	19.88
Urbanization	0.66	2.17	1.43	61.43
Priority of R&D	0.16	7.35	1.19	51.16
Commercial revenue	-0.30	11.98	-3.61	-154.97
Residue			2.13	91.54
Total			2.33	100

Sources of Increase in Commercial Revenue.

Factors	Elasticities	Factor Growth Rate (percent per year)	Contribution of factors	
			Growth	(Percent)
GDP	0.30	12.02	3.63	30.30
Amount of technology	3.48	-1.66	-5.77	-48.14
Quality of technology	-0.74	2.33	-1.71	-14.31
Residual			15.83	132.16
Total			11.98	100

[a] Elasticities are calculated from coefficients reported in Appendix 3 and means of variables reported in Appendix 2.
[b] Growth contribution of each factor is calculated by multiplying factor growth rate (column 2) by elasticity (column 1).
[c] Percent of contribution of each factor is calculated by dividing the growth contribution of each factor by total growth rate.

Appendix 1. Changes in Agricultural Research Expenditures (in million 1985 yuan) by Province in China, 1990 to 1994 (Ranked by the change of total research expenditures)

Province	Government Expenditure			Development Funding			Total Income		
	1990	1994	Change[a]	1990	1994	Change	1990	1994	Change
Sichuan	23.6	26.7	13.6	11.0	62.2	466.6	37.6	101.4	169.4
Guangdong[b]	28.7	71.0	147.9	49.2	115.7	135.4	88.1	207.0	134.8
Jiangxi	11.7	9.8	-16.6	15.8	41.6	163.9	34.1	70.0	105.2
Anhui	5.4	6.5	21.1	2.2	4.1	86.4	7.8	15.1	93.4
Shanghai	8.1	11.9	46.6	3.7	9.7	164.1	12.4	23.0	86.2
Henan	10.8	12.1	12.2	4.6	14.5	213.7	16.1	29.1	81.4
Jiangsu	16.8	31.3	85.8	16.1	20.4	27.1	34.5	57.3	66.0
Yunnan	15.4	26.1	69.7	8.5	11.1	31.0	25.7	41.3	60.4
Guangxi	12.2	17.0	40.2	9.0	15.3	69.7	2.3	36.7	57.2
Shanxi	14.0	20.6	47.1	3.1	4.6	47.7	17.6	27.0	53.4
Ningxia	5.9	6.8	14.4	8.8	2.4	175.9	7.3	11.0	51.1
Tianjing	4.1	4.5	9.1	2.3	6.5	179.5	7.9	11.7	47.6
Zhejiang	13.7	19.7	44.2	6.0	5.8	-3.8	20.4	29.3	43.6
Hunan	12.7	14.3	11.9	15.0	18.3	21.8	32.7	42.9	31.2
Liaoning	27.7	32.2	16.5	12.9	17.0	31.8	44.6	57.3	28.4
Shandong	19.1	19.6	2.4	9.9	14.2	42.8	30.3	38.5	26.8
Heilongjiang	21.9	21.7	-1.0	7.1	14.6	105.4	30.5	38.6	26.7
Hebei	16.3	17.4	6.8	3.9	6.6	69.2	20.6	26.0	26.2
Xingjiang	17.0	19.5	15.0	2.9	6.3	119.4	22.0	26.9	22.3
Hubei	11.6	12.3	6.6	15.5	17.3	11.1	30.8	37.1	20.5
Guizhou	11.1	11.4	2.7	1.6	2.0	27.3	12.5	15.0	19.6
Beijing	10.5	9.1	-13.8	11.0	14.1	27.7	21.6	24.4	13.0
Mongolia	10.5	11.4	8.9	1.2	0.6	-52.6	11.8	12.3	4.5
Fujian	12.5	16.3	30.0	4.0	1.8	-55.0	18.5	19.1	3.2
Jilin	19.3	20.8	7.9	12.5	12.9	3.6	38.0	36.0	-5.1
Qinghai	5.3	4.4	-16.5	0.1	0.3	432.34	5.4	4.7	-14.1
Gansu	11.9	11.0	-7.5	2.2	0.5	-76.5	14.4	12.0	-16.7
Shaanxi	14.1	9.6	-31.9	1.8	1.8	-4.6	17.2	13.2	-23.4
Tibet	2.6			0.1			3.3		

(Sources: MOA, 1991 and 1995)

[a] Change in 1990-1994

[b] Guangdong includes Hainan.

Appendix 2. Data descriptive statistics

Variables	Unit	Mean	Standard Deviation
Model of Government-Sponsored Research Intensity			
Independent Variable			
Government- sponsored research intensity	Percentage	0.182	0.132
Sources of Agricultural Growth			
Land Scarcity	Hectare	1.015	0.592
Irrigation potential	Hectare	0.450	0.305
Yield potential	Growth rate	0.040	0.015
Demand for Agricultural Technology			
Size of agricultural Economy	1,000 Yuan	0.286	0.078
Cost of Research			
Fixed costs of system	Heads	0.128	0.091
Crop concentration		0.213	0.080
Political Variables			
Fiscal solvency	1,000 Yuan	0.109	0.047
Food dependency	Ton	-0.005	0.016
Urbanization	Ratio	0.230	0.094
Agricultural sector influence	Ratio	0.090	0.026
Priority of R&D	Ratio	0.025	0.021
Alternative Funding			
Development income	Percentage	0.094	0.132
World Bank		0.320	0.468
Time Trend			
Year		1992	1.420

Model of Development Income			
Dependent Variable			
Development income intensity	Percentage	0.094	0.132
Market Demand			
GDP	1,000 Yuan	1.181	0.473
Agricultural GDP	1,000 Yuan	0.286	0.078
Technology Opportunities			
Amount of technology	Heads	0.127	0.091
Quality of technology	Percentage	0.182	0.132
World Bank		0.320	0.468
Appropriability variables			
IPR environment		0.945	0.767
Commrcializability	Ratio	0.271	0.057
Time Trend			
Year		1992	1.420

Appendix 3. Two Stage Least Square Estimates of Government-sponsored Research Funds and Commercial Revenue Models

	Without Trend	With Trend
Model of Government-Sponsored Research Funds		
Dependent variable: government-sponsored research funds		
Sources of Agricultural Growth		
Land scarcity	--0.22 (-2.54)**	-0.21 (-2.47)**
Irrigation potential	0.16 (1.69)*	0.16 (1.68)*
Yield potential	-2.86 (-1.58)	-2.54 (-1.38)
Demand for Agricultural Technology		
Size of agricultural Economy	0.92 (2.07)**	0.83 (1.82)*
Cost of Research		
Fixed costs of system	3.94 (6.71)***	3.89 (6.76)***
Crop concentration	-0.34 (-1.22)	-0.27 (-0.91)
Political Variables		
Fiscal solvency	1.70 (3.55)***	1.78 (3.66)***
Food dependency	0.78 (0.65)	0.54 (0.44)
Urbanization	1.42 (3.82)***	1.39 (3.74)***
Agricultural sector influence	-0.87 (-0.90)	-0.64 (-0.65)
Priority of R&D	3.22 (3.00)***	3.04 (2.80)***
Alternative funding		
Commercial revenue	-0.78 (-2.89)***	-0.78 (-2.96)***
World Bank	-0.15 (-3.20)***	-0.15 (-3.03)***
Time trend		
Year		0.01 (0.88)
Adjusted R-Squared	0.76	0.76
Model of Commercial Revenue		
Dependent variable: Commercial earnings		
Market Demand		
GDP	0.30 (3.92)***	0.33 (3.65)***
Agricultural GDP	0.24 (0.66)	0.20 (0.51)
Technology opportunities		
Amount of Technology	3.48 (5.65)***	3.57 (5.64)***
Quality of technology	-0.74 (-3.81)***	-0.77 (-3.82)***
World Bank	-0.12 (-2.56)	-0.12 (-2.59)**
Appropriability variables		
IPR environment	0.10 (3.41)	0.10 (3.23)***
Commercializability	0.28 (0.75)	0.36 (0.89)
Time Trend		
Year		-0.01 (-0.49)
Adjusted R-Squared	0.44	0.43

Notes: Numbers within parentheses are t-ratios.
***, **, and * refer to statistical significance at 1%, 5% and 10%, respectively