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Technological change: Rediscovering the engine of productivity growth in China's rural economy

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Abstract

This paper focuses on measuring the relative importance of the role of technology versus that of institutional innovation in China's rural economy. A six-equation rice sector model explaining provincial-level technology adoption, yield, and factor demand are econometrically estimated using data from China's 13 rice growing provinces for the period 1975–90. Growth decomposition analysis identifies technology adoption as the most important determinant of rice yield growth during 1978–84, accounting for nearly 40 percent the change; institutional reform accounted for 35 percent of the growth. In 1985–90, technology accounts for all of the increase in rice yields. The study demonstrates earlier studies may have over-estimated the impact of decollectivization.

JEL classification: 053; 033; P27

Keywords: Technological change; Institutional reform; Growth decomposition; China; Rice economy

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1. Introduction

Since the mid-1970s, economic reform and other innovations have caused rapid growth and contributed to rising incomes in many parts of China's rural sector. Economists have focused much of their attention on understanding the implica-

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tions of the bold moves to decollectivize agricultural production and liberalize rural markets (Lardy, 1983; Sicular, 1988). The earliest empirical investigations by McMillan et al. (1989) and Lin (1992b) centered around measuring the contribution of organizational and marketing reforms to agricultural growth. Their results showed that implementation of the household responsibility system (HRS) created most of the rise in productivity in the early reform years. Few researchers have given serious consideration to the role of technical change in agricultural productivity growth. Most studies have assumed that technology is either static (e.g., McMillan et al., 1989; Ma et al., 1989) or exogenously given, measured with a simple time trend variable (e.g., Perkins and Yusuf, 1984; Fan, 1991; Lin, 1992b). Two notable exceptions explore empirically the determinants of technological change (Lin, 1992a) and try to understand better its role in the growth of agricultural productivity (Fan and Pardey, 1992). These studies expand the understanding of factors that influence the adoption of technology. However, even in these studies, the authors adopt a number of restrictive assumptions on how technology influences production decisions of rural households. The technological adoption decision is not related to the system's productivity or other production behavior (i.e., it is exogenously generated). The analyses, use simple proxies for technological change and try to explain aggregate measures of agricultural value or total grain production. In contrast, Stone (1988) and Huang and Rosegrant (1993) suggest that technology may not be exogenously determined and that it is preferable to use disaggregated data since the changing structure of China's crop and variety mix affects agricultural growth.

This paper carefully explores the role of technological change in the growth of agricultural productivity. Focusing on the rice subsector, technology adoption is treated as a decision to be made by the producer, and explicit measures of technology are used. The relative importance of the different factors of productivity growth are considered, especially focusing on measuring the relative importance of the role of technology versus that of institutional innovation. Growth decomposition analysis will be done in both the early reform (1978–84) and the late reform periods (1985–90), in an attempt to identify the sources of agricultural growth after the one-time decollectivization effects have been exhausted. If technological change is found to be a major determinant of agricultural productivity growth, especially in recent years, it may be that a critical reassessment of China's agricultural research system is warranted, given recent studies reporting its weakening tendencies or collapse (Conroy, 1987; Lin, 1991b).

In this paper, two important and independent technology decisions – the adoption of hybrid rice and the choice of single or double cropped rice – are explained. Particular emphasis is placed on understanding the impact that the rural reforms have had on the adoption of technology. This is accomplished as the first step in the estimation of a system of rice area, yield (measured as output per unit of sown area), and input demand equations made possible by access to a unique set of data from China's State Price Bureau. Predicted values of the two technology variables are used in the second phase of the study, helping explain changes in yields, the patterns of input use, and the contributions which technology and institutional innovation have had on agricultural productivity. Because of the economic and political importance of China's rice sector, an intensive investigation of this vital crop can increase the understanding of the performance of China's overall agricultural system in the reform era. The paper provides the first sectoral analysis of the impact of technology, institutional change, price adjustments, and other fixed effects on the use of labor, chemical and organic fertilizer in rice production.

2. Rice production in China

Rice has long been the most important food crop in China's agricultural economy. During the last decade rice accounted for approximately 30 percent of grain area, 45 percent of grain output, and nearly 40 percent of the nation's caloric intake (IRRI, 1990–1991). China's rice sector also is the largest component of the world rice economy. Since 1980, the rice area of China has accounted for about 23 percent of the world's sown area and 37 percent of its rice production. Although China's net exports have been less than 1 percent of domestic production, its share of world total rice exports typically ranges from 10–20 percent. The future performance of China's rice sector is of critical importance to the welfare of China's domestic population and could have pervasive impacts on world food markets.

Yield performance of rice sector has been impressive throughout most of the People's Republic period. During the period 1964–78, yields grew at an annual rate of nearly 2 percent; during 1978–84, the rate increased to over 5 percent. Although growth rates slowed somewhat during the late 1980s, rice yields are still among the highest in the world, reaching 5.7 metric tons per hectare by 1990 (ZGNYNJ, 1981–1992). These successes have depended on the government's continual effort to modernize the nation's rice economy (Stone, 1988). China developed and extended their first fertilizer-responsive, semi-dwarf rice varieties in the early 1960s before the rest of the world had been introduced to 'Green Revolution' technology. By the early 1980s, over 98 percent of China's rice area was planted with improved varieties. [1] Expansions in water control and chemical fertilizer manufacturing capacity complemented these technological breakthroughs.

This paper concentrates on two of the most important research programs that came to fruition in the 1970s. In 1971, Yuan Longping, a scientist in Hunan Province, identified breeding material that allowed his laboratory to create the first

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[1] Conventional high yielding varieties and hybrid rice cultivars are both improved varieties. In order to differentiate between them, they will be referred to as 'hybrid rice' and 'conventional varieties'.

commercializable hybrid rice cultivar. During this same period, conventional breeding programs were finding ways to control the photosynthetic sensitivity of the rice plant, establishing control over the planting time and length of maturation period. Hybrid rice and double-cropping technology became two of China's most powerful tools in increasing the sector's output over the next two decades. Although these breakthroughs appeared during the same time period, hybrid rice and double-cropping decisions are independent in the sense that hybrid rice plants can be cultivated as single season rice, or during either the early or late season in a double-cropping rotation.[2] The next two subsections review the breakthroughs in hybrid rice and double-cropping, and discuss some of the major features of the products which have helped extend and constrain their spread into farmers' fields.

2.1. Hybrid rice adoption

In 1976 China began to extend F_1 hybrid rice varieties for use by producers (Yuan and Chen, 1991; CAAS/HAAS, 1991). With a potential 15–20 percent yield advantage over conventional high yielding varieties (He et al., 1984), the area under hybrid rice expanded rapidly from 4.3 million hectares in 1978 to 15.9 million hectares in 1990, increasing from 12.6 percent of rice sown area to 41.2 percent (Table 1, bottom row).

These aggregate figures, however, mask the significant differences in rates of adoption among the provinces. For example, in 1990 Shanghai had less than 1 percent of its rice area sown to hybrid rice; while in Guangdong Province it was 36.6 percent. In Hunan Province, 56.6 percent of rice was devoted to hybrid rice, and in Sichuan Province it was 88.0 percent (Table 1). The timing of the rise of hybrid rice also varied. Adoption rates in some provinces, such as Fujian Province, had exceeded 30 percent by 1978. In others, such as Anhui and Guangxi Provinces, producers had put less than 10 percent of their area into hybrid varieties by the mid-1980s.

Little formal attention has been paid to explaining the differences in these adoption rates. One notable exception identifies a centrally planned economy version of the induced innovation hypothesis (Lin, 1992a). The size of the rice market in a region (which in China's relatively closed economy is also equated with the number of rice producers) is shown to be positively correlated with the level of adoption.[3] Based on the observations and work of Griliches (1957), Lin

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[2] Technologically, hybrid rice and double/single cropping are two distinct research problems. There are hybrid rice cultivars that can be grown in any season – as first or second crop in a two season rice rotation, or a single season variety. Breakthroughs affecting double cropping technology – e.g., photosynthesis sensitivity and maturation dates – are just as easily incorporated into either new hybrid or conventional rice cultivars.

[3] Lin (1992a) contains a table showing the correlation between the size of the area sown to rice and the adoption rates. He also performs a number of exercises demonstrating the importance of sown area in the determination of the amount of research resources allocated to hybrid rice.

Table 1
Hybrid rice area and yields in 13 major rice growing provinces, 1976–90

	Percentage of rice sown area sown to hybrid rice								Yield in 1988–90 (ton/ha)		
Province	1976	1978	1980	1982	1984	1986	1988	1990	Hybrid rice	Conven. rice varieties	Yield gap ratio
South											
Guangdong	0.2	4.7	3.5	16.7	37.2	18.8	29.8	36.6	5.31	4.64	1.14
Guangxi	1.0	15.2	4.7	6.3	8.5	20.3	40.7	49.8	4.84	4.11	1.18
Fujian	0.2	31.6	31.1	25.6	32.6	39.1	54.4	60.0	5.47	4.36	1.25
East											
Shanghai	0.0	1.8	2.3	0.7	0.7	0.1	0.2	0.2	7.54	6.95	1.08
Jiangsu	0.0	15.7	24.1	26.7	36.3	31.8	41.5	45.5	7.54	6.83	1.10
Zhejiang	0.0	6.5	22.2	18.4	21.8	24.3	25.8	26.1	5.66	5.51	1.03
Central											
Auhui	0.0	1.5	4.9	8.6	20.9	27.3	33.5	42.7	6.93	4.83	1.43
Jiangxi	0.2	19.5	22.6	18.6	19.4	22.4	34.3	36.5	5.05	4.55	1.11
Hubei	0.0	10.5	3.0	3.4	15.1	26.2	39.7	41.0	7.03	6.29	1.12
Hunan	1.9	26.3	22.2	25.8	34.7	38.2	53.4	56.6	6.06	5.23	1.16
Southwest											
Sichuan	0.0	6.2	22.2	33.3	56.9	61.3	79.9	88.0	7.31	4.76	1.54
Guizhou	0.1	8.4	12.3	6.0	13.0	15.5	41.9	63.1	4.78	2.37	2.02
Yunnan	0.0	0.2	1.2	1.3	5.0	10.4	19.2	26.3	4.99	4.64	1.08
National Average	0.4	12.6	14.6	17.0	24.7	27.9	38.8	41.2			

Sources: Area data are from CNRRI (1993). Yield data are from a survey of provincial agricultural bureau officials conducted by the authors in the above 13 provinces in 1992.

argues that large markets increase the potential gain from new technological innovation which in turn induce higher research expenditures on new technology and justify the use of funds for activities such as adaptive breeding. This research effort makes the new technology product available on a wider basis and increases the access of would-be adopters. In the case of hybrid rice, increasing the stock of breedable material is a particularly important factor because of the technical complexities associated with the production of high quality and reliable seed that is suitable for use in any given locality. In other words, more rice consumers mean more rice producers which lead to a higher commitment of research and breeding resources. Well-funded research programs, in turn, produce products which are available to farmers in a greater number of regions, leading to higher adoption rates.

Even when hybrid varieties are commercially available, factors that directly affect the profits of local producers must still be considered. Since the output price for hybrid rice and conventional varieties has historically differed only marginally (He et al., 1984), the relative profitability of the new variety can be assessed on the basis of its yield advantage. The yield gap ratios – hybrid rice yields divided by conventional variety yields – of China's provinces in 1990 range from 1.03 to 2.02 with a median value of 1.14 (Table 1, right-hand column). The adoption level of hybrid rice appears to vary systematically with these yield differences. Sichuan Province, for example, which has the highest level of adoption, also has one of the highest yield gaps (54 percent – 7.31 versus 4.76 tons per hectare). On the other hand, Zhejiang producers use hybrid rice in only 26.1 percent of the area they sow to rice; the yield gap in that province is less than 3 percent. The correlation coefficient between 1990 provincial adoption rates and the yield gap ratio is 0.60, and statistically differs from zero at a 5 percent confidence level.

On the input side, there is no discernable pattern of differences in the amount of labor required for hybrid rice in any of the main rice producing provinces included.[4] Cost of production data do show, however, that hybrid rice requires relatively high levels of chemical fertilizer applications. For example, in the late 1980s, hybrid rice producers in some provinces used as much as 30 percent more chemical fertilizers per hectare than their counterparts who produced conventional varieties.[5]

2.2. Double and single cropping

During the 1960s and 1970s, China's agricultural leaders set high grain-production targets to achieve regional self-sufficiency (Donnithorne, 1969). Officials had strong incentives to maximize their grain output. Researchers responded by focusing on rice varieties that allowed producers to switch from one to two crops of rice per year (Lin and Min, 1991). This breeding task required the production of quicker maturing varieties that could be cultivated in the colder extremes of the growing season. The development of photo-period insensitivity technologies facilitated this transformation by making it possible for breeders to create early rices that could be planted earlier and late varieties that could be harvested later in the season regardless of the amount of sunlight energy available during these seasons. Researchers also reduced the average maturation time of early and late rices and made them inherently more cold tolerant.

In 1975, the annual per hectare yield of double cropped rice (7.04 tons per hectare, a combination of early – 3.80 – and late rice production – 3.24) exceeded

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[4] From a purely technical point of view, one should not expect any systematic differences between the labor requirement for hybrids or conventional varieties. Since hybrid rice requires fewer plants per hectare of sown area, farmers save labor in seed-bed management and transplanting activities. Bigger harvests, however, increase the demand for harvesting and threshing labor.

[5] Most researchers find that hybrid rice requires significantly higher uses of chemical fertilizer (He et al., 1984; Rozelle, 1991; Lin, 1991b).

Table 2
Early, late, and single rice production, 1975–90

	Proportion of rice area planted to:			Yield (ton/hectare)		
	Double season		Single	Double season		single
	Early	Late	season	Early	Late	season
National						
1975	36	35	29	3.80	3.24	4.43
1980	33	33	34	4.43	3.29	4.64
1985	30	30	40	5.10	4.65	5.96
1990	28	30	42	5.49	5.13	6.50
Shanghai						
1975	41	56	3	5.61	4.43	5.26
1980	39	53	8	5.12	2.72	4.95
1985	23	34	43	5.94	5.04	6.12
1990	4	15	85	6.09	5.08	7.35
Jiangsu						
1975	23	24	52	4.40	3.04	3.94
1980	19	22	59	4.78	2.46	5.09
1985	3	4	93	5.73	4.86	6.86
1989	1	1	98	5.85	5.48	7.08

Source: CNRRI. 1993.

that of single season rice (4.43 tons per hectare) by 56 percent (Table 2, row 1). Large yield differences induced agricultural leaders during the 'Agricultural First' campaigns of the 1960 and 1970s to push the level of adoption of double cropping technology to 71 percent of rice sown area in 1975 (36 percent in early rice, plus 35 percent in late rice – Table 2, row 1). By 1990, the per hectare difference between double- and single-cropped rice had grown to 63 percent; the rice yields of single season rice rose to 6.50 tons per hectare and those of two season varieties to 10.62 tons per hectare.[6]

The yield gains from the adoption of double cropping technology, however, came at the expense of increased labor and chemical fertilizer use. For example, in Fujian Province throughout the 1980s, and in Sichuan Province in 1985, labor use on two-season rice is over double that of single season rice. During these same years, fertilizer use on both crops of two-season rice is also almost twice the level used on single season rice. As the opportunity cost of labor rose during the early 1980s in response to the market-oriented diversification policies, producers' resistance to double cropping increased. In the dynamic southern Jiangsu area, for example, two season rice was economically inefficient in the early 1980s due to

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[6] Single season rice yields per hectare of sown area, however, nearly always dominate the yields of either the early or late crop.

the high wage levels (Weins, 1982). When farmers moved into single season rice, labor devoted to agriculture fell sharply and agricultural profits increased (as did total household income which was being supplemented by off-farm employment earnings). Nationally, the area planted to two season rice has fallen from 66 percent in 1980 to 58 percent in 1990 (Table 2, rows 2 and 4). The switch to single season rice has been sharpest in the coastal provinces of Jiangsu Province (falling from 47 to 2 percent during the 1980s) and Shanghai (falling from 97 to 19 percent).[7]

Ignoring the differences in fertilizer application rates, there appears to be a point when rising wages makes the shift from double-to single-cropping profitable from the farmers point of view. Interviews with local leaders, who in some areas have historically pressured farmers to continue double cropping, confirm that the move out of double season rice becomes unavoidable at high wage levels even though local grain production invariably falls. At certain levels of industrialization, the cost of maintaining a double cropping system (in time lost from factory work due to the temporary factory shutdowns during the agricultural busy seasons) becomes too great.

3. A rice supply model with endogenous technological change

The discussion in the previous section illustrates the important contribution of hybrid rice to the sharp rises in yields per unit of sown area during the 1970s and 1980s. It also demonstrates that the adoption of new technology is part of the producer's decision making process, inextricably tied up with other production choices. In this section, a rice sector model explaining provincial rice area, yield, and input use is created, with special attention focused on explaining the trends in technological adoption. The ultimate purpose of the model is to compare the importance of hybrid rice and double/single cropping technology with that of institutional change in the generation of higher rice yields. Rice cultivators in China are assumed to make two sets of decisions.[8] At the beginning of the cropping season, producers plan their planting strategy, deciding what proportion of their fixed paddy area to commit to hybrid rice, and what proportion to allocate

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[7] The rising opportunity cost of labor is an important factor in the decision to adopt single cropping technologies nationwide. Inter-provincial comparisons in 1990 reveals a close association between the wage level and the willingness to raise two crops of rice. For example, two coastal provinces, Shanghai and Jiangsu had an average wage level of 11 yuan per day in 1990 and experienced a decline during the 1980s in the proportion of double season rice of 78 and 45 percent, respectively (Table 2). In the three central China rice-producing provinces (Hunan, Hubei and Jiangxi Provinces – not shown in table) where the average wage was only 6 yuan per day, double cropped rice only fell by 2.6 percent.

[8] The works of McGuirk and Mundlak (1991) and Rosegrant and Faisl (1993) have been particularly helpful as a guide in creating the conceptual and empirical model.

to a single or double season rice rotation. Yields are determined as producers make their variable input decisions – choosing the level of labor, fertilizer, and organic manure that they will apply to their rice crops. This framework is consistent with models of production behavior estimated from data collected at the village level in China (Rozelle and Boisvert, 1994), as well as analytical models of supply in developing economies (McGuirk and Mundlak, 1991; Rosegrant and Faisl, 1993). In summary, the model has three basic components (6 equations) that will be estimated empirically, a hybrid rice area equation, a double-cropping area equation, and a set of rice yield and 3 rice input demand equations.

3.1. Hybrid rice equation

Hybrid rice adoption depends in part on both the availability of new varieties and the relative profitability of hybrid rice versus conventional varieties. As in Lin (1992a), it is assumed that as the size of the rice market increases, greater investment of research and extension resources are induced into the development of new varieties, making them more available for use by farmers. The greater availability of hybrid rice varieties (which is proxied by the size of the rice market – *TECHAVAIL*) is expected to positively correlated with adoption levels.

The ability to reproduce and extend this newly available technology, however, may have been influenced by the organization of the agricultural sector (Lin, 1991a). The pre-1980s collective system had advantages in coordinating seed reproduction and distribution, and the breeding system probably enjoyed economies of scale in screening new varieties. Government agricultural officials were also more easily able to persuade collective leaders to use new technologies. There is evidence that China's technology generation and extension systems may have been weakened after the introduction of the HRS reforms which would increase the cost of technology adoption. A variable representing the implementation of the household responsibility system developed by Lin (1992b) is used to account for the rural reform policies, and is expected to show the negative impact of the institutional innovations on technology adoption (*HRS*).

However, the collective system also had some disadvantages when it came to efficiently extending and using technical innovations. When Chinese farmers were still organized as collective production teams, incentives were lacking to use the new technology in the most optimal manner since each individual only received a fraction of the marginal return for any extra effort put into the collective's farming activities (Putterman, 1993). Local leaders may also have been making adoption decisions based on criteria other than profit maximization (Oi, 1989). Hence, while technologies which were more profitable were probably always more welcome (and hence adopted a greater rates than less profitable conventional varieties), as decollectivization proceeded, there should have been a greater incentive for farmers to adopt the more profitable hybrid rice. The relative profitability of the hybrid rice is measured by the average gap between hybrid and conventional variety yields (*YIELDGAP*).[9] Given that price differences between hybrid and conventional varieties are insignificant over most of the period, profit-seeking producers are expected to adopt higher levels of hybrid rice in areas where there are larger yield gaps. Both *YIELDGAP*, and an interaction term (*YIELDGAP* * *HRS*) should both be expected to be positively correlated with hybrid rice adoption.

Other factors may also affect hybrid rice adoption. A number of Chinese sources have reported on the inferior quality of hybrid rice (e.g., Zhang et al., 1991). In one survey done by the authors in northern Jiangsu and Hubei Provinces in 1988–89, over 80 percent of the respondents reported that because of taste preferences, farm households would choose to consume higher quality conventional varieties over hybrid varieties. In 1992, after a drive in China was launched to increase the quality of their agricultural output (Tian, 1992), Bureau of Agriculture officials interviewed in the coastal provinces forecast a large quality-induced decrease in the area sown to hybrid rice varieties, especially in relatively well-off areas. Assuming rice quality is a normal good, farmers in China, who still consume about 70 percent of the rice that they produce, are expected to decrease the proportion of rice area planted to hybrid varieties as incomes rise. Rural per capita income deflated by the rural consumer price index (*INCOME*) is included in the model as an independent regressor.

The process of seed reproduction is another important factor influencing the extension of hybrid rice (He et al., 1987; Xu et al., 1991). The continuous improvement in seed technology since the mid-1970s is well documented (Yuan and Chen, 1988). The number of farmers who are able to reproduce seed has risen monotonically since the 1970s (CAAS/HAAS, 1991). Per hectare seed yield has also increased steadily (from an average of around 200 jin per mu in the early 1980s (He et al., 1984) to over 450 jin per mu in recent years (CNRRI, 1993)). This increase in seed technology is associated with improved quality of seed at a lower real cost. A time trend (*TREND*) is included to reflect the constant increase in the quantity and quality of seed since complete provincial series on hybrid rice seed production are not available. Dummy variables for each province are also included since hybrid rice varieties are sensitive to local growing conditions, and progress in their commercial extension depends on the effort and investment behavior of the agricultural officials of each area (Yuan and Chen, 1988).

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[9] This measure differs from that used in the empirical work of Lin (1992a), who used lagged average yield levels (most likely since did not have access to information on the adoption and yields for each province by variety). The measure used in this paper is a purer measure of profitability, since there is on reason to expect that the level of yields is positively related to the average yield gap. In fact, the correlation coefficient between the yield gap ratio and lagged average rice yields in the late 1980s is −0.295.

The proportion of rice area sown to hybrid rice (*HYBRID-ADOPT*) can be explained by the following equation:

$$\begin{aligned}&\text{Hybrid Rice Adoption}\\&\quad = f_1(\text{Technology Availability; Profitability—Yield Gap between Hybrids}\\&\qquad \text{and Conventional Varieties; Institutional Factors;}\\&\qquad \text{Interaction between Profitability and Institutional Factors; Income;}\\&\qquad \text{Time Trend; Provincial Dummies}).\end{aligned}$$

This equation is the first of two area equations that are estimated simultaneously as a six-equation supply system.[10]

4. Double-cropped rice technology equation

The double-cropped rice equation contains the same set of variables as the hybrid rice equation except that the income variable is excluded since there is no reason to expect that quality of rice is connected with double cropping.[11] Instead the wage level of each province is included (P_w) to account for the observed fact that double cropping seems to be negatively related to the opportunity cost of labor (see discussion in preceding section of the paper).

Additionally, the Hayami and Ruttan (1985) induced innovation hypothesis predicts that an area's labor-to-land ratio is an important determinant of a region's choice of technology if labor differences are a factor in the technological choice; areas with scarce land, ceteris paribus, demand technologies from breeders that are

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[10] Since the dependent variable in this equation is censored (between zero and one), ordinary least squares may produce biased and inconsistent parameter estimates (Maddala, 1983). To check the seriousness of this potential problem, a Tobit model is used to estimate the parameters (Appendix, Table A.1, columns 3 and 6). In fact, the bias is empirically unimportant; the coefficients are robust to the selection of the estimator.

[11] Even though hybrid rice and double-cropping are independent decisions, it might be argued that income could affect the double-cropping decision, and that wages and population density (variables that appear in the double-cropping equation but not the hybrid rice one) could affect the hybrid rice adoption decision. In fact, for the hybrid rice equation, the F-test examining the validity of the restricted model (the one used in this paper) versus the full model cannot reject the restrictions (i.e., *WAGE* and *POPDENSE* do not belong in the hybrid rice adoption equation). While the t-ratio of the income variable in the double-cropping equation is high, the full model is not appropriate given the unreasonableness of the estimates of not only the coefficient of the income variable, but also because the coefficient of the wage variable (which had been reasonable in the restricted equation, but which increased by a magnitude of 10 in the full equation). The adverse performance of the full double-cropping model is most likely due to multicollinearity between wages and income. Diagnostic tests show that the condition index jumps sharply once income is added to the X matrix in the double-cropping decision. Moreover, the variations of the income and wage variables (as measured by their variance proportions) are clearly clustered around the eigenvectors with the highest condition numbers.

land-saving. [12] Population density (of rural residents per hectare of cultivated area – *POPDENSITY*) is included to control for this effect and is expected to be positively related to the rate of double-cropping technology adoption. A time trend in this equation is needed to in part capture breakthroughs in the breeding of conventional rice varieties.

The proportion of rice area sown to double cropped rice (*DOUBLE-ADOPT*) can be explained by the following equation:

Double Rice Technology Adoption
$=f_2$(Technology Availability; Profitability—Yield Gap between single
and double rice; Institutional Factors; Interaction
between Profitability and Institutional Factors; Wages; Trend;
Population Density; Provincial Dummies).

The equation describing the decision to cultivate rice in two seasons is also estimated as part of a system with the five other equations.

4.1. Yield response and input demands

The yield and three input demand equations are empirically estimated in a framework is assuming that the yield response and input demand equations follow the Diewert (1971) formulation of the flexible generalized Leontief profit function:

$$\pi^* = \Sigma_i^m \sum_j^m \beta_{ij} p_i^{1/2} p_j^{1/2} + \sum_j^m \sum_k^n \beta_{ik} p_i Z_k, \tag{1}$$

where π^* is maximized profits, p_i represents output or input prices, z_k are shifter variables – including technology, fixed inputs, and other institutional and environmental factors, and $ß_{ij}$ is a set of parameters to be estimated.

Invoking Shephard's Lemma, the yield response and input demand system can be derived from Eq. (1). The equations to be estimated take the following form:

$$x_j = a_i + \sum_{i \neq j}^m \beta_{ij} (p_j / p_i)^{1/2} + \sum_k^n \beta_{ik} Z_k. \tag{2}$$

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[12] According to this statement, and as specified in Lin (1992a), it may be argued that this variable should also be included in the hybrid rice equation. When doing so, however, we found a negative coefficient. Regression diagnostics identified a fairly high degree of collinearity between the income variable and land to labor ratio. This is because in this sample of southern China provinces, the rich coastal provinces also have the highest land to labor ratios. Lin (1992a) finds a positive coefficient in his regression mainly because he includes the less populated, poorer northern provinces which are unable to use hybrid rice due to climatic factors. We argue that since hybrid rice in general does not use more labor than conventional varieties, there would be no reason to adopt or not adopt hybrid rice on the basis of differences in labor requirements.

In this application, x_i represents the optimal yield response and the factor demands for labor, chemical fertilizer, and organic manure. The dependent variable for the yield equation is average rice yields per sown area (*RICEYIELD*). The dependent variable for the rice labor equation is defined as labor days per hectare (*LABOR*). Chemical fertilizer use (*CHEMFERT*) is measured as the actual weight of chemical fertilizer consumed per hectare. The dependent variable of the organic manure equation (*ORGANIC / FERTILIZER*) enters as the ratio of the value of organic manure to the value of all fertilizers, both chemical and organic. Yields and factor demands should be expected to be price responsive in China's agricultural economy, given the use of bonus payment systems since the mid-1970s, and the marketing reforms instituted since 1978. Because prices are normalized (P_i/P_j), homogeneity is imposed in the system.

Two of the key elements of the z_k matrix in Eqs. (1) and (2) are the areas devoted to hybrid rice (*HYBRID-ADOPT*) and double cropping (*DOUBLE-ADOPT*). These variables clearly affect yields and input demands. Since the choice of these variables are endogenous, predicted values from the adoption equations are employed to avoid simultaneity bias.[13] The variable representing the implementation of the household responsibility system (*HRS* – also used in the technology equations) is included in each of the four equations.

Huang and Rozelle (1996) demonstrate the increasingly important role of environmental factors in the determination of China's overall grain yields.[14] In this paper, variables most likely to affect rice yields are employed in the yield response equation. Salinization[15] and 'easily flooded and drought damaged'

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[13] Tests of the endogeneity of hybrid rice adoption and double-cropping to yields confirm the need to account for the enendogeneity of technology adoption. Using a specification test devised by Hausman (1978), the chi-square distributed test statistic (with 2 degrees of freedom) is 10.08 which indicates that the null hypothesis of no endogeneity must be rejected. To properly account for the endogeneity, the predicted values from the technology equations which are uncorrelated with the structural disturbances of the yield equation are used. To test if the set of identifying instruments are exogenous, a Lagrange multiplier test can be used (Hausman, 1983). The chi-square distributed test statistic with 2 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 yield equation on the variables which are exogenous to the system. The test statistic is 3.41 which indicates that the null hypothesis that there is no correlation between the exogenous instruments and the disturbance term from yield equation can not be rejected.

[14] When explaining aggregate grain yields in China's provinces, Huang and Rozelle (1996) found four factors to have an important and robust effect: erosion, soil fertility exhaustion from over-intense land use, salinization and damage due to the deterioration of the local environment.

[15] Land is classified as 'salinized' if 70 percent of the plants in any given area do not grow to maturity due to the salinity and alkalinity content of the soil. The salinity or alkalinity of land can be either naturally occurring or due to factors related to farm management practices (e.g., poor irrigation management or drainage, waterlogging, or use of abnormally saline or alkaline water). Salinized land also includes 'land successfully treated for salinization' – which means that due to irrigation management practices or the development of new infrastructure, the salinity and alkalinity in the soil has been reduced so more than 70 percent of the seedlings survive until maturity. Salinization enters the equation as a proportion of cultivated land.

area[16] (*SALINITY* and *DISASTER*) are expected to affect yield response negatively.

Chemical fertilizer supplies may have been constrained in some areas prior to the mid-1980s (Ye, 1994). Over the course of the 1980s, however, chemical fertilizer has become more widely available. If so, farm households may not have always been completely free to respond to price changes. To test this hypothesis, a time trend variable is included. If supply constraints did limit chemical fertilizer use, the sign on this variable would be positive since in the absence of such a constraint, more of the input would have been utilized. The yield and three factor demand equations are estimated as a system with the two adoption equations using an iterative Three Stage Least Squares framework. This modelling approach takes into account the contemporaneous correlation among the error terms of the 6 equations and the endogeneity of the technology variables in the yield equation. Provincial dummies help guard against heteroskedasticity.[17]

Using the estimated parameters from Eq. (2), own price elasticities are

$$\epsilon_{ij}^* = -\sum_{i \neq j}^{m} (\beta_{ij}/2X_i)(p_j/p_i)^{1/2}, \tag{3}$$

and the cross price elasticities can be written as

$$\epsilon_{ij}^* = (\beta_{ij}/2x_i)(p_j/p_i)^{1/2}. \tag{4}$$

Details on these calculations can be found in Diewert (1971).

4.2. Data

Provincial-level cross section, time series data for China's 13 southern rice-growing provinces for the years 1975–90 are used in the analysis.[18] Hybrid rice

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[16] In China's statistical system, an area is classified as easily flooded or drought damaged if it can *not* with stand a three-year flood or drought with *no* loss of yield. In other words, this measures rises when a region, which previously had withstood a three year disaster, suffers weather-induced yield reductions when facing mild flooding or dry conditions. Three elements can lead to an increase in easily flooded and drought damaged area: a change in irrigated area; reduced efficiency of the water conservation systems (due to some problem such as erosion); and the increased impact of a 'three-year' event due to a deterioration of the environment. This variable is normalized by cultivated area in the equation.

[17] Results from tests for heterogeneous error terms from the models were mixed. In each of the equations, four tests were run (Greene, 1993), and in the case of the hybrid adoption equation two of the four indicate the presence of heterogeneity. However, only one test found heterogeneity in the other equations. To account for the possibility of heterogeneity, White's standard errors were reported in the OLS II version of the adoption equations in Table A.1 (see appendix), and the OLS II version of the yield equation in Table A.2 (see appendix). The t-ratios of the coefficients (which are identical with the OLS estimates since heterogeneity causes inefficiency, but not bias) in fact differ little from those in OLS I which did not account for heterogenous errors.

[18] Although representing less than half of China's provincial regions, the 13 sample provinces produce over 90 percent of China's rice output and cultivate more than 90 percent of the crop's sown area (ZGTJNJ, various years; 1991).

adoption rates (*HYBRID-ADOPT*) and information on rice sown area by season (*DOUBLE-ADOPT*) come primarily from a data base managed by the China National Rice Research Institute. These data are generally consistent with the information collected by each province's bureau of agriculture. Missing data for earlier years were collected by the authors through a mail survey sent to officials in the bureaus of agriculture of each province. Total area sown to rice, cultivated area, population, and other general variables since 1978 are from ZGTJNJ (various years) and ZGNYNJ (1981–1992). The Ministry of Agriculture provided data for earlier years. The environmental data (*SALINITY* and *DISASTER*) come from statistical compendia collected and organized by the Ministry of Water Resources and Electrical Power (MWREP, 1988–1990). Details of these variables are in footnotes 14 and 15. The *HRS* variable, which measures the cumulative proportion of households in China that had implemented decollectivization policies each year, comes from Lin (1992b).

The most unique part of the data set used in this study, permitting the estimation of a complete rice sector supply system, comes from China's national 'Cost of Production Survey.' This information is generated as part of a data-collection program run by the State Price Bureau since the mid-1970s (SPB, 1988–1990). Based on annual household surveys conducted by county Price Bureau personnel, detailed information is available by-crop and by-variety for over 50 variables, including both expenditure (in value terms) and quantity data.[19] Yields are measured as output per unit of sown area. The use of labor and fertilizer on rice (*LABOR* and *CHEMFERT*) come directly from the survey and are measured on a per sown hectare basis. The organic manure variable (*PROP-ORGANIC*) is created by dividing expenditures on organic manure by the total expenditure on all fertilizers. Rice and chemical fertilizer prices (P_r and P_f) are derived by dividing the quantity of the good into its total value. The construction of these average prices implicitly assumes that producers are responding to an average price, constructed of quantity-weighted state and market (or 'negotiated') prices. Under certain conditions (e.g., perfectly operating and complete markets), the appropriate price would be the marginal price faced by the producer (Sicular, 1988). Recent

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[19] Some people have questioned the reliability of the data, and criticized that it is based on a relative small sample size. A closer examination would indicate otherwise. In the 1990 enumeration, over 15000 households living in 2245 counties were questioned about their costs of production for the six major grain crops. Among these households, 4770 households from 710 counties were surveyed about the inputs they used on rice. These are the data, aggregated to the provincial level for each year, that are used in this paper. Price Bureau officials claim that they have maintained a random selection process. Consistency in the data is maintained by carrying over respondents for an average period of three to four years. Data are self-recorded by the households. During the last several years, these data have been published as SPB (1988–1990).

Table 3
List of variables used in adoption, yield, and factor demand equations

Variable name	Variable description
HYBRID-ADOPT	Proportion of total rice area sown to hybrid rice
DOUBLE-ADOPT	Proportion of total rice area sown to double-cropped rice (early plus late rice sown area)
RICEYIELD	Rice yields – Total rice output divided by total rice sown area
LABOR	Labor days per hectare devoted to rice production
CHEMFERT	Chemical fertilizer use per hectare for rice production
ORGANIC / FERTILIZER	Ratio of expenditure on organic manure to expenditure on all fertilizer, both chemical and organic
TECHAVAIL	Total rice sown area, lagged one year (proxy for technology availability assuming the induced innovation hypothesis)
YIELDGAP	In hybrid rice equation: Hybrid rice yields minus conventional variety yields, lagged one year; In double-cropping equation: Single-season yields minus double-cropping yields, lagged one year
INCOME	Real per capita rural income, lagged one year
TREND	Time trend: In hybrid rice equation: represents increase in production efficiency of hybrid rice seed In double-cropping equation: represents breakthroughs in conventional rice breeding In chemical fertilizer demand equation represents the supply constraint on fertilizer supply
HRS	Cumulative proportion of households adopting household responsibility system
POPDENSITY	Total cultivated area divided by rural population
P_r	Average rice price: Total rice revenues divided by total rice production
P_w	Wage in rural area, lagged one year in double-cropping equation.
P_f	Average chemical fertilizer price: Total chemical fertilizer expenditures divided by total chemical fertilizer consumption
SALINITY	Proportion of total cultivated land subject to salinization
DISASTER	Proportion of total crop area classified as 'easily flooded and drought damaged'

work by Lin (1993) demonstrates the importance of including both prices when explaining the behavior of Chinese farm households.[20] The wage variable (P_w) is defined as average annual earnings per agricultural laborer. The wage data come from provincial and national statistical yearbooks. Table 3 contains a list and brief definition of the variables included in the six equations.

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[20] Lin (1993) theoretically shows that if the producer's marketing quota is yield- or output-dependent (that is, if one year's quota is in some way linked to a previous year's production performance), then the producer's production decisions depend on both the quota and market price. The best specification would include both prices. Unfortunately, these data are unavailable and the 'mixed' price is used as a proxy.

5. The determinants of technological change

The results of the estimates for the coefficients of the hybrid rice and double-cropping adoption equations are reported in columns 1 and 2 of Table 4. Given the log form of the market size, income, wage, and population density variables, the coefficients on the these variables can be interpreted as changes in adoption levels due to percentage changes in these variables. In order to make the presentation concise, the estimates of the provincial dummies are omitted.

The estimated coefficients are nearly all as expected and significantly different from zero. The R^2 are 0.83 and 0.97 (bottom row, Table 4), indicating the strong explanatory power of the specifications. The results are robust to specification changes and functional form selection.[21]

The positive coefficients on the technology availability variable (*TECHAVAIL*) in both equations confirms the results of Lin (1992a). Assuming the operation of the Griliches (1957) hypothesis which states that high market demand will lead to the availability of technology, the positive and significant coefficient in the case of hybrid rice means that in areas where there is a large rice market, there is high level of hybrid rice adoption since producers have access to a wider choice of hybrid rice technology. Similar results in the double-cropping equation demonstrate the generalizability of these forces to other important technological decisions in China. There are alternative explanations. For example, the rice sown area variable may also be measuring the impact of government planning and procurement policies. High market delivery obligations for rice induce producers to expand sown area. The positive coefficient on *TECHAVAIL* (which is proxied by rice area) could mean that one way farmers meet their procurement burden is by the adoption of two-season rice technology.

Increasing costs of technology adoption due to the spread of the household responsibility system (*HRS*) in the early 1980s, however, appears to have slowed the spread of hybrid rice by 12 percent (Table 4, column 1, row 14). Decollectivization had less effect on double cropped area (the absolute value of its coefficient was 0.07). While this rather tenuous relationship between decollectivization and technology adoption may be rather surprising, it should be remembered that China was successful in rapidly extending new agricultural technology in the pre-reform era (Stone, 1988). Apparently after decollectivization there has been a gradual deterioration of the ability of the state to deliver new technology (Lin, 1991b). An alternative explanation may be that after the break up of the collective, farmers moved out of hybrids and double-cropping due to any number

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[21] All explanatory variables are specified in log form except the yield gap, time trend and HRS variables. Estimates from a specification in the linear form produced elasticities of comparable magnitude, and did not substantially change the decomposition results. Table A.1 in the appendix reports the estimates from two alternative estimators, OLS and a Tobit Model. The coefficients vary little among the alternatives in either magnitude or level of significance.

Table 4
Rice yield and input demand system, estimated by iterative three stage least squares, 1975–90 [a]

Variables	Code name	Hybrid rice (*HYBRID*)	Double rice (*DOUBLE-ADOPT*)	rice yields (*RICEYIELD*)	Input demand equations		
					Chemical fertilizer (kg/ha) (*CHEMFERT*)	Labor (day/ha) (*LABOR*)	Organic fert. ratio (*ORGANIC / FERTILIZER*)
Intercept		−2.88 (−2.66)	−6.92 (−5.04)	6.93 10.33)	−45.18 (−3.74)	330.42 (4.63)	0.27 (3.49)
$(P_f / P_r)^{1/2}$	Price ratios			−1.01 (−3.26)	−30.69 (−0.21)	5448.80 (1.54)	
$(P_w / P_r)^{1/2}$	Price ratios			0.02 (3.40)	18.83 (6.28)	4885.50 (1.80)	10.72 (3.50)
Ln(Market size)$_{t-1}$	*TECHAVAIL*	0.41 (3.30)	0.86 (6.65)				
Yield gap$_{t-1}$	*YIELD GAP* [c]	0.001 (0.04)	−0.02 (−1.37)				
HRS * Yield gap$_{t-1}$	*HRS * YIELDGAP*	0.06 (4.59)	−0.07 (−5.22)				
Ln(Income)$_{t-1}$	*INCOME*	−0.09 (−1.77)					

Ln(Wage)_{t-1}	*WAGE*		−0.09 (−2.12)				
Ln(Population density)	*POPDENSITY*		0.45 (2.09)				
Hybrid rice adoption [b]	*HYBRID-ADOPT*			2.44 (9.18) (9.18)	219.65 (1.16)	−198.98 (−4.12)	
Double-rice adoption [b]	*DOUBLE-ADOPT*			−1.93 (5.31)	827.84 (6.37)	92.38 (1.58)	
Severity of disaster	*DISASTER*			−1.53 (−3.28)			
Salinization	*SALINITY*			−12.07 (−3.34)			
Household responsibility	*HRS*	−0.12 (−2.960	0.07 (2.06)	0.47 (3.86)	−80.57 (−1.65)	−135.86 (−5.72)	−0.18 (−6.98)
Time	*TREND*	0.05 (13.49)	−0.01 (−1.96)		17.26 (2.10)		
R^2		0.83	0.97	0.92	0.81	0.84	0.65

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[a] Figures in parentheses are *t*-values. Provincial dummies are not shown.

[b] P_i is fertilizer price in the rice yield equation, while it is the rice price for all input demand equations; P_j is the wage for the rice yield and chemical fertilizer demand equations, while it is the chemical fertilizer price in the chemical and organic fertilizer demand equations; P_k is the rice price for the rice yield equation, fertilizer price for the chemical fertilizer equation, and wage for the labor and organic fertilizer demand equations.

[c] Yield gap variable defined differently in each equation – see Table 3.

of constraining factors at the household level (e.g., they were cash constrained or labor short during the peak season).

All other things equal, however, profit-seeking farmers and cost conscious local leaders in China appear to adopt these newly available varieties more frequently if they are more profitable, overcome production constraints, or save on scarce resources. Given the small difference between the prices between hybrid and conventional rices during much of the sample period, the positive sign on the coefficient of *YIELDGAP* in the hybrid rice equation shows that producers choose new technologies based on the profits associated with higher expected yields. Likewise, as the yields of single season rice rise relative to those of double cropped rice, there is a movement away from cultivating rice in two seasons. And this profit seeking behavior appears to be growing stronger over time. Similar to Lin (1991a), the interaction terms between profitability and institutional innovation are positive and significant in both equations. Hence, while HRS may have put a drag on the supply of new technology, demand factors favor the spread of technology which increases the profitability of farming.

The role of taste preferences in the hybrid rice adoption decision is demonstrated by the negative sign on the coefficient of the income variable (*INCOME*). Producers in economically well-off areas apparently can afford to forego the additional yields provided by hybrid varieties so they can consume higher quality conventional varieties. This trend, which has been slowly unfolding throughout the 1980s, has accelerated since 1991. Many counties in the rapidly growing east coast areas report sharp shifts away from hybrid rice in the 1992 and 1993 planting season, citing the desire for higher quality as their primary motive for the change. In future studies as the output price of rice is allowed to fluctuate and quality begins to be reflected in the price, it will be necessary to include variety-specific prices to fully account for the quality premium.

The negative (and significant) sign on the coefficient of the wage variable (P_w) points to the influence that wages exert on cropping pattern selection. Rising wages in the east coast provinces are responsible for the movement to single-cropping in these areas. The magnitude of the coefficient (-0.09) means that as wages double, the proportion of area sown to two-season rice drops by 9 percent. In some regions the wage factor may be a significant determinant of double-cropping, since wages have risen several times in real terms during the 1980s.

The negative sign on the coefficient of the time trend (*TREND*) variable and the positive sign on that of the population density (*POPDENSITY*) variable in the double cropping equation are consistent with the results implied by the wage variable and support the induced innovation hypothesis. Likewise, given equal levels of wages, areas with scarce land resources (as measured by *POPDENSITY*) require technologies that conserve on land, which is the role of double-cropping technologies. The positive coefficient on the time trend variable (*TREND*) in the hybrid equation (0.05 in net regression terms) in part supports the earlier conjecture (and previous research; He et al., 1984) that the seed production process has been a limiting factor to the spread of hybrid rice in the early years. The development of seed production capacity (and other cultivating techniques) has facilitated the expansion of hybrid rice production at a rate of 5 percent per annum.

6. Rice yield and factor demand results

The yield and factor demand equations of the rice sector model also produce robust results consistent with most a priori expectations (Table 4, columns 3–6). Table 8 in the appendix demonstrates that similar estimates are obtained when using OLS and Two Stage Least Squares specifications.[22] The R^2 for the rice yield equation is 0.92; those for the three factor demand equations range from 0.84 to 0.65. A special case of Breush and Godfrey's Lagrangian multiplier test proposed by McGuirk et al. (1993) showed that there was no serious serial correlation in the error term.

The coefficients of the price variables (rows 2 and 3) have relatively high t-ratios and the expected signs except for the wage variable in the yield equation.[23] The price elasticities implied by these estimates are presented in Table 5 (top three rows). The own price elasticities for rice (0.06), fertilizer (-0.681), and labor (-0.247) are all of the expected sign. The small yield response of rice to an increase in its own price is consistent with other Asian economies with strong government intervention (Rao, 1989). In many areas, there are also administrative pressures put on farmers to maintain high yields even when prices fall (Rozelle, 1994). The own price elasticities for fertilizer and labor demand are relatively high, showing the price responsiveness of input demands to changes in factor prices. This should be encouraging to those leaders who argue that China should

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[22] In addition to estimating the model presented in this paper a number of alternative specifications were tried in order to check the consistency of the estimates across the regions of China. Specifically, all of the continuous regressors were allowed to vary by region by including a slope dummy variables for each of the four major economic-geographic regions in rice-growing China, east China (Jiangsu, Shanghai, Zhejiang and Anhui), south China (Fujian, Guangdong and Guangxi), central China (Hubei, Hunan and Jiangxi) and southwest China (Sichuan, Guizhou and Yunnan). In addition, a number of interaction terms were included between the HRS variable and other behavioral variables. These alternative specifications made little impact on the overall performance of the model. Only 2 of the 12 slope dummy variables, and only one of the additional interaction terms were significant. Most importantly, these specification changes had little impact on the estimates of the coefficients of either the technology or institutional innovation variables.

[23] There are several plausible explanations for this sign. It may be the case that as wages rise, previously binding liquidity constraints are relaxed allowing producers to increase yields through to use of more material inputs. In addition, it also may be that the wage coefficient is contaminated by simultaneity bias; wages are higher in more productive, higher-yielding regions (since the wage must equal the marginal productivity of labor).

Table 5
Rice yield and input demand elasticities evaluated at the sample mean, 1975–90

	Rice yield	Fertilizer		Labor
		Chemical	Organic	
Rice price	0.006	−0.024		0.130
Fertilizer price	−0.107	−0.681	0.308	0.117
Wage	0.102	0.705	−0.308	−0.247
Hybrid rice adoption	0.101	0.067		−0.087
Double cropping rice adoption	−0.249	0.788		0.125
Severity of disasters	−0.023			
Severity of salinization	−0.083			

rely more on factor price policies. The positive signs on the cross price elasticities between labor and fertilizer (0.117 and 0.705) are consistent with the results of Ye and Rozelle (1993) who find that in the reform era fertilizer and labor have become substitutes in production.[24] The positive sign on the chemical fertilizer price to wage ratio variable in the organic fertilizer equation shows how rising wages (especially relative to fertilizer price) has contributed to the decline in the use of organic manures and other composting activities.

The coefficients of the shifter variables in the rice-yield response equation have the expected signs and are significant. The importance of the technology variables in the determination of China's rice yields can be seen from the value of their elasticities (Table 5). If the adoption rates of hybrid rice and single season rice simultaneously increase by 10 percent, rice yields increase by 3.50 percent (the sum of the elasticities, 0.101 + 0.249).

Technological choice also influences the optimal use of fertilizer and labor in rice production. The negative net regression coefficient for the hybrid rice variable in the labor equation suggests that the technology may be labor-saving.[25] The coefficient on the two-season rice technology variable in the labor equation is positive and the elasticity relatively large indicating the extra effort which is required to double-crop even though LABOR is measured on a sown area basis.

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[24] In China's reform economy where factor markets are still developing, there is a fear that factors (such as labor) may not be available during crucial peak season periods (Rozelle, 1994). If farm households are still required to hit high yield targets (e.g., because they are burdened with high quota allotments), there is a preference to substituting farm chemicals for own family labor instead of relying on migrant labor.

[25] Although the elasticity is small (Table 5), this result is of interest; the data used in this study (discussed earlier) and field research on this issue have generated mixed outcomes. Farm household surveys conducted in central Jiangsu Province in Eastern China by Ye and Rozelle (1993) and Rozelle (1991) find that farmers use significantly more labor in hybrid rice production. Lin (1992a and Lin, 1994), on the other hand, reports that Hunan farmers in Central China use less labor on hybrid rice. The results in this paper show nationwide, net of the effect of other factors, hybrid rice producers use less labor.

Institutional factors are also important determinants of yields and factor demands. The incentive effect of decollectivization on agricultural productivity, which has been reported for aggregate crop production (Lin, 1992b) and on the aggregate output of the non-industrial rural economy (McMillan et al., 1989; Fan, 1991), is also present in rice productivity (see the 0.47 coefficient on the *HRS* variable in the yield equation, Table 4, row 14). The strong negative impact that the reforms have had on labor and organic manure use show how increased effort has enabled true labor input to rise even though the number of labor days has fallen.

The coefficients of the two environmental stress variables, *SALINTY* and *DISASTER*, are both negative and their corresponding elasticities are of similar sign and magnitude to those estimated in Huang and Rozelle (1996). The positive coefficient on the time trend variable (*TREND*) in the chemical fertilizer equation may imply that supply constraints in this sector have suppressed demand; its use has been increasing at a rate in excess of the amount changes in prices would justify.

7. Sources of yield growth

Between 1975 and 1990, rice yields actually increased by a total of 2.082 tons per hectare (Table 3, column 3). This paper's results have identified a number of factors that have been influential in the determination of this growth. One of the main objectives of this paper is to identify which factors have made the biggest contributions. Also, do the sources of yield growth differ between the early reform period when decollectivization was being implemented (1978–84), and in more recent times (1985–90) after the one-time impact of the reform measures were realized? What role has technological change played in these periods, and how has technology interacted with the institutional innovations? Decomposition analysis can be used to distinguish the contribution of the different determinants of yield growth. Three decompositions are conducted: over the whole period, 1975–90, and during two critical sub-periods, 1978–84, and 1985–90. Based on the estimated coefficients reported in Table 4, the results are reported in Table 6. Moreover, these results are robust to the use of coefficients estimated under alternative assumptions (see Table 9 in the appendix).

Perhaps the most surprising result of the analysis is that while institutional innovations are important, technology has contributed the most to rice yield growth during the period 1975–90. Improvements in technology have contributed 60.0 percent of the growth of rice yields, accounting for 1.247 tons per hectare (Table 6, column 3). Hybrid rice adoption is responsible for most of the technical change component (1.109 tons of the 1.247 tons arising from technology), and 49.0 percent of the total change. The expansion of single-season area (with improved varieties) contributed 11.0 percent of the overall rice yield increase.

Table 6
Decomposition changes in rice prodictivity in China by source, 1975–90

Sources		1975–90			1978–84			1985–90			1978–84
	Estimated coefficient (1)	Change in explanatory variable (2)	Yield changes (percent) (3) = (1) * (2)	Std error (4)	Change explanatory variable (5)	Yield changes (percent) (6) = (1) * (5)	Std error (7)	Change in explanatory variable (8)	Yield changes (percent) (9) = (1) * (8)	Std error (10) (9) = (1) * (8)	Model without technology variables yield changes(11)
I. Technologies			1.247 (60.0)	0.152		0.504 (38.8)		0.067	(132.4)	0.496	0.058
–Hybrid rice	2.444	0.417	1.019 (49.0)	0.111	0.143	0.348 (26.8)	0.038	0.184	0.449 (119.9)		
–Indirect HRS [a]	2.444	− 0.062	− 0.152 − (7.3)		− 0.062	− 0.139 (− 10.7)		− 0.000	− 0.000 (− 0.1)		
–Cropping system	− 1.928	− 0.118	0.228 (11.0)	0.043	− 0.081	0.156 (12.0)	0.029	− 0.024	0.047 (12.4)	0.009	
–Indirect HRS [a]	− 1.928	0.037	− 0.071 (− 3.4)		0.037	− 0.052 (− 4.0)		0.000	− 0.000 (− 0.0)		

II. Direct HRS [a]	0.470	0.990	0.465 (22.3)	0.121	0.984	0.462 (35.6)	0.120	0.003	0.001 (0.4)	0.000	1.158 (89.2)
III. Environmental effects			−0.185 (−8.9)	0.063		−0.058 (−4.4)	0.019		−0.082 (21.8)	0.024	−0.024 (−1.8)
-Disaster	−1.530	0.082	−0.125 (6.0)	0.038	0.017	−0.025 (−1.9)	0.008	0.037	−0.057) (−15.1)	0.017	−0.006 (−0.4)
-Salinity	−12.073	0.007	−0.085 (−4.1)	0.025	0.003	−0.033 (−2.5)	0.011	0.002	0.025 (−6.7)	0.007	−0.018 (−1.4)
IV. Residuals (inputs and others)			0.580 (12.6)			0.390 (30.0)			−0.041 (−11.0)		0.164 (12.6)
Total			2.082 (100)			1.298 (100)			0.374 (100)		1.298 (100)

[a] Indirect HRS effects are those associated with the net negative impact that HRS has on technology adoption (Table 5). Direct effects are those associated with the positive incentive effect report in the yield equation (Table 6). The 'change in explanatory variable' (columns 2, 5, and 8; rows 3 and 5) are the net changes in the technology adoption levels due to the impact of HRS as calculated from the coefficients in Table 5.

Between 1975 and 1990, the implementation of HRS was the second most important factor; institutional changes have augmented rice yields by 22.3 percent. In contrast, natural disasters and salinization (reported in Table 8 as 'Environmental Factors') led to a 185 kilogram per hectare loss in rice yields. [26] The rest of the growth (captured in the 'Residual' component) is accounted for by increases in inputs and non-hybrid rice related technological change.

The results in Table 6, columns 5–7, facilitates comparisons of the results of this study's decomposition analysis with those of previous research by providing a breakdown for the period coinciding with the early rural reforms, 1978–1984. Even during this period of intense institutional change, 38.8 percent (Table 6, row 1) of the 1.298 tons of rice yield increase was contributed by technological factors, 26.8 percent of the total from hybrid rice. The decomposition exercise shows that 35.6 percent of the rice yield improvements was due to the implementation of *HRS*. Over a same time period Lin (1992b) estimates the shift from collective production to the *HRS* created 47 percent of agricultural output growth and over 90 percent of agricultural productivity growth. Using a growth accounting procedure, McMillan et al. (1989) estimate that over 60 percent of the rise in agricultural productivity can be attributed to decollectivization.

What accounts for these differences? It may be that technological change has been sharper in the rice sector. Or, institutional innovations could have had somewhat less effect in rice areas where the technology depends on good water control and careful pest and crop management, tasks that have an important collective component. However, two pieces of evidence demonstrate that when technology is explicitly specified and modelled as an endogenous decision, as has been done in this paper, the estimated importance of technological change rises dramatically. When accounting for the indirect impact of HRS through its effect on technology, it appears that even the *HRS* impact is overstated. Rows 3 and 5 of Table 6 contain estimates of the *net negative* impact that the institutional changes had on technology adoption. The term in each row accounts for both the negative supply and positive demand components of the impact of *HRS* on technology adoption (see discussion in previous section). Hybrid rice would have increased rice yields by an additional 10.7 percent in the period 1978–84 if adoption had not fallen in areas where HRS was implemented (Table 6, column 6, row 3).

Moreover, when the technology variables are not included in the model (using a specification just as in Table 4, column 3, but without *HYBRID-ADOPT* and *DOUBLE-ADOPT* variable), [27] the decomposition exercise shows that 89.2 percent of the change to rice yields between 1978–84 are due to institutional

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[26] The impact on rice yields is about the same as those found in Huang and Rozelle (1996), who estimate that during the same period total grain yields fell by 8.1 percent due to environmental factors.

[27] The results of a production function analysis (comparing the HRS coefficients from yield response models with and without technology explicitly included) shows that the omission of the technology variable leads to an overestimation of the impact on rice yields of *HRS* by over 20 percent.

innovation (Table 6, column 11, row 6). This magnitude is remarkably close to Lin's calculation. It may be that institutional innovations did contribute more in the overall agricultural sector (the subject of Lin's inquiry) than in the rice subsector. But, one cannot overlook the possibility that the HRS effect is overstated when the impact of technology is not explicitly accounted for.

The importance of technological change in the long-run growth of China's agricultural economy is most vividly illustrated by the decomposition analysis in the post-HRS period (Table 6, columns 8–10). While the increase in overall rice yields in the period 1985–90 is less than those in 1978–84 (374 kg per hectare versus 1.298 tons per hectare – Table 6, bottom row), virtually all of the growth in the latter period comes from technological change. Without technological change, environmental stress and other factors (rows 7 and 10) would have caused the increase in rice yields to be 32.8 percent lower (−21.8 − 11.0).

8. Conclusions

The purposes of this paper are to identify the determinants of technological adoption in rice growing regions of China and measure the importance of technological change in the growth of rice yields in the reforming rural economy. Adoption of new technologies is shown to depend on two basic factors: the availability of a new technologies and their profitability. In addition, taste preferences and the relative scarcity of key factors (e.g., labor) also induces producers to demand technologies that use less of that input. Even though China still has a partially planned economy, the results of this paper demonstrate that some of the important elements of induced innovation are present in China's rural economy. Interestingly, everything else equal, decollectivization raised the cost of adopting new technology which led to lower adoption levels of hybrid rice. This decrease, however, has been partially offset by the willingness of profit-seeking farmers to use new technologies. It might also be that during China's collective period, the government was successful in pushing new technology through a variety of means, including administrative decree. Hence, some of the drop in technology use may represent the situation where farmers are drifting back to more appropriate levels as described by Lardy (1983) and Weins (1982).

Whatever its means of extension, what is clear is that technological change has been the primary determinant of yield growth in rice growing China. Even during reform period when the HRS increased the incentives of farmers to produce more efficiently, technological change is shown to have contributed to nearly 40 percent of the growth in rice yields. The paper's results demonstrate that when technological change is specified explicitly (as the proportion of rice sown to hybrid varieties), the proportion of yield change due to technology exceeds the fraction contributed by HRS, which was found by previous researchers to be the most important factor (McMillan et al., 1989; Lin, 1992b). But even if the order of importance was reversed in the agriculture as a whole in the early 1980s, the institutional reforms were one time only events. In the late 1980s, all of the growth in yields arise from technological change. In fact, the positive effect of technology has helped offset the downward drag on yields caused by environmental problems and other factors, such as the reduction in the use of inputs due to rising input prices relative to those of output.

In the future, China will still rely on technology as the engine of productivity growth. Unfortunately, there are signs that China research system itself is being negatively affected by budget cutbacks and other measures in recent years (Lin, 1991b; Conroy, 1988; Fan and Pardey, 1992). According to officials, efforts to 'privatize' the research system are based on the need to make institutes more responsive to the needs of society. The results of this paper suggest that these signals on the supply side were already being transmitted quite efficiently, in a manner similar to that observed in market economies (Hayami and Ruttan, 1985). More likely, budget pressures have forced cutbacks and other cost-saving and revenue-generating reforms. There is a danger that such measures could induce Chinese researchers to turn away from the basic types of research work which has carried the sector for these many years to more applied work which is patentable and is more likely to lead to greater short-run profit in the commercial sector. If China wants to maintain its high yield levels, the long term consequences of a breakdown of China's research system on the nation's agricultural sector can be found in the results of the final decomposition analysis. Without new technology China will almost certainly face serious domestic shortfalls in the future.

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Appendix A

This appendix presents Tables 7, 8 and 9.

Table 7
Estimations for hybrid rice adoption and double-cropped rice equations in China using alternative estimators, 1975–90 [a]

Variables	Code name	Hybrid rice adoption rate (*HYBRID-ADOPT*)			Double-cropped rice ratio (*DOUBLE-ADOPT*)		
		Model 1OLS I	Model 2OLS II [b]	Model 3Tobit [c]	Model 1OLS I	Model 2OLS II [b]	Model 3Tobit [c]
Intercept		−3.21 (−2.76)	−3.21 (−2.48)	−2.60 (−2.24)	−7.13 (−4.77)	−7.13 (−3.47)	−7.20 (−4.86)
Ln(Market size)$_{t-1}$	*TECHAVAIL*	0.45 (2.71)	0.45 (2.91)	0.37 (2.71)	0.90 (6.47)	0.90 (4.82)	0.90 (6.40)
Yield gap$_{t-1}$	*YIELDGAP* [d]	0.01 (0.83)	0.01 (0.68)	0.04 (2.40)	−0.02 (−0.95)	−0.02 (−1.14)	−0.01 (−0.91)
Household responsibility	*HRS*	−0.10 (−2.44)	−0.10 (−2.61)	−0.09 (−2.22)	0.07 (−1.95)	0.07 (1.68)	0.07 (2.05)
Interaction term– HRS * Yield Gap$_{t-1}$	*HRS * YIELDGAP*	0.05 (3.50)	0.05 (3.27)	0.03 (1.92)	-0.07 (−4.75)	−0.07)(−4.44)	−0.07 (−4.79)
Ln(Income)$_{t-1}$	*INCOME*	−0.070 (−1.33)	−0.070 (−1.33)	−0.08 (−1.51)			
Ln(Wage)$_{t-1}$	P_w				−0.08 (−1.78)	−0.08 (−1.78)	−0.08 (−1.72)
Ln(Population density)	*POPDENSITY*				0.38 (1.58)	0.38 (1.15)	0.39 (1.68)
Time trend	*TREND*	0.04 (11.96)	0.04 (12.6)	0.05 (10.94)	−0.01 (−1.62)	−0.01 (−1.35)	−0.01 (1.85)
Log-likelihood value		243.28	243.2	219.3	261.48	261.48	252.6
R^2 between observed and predicted		0.82	0.82	0.87	0.96	0.96	0.97

Table 8
Rice yield equation using alternative estimators, 1975–90 [a]

		Rice yields (*RICEYIELD*)		
Variables	Code name	Model 1OLS I	Model 2OLS II [b]	Model 3Tobit + 2SLS [c]
Intercept		6.37	6.37	6.86
		(9.13)	(9.55)	(9.97)
$(P_f/P_r)^{1/2}$	Price ratios	−1.15	−1.15	−1.21
		(−3.63)	(−3.02)	(−4.29)
$(P_w/P_r)^{1/2}$	Price ratios	0.03	0.03	−0.02
		(3.82)	(3.99)	(3.00)
Hybrid rice adoption	*HYBRID-ADOPT*	2.30	2.30	−2.65
		(10.66)	(10.63)	(−8.92)
Double-rice adoption	*DOUBLE-ADOPT*	−1.37	−1.37	−2.13
		(−4.28)	(−4.52)	(−5.03)
Severity of disaster	*DISASTER*	−1.29	−1.29	−1.87
		(−2.58)	(−2.15)	(−3.87)
Salinization	*SALINITY*	−9.48	−9.48	−8.95
		(−2.44)	(−2.63)	(−2.52)
Household responsibility	*HRS*	0.50	0.50	0.47
		(4.33)	(4.55)	(3.93)
R^2		0.91	0.91	0.92

[a] Figures in parentheses are t-values. Provincial dummies are not shown.

[b] Coefficients are the same as those in OLS I, but standard errors use White's methods of correcting for heterogeneity.

[c] Reported equation is one of a system of 4 equations Estimated by Two Stage Least Squares with predicted value of technology adoptions using Tobit estimation (appendix, Table 7). Other equations in systems (not shown) are for chemical fertilizer, labor, and organic fertilizer.

Notes to Table 7:

[a] Figures in parentheses are t-values. Provinces dummies are not shown.

[b] Coefficients are the same as those in OLS I, but standard errors use White's method of correcting for heterogeneity.

[c] Reported parameters are the net regression coefficients. The figures in the parentheses are absolute asymptotic t-values.

[d] Yield gap variable is defined differently in each equation – see Table 3.

Table 9
Decomposition changes in rice productivity in China by source, 1975–90 [a]

	Yield changes [b]			
	Model I, OLS		Model 3, Tobit + 2SLS	
Sources	1978–84	1984–90	1978–84	1984–90
I. Technologies	0.439	0.456	0.551	0.538
	(33.8)	(121.9)	(42.4)	(143.8)
- Hybrid rice	0.328	0.423	0.379	0.487
	(25.3)	(113.0)	(29.1)	(130.1)
- Indirect HRS	−0.116	−0.164	−0.000	
	(−8.9)	(−0.1)	(−12.7)	(−0.1)
- Cropping System	0.111	0.033	0.173	0.051
	(8.5)	(8.8)	(13.3)	(13.7)
- Indirect HRS	−0.052	−0.000	−0.080	−0.000
	(−4.0)	(−0.0)	(−6.2)	(−0.1)
II. Direct HRS	0.492	0.002	0.459	0.001
	(37.9)	(0.4)	(35.3)	(0.4)
III. Environmental effects	−0.047	−0.068	−0.056	−0.087
	(−3.6)	(−18.1)	(−4.3)	(−23.4)
- Disaster	−0.021	−0.048	−0.032	−0.069
	(−1.6)	(−12.8)	(−2.4)	(−18.4)
- Salility	−0.026	−0.020	−0.024	−0.018
	(−2.0)	(−5.3)	(−1.9)	(−5.0)
IV. Residuals	0.414	−0.016	0.344	−0.079
	(31.9)	(−7.8)	(26.6)	(−20.0)
Total	1.298	0.374	1.298	0.374
	(100)	(100)	(100)	(100)

[a] Figures in the parentheses are the percentage change of rice yield.

[b] Calculated from coefficients in Table 8 (appendix), columns 1 and 3.

References

CAAS/HAAS, 1991, The development of hybrid rice in China (China Agricultural Press, Beijing, China).

CNRRI (China National Rice Research Institute), 1993, Rice economy database (China National Rice Research Institute, Hangzhou).

Conroy, Richard, 1987, The disintegration and reconstruction of the rural science and technology system, In: A. Saith, ed., The reemergence of the Chinese peasantry (Croom Helm Press, London).

Conroy, Richard, 1988,

Diewert, W., 1971, An application of the Shephard duality theorem: A generalized Leontieff production function, Journal of Political Economy 79, 481-507.

Donnithorne, A., China's economic system (Praeger Press, New York, NY).

Fan, S., 1991, Effects of technological change and institutional reform on production growth in Chinese agriculture, American Journal of Agricultural Economics 73, 266-275.

Fan, S. and P. Pardey, 1992, Agricultural research in China: Its institutional development and impact (International Service for National Agricultural Research, The Hague, Netherlands).

Greene, William. H., 1993, Econometric analysis (Macmillan Publishing Company, New York).

Griliches, Z., 1957, Hybrid corn: An exploration in the economics of technological change, Econometrica 25, 501-522.

Hausman, J., 1983, Specification and estimation of simultaneous equations models, In: Zvi. Griliches and M. Intriligator, eds., Handbook of econometrics (North-Holland Press, Amsterdam).

Hausman, J., 1978, Specification tests in econometrics, Econometrica 46, 1251-1271.

Hayami, Y. and V. Ruttan, 1985, Agricultural development: An international perspective (second edition) (John Hopkins University Press, Baltimore, MD).

He, G., X. Zhu and J. Flinn, 1987, A comparative study of economic efficiency of hybrid and conventional rice production in Jiangsu Province, China, Oryza, 285-296.

He, G., A. Te, L. Travers, X. Lai and R. Herdt, 1984, The economics of hybrid rice production in China, IRRI research paper series, no. 101 (International Rice Research Institute, Los Banos, Philippines).

Huang J. and M. Rosegrant, 1993, Grain supply response in China: A preliminary analysis, Paper presented at the second workshop on projections and policy implications of medium and long term rice supply and demand (International Rice Research Institute, Los Banos, Philippines) April.

Huang, J. and S. Rozelle, 1996, Environmental stress and grain yields in China, American Journal of Agricultural Economics, forthcoming.

IRRI (International Rice Research Institute), 1990–1991, World rice statistics (1990 and 1991) (Department of Social Sciences, International Rice Research Institute Press, Los Banos, Philippines).

Lardy, N., 1983, Agriculture in China's modern economic development (Cambridge University Press, Cambridge).

Lin, J., 1991a, The household responsibility system reform and the adoption of hybrid rice in China, Journal of Development Economics 36, 353-373.

Lin, J., 1991b, Prohibitions of factor market exchanges and technological choice in Chinese agriculture, Journal of Development Studies 27, no. 4, 1-15.

Lin, J., 1992a, Hybrid rice innovation in china: a study of market-demand induced technological innovation in a centrally planned economy, Review of Economics and Statistics 74, no. 1, 14-20.

Lin, J., 1992b, Rural reforms and agricultural growth in China, American Economic Review 82, no. 1, 34-51.

Lin, J., 1993, Government procurement and rice supply response in China, Paper presented at the Second Workshop on Projections and Policy Implications of Medium and Long Term Rice Supply and Demand (International Rice Research Institute, Los Banos, Philippines) April.

Lin, J., 1994, Impact of hybrid rice on input demand and productivity, Agricultural Economics 10, no. 2, 165-178, April.

Lin, S.C. and S.K. Min, 1991, Rice varieties and their geneology in China (Shanghai Science and Technology Press, Shanghai, China).

Ma, N., P. Caulkins and S. Johnson, 1989, The household responsibility system: Technical and allocative efficiency vs. equity, in: J. Longworth, ed., China's rural development miracle, with international comparisons (University of Queensland, Queensland, St. Lucia, Qld).

Maddala, A., 1983, Limited and qualitative variables in econometrics (Cambridge University Press, Cambridge).

McGuirk, Anya, Paul Driscoll and Jeff Alwang, 1993, Misspecification testing: A comprehensive approach, American Journal of Agricultural Economics 75, no. 4, 1044-1055.

McGuirk, Anya and Yair Mundlak, 1991, Incentives and constraints in the transformation of the Punjab, Research report 87 (International Food Policy Research Institute, Washington, DC).

McMillan, J., J. Whalley and L. Zhu, 1989, The impact of China's economic reforms on agricultural productivity growth, Journal of Political Economy 97, 781-807.

MWREP (Ministry of Water Resources and Electric Power), 1988–1990, Compiled statistics on the development of China's water conservancy system (1988, 1989, and 1990) (Ministry of Water Resources and Electric Power, Beijing).

Oi, Jean, 1989, State and peasant in contemporary China: The political economy of village government (University of California Press, Berkeley, CA).

Perkins, D. and S. Yusuf, 1984, Rural development in China (The Johns Hopkins University Press, Baltimore, MD).

Putterman, Louis, 1993, Continuity and change in China's rural development (Oxford University Press, New York).

Rao, J.M., 1989, Agricultural supply response: A survey, Agricultural Economics 3, 1-22.

Rosegrant, Mark and ? Faisl, 1993, Supply response in Asia's rice economy, Paper presented at the Second Workshop on Projections and Policy Implications of Medium and Long Term Rice Supply and Demand (International Rice Research Institute, Los Banos, Philippines) April.

Rozelle, S., 1991, The economic behavior of village leaders in China's reforming economy, Ph.D. dissertation (Department of Agricultural Economics, Cornell University, Ithaca, NY).

Rozelle, S., 1994, Decision making in China's rural economy: The linkages between village leaders and farm households, China Quarterly 137 (March), 99-124.

Rozelle, S. and A. Boisvert, 1994, Quantifying the multiple objectives of village leaders in China, Journal of Comparative Economics 24 (March), 44-66.

Sicular, T., 1988, Plan and market in China's agricultural commerce, Journal of Political Economy 96.

SPB, 1988–1990, National agricultural production cost and revenue information summary (in Chinese) (China Price Bureau Press, Beijing).

Stone, B., 1988, Developments in agricultural technology, China Quarterly 116.

Tian, J.Y., 1992, Accelerate the pace of reforms: Strive for higher quality and higher efficiency in agriculture (in Chinese), Renmin Ribao [People's Daily], p. 3, July 3.

Weins, T., 1982, The limits to agricultural intensification: The Suzhou experience, China under the four modernizations, part I (US Government Printing Office, Washington, DC) 462-474.

Xu, S.J., W.L. Pan and K. Xu, 1991, Research and application of super high yield seed production technologies, Hybrid Rice, special issue.

Ye, Q., 1994, Fertilizer policy in China's reforming economy, Canadian Journal of Agricultural Economics 42 July, 191-208.

Ye, Q. and S. Rozelle, 1993, Fertilizer demand and economic reforms: The effectiveness of China's fertilizer distribution policies, Working paper (Food Research Institute, Stanford University, Stanford, CA).

Yuan, L.P. and H.X. Chen, 1988

Yuan, L.P. and H.X. Chen, 1991, The breeding and cultivation of hybrid rice (in Chinese) (Hunan Science and Technology Press, Changsha, China).

ZGNYNJ, 1981–1992, China agricultural yearbook (in Chinese) (China Agricultural Press, Beijing).

ZGTJNJ, various years, China statistical year book (in Chinese) (1980, 1986-1992) (China Statistical Press, Beijing).

Zhang, Y.K., J. Min, Y.K. Luo, M.J. Wu and J.P. Ge., 1991, Research on the quality of rice breeding system in the seventh five-year plan (in Chinese), Zhejiang Nongye Kexue (Zhejing Agricultural Sciences), no. 6.