Economies of Scale and Scope, and the Economic Efficiency of China's Agricultural Research System

Songqing Jin, Scott Rozelle, and Julian Alston

Department of Agricultural and Resource Economics
University of California, Davis

Jikun Huang

Center for Chinese Agricultural Policy
Institute for Geographical Sciences and Natural Resource Research
Chinese Academy of Sciences

Paper prepared for presentation at the American Agricultural Economics Association Annual Meeting, Montreal, Canada, July 27-30, 2003

Economies of Scale and Scope, and the Economic Efficiency of China's Agricultural Research System

Abstract

Faced with the task of reorganizing the largest agricultural research system in the world, officials in China are developing a strategy for reform. This paper investigates economies of scale and scope and other potential sources of improvements in the economic efficiency of crop breeding, an industry at the heart of the nation's food economy. Using a panel data set covering 46 wheat and maize breeding institutes from 1981 to 2000, we estimate both single output and multiple output cost functions for the production of new varieties at China's wheat and maize breeding institutes. Our descriptive and analytical results indicate strong economies of scale, along with small to moderate economies of scope related to the joint production of new wheat and maize varieties. Cost efficiency increases significantly with increases in the breeders' educational status and with increases in access to genetic materials from outside the institute. Our results can help guide reformers in their efforts to increase the efficiency of China's crop breeding system.

Keywords: Agricultural research; China, Economies of scale; Economies of scope

JEL Codes: L23; H41; O32; O13

The authors are grateful for helpful comments from Derek Byerlee. We also thank Hewu Chen, Xiaofeng Li, Rongnan Li, Lingyu Zhang, Qingzhong Du for their help with the data collection. We have also benefited from the support of Jock Anderson, Alan deBrauw, Aron Smith, Paul Heisey, Xin Xian, Xiaobo Zhang, Ruifa Hu, Catherine Morrison Paul, Sandeep Mohapatra, Siwa Msangi, Carl Pray and the staff of the Center for Chinese Agricultural Policy. This project received financial support from the World Bank's Research Grants Program and the USDA's National Research Initiative.

Economies of Scale and Scope, and the Economic Efficiency of
China's Agricultural Research System

Introduction

Crop breeding centers in agricultural research institutes around the world played a major role in feeding the world's population during the 20th century (Borlaug, 2000). In the immediate aftermath of World War II and through the 1960s, scientists and politicians forecast serious food shortages, malnutrition and starvation across large parts of the world. Between 1960 and 2000, the world's population doubled, from 3 billion to 6 billion, but over the same period, grain production more than doubled, and this increase was due almost entirely to unprecedented increases in yields. The Malthusian nightmare never materialized, mainly because scientific innovations in the developed world and the Green Revolution in the developing world produced new technological packages that raised productivity and expanded output beyond anyone's expectations (Pingali et al., 1997). New crop varieties made up the heart of the package, although they were supplemented by improved water control, greater use of chemical fertilizers, and increased know-how.

Despite these enormous successes in the second half of the 20th century, agricultural science has not eliminated the possibility of serious global food shortages, and agricultural research establishments must meet even greater challenges in the first part of the 21st century (Byerlee et al., 2000). Growth rates of yields slowed during the 1980s and 1990s and the yield gap—the difference between yields on experimental plots and farmers' fields—has shrunk (Pingali et al., 1997). When the falling yield potential is coupled with rising demographic pressures, water shortages, and environmental concerns, new varieties that produce more food under increasingly challenging environments will be essential to meeting world demand, which is predicted to rise by 40 percent between now and 2025 (Rosegrant et al., 1999).

The task of those responsible for breeding new varieties, however, will have to be executed at a time (or at least begin during a time) when support for agricultural research in both developed and developing countries is waning. During the 1950s, 1960s and 1970s, agricultural scientists enjoyed rapidly expanding budgets, but during the past two decades the growth has slowed. For example, Pardey and Beintema (2001) reported a real growth rate of global agricultural research spending during 1976-1981 of 4.5 percent per annum (7 percent in developing countries and 2.5 percent in developed countries), but by 1991-96 this growth rate had fallen to 2.0 percent per annum (3.6 percent in developing countries and 0.2 percent in developed countries), and it has continued to decline since then. China is no exception. China's real annual growth rate of agricultural research expenditure fell from 7.8 percent in 1976-81 and 8.9 percent in 1971-86 to 5.5 percent in 1991-96 (Pardey and Beintema, 2001).[1] Similar patterns but in more exaggerated terms can be seen in the expenditures of research institutes in developed or developing countries, and in the international agricultural research system (which includes centers such as the International Rice Research Institute – IRRI) that are dedicated to crop varietal improvement (Alston and Pardey, 1999; Pardey and Beintema, 2001). Hence, in an era of shrinking support and increased demands for output, there will be rising pressure on the research system to come up with new and better ways to produce more for less. In the parlance of production economics, this means that it will be necessary to become increasingly efficient at producing new varieties.

Although several authors have recognized the importance of economies of scale and economies of scope in agricultural research (Evenson, 1978; Ruttan, 1978; Pardey, et al. 1991; Alston et al. 1995), very few studies have attempted to measure the nature of the processes used by the agricultural research "industry" to create new varieties – the technology used to produce varietal technology, sometimes called the research production function. Since the seminal work of Baumol et al. (1982), economies of scale and economies of scope have been studied in a wide range of industries (e.g., Cowing and Holtmann, 1983; Murray and White, 1983; Kwabena Gyimah-Brempong, 1987; Deller et al., 1988; Cohn et al., 1989; Callan and Santerre, 1990; de Groot et al., 1991; Fournier and Mitchell, 1992; Wholey et al., 1996; Paul, 1999, 2000; MacDonald and Ollinger, 2000). However, only two studies – Branson and Foster (1987) and Byerlee and Traxler (2001) – have produced any empirical evidence on economies of size in agricultural research, and there have not been any empirical studies on economies of scope in agricultural research.[2] Moreover, the limited evidence on economies of size in agricultural research is mixed. For example, Branson and Foster (1987) found a U-shaped average cost curve of agricultural research based on the data drawn from 108 stations associated with the Agricultural Research

[1] Huang (2001) reported that China's annual growth rate of agricultural research funding in real terms fell from 13.5 percent in 1976-85 to 4.0 percent in 1985-99, a much more dramatic change. Pardey and Beintema (2001) used purchasing power parity exchange rates to express their figures in real international dollars, and their figures apply to slightly different time periods.

[2] Byerlee and Traxler (2001) distinguished *economies of market size* from economies of size. Economies of market size applies if the intensity of R&D investment (measured in research expenditure or number of scientists per unit of production of the "mandate area") decreases as the market size served by research program (measured in size of the mandate area) increases. They found that economies of market size is likely to exist if the mandate area of an agricultural research program (or system) is smaller than the agroecological area. However, information on economies of market size is not as useful as information on economies of size because it does not measure research efficiency, and it confounds information on research efficiency with other elements of research policy. Hence, we study economies of size rather than economies of market size.

Service (ARS) of the United States Department of Agriculture (USDA).[3] In contrast, in one part of their paper, Byerlee and Traxler (2001) reported significant diminishing returns to size in producing varieties (or diseconomies of size) based on a cross-country data set; but in another part (on India's wheat program based on data from 50 wheat-breeding stations), they reported strong economies of size.[4] No study, to our knowledge, has attempted to measure other facets of the organization of varietal breeding, such as the existence or absence of economies of scope.

Based on a unique set of data, collected specifically to examine the production economics of crop breeding centers, we use a cost function approach to estimate economies of scale, economies of scope, and other aspects of the technology of crop varietal production in China. Most of the data used in this study were collected by the authors during 12 months of fieldwork in China that began in the summer of 2001. The data collection effort assembled a panel data from 46 wheat and maize breeding institutes covering the years from 1981 to 2000. Chosen from seven major wheat and maize provinces in northern China, the sample institutes include 40 prefectural-level institutes and six provincial-run institutes.

There are a priori reasons to believe that the small scale of many institutes may be an important source of inefficiency. To examine economic efficiency, as well as to measure economies of scale and scope, data are needed in particular on two key variables, costs and output. In using our survey data to define measures of these key variables, we have had to deal with several methodological issues. As an economic activity, crop breeding has several characteristics that make it relatively hard measure output and match measures of output to measures of costs associated with those outputs.[5] These characteristics include the long lags between the time when

[3] Their finding suggests strong economies of size for small programs, and diseconomies of size for large programs. The research output used in that study is a weighted output of refereed journal articles, abstracts, book chapters, other publications, plant variety or germplasm release and patents. The weight for each type of product was assigned based on the survey responses from 20 of the 21 ARS areas and center directors. However, this work is subject to several shortcomings. First, the omission of lag structure of research output and the cost of research could lead to serious bias. Second, 61 research stations in the study consist of 7 different types of specialized institutes (i.e., human nutrition, animal protection, animal production, soil and water, product use, crops production and crops protection). It is too restrictive to estimate a single cost function using the data for such highly heterogenous technologies and research products.

[4] This study has some shortcomings. First, as in Branson and Foster, it also does not account for the lag structure. Second, it does not control for institutional characteristics, for example, human capital, genetic material exchange, etc. In addition, the analysis uses a production function rather than a cost function.

[5] These are quite general conceptual and measurement problems in empirical production economics, but they are more pronounced in applications to crop breeding than in many other production processes given the small (integer) output, measured as varietal releases, the cumulative nature of the development of "knowledge," and the lags of many years between investments in research and the production of a variety. In other settings, too, it is often difficult to translate information about continuous, long-time, dynamic processes meaningfully into discrete, matching, observations of costs and output that can be used in a static model of the technology of production. But in practice it is common simply to ignore the issues.

costs are incurred and the resulting output is realized (and hence an inability to observe actual output when expenditure decisions are being made), uncertainty about what is an appropriate measure of output both conceptually and in practice (given that varieties are not sold on a market and vary considerably in quality), and the fact that output itself is uncertain when costs are incurred (only a few varieties are released and become commercially successful in a given year, and for some institutions in a given year the number is zero).

We find that there is striking evidence of strong economies of scale in crop breeding. The small and highly significant coefficients of economies of scale imply a significant cost saving associated with expanding the scale of breeding institutes. Such results are robust to the specification of the output of the breeding process, whether we examine the production of wheat, maize or both crops, and when we use an Instrumental Variables approach to treat the errors-in-variables problem in our measure of actual output of varieties (which is a proxy for expected output of varieties). In addition, a number of other potential areas for gains in efficiency are identified, including the existence of some, though less strong, economies of scope between wheat and maize variety production. In short, there appears to be considerable room to realize greater efficiencies by reorganizing crop-improvement research in China.

Although we are interested in the production economics of crop breeding in general, our focus on China is appropriate for several reasons. First, China has a long and successful history of crop breeding and, although it is a developing country, its breeders have made breakthroughs that rival those of most developed countries (Stone, 1988). Hence, in some sense, our findings are relevant for the breeding programs of all nations. In addition, China is important in its own right as the largest country in the world, and in its role as an example of a large developed country. Many have predicted that such nations must bear much of the responsibility to produce the varieties that will feed the world in the coming decades (Huang et al., 2002). The large number of breeding centers in China (that produce a similar set of varieties), the decentralized nature of its research system, and the great heterogeneity among its centers offer a unique research opportunity to identify the relationship between varietal production, size of institute, and mix of crops in the breeding program. Finally, the results are of interest to those in charge of China's research system, since they have recently announced their intention to search for ways to increase the efficiency of crop breeding and other agricultural research (Huang et al., 2001).

The rest of the paper is organized as follows. In the next two sections we discuss the data and present a set of descriptive results to illustrate the observed relationship between research output and costs. The following sections develop the empirical model and present the results of econometric analysis. Next, we discuss the findings, analyze the implications for cost savings of various reorganization schemes, and, finally, conclude.

Data

Most of the data used in this study were collected by the authors during 12 months of field work in China that began in the summer of 2001. Data were assembled from 46 wheat and maize breeding institutes covering the years from 1981 to 2000. The sample institutes include 40 prefectural-level institutes and 6 provincial-run institutes, selected at random from a comprehensive list of prefectural and provincial institutes in seven major wheat and maize provinces in northern China.[6] Thirty-two of the sample institutes produce both wheat varieties and maize varieties (in short, *joint wheat and maize* institutes). Four institutes specialize in producing wheat varieties (*wheat-only* institutes). The other ten only produce maize varieties (*maize-only* institutes).[7]

To collect the data, teams of enumerators visited each institute for periods of up to one week and completed a set of questionnaires filled out by accountants and by enumerators. In general, the data cover four broad categories: income, costs, research output, and data on other characteristics of the institute. Since the data were not kept by a single department in any of the institutes, a great deal of cross-checking was needed to make the data consistent among the various departments. For example, the research coordination department typically kept information on income and expenditures. Personnel departments provided the data on salaries, educational accomplishments, and other information about current and past staff. Breeders kept the best information on the varieties they produced and the methods that they used in their breeding efforts.

To examine cost efficiency, information is needed on two key variables, costs and output, especially since there is an *a priori* reason to believe that the small scale of many institutes may be an important source of inefficiency. Our measure of the total variable costs of each crop's breeding activities includes the institute's operating expenses, such as salaries, project administration, and other direct operating expenses. For cost categories that cannot be matched directly to a breeding project (for example, transportation costs, administration, costs associated

[6] The total wheat sown area and total maize sown area in these seven provinces in 2000 were, respectively, 16,900,000 and 14,500,000 hectares, accounting for 57 percent and 62 percent of the national total. The total sown area of wheat (or maize) planted with the varieties produced from the 46 institutes reached 9,340,000 (or 8,530,000) hectares, accounting for more than 55 percent (or 60 percent) of the total sown area in these provinces.

[7] We use "wheat" institute (or "maize" institute) to refer to any institute that produces wheat (maize) whether it is jointly with another crop or by itself.

with certification), we assigned a share of the costs of each category to breeding according to the number of full-time breeding staff (that is, the ratio of the number of full-time breeding staff to the total number of employees in the institute). We deflated total variable costs by a provincial consumer price index, putting our cost figures into real 1985 terms (SSB, 1981-2001).

We assume that the products of China's wheat and maize variety "factories" are the varieties that the breeders produce that are adopted by farmers. To measure output, we collected information on (i) the number of varieties that were produced by the research institutes (conditional on their being adopted by farmers), (ii) the area sown to the varieties, and (iii) the trial yields of each variety (which is the yield that is part of the certification record of the variety during the year that it is released). With these data, we constructed four measures of research output: (i) the *number of varieties* released by the institute sown in the field during a given year, (ii) the number of varieties, weighted by the trial yields of the variety (in short, *yield-weighted output*), (iii) the total area sown to all of the institute's varieties during a given year (*area-weighed output*); and the number of varieties weighted by sown area and trial yields (*yield-area weighted output*).[8]

Each of the four output measures has strengths and weaknesses. Although it is the most readily measured, the obvious flaw with number of varieties is that it does not take into account any quality characteristics of each variety, either yield or its other characteristics (such as its level of insect resistance or other qualities that could make it attractive to farmers). Yield-weighted output accounts for the relative productivity of a variety in pure output terms. However, such a measure still leaves out all other quality characteristics, which an earlier study shows may be highly valued by farmers (Jin et al. 2002). For this reason, our third measure, area-weighted output, should be superior to the other two measures. If farmers value the characteristics in a variety—whether high yields or some other characteristic—they demonstrate their preference by adopting the variety (Byerlee and Traxler, 2001). The last measure, yield-area weighted output combines the second and third measures. Since the variation in trial yields is small, the correlations between the third and fourth output measures are high (0.99 for wheat; 0.95 for maize). Hence, we would not expect much difference to result from using one versus the other.

One special feature of crop variety production is the significant time lag between the time when costs are incurred in a breeding research program and the time when the resulting research

[8] The *yield-weighted output* of each research institute is constructed as follows. First, we divided the trial yield of each variety by the grand mean trial yield of all the varieties for all the years of the same crop (either wheat or maize). This gives us an index number for each variety. The index numbers for wheat, for example, range between 0.61 and 1.46. The index number is less than one if the variety has a trial yield that is less than grand mean of the trial yields, and greater than one if the variety has a trial yield that is greater. In the second step, we create the measure, yield-weighted output, for each year by summing the index numbers of all the varieties that are being used in the field by producers of an institute for any given year.

output (if any) is realized. This issue is commonly discussed in studies of the returns to agricultural R&D (Alston et al. 2000; Fan, 2000), especially in relation to specification of econometric models relating agricultural productivity to research expenditures. In the present setting, the lag between investment and output has some further (and different) implications, akin to those that arise more generally in agricultural production economics, associated with biological lags. In microeconomic theory texts, the firm manager first chooses an output level (or combination of output levels), and then determines the cost-minimizing combination of inputs that will produce that output at minimum cost. The crop breeding institute's director does not have that luxury, because the output from today's investment is uncertain and will not be known for many years (this uncertainty applies both to the quality and quantity of the research output and to when it will be obtained and over what period the benefits will flow).

As an approximation to this problem of decision-making under uncertainty, we might suppose that the director seeks to minimize the institute's cost based on current expectations of the output that will be produced in the future as a result of the current research expenditures. Unfortunately, we cannot observe or measure, ex post, such expectations. One option is to use the output that was actually produced from the expenditures as a proxy of those expectations, but the problem remains of matching actual outputs to particular expenditures (an example of what Alston and Pardey, 2001, termed the "attribution problem" in agricultural research evaluation).

To deal with this problem empirically, we defined an average research lag to represent the number of years between the time when a breeding project officially begins (in China, this is usually when a formal research project is granted by a funding agency to the institute) and the time when a variety is released for commercial extension to the fields of farmers.[9] Using this defined lag length, we modeled the cost of variety production as a function of the research output produced after a certain lag. To find the length of lag, we designed a section of the questionnaire to ask breeders in each of the 46 institutes specifically to estimate the average lag length for each crop. Based on the data we collected, the average lag length was 5.3 years for wheat and 4.5 years for maize. In our base model, we used a 5-year lag for both wheat and maize variety production. However, we also tried different lag lengths to check the robustness of our results.

[9] With traditional crop breeding, breeders generally have to cross a variety's parental materials several times (about 2-3 years) to get a stabilized inbred line. It then takes breeders a couple more years to conduct field trials.

The Production of Varieties and the Cost of Breeding

China's agricultural research system has produced a steady flow of crop varieties in the past. On average, in each year during the period 1982-1995, China's farmers grew 200 to 300 wheat varieties and 130 to 180 maize varieties in their fields (Jin et al., 2002). However, the number of new varieties being produced by research institutes varied significantly over time and across institutes. Based on our survey, 141 wheat varieties and 155 maize varieties were produced by our sample institutes during the period 1985-2000 (row 3, column 4 of Appendix Table 2). Nineteen percent (26 percent) of the wheat (maize) varieties were developed by provincial institutes. The rate of production of new wheat and maize varieties increased over time. For example, prefectural maize institutes produced 34 maize varieties during 1985-1990, 47 varieties during 1990-1995, and 74 during 1995-2000 (row 1, column 1-3). The number of wheat varieties created and commercialized by the sample institutes rose from 31 in 1985-1990 to 55 during each subsequent period (1990-1995 and 1995-2000).

The number of varieties, however, varies sharply among institutes. For example, the Henan provincial wheat institute produced 12 wheat varieties from 1985 to 2000. The Mianyang prefectural crop breeding institute in Sichuan produced 14 wheat varieties. In contrast, 24 out of 36 (or 67 percent) of the sample wheat institutes produced fewer than 5 varieties. In fact, three wheat institutes did not produce a single variety during the entire 15-year sample period. Maize variety production also varies greatly among the sample institutes.[10]

The success of the sample institutes in extending their varieties to farmers' fields also differs over time and across institutes. The varieties from provincial institutes are more widely adopted, especially for maize: 40 percent of the total maize area was planted with varieties developed by provincial maize institutes. This might have something to do with the broader mandate that provincial institutes have relative to prefectural ones. Data from our survey also show that those institutes that produced a larger number of varieties also had more adoption. Pair-wise correlations between the number of varieties and total sown area to varieties of a wheat breeding institute (0.61) and of a maize breeding institute (0.72) show a statistically significant association (in those cases that had positive varietal production), although there were exceptions. For example, some institutes produced a relatively high number of varieties, but these varieties covered a relatively modest area. In contrast, others introduced only one or two varieties, but they were

[10] For example, the Shandong provincial maize institute and the Dandong Prefectural institute in Liaoning provinces produced 12 and 19 maize varieties for the same time period, while the majority of the institutes, 29 of the 42 (or 69 percent) maize institutes produced fewer than 5 varieties. Five of the 42 (or 12 percent) maize institutes produced zero varieties during the 15 years.

adopted by farmers over a large sown area.[11] Clearly, the choice of the measure of the output of breeding institutes matters for the findings.

Variety Production Costs and Scale

In the same way that output varies across time and space, so does total cost. On average, the annual real total variable costs of the breeding program per institute for our sample of wheat institutes increased from 24,000 yuan to 38,000 yuan between 1981 and 2000. Similarly, the average annual total variable breeding cost for our sample of maize institutes rose from 38,000 to 53,000 yuan.[12] The total cost of wheat and maize breeding, however, varies greatly among institutes. For example, the average provincial institute invested five times more in wheat breeding and about six times more in maize breeding than the average prefectural institute did. When comparing prefectural breeding stations, the total cost of wheat breeding in one institute (e.g., the Yantai prefectural institute of Shandong Province or the Mianyang prefectural institute in Sichuan Province) could be more than three times that of the average prefectural institute. Dandong prefectural institute in Liaoning spent five times more than the average maize-breeding institute did.

The average cost of variety production (measured in cost per unit of output) also varies from institute to institute and can be seen to move systematically with research output. To compare costs and output, we have to account for the research lag. In the analysis that follows, research output is the annual mean of five year's total research output from one of three five-year periods, 1985-1990, 1991-1995 and 1996-2000. The average annual cost associated with this output is the annual mean of five year's total cost, lagged by five years. Therefore, the corresponding three five-year periods of cost are, respectively, 1980-1985, 1986-1990 and 1990-1995.

Unlike total costs, average costs fall as the institutes produce more varieties (Table 1). For wheat (maize) the cost per variety falls from 152,000 yuan (150,000 yuan) for breeding institutes that produce only one variety to 60,000 yuan (66,000 yuan) for those that produce more than four varieties (rows 2 and 5). Similar patterns can be seen in the data when using area-

---

[11] For example, Luyang prefectural institute in Henan Province produced only two varieties from 1985 to 2000, but its total sown area reached 645,000 hectares, much larger than the total sown area (428,000 hectares) of Dezhou prefectural institute in Shandong Province, although it had produced seven varieties. Similarly in the case of maize institutes, Handan prefectural institute of Hebei Province produced only one maize variety during 1985 to 2000, but the total sown area of that single variety reached 4.1 million hectares, making it the third-largest producer of varieties in terms of sown area among the sample's 42 maize breeding institutes. In contrast, Xianyang institute in Sichuan province produced seven maize varieties during the 15-year period, but its varieties were planted to only 157,000 hectares.

[12] In year 2000 purchasing power parity terms, the annual total variable cost of a wheat institute (or maize institute) increased from US $44,000 (or US$71,000) to US$71,000 (or US$99,000).

weighted output (rows 7 and 11). A plot of the data reveals a distinct L-shaped relationship between average cost and the size of research output (Figure 1).[13] No matter what measure of output is used, or for what crop, as research output increases, the average cost of breeding research falls. The L-shaped relationship also is robust, holding over time (Figure 2) and over institutes. The sharp fall in average costs of breeding as an institute's output rises suggests that China's wheat and maize research institutes are producing in an output range with strong economies of scale. This evidence would also suggest that a potential efficiency gain in terms of cost saving may be made by expanding the scale of production of China's wheat and maize research institutes.

Economies of Scope and Other Determinants of Breeding Costs

The data also show some evidence that average costs fall with increases in output in joint wheat and maize institutes. The average cost per wheat variety is consistently lower in joint (wheat and maize) institutes than in wheat-only institutes (top four rows of Table 2). Similarly, the average cost per maize variety is consistently lower in joint institutes compared to maize-only institutes (bottom four rows of Table 2). For wheat (or maize), the cost per variety falls from 187,000 yuan (225,000 yuan) in wheat-only institutes (maize-only institutes) to 145,600 yuan (128,900 yuan) in joint wheat and maize institutes. The same patterns also appear in data when the area-weighted output measure rather than number of varieties is used. Moreover, the evidence of economies of scope becomes stronger as the scale of research effort increases (column 3 and 4 of Table 2). Hence, our descriptive data provide evidence that economies of scope may be a source of efficiency differences among institutes. The evidence of economies of scope suggests a potential cost saving associated with combining a wheat-only institute and a maize-only institute into a bigger, joint, wheat and maize institute.

Further analysis of the data also points to other factors that potentially could affect costs, although in some cases the descriptive statistics do not show a particularly strong correlation. The relatively low education level of China's agricultural researchers has long been claimed to be one of the key factors limiting agricultural research productivity (Huang et al., 2001). Based on our data, the human capital in China's wheat and maize breeding institutes is low compared to other countries (46 percent of wheat breeders and 43 percent of maize breeders with "BS degree and above" education in China's wheat and maize institutes, compared to 80 percent of research staff with "B.S. and above" education in Latin American—Echeverria, 1998). Our data also show that increases in the educational level of breeders help to reduce the cost of variety production. The

[13] For each data point on the graph, research output is the annual mean of five years' total research output from one of the three five-year periods (i.e., 1985-1990, 1991-1995 and 1996-2000), for which costs were incurred in the corresponding three five-year periods, 1980-1985, 1986-1990 and 1991-1995, respectively.

institutes that have the highest average cost of variety production (both wheat and maize varieties) also tend to have the lowest proportion of breeders with post-secondary education (column 1 of Table 3). Byerlee and Traxler (2001) suggest that efficiency in crop breeding increases when agricultural scientists from other disciplines (e.g., agronomy and plant pathology) work in conjunction with breeders. Although the share of scientists working on other agricultural disciplines in wheat and maize breeding institutes is quite high (48 percent—column 3 of Table 3), compared to 30 percent in an average wheat improvement research program in a developing country (Bohn et al. 1999), there is little difference in this share between institutes with low and high average costs. Finally, it is also unclear from visual inspection of the data whether breeding efficiency is affected by the source of a breeding institute's genetic materials (i.e., either from outside or from within the province) or the presence of retirees (column 2 and column 4 of Table 3).

Empirical Model

In this section, we specify the econometric model to be used to study the efficiency of China's crop breeding institutes, and discuss our strategy for estimating the model. We begin by specifying the relationship between costs and the factors that affect them in institutes that produce either one or two types of varieties (maize or wheat). We also define measures for economies of scale, ray economies of scale, and economies of scope.

Here we treat a breeding institute as a typical "firm" which applies inputs (in this case scientist time and other research inputs) to produce research output (new varieties). The total variable cost of an individual institute is expressed as a function of its research output, the price of its inputs and other institutional characteristics affecting the cost structure of crop breeding research.[14] A wide range of different types of cost functions (e.g., Cobb-Douglas, Generalized Quadratic, Translog, Generalized Leontief, etc.) have been applied in the literature. We chose a flexible quadratic cost function, which we can express in a single output setting as:[15]

---

[14] The important behavioral assumption in this model is that research institutes make prior choices of input in order to minimize the total variable cost to achieve a prior choice of certain level of research output. Since the actual level of output is not achieved until the passage of several years, in fact, research institute managers are assumed to be minimizing costs of expected output.

[15] One limitation of Cobb-Douglas function is its imposition of constant cost elasticity over the entire range of output. See Berndt and Khaled (1979) for detailed discussion. The translog, or generalized translog, cost function is probably the most popular functional form in the literature. However, the high proportion of zeros in our measure of research output precludes its use in our analysis. The generalized Leontief has a similar shortcoming. A disadvantage of the generalized quadratic cost function is that it is not possible to impose the homogeneity condition needed for cost minimization, but this problem is not significant since we only use one price, annual salary, as our measure of factor prices. To show that our results are not

$$C_{it}{}^{j} = \alpha_0^j + \alpha_y^j \overline{Y}_{it}{}^{j} + \alpha_{yy}^j (\overline{Y}_{it}{}^{j})^2 + \alpha_w^j W_{it}^j + \alpha_{ww}^j (W_{it}^j)^2 + \alpha_{yw}^j \overline{Y}_{it}{}^{j} W_{it}^j + \sum_{k=1}^{4} \beta_{z_k}^j (Z_k)_{it}^j$$
$$+ \sum_{k=1}^{4} \beta_{yz_k}^j \overline{Y}_{it}{}^{j} (Z_k)_{it}^j + \sum_{t=1}^{T-1} \delta_t Time_t + \sum_{m=1}^{m-1} \varphi_m \Pr ovince_m + \sum_{n=1}^{N-1} \phi_n Crop_n + \varepsilon_{it}^j, \quad (1)$$

where $C_{it}{}^{j}$ is the total variable cost of breeding research for crop *j* (*j* = wheat or maize) in institute *i* during the five-year time period ending in year *t*; $\overline{Y}_{it}{}^{j} = (\sum_{l=5}^{9} Y_{i,t+l}^j)/5$ is yearly average of the research outputs that are produced between the 6th year and the 10th year after the cost is incurred;[16] W_{it}^j is annual scientist's wage rate; and Z_k is k^{th} institutional characteristics (which includes a *human capital* variable—the share of breeders with B.S. degree and above education, *other scientists*—measures of the proportion of non-breeders in the agricultural scientific staff, *a spill-in variable*—the proportion of genetic material from outside, and *a retiree effect*—the number of retirees supported by the institute's staff as a proportion of total staff). We also included dummy variables to capture the effects of time, province and type of institutes (i.e., wheat-only institutes, maize-only institutes and joint wheat and maize institutes). The terms α, β, δ,ϕ and φ, are parameters to be estimated.

Since most institutes produce both wheat and maize varieties, we also specify a multiple-output cost function:

$$C_{it} = \alpha_0 + \sum_{j=1}^{2} \alpha_y^j \overline{Y}_{it}^j + \sum_{j=1}^{2}\sum_{r=1}^{2} \alpha_{yy}^{js} \overline{Y}_{it}{}^{j} \overline{Y}_{it}^r + \alpha_w W_{it} + \alpha_{ww} (W_{it})^2 + \sum_{j=1}^{2} \alpha_{yw}^j \overline{Y}_{it}{}^{j} W_{it} + \sum_{k=1}^{4} \beta_k (Z_k)_{it}$$
$$+ \sum_{j=1}^{2}\sum_{k=1}^{4} \beta_{yz_k}^j \overline{Y}_{it}{}^{j} (Z_k)_{it}^j + \sum_{t=1}^{T-1} \delta_t Time_t + \sum_{m=1}^{M-1} \varphi_m \Pr ov_m + \sum_{n=1}^{N-1} \phi_n Crop_n + \varepsilon_{it} \quad (2)$$

where all of the variables and the parameters are defined the same way as in equation (1). The only difference between equations (1) and (2) is that the total variable cost of equation (2) is now the sum of total variable costs of the wheat program and the maize program of each institute, and there is an interaction term (between the two outputs) on the right hand side. This term will be used to measure the effect of the interaction between wheat and maize variety output on the total variable cost.

---

dependent on the selection of the functional form, however, we perform the analysis using several different functional forms.

[16] The output variable is constructed so as to take into account the five-year time lag between cost and research output, which is discussed in detail at the end of data section.

Economies of Scale, Ray Economies of Scale and Economies of Scope

To assess the effect of some of the plans that have been discussed by agricultural research reformers to merge, consolidate, or reconstitute China's existing research institutes, we need to understand the efficiency that can be realized if the scale or scope of research institutes are broadened. Following Christensen and Greene (1976) and others, the coefficient of economies of scale (*SCE*) is simply the cost-output elasticity:

$$SCE = \partial \ln C / \partial \ln Y \quad (3)$$

where *SCE* < 1 indicates the presence of economies of scale; and *SCE* > 1 indicates diseconomies of scale. In the context of our study, economies of scale of variety production of a crop-breeding institute means that the total cost of running a breeding program rises less-than proportionately as the number of varieties expands. The coefficient of economies of scale of crop *j*'s (wheat-only or maize-only) institutes can be calculated directly from equation (1). After the data are normalized at their mean, the cost elasticity with respect to research output (measure of economies of scale) of the model defined in (1) is *SCE* = $\alpha_y^j + 2\alpha_{yy}^j + \alpha_{yw}^j$.

The elasticity of cost with respect to output when using results from multiple-output cost functions is the ray economies of scale, (SCE^{ray}) defined as the change in cost resulting from a proportionate change in all the outputs:

$$SCE^{ray} = \sum_{i=1}^{2} \partial \ln C / \partial \ln Y_i \quad (4)$$

This is the sum of elasticities of total cost with respect to two outputs, where C is a multiple-output cost function as defined in (2). We say there are ray economies of scale if $SCE^{ray} < 1$, and ray diseconomies of scale if $SCE^{ray} > 1$. The ray economies of wheat and maize breeding institutes implies that if a wheat and maize institute increases the production scale of wheat varieties and maize varieties simultaneously in fixed proportions, the total cost of wheat and maize variety production will increase less than proportionately. The coefficient of ray economies defined in (4) can be directly calculated from the estimation of the multiple-output cost function defined in equation (2). For example, the ray economies of scale of the base model of the multiple-output cost function defined in (2) is $SCE^{ray} = \alpha_y^1 + \alpha_y^2 + 2\alpha_{yy}^{11} + 2\alpha_{yy}^{12} + 2\alpha_{yy}^{22} + \alpha_{yw}^1 + \alpha_{yw}^2$.

Economies of scope (*SOE*) refers to the economies associated with the composition of output. It is a concept that can be measured with the result of the estimation of equations (1) and (2), the two separate single-output cost functions and the multiple-output cost function.

Following Baumol et al. (1982), we can measure the economies of scope between wheat and maize variety production by the following definition:

$$SOE^{1,2} = [C(Y_1,Y_2) - C(Y_1,0) - C(0,Y_2)] / C(Y_1,Y_2)] \qquad (5)$$

where $C(Y_1,Y_2)$ is multiple output cost function of joint production of wheat and maize varieties defined in (2); $C(Y_1,0)$ is a cost function when only wheat is produced, and $C(0,Y_2)$ is a cost function when only maize is produced; Y_1 refers to wheat varieties and Y_2 refers to maize varieties. Economies of scope are said to exist if $SOE^{1,2} < 0$, and diseconomies of scope if $SOE^{1,2} > 0$. Intuitively, economies of scope between wheat and maize variety production implies that the cost of producing wheat and maize varieties jointly is less than the cost of producing them separately. There are several potential sources for the existence of economies of scope between wheat and maize variety production, for instance, through the sharing of administration cost, support staff, experiment fields and other facilities.

Empirically, $SOE^{1,2}$ can be calculated and evaluated at the mean of the sample based on the estimation of (1) and (2). To do this, we predict $C(Y_1,Y_2)$ based on the estimates of multiple-output cost function defined in (2) evaluated at the mean level of all the right hand side variables. We can also predict $C(Y_1,0)$ and $C(0,Y_2)$ based on the estimates of single-output cost function defined in (1) evaluated at the mean of all the explanatory variables. We can then substitute the predicted values for $C(Y_1,Y_2)$, $C(Y_1,0)$ and $C(0,Y_2)$ into (5) to compute $SOE^{1,2}$ to evaluate economies of scope in the production of wheat and maize varieties. Finally, we can obtain the confidence interval of the coefficient of $SOE^{1,2}$ by "bootstrapping."[17]

Estimation Strategy

We estimate economies of scale and scope in two ways: (i) based on a *base model*, which estimates the relationship between cost and output taking account of the effects of annual salaries (or prices), time, province and institute type (this is equation (1) without the Z variables); and (ii) based on a *full model*, which adds the four covariates (and their interaction terms with output). In the final section we discuss the implications for economic efficiency of crop breeding that can be drawn from the estimated relationship between cost and output after controlling for other variables (Z). We do so for both equation (1), the single-output cost function, and equation (2), the multiple-output cost function. Hence in our analysis we have four fundamental units of analyses: the basic model for the single-output cost function (one for wheat and one for maize); the full model for the single output cost function (also one for wheat and one for maize), and the basic and full models for the multiple-output cost function.

[17] Bootstrapping generates the mean and confidence interval of the scope coefficient defined in (5). A sample size of 400 with replacement was implemented.

We estimate the basic cost function model with ordinary least squares (OLS) to get initial estimates of economies of scale and scope. However, the OLS estimates of the parameters may be underestimated if there is measurement error in the construction of the output variable (Deaton, 2000). One source of measurement error arises from the special nature of crop breeding and the decision making of its directors. The implicit behavioral assumption that underlies the cost function is that the research manager minimizes costs given the output of the institute. Such an assumption, even for a quasi-productive entity like a research institute, often has been made in cost analyses (e.g., by Cowing and Holtmann, 1982; Fournier and Mitchell, 1992 in their studies of hospitals; by Cohn et al, 1989; de Groot et al., 1991 in their studies of universities). While it is not difficult to imagine that the typical research manager in a breeding station strives to minimize the institute's costs of given output, one characteristic that makes the plant breeding industry special is the long time lag between expenditure and the realization of the output.

We are assuming that research managers make their cost-minimizing expenditure decisions based on the expected output of the breeding station. But the econometrician does not observe expected output; only actual output is measured. We measure actual output from a crop-breeding institute as the number of new varieties from that research institute adopted by farmers (or the area of them sown) in the 6^{th} to 10^{th} year after the research expenditure. This measure might vary systematically from the output that the manager was anticipating when expenditure decisions were made. As a consequence, the realized research output may not be the same as expected research output. If so, we are facing a measurement error problem.

One solution to measurement error is the use of instrumental variables (Greene, 1997). In order to account for the measurement error, we identify a set of instrumental variables (IVs) and re-estimate our model using three-stage iterative least squares.[18] Since the relationship between output and costs basically depends on factors associated with supply-side decisions of the research institute, we turn to a series of demand-side factors in our search for exogenous IVs. Specifically, we assume that the farm gate prices of wheat and maize, the prices of fertilizer and pesticides in input markets, the land-labor ratio in a region, the share of irrigated land to total cultivated land, and the multiple cropping index, all affect the research output variable (since these all will have an effect on the demand by farmers for new varieties). However, such variables should not directly affect the costs of the production of the varieties in the crop breeding station.

[18] A reliable exogenous instrumental variables needs to satisfy two conditions. First, it should be uncorrelated with the error term of the total variable cost function. Second it should be correlated with the output variable, and have no direct effect on total cost except through its impact on output. Empirically, a simple Lagrange multiplier test can be used to test the validity of an instrumental variable or a joint set of instrumental variables (Hausman, 1983; Berndt and Khaled, 1979)

We are also concerned with several other assumptions. In order to test for the effect of our assumption about the length of the lag between costs and research output (according to our survey, the mean lag reported by breeders was five years, but the range was between three and seven years), we conducted sensitivity analysis using data generated by an array of different lag structures. We also are concerned that the presence of unobserved heterogeneity may bias the estimates of our parameters of interest. To eliminate the unwanted covariance between the unobserved factors and the other regressors we took advantage of the panel nature of the data, using both fixed- and random-effect methods.

Estimation Results

The estimates of the basic restricted model perform well and produce remarkably robust estimates of many of the parameters (Tables 4 to 6). The quadratic specification fits the data well with R^2 estimates ranging from 0.53 to 0.75 for wheat and 0.52 to 0.72 for maize (Table 4, row 9). The goodness of fit measures, however, systematically demonstrate that for both wheat and maize the models that use the area-weighted and area-yield weighted outputs have a significantly better fit. In all of the models the effect of an increase in wages on costs is positive and significant, in keeping with expectations and theory.[19] All of the variables were normalized by dividing at their sample mean such that we can interpret the regression coefficients as elasticities at the mean.

Economies of Scale

After controlling for wages, region and year effects, and the institute type, the estimates of economies of scale calculated from the estimated parameters are all much less than one and significantly so (Table 4, row 11). The estimates of *SOE* for wheat institutes range from 0.22 to 0.26; those for maize institutes range from 0.14 to 0.32. The results imply that at the mean levels of research output and other explanatory variables, strong economies of scale exist for both wheat and maize institutes. If output increases by 10 percent, costs would increase no more than 3.2 percent. Evidence of such strong economies of scale from the multivariate analysis is consistent with the descriptive evidence and reflects the patterns in Figures 1 and 2. The scale elasticities are relatively small compared with those found in other studies of non-profit institutions (i.e., 0.70-0.90 for public education institutions from de Groot et al. 1991; Cohn et al. 1989, and 0.60-0.83 for hospitals from Cowing and Holtmann,1983; Fournier and Mitchell, 1992). The strong economies of scale are largely unchanged when we control for other institutional factors (Table 5). After controlling for the four Z factors and their interactions with output, the measured economies of

---

[19] The sum of coefficients of salary, salary squared, and the interaction of salary and output is positive in all models.

scale still fall in a similar range (0.27 for wheat institutes; from 0.29 to 0.32 for maize institutes). Although the coefficients on variables representing several of the institutional factors are significant and suggest that there are other ways to affect breeding efficiency (the discussion of which is deferred until below), the remarkably low and highly significant measures of economies of scale indicate that significant cost savings could be readily available if the scale of China's breeding institutions were expanded.

Accounting for a number of the potential econometric problems does not significantly alter the magnitude or significance of the measures of economies of scale (Table 6). To address concerns of measurement error, exclusion restriction tests of the validity of our demand-side instrumental variables show that they meet the statistical criteria required for identification. Using these instrumental variables and the 3SLS estimator does not substantively change the estimates of the economies of scale parameters (row 21). The results hold for both wheat and maize in both the base model (columns 1 and 3) and the full model (columns 2 and 4). Allowing for lags of different lengths, or controlling for the unobserved heterogeneity also does not materially affect the estimates of economies of scale (Table 7, columns 1- 4).[20]

Similar to the results generated by the parameter estimates of the single output cost function, results based on the multiple output cost function (equation 2) also imply high and statistically significant estimates of ray economies of scale (Table 8, column 1). The estimates of SOE^{ray}, which range from 0.33 to 0.39, mean that if wheat and maize institutes double their output of both wheat and maize varieties, the total variable cost of wheat and maize breeding would increase by only 33 to 39 percent (rows 1 to 4). The strong ray economies of scale are also not affected by alternative estimation strategies or model specifications (Table 7, row 3).

Economies of Scope

While not as strong or as robust as the estimates of economies of scale, our multivariate analysis of the multi-output cost models shows the existence of economies of scope between wheat and maize variety production (Table 8, column 2). The estimates of *SOP* based on the parameter estimates of the base model (column 2, row 1) indicate that there would be about 10 percent cost saving if a wheat-only and maize-only breeding institute were combined into a joint wheat-maize institute. Bootstrapped confidence intervals show that the measured economies of scope are significantly different from zero. Unlike economies of scale, however, economies of scope are affected when other institutional factors are added to the model (column 2, row 2 to row 4). For

[20] Results are also not affected after models are corrected for potential autocorrelation and heteroskedasticity (Table 7, columns 5-6). The results are also robust over the choice of functional form. The coefficients of economies (or ray economies) of scale obtained from the translog cost function are very close to those obtained originally (columns 7-8).

example, if we control for the educational level of breeders, the cost savings from merging wheat and maize institutes drops from 10 to 5 percent, and it drops to only 3.8 percent when both human capital and spill-in variables are added.

Other Institutional Characteristics

In addition to the cost efficiency associated with the scale and scope of wheat and maize variety production, the statistical analysis supports the early descriptive findings and shows that economic efficiency is also affected by other institutional variables. For example, except for one case, the coefficients on the interaction between breeder's education and output are negative and significant (Table 5, row 7). The magnitudes of the coefficients show that if research managers can increase the share of breeders with college and more education by 10 percent (for the average institute this means the addition of about one college-educated breeders), the marginal cost will fall by around 1.0 percent.

An increase in the proportion of genetic material used in breeding that comes from outside the province also increases efficiency (by reducing costs—Table 5, row 9). If breeders can increase their imported genetic materials by 10 percent, the marginal cost of wheat (or maize) variety production will fall by 2.2 percent (or 1.3 percent). Such an effect, a type of spillin, has long been known to play an important role in the effectiveness of spending on agricultural research (Pardey, Roseboom, and Anderson, 1991; McCalla, 1994; Byerlee and Traxler, 1995; Johnson and Evenson, 1999; Alston, 2002). Our study demonstrates that spillins are also an important source of efficiency gains at the level of the crop breeding institute, and policies and institutions that facilitate the free flow of germplasm will raise the productivity of the agricultural research system.

Compared with increasing an institute's human capital and access to genetic material, the effects of having scientists from other disciplines and the burden of caring for retirees are less clear. Having scientists from other disciplines in a breeding program marginally reduces wheat-breeding costs. It has the opposite effect (though small) in maize institutes (Table 5, row 11), although the effect disappears in estimations that correct for measurement error (Table 6). Hence, at the very least, it seems that the addition of soil scientists, plant pathologists and other agricultural scientists does not significantly detract from productivity even in the types of crop breeding institutes that dominate China's research system.

Our findings also do not provide evidence that would validate the complaints of scientists and research administrators about the adverse effects of bearing the burden of the welfare of retirees (row 13). While this result is surprising (since almost every research administrator complains about such welfare obligations), it could be that there are two offsetting effects of having breeders remaining formally attached to the institute after they retire. On one hand, retirees probably do take away resources that could otherwise be used for research. On the other hand, the presence of retired breeders could be an asset. They have experience, an inventory of breeding materials, and contacts in the seed system that could help reduce costs.

Summary and Conclusion

Agricultural science in the public domain is increasingly being asked to do more with less. The scientists responsible for breeding new varieties today will have to meet even greater challenges than those that gave rise to the Green Revolution of the 1970s and 1980s. In an era of shrinking support and increased demands for output, it will be necessary to become increasingly efficient at producing new varieties. However, there is almost no empirically-based evidence to guide the efforts of reorganizing the current agricultural research system.. In this study, we attempt to identify sources of efficiency in China's crop breeding system. Using a panel data of 46 wheat and maize breeding institutes from 1981 to 2000, we examine the factors that affect the variable costs of wheat and maize varieties. Using a number of approaches and accounting for a number of econometric issues, our analysis produces a set of robust results that can help guide reformers in their efforts to increase the efficiency of China's crop breeding system.

Perhaps the most striking finding in this paper, an observation that is perhaps relevant for crop breeding centers around the world, is the existence of strong economies of scale. The coefficients of economies of scale imply a significant cost saving associated with expanding the research scale of crop breeding institutes. According to our findings, the practice of creating a large number of small crop breeding institutes is the main source of inefficiency. In addition, a number of other sources of inefficiency are identified. Though not as strong or consistent as the results for economies of scale, we find there are economies of scope in the production of varieties of different crops. Merging a wheat-only institute with a maize-only institute can lead to small, but significant cost savings. We also find that raising the human capital of the breeding staff and facilitating the access of breeders to wider sources of germplasm increases the efficiency of breeding. All of these results fit squarely with our expectations based on knowledge of the crop breeding system in China as well as from a consideration of the counterpart institutions in other countries and in international agricultural research centers.

Taken at face value, our findings can support a blueprint for the reform of crop breeding in developing countries, from a system dominated by a multitude of small, fragmented, and isolated breeding stations to one characterized by a smaller number of "super" breeding centers. New centers would be larger, broader in scope, and be staffed by well-trained scientists representing a number of different agricultural science disciplines. Expanding the size of the institutes, either by merging two or more or by expanding a single institute and shutting down others, would take advantage of the strong economies of scale. Our results do not give exact guidance on how big the institutes should be, in part because we are not observing many institutes that have reached or passed the bottom of the average cost curve. However, even casual observation of the descriptive data shows that crop breeding institutes can be expanded by at least several times their current size. Such a move would start to shift the size of breeding programs in developing countries more towards those of developed nations.

The new centers could also take advantage of other sources of efficiency gains. The positive economies of scope mean that the new super centers (at least in northern China) should have at least two departments, one for wheat and one for maize. In addition, it can be argued that additional departments should be created in the new centers for the support of work by scientists from other disciplines. Although we did not always find strong efficiency gains from the addition of other scientists, there was even less evidence of any diseconomies associated with institutes that contained non-breeders. But, in anticipation of changes in the technology of crop breeding in the future, that almost invariably will confront any modern agricultural research system (e.g., the increasing importance of biotechnology and precision agriculture), it is likely that there will be substantial gains to having an institutional structure in place that can take advantage of and develop its own high technology products. Finally, the new centers should be staffed by well-trained scientists

However, a number of factors potentially could undermine part or even all of these efficiencies, should the government implement an approach based on merging and expanding smaller crop-breeding institutes into a smaller number of super breeding centers. First, there will be non-pecuniary costs associated with mergers or expansions. For instance, researchers who are likely to lose their jobs and directors who are likely to lose their political positions will do whatever they can to prevent any ambitious reorganization from happening. The more ambitious the reform is, the greater will be the opposition. Second, merging or cutting will encounter transaction costs associated with the reform process itself and with reorganizing operations of merged or expanded institutes. Finally, a smaller number of super stations could mean less competition, leaving less incentive for innovative research. Hence, in deciding how to implement a reorganization of the crop breeding research system, research sector leaders should also take into account these adverse factors and potential transactions costs.

References

Alston, J.M. 2002. “Spillovers” *Australian Journal of Agricultural and Resource Economics* 46(3)(September 2002): 315-346.

Alston J.M. and P.G., Pardey. 2001. “Attribution and Other Problems in Assessing the Returns to Agricultural R&D.” *Agricultural Economics* 25(2-3): 141-152.

Alston, J.M., G.W. Norton and P.G. Pardey. 1995. *Science Under Scarcity: Principles and Practice for Agricultural Research Evaluation and Priority Setting*. Ithaca: Cornell University Press.

Alston, J.M., M.C. Marra, P.G. Pardey, and T J Wyatt, 2000. “Research Returns Redux: A Meta-Analysis of Agricultural R&D Evaluations.” *Australian Journal of Agricultural and Resource Economics,* 44(2)(June 2000): 185-216.

Baumol, J.W., J.C. Panzar and R.D.Willig. 1982. Contestable Markets and The Theory of Industry Structure. Harcourt Brace Jovanovich, Inc.

Berndt, Ernst R., and Mohammed S. Khalad. 1979. “Parametric Productivity Measurement and Choice among Flexible Functional Forms,” *Journal of Political Economy* 87(6): 1220-1245.

Bohn, A., and D. Byerlee and M. K. Maredia. 1999. Investment in Wheat Improvement in Developing Countries. In Maredia M. K. and Byerlee D. (eds). *The Global Wheat Improvement System: Prospects for Enhancing Efficiency in the Presence of Spillovers*. CIMMYT Research Report No. 5. Mexico, D.F.: CIMMYT.

Borlaug, N.E. “The Green Revolution Revised and the Road Ahead.” Special 30th Anniversary Lecture, The Norwegian Nobel Institute, Oslo, September 8, 2000.

Branson, I., and P. Foster. 1987. “Economies of Size of USDA Agricultural Research Stations.” *IEEE Transactions on Engineering Management,* 34:156-60.

Byerlee D., P.Heisey, and P.L. Pingali. 2000. “Realizing Yield Gains for Food Staples in Developing Countries in the Early 21st Century: Prospects and Challenges.” in Food Needs of the Developing World in the Early Twenty First Century, Pontifical Academy of Sciences, Vatican City, pp207-250.

Byerlee D., and G. Traxler. 2001. “The Role of Technology Spillovers and Economies of Size in the Efficient Design of Agricultural Research Systems,” In Alston, J.M., Pardey, P.G., Taylor, M.J.(eds), Agricultural Science Policy: Changing Global Agendas. John Hopkins University Press, Baltimore, MD (Chap. 9).

Callan S.J. and R.E. Santerre, 1990. “The Production Characteristics of Local Public Education: A Multiple Product and Input Analysis.” *Southern-Economic-Journal* 57(2), October 1990: 468-80.

Christensen L.R. and W. H.Greene, 1976. “Economies of Scale in U.S. Electric Power Generation.” *Journal of Political Economy* 84(4): 655-676

Cohn, E., S.L. Rhine, and M.C. Santos. 1989. “Institutions of Higher Education as Multi-Product Firms: Economies of Scale and Scope.” *The Review of Economics and Statitistics* 71(2): 284-290.

Cowing, T.G. and A.G. Holtmann. 1983. “Multiproduct Short-Run Hospital Cost Functions: Empirical Evidence and Policy Implications from Cross-Section Data.” *Southern Economic Journal* (January) 637-53.

Deaton Angus. 2000. The Analysis of Household Survey: A Microeconometric Approach to Development Policy. The World Bank.

Deller, S.C., D.L. Chicoine and N.Walzer. 1988. “Economies of Size and Scope in Rural Low-Volume Roads.” *The Review of Economics and Statistics*” 70(3):459-465.

de Groot, H., W.W. McMahon and J.F. Volkwein. 1991. “The Cost Structure of American Research Universities.” *The Review of Economics and Statistics* 73(3):424-31

Elonson, R.E. 1978. The Organization of Research to Improved Crops and Animals in Low-Income Countries. In T.W. Schultz (ed), *Distortions of Agricultural Incentives*. Bloomington, Indiana:Indiana University Press.

Fan, S. 2000. “Research Investment and the Economic Returns to Chinese Agricultural Research.” *Journal of Productivity Analysis* 14:163-182.

Fournier, G.M. and J.M. Mitchell. 1992. “Hospital Costs and Competition for Services: A Multiproduct Analysis.” *The Review of Economics and Statistics* 74(4):627-634.

Greene, William. Econometric Analysis (Chapter 9). New Jersey: Prentice-Hall. 1997.

Hausman, J. “Specification and Estimation of Simultaneous Equations Models.” *Handbook of Econometrics,*Volume I. Griliches and Intriligator, eds., pp. 392-445. Amsterdam, 1983.

Huang, Jikun, Carl Pray and Scott Rozelle. 2002. "Enhancing the Crops to Feed the Poor," *Nature* 418 (6898 August): 678-684.

Huang, Jikun, Ruifa Hu and Scott Rozelle, Funding Options for Agricultural Research in PRC, A Project Report Submitted to Asian Development Bank, 2001.

Jin, S.Q., J.K.Huang, R.F.Hu and S.Rozelle. 20002. “The Creation and Spread of Technology and Total Factor Productivity in China’s Agriculture.” *American Journal of Agricultural Economics* (forthcoming)

Johnson, D.K.N., and R.E., Evenson. 1999. “R&D Spillovers to Agriculture, Measurement and Application.” *Contemporary Economics Policy* 14(4):432-456.

Gyimah-Brempong, K. 1987. “Economies of Scale in Municipal Police Department: The Case of Florida.” *The Review of Economies and Statistics* 69(2): 352-56.

MacDonald, J. and M.E. Ollinger. 2000. "Scale Economies and Consolidation in Hog Slaughter." *American Journal of Agricultural Economies* 82(May) 334-346.

McCalla, A.F. 1994. “Ecoregional Basis for International Research Investment.” In J.R. Anderson (ed.), *Agricultural Technology: Policy Issues for the International Community*. Wallingford, U.K.: CAB International.

Murray, J.D. and R.W. White. 1983. “Economies of Scale and Economies of Scope in Multiproduct Financial Institutions: A Study of British Columbia Credit Unions.” *The Journal of Finance* Vol. XXXVIII, No.3

Pardey, P.G. and N.M., Beintema. 2001. “Slow Magic: Agricultural R&D a Century after Mendel.” IFPRI Food Policy Report, Washington D.C.

Pardey, P.G., J. Roseboom, and J.R. Anderson. 1991. “Topical Perspectives on National Agricultural Research.” In P.G. Pardey, J. Roseboom, and J.R. Anderson (eds) *Agricultural Research Policy: International Quantitative Perspectives*. Cambridge: Cambridge University Press.

Paul, C.J.M. 1999. *Cost Structure and the Measurement of Economic Performance: Productivity, Utilization, Cost Economics, and Related Performance Indicators.* Boston; Dordrecht and London: Kluwer Academic Publisher.

Paul, C.J.M, 2001. “Market and Cost Structure in the U.S. Beef Packing Industry: A Plant-Level Analysis.” *American Journal of Agricultural Economics* 83(1):64-76

Pingali, P.L., M. Hossain, and R.V. Gerpacio. 1997. Asia Rice Bowls, CAB International, Wallingford, 1997.

Rosegrant, M.W., N. Leach, and R.V. Gerpacio 1999. Alternative Futures for World Cereal and Meat Consumption. *Proc. Nutr. Soc.* 58:219-234.

Ruttan, V.W. 1978. Comment on the Organization of Research to Improve Crops and Animals in Low-Income Countries. In T.W.Schultz (ed), *Distortions of Agricultural Incentives.* Bloomington, Indiana:Indiana University Press.

Stone, B. 1988. "Developments in Agricultural Technology." *China Quarterly* 116 (December.).

Weninger, Q 1998. “A General Approach for Estimating the Translog Function in the Presence of Zero-Value Arguments.” Iowa State University Staff Paper Series, No. 335, Ames, IA 50011.

Wholey, D., R. Feldman, J.B. Christianson and J. Engberg. 1996. “Scale and Scope Economies among Health Maintenance Organizations.” *Journal of Health Economics* 15:657-684.

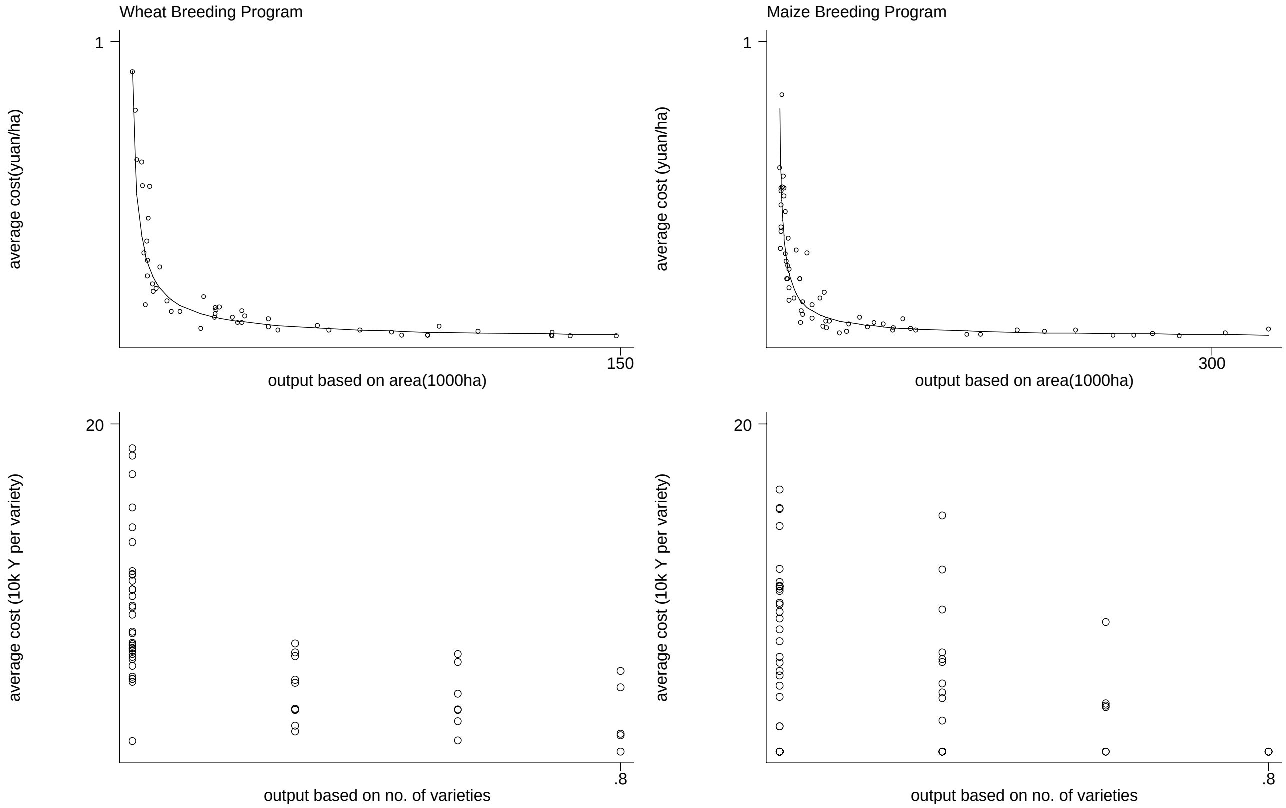

Figure 1. Average Cost of Breeding Research and Research Output

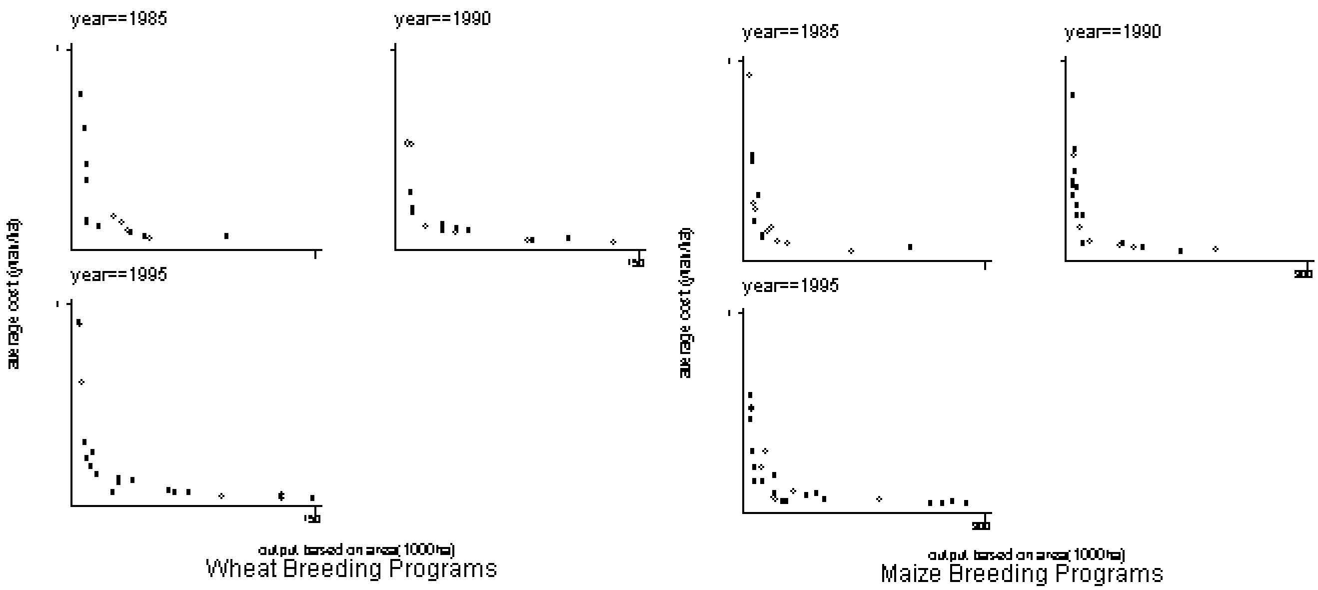

Figure 2.   Average Cost of Breeding Research and Research Output over Time

Table 1. Number of varieties, total cost and average cost for wheat and maize breeding institutes based on three distinct five year periods.

Research output based on number of varieties

Wheat program			Maize Programs		
Research Ouput (no. of varieties)	Total Cost (1,000 yuan in real 1985 terms)	Average Cost per variety (1, 000 yuan in real 1985 terms)	Research Ouput (no. of varieties)	Total Cost (1,000 yuan in real 1985 terms)	Average Cost per variety (1,000 yuan in real 1985 terms)
0	66.41	n.a	0	92.31	n.a
1	152.42	152.42	1	146.96	146.96
2	172.43	86.22	2	161.67	80.84
3	204.76	68.25	3	242.07	80.70
>4	276.25	60.56	>4	485.41	66.07

Research output based on sown area

Research output (1,000 hectares)[a]	Total Cost (1,000 yuan in real 1985 terms)	Average Cost per hectare of sown area (1985 real yuan)	Research output (1,000 hectares)[a]	Total Cost (1,000 yuan in real 1985 terms)	Average Cost per hectare of sown area (1985 real yuan)
0.00	6.39	n.a.	0.00	7.37	n.a.
10.58	9.46	1.60	3.64	8.17	3.75
64.02	9.83	0.19	27.17	11.52	0.49
288.11	13.35	0.06	160.03	16.70	0.13
3134.69	31.90	0.01	1506.26	30.80	0.03

[a] approximately 20 percent of observations in each category

Table 2. Average cost of wheat (or maize) variety production in wheat only institutes (or maize only institutes) versus joint wheat and maize institutes (based on three distinct five year periods)

Type of Institutes	Output based on no. of varieties (1000 Yuan per variety)[a]	Output based on yield weighted no. of varieties (1000 Yuan per weighted variety)	Output measure based on sown area (Yuan per hectare) 0-100,000 ha	Output measure based on sown area (Yuan per hectare) > 100,000ha
		Average Cost of Wheat Output		
Wheat Only Institutes	187.9	180.5	4.20	1.03
Wheat and Maize Institutes	145.6	146.0	3.13	0.18
		Average Cost of Maize Output		
Maize Only Institutes	225.0	275.0	8.30	4.60
Wheat and Maize Institutes	128.9	130.7	5.10	2.30

[a] All average costs are in 1985 real values.

Table 3. Average cost of wheat and maize variety production and institutional characteristics

Rank by average cost (lowest to highest 20 percentile)	Share of breeders with college and above education	Share of scientists working on other disciplines	Share of genetic materials from outside provinces	Share of retiree[a]
		Wheat Institutes		
1st	0.56	0.43	0.29	0.19
2nd	0.47	0.51	0.25	0.31
3rd	0.41	0.47	0.28	0.16
4th	0.41	0.51	0.18	0.30
5th	0.44	0.51	0.31	0.23
Average	0.46	0.48	0.26	0.24
		Maize Institutes		
1st	0.48	0.48	0.15	0.21
2nd	0.44	0.44	0.17	0.28
3rd	0.47	0.53	0.19	0.25
4th	0.36	0.48	0.29	0.22
5th	0.42	0.44	0.17	0.20
Average	0.43	0.47	0.19	0.23

[a] Share of retiree is measured as the ratio of total salary payments of the retirees in the institute to the total salary payments of the entire institute.

Table 4. Single-Output Cost Function of Wheat/Maize Variety Production of Prefectural Institutes with Basic Specification

	Wheat Breeding Program				Maize Breeding Program			
	Area-yield weighted output	Area-weighted output	Number of varieties	Yield-weighted output	Area-yield weighted output	Area-weighted output	Number of varieties	Yield-weighted output
Output	-0.152*** (2.90)	-0.107*** (2.65)	-0.143 (1.21)	-0.085 (0.81)	-0.175*** (2.69)	-0.169** (2.46)	0.175 (1.31)	0.215* (1.91)
Output squared	-0.006 (1.34)	-0.005 (1.56)	0.069*** (4.51)	0.021 (1.32)	-0.018*** (6.28)	-0.020*** (6.54)	0.027*** (3.48)	0.021*** (3.72)
Salary	1.721*** (3.20)	1.297** (2.54)	-0.380 (0.59)	0.050 (0.09)	0.486 (0.91)	0.480 (0.89)	-0.404 (0.57)	-0.286 (0.51)
Salary squared	-0.776*** (3.02)	-0.552** (2.26)	0.300 (0.98)	0.063 (0.23)	-0.117 (0.46)	-0.127 (0.49)	0.576* (1.68)	0.475* (1.72)
Output*Salary	0.385*** (9.92)	0.336*** (8.60)	0.264** (2.32)	0.292*** (2.90)	0.523*** (10.15)	0.532*** (9.87)	-0.070 (0.54)	-0.123 (1.12)
Dummy of wheat institute	-0.437*** (5.33)	-0.403*** (5.16)	-0.366*** (3.68)	-0.328*** (3.89)				
Dummy of maize institute					0.344*** (2.65)	0.409*** (3.14)	0.671*** (3.99)	0.511*** (3.90)
Constant	0.025 (0.09)	0.212 (0.79)	1.029*** (3.01)	0.617** (2.14)	0.322 (1.14)	0.328 (1.14)	0.613 (1.64)	0.450 (1.55)
Observations	352	352	352	352	399	399	399	399
R-squared	0.72	0.75	0.60	0.53	0.72	0.71	0.52	0.53
Economies of scale	0.22*** (21.04)	0.22*** (33.46)	0.26*** (20.49)	0.25*** (17.38)	0.31*** (26.80)	0.32*** (25.76)	0.16*** (23.15)	0.14*** (29.20)

Absolute value of t statistics in parentheses; * significant at 10 percent; ** significant at 5 percent; *** significant at 1 percent.
Time and regional dummies are included in the model, but we don't present the results in this table.

Table 5. Estimation Results of Single-Output Cost Function with Other Institutional Variables. (Based on yield-area weighted output)

	Wheat Program		Maize program	
	Human Capital + Spill-in Variable	Full Model	Human Capital + Spill-in Variable	Full Model
Output	0.257***	0.358***	0.078	-0.141
	(3.09)	(3.73)	(1.06)	(1.35)
Output squared	-0.009**	-0.013***	-0.023***	-0.025***
	(2.24)	(3.31)	(8.10)	(8.69)
Salary	1.382***	1.296**	0.310	0.257
	(2.69)	(2.54)	(0.62)	(0.52)
Salary squared	-0.595**	-0.596**	0.016	0.009
	(2.41)	(2.43)	(0.07)	(0.04)
Output*Salary	0.347***	0.293***	0.494***	0.587***
	(8.87)	(7.06)	(10.18)	(10.69)
Share of breeders with college	0.102*	0.039	0.101**	0.164***
education	(1.67)	(0.66)	(2.00)	(3.09)
Output*Share of breeders with college	-0.089***	-0.001	-0.103***	-0.066**
education	(4.31)	(0.05)	(3.81)	(1.99)
Share of genetic materials from	0.080	-0.012	0.067**	0.068**
outside	(1.42)	(0.39)	(2.22)	(2.21)
Output*share of outside genetic	-0.225***	-0.236***	-0.134***	-0.129***
materials	(6.00)	(7.76)	(6.56)	(4.86)
Share of other scientists		0.057		-0.028
		(1.47)		(0.67)
Output*share of other sci		-0.103***		0.105***
		(3.22)		(2.97)
Share of retiree		-0.043		0.176***
		(1.00)		(4.14)
Out*Share of retiree		-0.017		-0.006
		(0.28)		(0.20)
Dummy of wheat institute	-0.465***	-0.363***		
	(5.88)	(4.58)		
Dummy of Maize Institute			0.127	0.073
			(0.96)	(0.55)
Constant	0.023	0.213	0.291	0.153
	(0.08)	(0.81)	(1.07)	(0.57)
Observations	352	352	399	399
R-squared	0.75	0.77	0.76	0.77
Economies of scale	0.27***	0.27***	0.29***	0.30***
	(24.94)	(25.06)	(26.80)	(26.25)

Absolute value of t statistics in parentheses; * significant at 10 percent; ** significant at 5 percent; *** significant at 1 percent.
Time and regional dummies are included in the model, but we don’t present the results in this table.

Table 6. Estimation of cost function of wheat variety production with measurement error being corrected by instrumental variables (output measure based on area*yield)

	Wheat breeding programs		Maize Breeding programs	
	Basic Model	Full Model	Basic Model	Full Model
Output	-0.191**	0.019	-0.428***	0.416***
	(2.16)	(0.10)	(3.68)	(2.78)
Output squared	0.001	0.051***	-0.030*	-0.023*
	(0.13)	(2.34)	(2.14)	(1.68)
Salary	1.036*	1.267	1.356*	0.042
	(1.80)	(1.08)	(1.96)	(0.06)
Salary squared	-0.498*	-0.633	-0.614	0.142
	(1.79)	(1.13)	(1.79)	(0.42)
Output*Salary	0.445***	0.421***	0.741***	0.619***
	(5.82)	(3.13)	(7.10)	(6.28)
Share of breeders with college education		0.146		0.317***
		(0.84)		(4.42)
Output*Share of breeders with college education		0.001		-0.297***
		(0.01)		(7.60)
Share of genetic materials from outside		0.057		0.225***
		(0.68)		(4.83)
Output*share of outside genetic materials		-0.154***		-0.362***
		(2.72)		(8.68)
Share of other scientists		0.315**		-0.030
		(2.17)		(0.27)
Output*share of other sci		-0.070		-0.060
		(0.89)		(1.11)
Share of retiree		0.109		0.219***
		(1.17)		(3.80)
Output*Share of retiree		-0.201***		-0.115**
		(3.06)		(2.46)
Dummy of wheat institute	-0.363***	-0.368*		-0.376**
	(3.87)	(1.88)		(1.91)
Dummy of Maize institute			0.242	-0.241***
			(1.31)	(2.89)
Constant	0.362	-0.222	-0.046	-0.220
	(1.20)	(0.36)	(0.13)	(0.61)
Observations	352	352	396	396
R-squared	0.48	0.68	0.42	0.63
[a]Validity Test of Instrumental variables $N*R^2$	1.94	2.18	0.23	1.02
Economies of Scale	0.26***	0.12***	0.25***	0.16***
	(20.18)	(27.72)	(14.23)	(20.11)

Absolute value of t statistics in parentheses; * significant at 10 percent; ** significant at 5 percent; *** significant at 1 percent.
Time and regional dummies are included in the model, but we don't present the results in this table.
[a] The chi-square distributed test statistic with 8 degrees of freedom, is $N*R^2$, where N is the number of observations, and R^2 is the measure of goodness of fit of the regression of the residuals from the research output equation (not shown) on the 8 variables which are exogenous to the system. The critical value of chi-square at 5 percent with 8 degrees of freedom is 2.73. All the test statistics are smaller than 2.73 indicating that we cannot reject the null hypothesis that there is no correlation between the exogenous instruments and the disturbance term from total variable cost equation.

Table 7. Economies of scale, Ray economies of scale of wheat and/or maize variety production of prefectural crop breeding institutes under different estimation strategies (based on yield-area weighted output) [a]

	Different lag length between research output and cost		Panel estimation		With correction of autocorrelation & heterosckedasticity	Translog Function[b]
	7 years	3 years	Random Effect	Fixed Effect		
Economies of scale from single output cost function of wheat programs	0.15*** (25.13)	0.23*** (28.32)	0.17*** (25.33)	0.14*** (19.73)	0.22*** (14.53)	0.15*** (8.64)
Economies of scale from single output cost function of maize programs	0.33*** (21.56)	0.32*** (27.53)	0.19*** (36.08)	0.17*** (38.70)	0.22*** (23.11)	0.23*** (13.54)
Ray economies of scale from multiple output cost function	0.30*** (20.17)	0.32*** (27.50)	0.22*** (28.77)	0.19*** (27.94)	0.28*** (18.52)	0.34*** (30.22)

[a] All the economies of scale coefficients are calculated from basic model specification, however, we tried for all different model specifications and the results are consistent with the ols results reported in table 5 and table 6.
[b] In order to include those institutes with zero output in our regression, for the translog model we replace zero values of outputs with a small number (0.0001), as suggested by Weninger (1998).

Table 8. Ray economies of scale and economies of scope based on the estimation of multiple output cost function

Model Specifications	[a]Ray Economies of Scale	[b]Economies of scope
Basic Model	0.33***	-0.099
	(24.93)	[-0.098, -0.103]
Human Capital	0.33***	-0.050
	(23.30)	[-0.049, -0.055]
Spill-in Variable	0.35***	-0.083
	(23.28)	[-0.080, -0.086]
Spill-in + Human Capital	0.38***	-0.038
	(21.09)	[-0.035, -0.042]
Full Model	0.39***	-0.010
	(20.01)	[-0.003, -0.011]

[a] Ray economies of scale is calculated by equation (5).
[b]The coefficient of economies of scope is calculated using equation (6). Bootstrapping generates the mean and confidence interval of the scope coefficient, 400 samplings with replacement were implemented.

Appendix Table 1. Multiple output cost function of wheat and maize variety production of prefectural institutes (output measure based on area*yield)

		1	2	3	6
Variable added	Basic Model	Education varaible	Spillin	Spillin and education	Full Model
Wheat output	-0.015	-0.050	0.153***	0.126**	0.273***
	(0.45)	(1.50)	(3.16)	(2.57)	(4.33)
Wheat output squared	-0.003	-0.002	-0.009***	-0.009***	-0.010***
	(1.15)	(1.03)	(3.80)	(3.76)	(4.35)
Maize output	-0.011	0.109*	-0.051	0.157**	0.190**
	(0.23)	(1.79)	(1.09)	(2.50)	(2.35)
Maize output squared	-0.010***	-0.012***	-0.008***	-0.012***	-0.011***
	(5.73)	(5.86)	(4.69)	(6.18)	(5.42)
Breeder’s salary	0.927**	1.007***	0.724*	0.750**	0.363
	(2.38)	(2.72)	(1.95)	(2.10)	(1.03)
Salary squared	-0.319*	-0.370**	-0.221	-0.237	-0.082
	(1.71)	(2.08)	(1.24)	(1.38)	(0.48)
Wheat output*salary	0.157***	0.081***	0.162***	0.128***	0.106***
	(5.96)	(2.80)	(6.42)	(4.43)	(3.66)
Maize output*salary	0.248***	0.262***	0.279***	0.254***	0.261***
	(6.87)	(7.17)	(8.02)	(7.13)	(6.59)
Wheat output*maize output	-0.014***	-0.015***	0.002	0.005	0.007
	(6.31)	(6.27)	(0.65)	(1.09)	(1.57)
Share of breeders with collge education		0.088*		0.084*	0.139***
		(1.94)		(1.90)	(3.00)
Wheat output*breeders with college education		0.109***		0.044*	-0.010
		(4.89)		(1.78)	(0.36)
Maize output*breeders with college education		-0.122***		-0.136***	-0.180***
		(5.52)		(6.35)	(6.83)
Share of genetic materials from outside			-0.010	-0.016	-0.002
			(0.38)	(0.62)	(0.07)
Wheat output*genetic materials from outside			-0.108***	-0.097***	-0.141***
			(4.57)	(4.24)	(5.75)
Maize output*genetic materials from outside			-0.054***	-0.060***	-0.060***
			(3.24)	(3.34)	(2.77)
Share of other scientists					0.119***
					(3.83)
Wheat output*share of other scientists					-0.091***
					(4.21)
Maize output*share of other scientists					0.011
					(0.59)
share of retiree					-0.014
					(0.46)
Wheat output*share of retiree					0.087**
					(2.08)
Maize output*share of retiree					-0.026
					(1.06)
Dummy of wheat institute	-0.647***	-0.661***	-0.654***	-0.666***	-0.623***
	(9.50)	(10.16)	(10.05)	(10.65)	(10.03)
Dummy of maize institute	0.053	0.017	-0.007	-0.029	-0.063
	(0.55)	(0.17)	(0.07)	(0.31)	(0.68)
Constant	0.306	0.247	0.468**	0.413**	0.430**
	(1.50)	(1.26)	(2.36)	(2.14)	(2.26)
Observations	440	440	440	440	440
R-squared	0.76	0.79	0.79	0.81	0.82

Absolute value of t statistics in parentheses; * significant at 10 percent; ** significant at 5 percent; *** significant at 1 percent; Time and regional dummies are omitted in this table.

Appendix Table 2. Number of Varieties Released and Area Adoption by Different Types of Institutes, 1985-2000

Institute Type	No of Varieties Released				Area Adopted of Released Varieties (1000ha)			
	1985-1990	1991-1995	1996-2000	All	1985-1990	1991-1995	1996-2000	All
Wheat Institutes								
Provincial Institutes	6 (19)[a]	11 (20)	10 (18)	27 (19)	769 (9)	9,391 (30)	7,499 (17)	17,658 (21)
Prefectural Institutes	25 (81)	44 (80)	45 (82)	114 (81)	7,980 (91)	22,170 (70)	36,195 (83)	66,345 (79)
All Institutes	31	55	55	141	8,749	31,561	43,694	84,004
Maize Institutes								
Provincial Institutes	8 (24)	15 (32)	17 (23)	40 (26)	1,858 (21)	5,835 (36)	17,128 (46)	24,821 (40)
Prefectural Instititutes	26 (76)	32 (68)	57 (77)	115 (74)	7,099 (79)	10,387 (64)	19,814 (54)	37,300 (60)
All Institutes	34	47	74	155	8,957	16,222	36,942	62,121

[a] Numbers in paranthesis are in percentage (e.g., six wheat varieties released by prefectural institutes during 1985-1990. The six varieties account for nineteen percent of total number of varieties released during that period)