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Impact of hybrid rice on input demand and productivity

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Abstract

This paper uses farm-level data collected from a sample of 500 households in Hunan province, China, to analyze the impact of hybrid rice on input demand and productivity. Based on regression analyses, it is found that, compared with conventional modern varieties, hybrid rice uses about 4% less labor inputs, 2% less draft animal services, and 6% more chemical fertilizers. The lesser requirements for labor and draft animal services probably arise from hybrid rice's lower seeding rate. Due to heterosis and high seed costs, the use of F_1 seed is economized to about one-third to one-fourth that of conventional varieties. Therefore, less labor and animal power is needed for seed-bed preparation and transplanting. It is also found that, given the same level of inputs, the yield advantage of hybrid rice over the conventional modern varieties is about 19%. Because of the productivity potential, hybrid rice is a candidate for the second-generation "Green Revolution" in other parts of Asia.

1. Introduction

Despite its many shortcomings concerning economic development, the socialist system in China seems to have contributed remarkably to China's rice research. China began the full-scale distribution of semi-dwarf rice varieties with high-yield potential in 1964, two years earlier than the first release of International Rice Research Institute's varieties, which marked the beginning of the Green Revolution in Asia. The diffusion of semi-dwarf varieties was rapid in China. By the end of the 1970s, more than 80% of the rice crop area was planted in the improved varieties. The commercial development of F_1 hybrids in 1976 was the second most important achievement of China's rice research. In 1990, about 40% of China's rice area was planted in hybrid rice. So far, China remains the only country in the world that produces hybrid rice commercially. [1]

There have been substantial studies concerning the nature and productivity impact of the Green Revolution in other economies. It has been found that the semi-dwarf varieties have undisputable yield advantages over the traditional varieties and that the technology embodied in the

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[1] For an historical overview of the innovation and diffusion of hybrid rice, see Lin (1991a). The development of hybrid rice in China can be interpreted as an innovation induced by market demand. For a test of this hypothesis, see Lin (1992).

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Table 1
Characteristics of sample farm households

	Hill		Lake-Plain		Mountain
	Tiaojian ($N = 100$)	Xiangxiang ($N = 100$)	Nanxian ($N = 100$)	Anxiang ($N = 100$)	Zhijiang ($N = 100$)
Mean household size (person)	4.28	4.26	4.59	4.60	4.20
Mean labor force (person)	3.11	3.32	3.40	3.61	3.26
Mean farm size (ha)	0.33	0.31	0.54	0.56	0.40
% of paddy land	79.3	83.4	72.8	73.0	78.1
Topology (%):					
Flat	82.8	64.1	98.9	99.4	20.9
Steep	11.5	29.1	0.3	0.6	56.2
Very steep	3.5	5.0	0.0	0.0	19.6
Mixed	2.2	1.8	0.8	0.0	3.3

Households in the two lake-plain counties, Nanxian and Anxiang, had the largest farm size. The main reason for the large farm size in the lake-plain region is that a substantial amount of cultivated land has been newly reclaimed from Dongting Lake, one of the five largest lakes in China. About three-quarters of cultivated land in each of these five counties is paddy land, indicating the predominate position of rice in the crop mix of the samples. As expected, in the two lake-plain counties almost all cultivated land is flat, whereas, in the mountain county, cultivated land is very hilly.

semi-dwarf varieties is scale neutral, labor using, and more suitable to irrigated conditions and favorable rain-fed conditions with adequate water control (Barker and Herdt, 1985). Except for that written by He et al. (1984, 1987a,b), few studies have been undertaken to examine the economic properties of hybrid rice. Hybrid rice, like any other new technology, may change the optimal levels of input applications. The price of each kind of input is different. The profitability of adopting F_1 hybrids will depend on how the input demands are altered and how large the productivity improvement is. An understanding of F_1 hybrid rice's effects on input demand and productivity is thus important for evaluating the desirability of diffusing this new technology to other countries. This study hopes to make a contribution to this understanding.

The organization of the paper is as follows. Section 2 provides a description of the data set. Section 3 analyzes the impact of F_1 hybrids on the demand for traditional inputs (labor and draft animal power) and for modern inputs (chemical fertilizers and mechanical power). In Section 4, the impact of F_1 hybrids on productivity is estimated by fitting a production function. The last section summarizes the findings and discusses their implications.

2. Data

The data come from a cross-sectional survey of 500 households in five counties in Hunan province. The survey was organized by the author during December 1988 and January 1989. [2] These five counties are located in three types of geographic setting – lake-plain, hill, and mountain. Samples of 100 households from each county were collected. These households were all included in the random samples surveyed annually by the State Investigation Team. Table 1 summarizes the key characteristics of the samples in each of the five counties.

The survey collected detailed information on a household's land use, input applications, and output of F_1 hybrids and conventional varieties in each of the early, middle and late seasons of 1988. The observations in the data set are made according to the season, variety, and household. That is to say, if a household planted both hybrids and conventional varieties for each of the early, middle and late seasons of 1988, we will have six observations from this household. The total number of observations in the data set is

[2] For a more detailed description of the study areas, see Lin (1991b).

1062. Of the 500 households surveyed, 495 devoted part of their land to rice. The number of households using hybrid and conventional seed in each of the five counties in 1988 is reported in Table 2. Whereas only a few (13) among the 495 households planted hybrids in the early rice season, the majority of households adopted hybrid seeds either in the middle season if only one crop of rice was grown, or in the late season if two crops of rice were grown each year. A substantial portion of the households in each county planted both hybrid and conventional rice in a single cropping season.

Although this data set gives us an opportunity to examine the effect of F_1 hybrid rice innovation on input demand and productivity, it also has some limitations. The major drawback is that the data set does not cover the information on seed production. The seed production of F_1 hybrid rice requires a complicated three-line system and is more labor-intensive than production of the conventional modern varieties (Yuan, 1985). Moreover, farmers have to purchase the F_1 seeds for each season. Unless the seed production and distribution issues are solved in an economy, the diffusion of F_1 hybrid rice may not be possible. To evaluate the total impact of F_1 hybrid rice innovation on the rice economy, it is also important to examine the efficiency of seed production.

3. Effects of hybrid rice on input demands

The rice varieties currently used in China are all modern varieties. The input and output comparisons in this study are made between F_1 hybrid rice and the semi-dwarf varieties. For our purpose, the semi-dwarf varieties will be termed "conventional varieties" in this paper. In this section, we will focus on the effects of input applications.

3.1. A model of input demand

We minimize costs on a unit of cultivated area, i.e.

$$p'x = c(p, q^*, e) \tag{1}$$

Table 2
Adoption of hybrid and conventional rice in 1988

	Tiaojian ($N = 100$)	Xiangxiang ($N = 100$)	Nanxian ($N = 97$)	Anxiang ($N = 99$)	Zhijiang ($N = 99$)
No. of households					
Early-season rice					
Hybrid	4	7	0	0	2
Conventional	98	98	92	98	6
Both	2	5	0	0	0
Middle-season rice					
Hybrid	0	1	8	8	99
Conventional	0	0	11	9	14
Both	0	0	0	2	14
Late-season rice					
Hybrid	79	67	63	90	9
Conventional	35	49	78	51	0
Both	14	18	46	43	0
Intensity of hybrid rice					
Percent of hybrid rice area in total rice area					
	39.5	33.3	25.6	40.1	95.7
Percent of hybrid rice area in middle- and late-season rice area					
	71.2	59.9	45.1	72.6	96.8

in which p is a vector of input prices, x is a vector of variable inputs, q^* is the expected output level of hybrid rice or conventional rice, and e is a vector of household endowments and characteristics and the physical environment in which the farm is located.

The expected output level is related to: variable inputs x; the technology d, i.e. hybrid rice or conventional rice and early-, middle- or late-season rice; and the household endowments and characteristics:

$$q^* = f(x \mid d, e) \tag{2}$$

Using Shephard's lemma on cost function, we obtain:

$$x_i = \partial c(p, q^*, e)/\partial p_i \quad \text{for all} \quad i \tag{3}$$

and the explicit demand function in a reduced form for a variable input is:

$$x_i = g_i(p, d, e) \tag{4}$$

If $\partial x_i/\partial p_j > 0$, where $i \neq j$, then x_i and x_j are gross substitutes, whereas $\partial x_i/\partial p_j < 0$ implies that two inputs are gross complements. Gross effects are generally larger than the net effect and are not symmetric.

3.2. Empirical estimations of input demand functions

Table 3 summarizes the application levels of seeds, labor, animal power, mechanical power, and chemical fertilizers for F_1 hybrids and conventional varieties in the whole sample. Labor and animal power belongs to the traditional inputs, whereas mechanical power and chemical fertilizers are modern inputs.

Due to high seed costs and heterosis, the use of hybrid seeds is economized. For the middle and late-season rice, the mean application levels of hybrid seeds are 30.0 kg per hectare, about one-third of the amount used for conventional varieties. The seed rate for the early-season hybrids is about 50% higher than the middle and late-season hybrids due to the cold weather in the seeding season. The seed rate for the early-season conventional rice, however, is also much higher. As a result, the seeding level for the hybrid rice is only about a quarter of that for the conventional rice. Table 3 also documents the application levels of labor, animal power, mechanical power, and chemical fertilizers. The table suggests that levels of input use for the hybrid and conventional varieties are not significantly different, except more mechanical power is used for early-season hybrids and more animal power is used for middle-season hybrids.

The information presented in Table 3, however, may be misleading. As discussed in Section 3.1, the application level of an input is itself a choice variable. In addition to the technical nature of a variety, a household's optimal application level of an input depends on the prices of

Table 3
Means and standard of inputs – hybrid and conventional rice

	Early-season		Middle-season		Late-season	
	Conv. ($N = 390$)	Hybrid ($N = 12$)	Conv. ($N = 32$)	Hybrid ($N = 116$)	Conv. ($N = 204$)	Hybrid ($N = 308$)
Seed (kg/ha)	176.3	47.0	104.1	31.3	93.0	30.0
	(63.8)	(33.2) ***	(46.8)	(13.5) ***	(49.5)	(35.0) ***
Labor (day/ha)	237.9	263.7	350.9	331.0	217.1	222.8
	(93.7)	(60.3)	(200.3)	(114.6)	(78.3)	(74.2)
Draft animals (day/ha)	18.3	26.9	37.9	55.2	12.3	13.4
	(17.5)	(16.7)	(44.3)	(37.2) *	(14.0)	(11.8)
Machine (day/ha)	8.2	19.8	3.0	0.9	8.6	8.7
	(13.2)	(20.4) ***	(13.5)	(4.6)	(13.6)	(15.0)
Fertilizer (kg/ha)	900.8	875.9	727.0	831.5	860.0	894.1
	(473.3)	(218.6)	(586.5)	(447.0)	(374.2)	(334.8)

Figures in the parentheses are standard errors. *, ** and *** indicate, respectively, that the means are significantly different at the 5%, 1% and 0.1% levels of significance.

Table 4
Regression results of the demand for traditional inputs ($N = 1062$)

	Labor input Ln(day/ha)		Draft animal service Ln(day/ha)	
	(1)	(2)	(3)	(4)
Constant	1.06	1.12	0.13	0.15
	(4.30) ***	(4.54) ***	(2.02) *	(2.51) **
Xiangxiang	−0.27	−0.26	−0.03	−0.02
	(6.09) ***	(5.90) ***	(2.52) **	(1.94) *
Nanxian	−0.27	−0.26	−0.17	−0.10
	(5.35) ***	(4.58) ***	(12.79) ***	(7.31) ***
Anxiang	−0.28	−0.29	−0.11	−0.09
	(6.27) ***	(6.45) ***	(9.71) ***	(8.61) ***
Zhijiang	0.25	0.26	0.13	0.14
	(4.49) ***	(4.57) ***	(8.62) ***	(9.98) ***
Hybrid rice dummy	−0.04	−0.04	−0.02	−0.02
	(1.66) *	(1.62)	(2.47) **	(2.37) *
Middle-season rice dummy	0.03	0.03	0.02	0.02
	(0.71)	(0.70)	(1.88) *	(1.61) *
Late-season rice dummy	−0.02	−0.02	−0.02	−0.01
	(0.81)	(0.84)	(2.37) *	(2.39) *
Ln wage rate	−0.12	−0.13	−0.003	−0.001
	(3.42) ***	(3.63) ***	(0.31)	(0.16)
Ln tractor rent	−0.03	−0.03	0.003	0.01
	(1.26)	(1.28)	(0.57)	(1.84) *
Ln draft animal rent	0.01	−0.003	−0.02	−0.02
	(0.02)	(0.06)	(1.51)	(1.76) *
Ln fertilizer price	−0.30	−0.30	−0.14	−0.11
	(3.52) ***	(3.47) ***	(6.48) ***	(5.06) ***
Ln years of schooling	0.02	0.02	−0.0002	−0.004
	(1.00)	(0.81)	(0.03)	(0.67)
Ln age	0.07	0.07	0.002	−0.003
	(1.64) *	(1.59)	(0.18)	(0.26)
Female dummy	0.10	0.10	0.01	0.01
	(1.86) *	(1.89) *	(1.11)	(1.00)
Ln family labor/landholding	0.01	0.01	0.004	0.008
	(0.19)	(0.36)	(0.49)	(1.02)
Ln landholding	−0.19	−0.19	−0.008	−0.01
	(5.97) ***	(5.87) ***	(0.95)	(1.47)
Ln capital stock/landholding	0.02		0.001	
	(1.47)		(0.24)	
Tractor dummy		0.09		0.003
		(1.22)		(0.18)
Hand tractor dummy		0.001		−0.04
		(0.02)		(3.51) ***
Thresher dummy		−0.002		−0.009
		(0.06)		(1.05)
Draft animal dummy		0.03		0.04
		(1.13)		(6.86) ***
Adjusted-R^2	0.35	0.34	0.59	0.62

Figures in parentheses are absolute values of t-statistics. *, ** and *** indicate, respectively, that the estimates are significantly different from zero at the 0.1, 0.01 and 0.001 levels of significance.

inputs, a household's endowments and characteristics, and other region-specific variables, such as the temperature and the topology. The appropriate method for analyzing the impact of F_1 hybrids on the application level of an input is the regression analysis in which the effects of other variables can be isolated.

The estimated demand functions are assumed to have the following form:

$$X = \alpha_0 + \alpha_1 C_1 + \ldots + \alpha_4 C_4 + \alpha_5 D_1 + \ldots + \alpha_7 D_3 + \alpha_8 P_1 + \ldots + \alpha_{11} P_4 + \alpha_{12} H_1 + \ldots + \alpha_{14} H_3 + \alpha_{15} E_1 + \alpha_{16} E_2 + \alpha_{17} E_3 \; (\text{or} + \alpha_{17} K_1 + \ldots + \alpha_{20} K_4) + \mu \quad (5)$$

in which the dependent variable, X, is the logarithm of the application level of inputs per hectare: labor days, draft animal days, quantity of chemical fertilizers measured in kg, and machine days; α_i's are the parameters to be estimated. C_1 to C_4 are county dummies that represent some county-specific characteristics, such as topology, frost-free periods, and temperature, which affect the input demand but are not observable to an econometrican. D_1 to D_3 are technological dummies indicating hybrid rice, middle-season rice and late-season rice; from the sign and significance of the coefficient of the hybrid rice dummy, we can infer the impact of F_1 hybrid rice technology on the application of inputs. P_1 to P_4 are the price variables: wages, tractor rent, draft animal rent, and fertilizer prices – representing the economic environment; [3] the coefficient of own-price of an input is expected to have a negative sign. H_1 to H_3 are the personal characteristics of the household head, including the years of schooling, age, and the dummy for sex; these variables may influence the levels of input use through the household head's managerial ability and the opportunity costs of time. The last group of variables represents a household's resource endowments: E_1 is the size of a household's landholding, which is included to estimate the effect of farm size on input use; E_2 is the labor–land ratio, which represents the availability of family labor in a household; E_3 is the capital–land ratio. Capital refers to the value of the aggregate stock of family-owned farm implements: machinery and draft animals. Different items of farm capital may have different technical properties – some are labor substitutes, and others are labor complements. An alternative way to estimate the impact of a capital endowment on input uses is to include the dummies for the various items of farm capital in the regressions. The dummies used in the study include tractors with 12 horsepowers and above (K_1), hand tractors with horsepower less than 12 (K_2), threshers (K_3), and draft animals (K_4). The last term in expression (5), μ, is the residual. In the regressions, all independent variables except for the dummies are in logarithmic form. [4] The input utilization functions estimated by OLS are reported in Tables 4 and 5. [5]

Columns (1) and (2) in Table 4 report the alternative estimates of the labor-use function. In both estimates, the coefficients of the hybrid rice dummy are negative, and it is significantly different from zero in the first estimate. This implies that, compared with the conventional semi-dwarf varieties, F_1 hybrid rice requires less labor per unit of land. The labor use for F_1 hybrids is about

[3] The prices are derived from each household's actual expenditures on hiring labor, tractors and draft animals and on purchasing chemical fertilizers, divided by the number of days using hired labor, tractors and draft animals and by the quantity of fertilizers. The prices used in the regression are the average prices in a village. In cases where a village has no observed price variable, the county average price is used as the price in the village. The wage includes both the money payment and the costs for food. Some portion of the fertilizers used by a household is rationed, and another portion is purchased from markets. The prices for chemical fertilizers are the average of the rationed price and the market price weighted by the quantity. The village-level prices, instead of the household-level prices, are used so as to prevent the possibility of simultaneity. The average prices in the whole sample are 7.70 yuan per day for hired labor, 9.60 yuan per day for draft animals, 14.24 yuan per day for tractors, and 0.42 yuan per kg for chemical fertilizers. In 1988, US$ 1.00 = 3.7 yuan.

[4] In taking the logarithm, 1 is added to a variable if some observations of the variable are 0.

[5] There is no gain in applying a SURE model to estimate the equations because the regressors in each equation are identical.

Table 5
Regression results of the demand for modern inputs ($N = 1062$)

	Mechanical service Ln(day/ha)		Chemical fertilizer application Ln(kg/ha)	
	(1)	(2)	(3)	(4)
Constant	0.17	0.16	2.04	2.16
	(2.95) **	(2.79) **	(7.04) ***	(7.49) ***
Xiangxiang	0.13	0.13	−0.10	−0.09
	(13.04) ***	(12.61) ***	(2.02) *	(1.82) *
Nanxian	0.04	−0.001	−0.10	0.02
	(3.08) ***	(0.11)	(1.71) *	(0.24)
Anxiang	0.006	−0.006	−0.09	−0.06
	(0.60)	(0.61)	(1.76) *	(1.25)
Zhijiang	−0.005	−0.012	−0.11	−0.09
	(0.39)	(0.94)	(1.71) *	(1.35)
Hybrid rice dummy	−0.001	−0.002	0.055	0.059
	(0.18)	(0.35)	(1.89) *	(2.05) *
Middle-season rice dummy	0.098	0.012	−0.172	−0.178
	(0.89)	(1.10)	(3.09) ***	(3.21) ***
Late-season rice dummy	0.006	0.005	−0.025	−0.024
	(1.03)	(0.98)	(0.84)	(0.85)
Ln wage rate	−0.014	−0.015	0.001	−0.002
	(1.71) *	(1.86) *	(0.03)	(0.05)
Ln tractor rent	−0.017	−0.021	−0.148	−0.138
	(3.22) ***	(4.16) ***	(5.59) ***	(5.23) ***
Ln draft animal rent	0.002	0.005	0.087	0.075
	(0.18)	(0.47)	(1.62) *	(1.40)
Ln fertilizer price	−0.02	−0.04	−0.367	−0.322
	(1.18)	(2.05) *	(3.61) ***	(3.17) **
Ln years of schooling	−0.001	0.001	0.061	0.056
	(0.13)	(0.17)	(2.38) *	(2.19) *
Ln age	−0.008	−0.003	0.059	0.037
	(0.75)	(0.26)	(1.12)	(0.69)
Female dummy	−0.003	−0.001	0.183	0.178
	(0.22)	(0.06)	(2.99) **	(2.94) **
Ln family labor/landholding	0.016	0.01	−0.029	−0.011
	(2.20) *	(2.02) *	(0.77)	(0.30)
Ln landholding	−0.011	−0.011	−0.163	−0.156
	(1.51)	(1.50)	(4.41) ***	(4.21) ***
Ln Capital Stock/landholding	0.002		0.003	
	(1.70)		(0.16)	
Tractor dummy		0.003		0.071
		(0.17)		(0.81)
Hand tractor dummy		0.037		−0.196
		(3.82) ***		(3.92) ***
Thresher dummy		0.009		0.056
		(1.11)		(1.34)
Draft animal dummy		−0.011		0.045
		(1.98) *		(1.55)
Adjusted-R^2	0.43	0.44	0.08	0.09

Figures in parentheses are absolute values of t-statistics. *, ** and *** indicate, respectively, that the estimates are significantly different from zero at the 0.1, 0.01 and 0.001 levels of significance.

4% less than that for the conventional varieties. The estimates indicate that the regional variations in labor use are very substantial, but the differences among early-, middle- and late-season rice are not significant. The wage rate has the expected significant and negative effect on labor use. The estimated coefficient indicates that a 100% increase in the prevailing wage rate in a village will result in a 12% or 13% reduction in labor use in the rice production of that village. The estimates of other price variables indicate that chemical fertilizers are net complements of labor input, and tractors and draft animals seem to be independent of labor use. The level of labor use is also affected by the age and sex of a household head. An old or female household head uses significantly more labor per unit of land in rice production than a young or male household head. This may be a result of the differences in opportunity costs due to the difference in off-farm and non-farm job opportunities. Farm size has a significantly negative impact on the level of labor use, whereas other household variables do not have significant effects.

Columns (3) and (4) of Table 4 report the estimates for the use of draft animal power per unit of land. The signs of the coefficients for the hybrid rice dummy are negative, and the estimates are significantly different from zero. The estimates indicate that the use of draft animal power for F_1 hybrid rice is about 2% less than for the conventional rice varieties. As in the case of labor use, there are large variations in the use of animal power across regions, as suggested by the estimated coefficients of the regional dummies. Compared with the case of early-season rice, significantly more animal power is used for middle-season rice but significantly less is used for late-season rice. The draft animal rental rate has the expected negative impact on the use of draft animals. The estimate is significantly different from zero in a two-tail test in the second variant but not in the first variant. However, if a one-tail test is used, the estimate in the first variant is also significantly different from zero at a 10% level of significance. The estimates of other price variables indicate that tractors, as expected, are a substitute for draft animals, whereas chemical fertilizers are a complement of draft animals. The estimates also indicate that the household head's personal characteristics, the farm size, and the family labor to land ratio do not have a significant effect on the use of animal power. Neither does the capital stock to land ratio. However, in the second variant in which the capital stock to land ratio is replaced by dummies for various farm capital, we find that a household uses significantly less draft animal power if it has a hand tractor and significantly more if it has a draft animal. This is because, if a household owns a draft animal, the opportunity costs for using draft animal power are reduced, and hand tractors are a substitute for draft animals. It is interesting to find that the dummy for the medium- and large-size tractors has no significant effect on the use of draft animal power. This evidence confirmed the casual observation that in southern China the medium- and large-size tractors are used mainly as transportation vehicles and not for farm operations on paddy fields.

Table 5 reports the estimates of the demands for modern inputs in rice production – mechanical power and chemical fertilizers. From the estimated coefficients of the hybrid rice dummy, we find that the demand for mechanical power is not affected by the hybrid rice technology, but hybrid rice has a significantly positive effect on the demand for chemical fertilizers. The estimates indicate that a household uses about 6% more chemical fertilizers with hybrid rice than with conventional rice. The coefficient for tractor rental in the demand function for mechanical power and the coefficient for fertilizer price in the demand function for chemical fertilizer both have the expected negative sign and are highly significantly different from zero. The estimates in the mechanical power demand function indicate that labor input and fertilizers are complements of mechanical power. That fertilizers and mechanical powers are complements is also confirmed in the chemical fertilizer demand function.

In the mechanical power demand function, the estimate of the hand tractor dummy is positive and that of the draft animal dummy is negative, and both are significantly different from zero. The signs of these two dummies are just the

Table 6
Yield of hybrid rice and conventional rice (kg/ha)

	Tiaojiang	Xiangxiang	Nanxian	Anxiang	Zhijiang
Hybrid rice	5182.1	6769.9	5527.2	5791.0	6545.0
	(1055.6)	(1071.3)	(1450.1)	(1031.5)	(1962.7)
Conventional rice	5133.3	6037.6	4735.0	4534.9	5391.7
	(1213.4)	(992.0)	(1624.5)	(920.5)	(2729.3)

Figures in the parentheses are standard errors.

opposite of those in the animal power function. This indicates that the possession of a draft animal reduces the use of mechanical power, whereas the possession of a hand tractor reduces the use of draft animals. The coefficient of the tractor dummy in the mechanical power demand function is not different from zero. This once again confirms the observation that tractors are not used in paddy fields. The coefficients of landholding have a negative sign and are highly significant in the chemical fertilizer demand function. This indicates that the increase in farm size reduces the application level of chemical fertilizers.

It is interesting to note that the educational level of a household head has a significantly positive effect on the application level of chemical fertilizers. The result is consistent with the empirical evidence found in other developing countries (Jamison and Lau, 1982). Finally, the estimates of regional dummies in columns (1) to (4) indicate that there are also significant variations across regions in the use of mechanical power and chemical fertilizers.

In short, the regression analyses in Tables 4 and 5 indicate that, compared with conventional semi-dwarf varieties, hybrid rice requires less labor and animal inputs per unit of sown acreage and also does not require more mechanical inputs. This may arise from the fact that, due to heterosis and the economization of seed use, the seeding rate for F_1 hybrid rice is only about one-third to one-fourth that of conventional varieties. Therefore, less labor and animal power is needed for seed-bed preparation and transplanting. [6] This is just opposite the case of replacing traditional varieties with semi-dwarf varieties. It is found that, compared with traditional varieties, the modern semi-dwarf varieties of rice increase labor use by increasing labor requirements for crop care and harvesting (Barker and Cordova, 1978; Barker and Herdt, 1985, pp. 153–154). Hybrid rice, however, requires more chemical fertilizers than the semi-dwarf varieties. The same phenomenon is also found in the comparison between semi-dwarf varieties and traditional varieties. This indicates that semi-dwarf rice is more fertilizer responsive than traditional rice, and the F_1 hybrid rice is more fertilizer responsive than the semi-dwarf rice. The estimates in Tables 4 and 5 also suggest that, except where tractors and draft animals are substitutes, the other inputs tend to be complements in rice production.

4. Impact of hybrid rice on productivity

Although its effect on the demand for inputs is an important property of a new agricultural technology, a new technology will not be acceptable to farmers unless it raises productivity. In this section we attempt to examine to what extent productivity is increased by the introduction of F_1 hybrid rice.

Table 6 reports the tabulation of average yields of F_1 hybrid rice and conventional rice in each county's samples. It shows that the average yield of F_1 hybrid rice is higher than that of conventional rice in each of these counties. However, because more chemical fertilizers are used in the production of hybrid rice, as found in the last section, we cannot decide whether the yield ad-

[6] Tractors are mostly used for land preparation. Because the requirements for land preparation are the same for the hybrids and for the conventional varieties, it is expected that the hybrid rice has no significant effect on tractor use.

vantage of hybrid rice simply reflects the impact of differences in the level of chemical fertilizer application or the technical properties of hybrid rice. An appropriate technique for determining the impact of F_1 hybrid rice technology on productivity is again the regression analysis.

A frequently used method of estimating the productivity impact of a new technology is the Cobb–Douglas function approach. The main reason for adopting this functional form is the ease of estimation and interpretation. The function can be written in a linear form by taking the logarithm of the output and input variables. The coefficient of an input in the function represents the production elasticity of that input. The sum of the elasticities of inputs is used as an indicator of the degree of returns to scale in production. The impact of a new technology on the total factor productivity can be estimated by adding a dummy variable to the function.

The empirical production function to be estimated in the study is assumed to have the following form:

$$\begin{aligned}\text{Ln } Q = \beta_0 &+ \beta_1 C_1 + \ldots + \beta_4 C_4 \\ &+ \beta_5 D_1 + \ldots + \beta_8 D_4 \\ &+ \beta_9 \text{ Ln } X_1 + \ldots + \beta_{13} \text{ Ln } X_5 \\ &+ \beta_{14} \text{ Ln } H_1 + \ldots + \beta_{16} H_3 + \nu \qquad (6)\end{aligned}$$

in which Q is the rice output measured in weight; β_i's are the parameters to be estimated. C_1 to C_4 are county dummies, which are included to capture the impact on productivity of county specific variables such as temperature, rainfall, soil quality, and so on. D_1 to D_4 are dummy variables for natural calamities, middle-season rice, late-season rice, and F_1 hybrid rice. The natural calamity dummy indicates whether a plot is affected by adverse weather conditions. This dummy is included to dissociate the effect of natural calamities. The F_1 hybrid rice dummy is included to estimate the effects of F_1 hybrid rice on rice production. From the coefficient of this dummy, we can infer F_1 hybrid rice's effect on total factor productivity. X_1 to X_5 are inputs, including sown acreage measured by hectares; labor input measured by days; chemical fertilizers measured by quantity; and machinery service, as well as draft animal service, both measured by days. H_1 to H_3 are personal characteristics of the household head, including years of schooling, age, and sex. The last term, ν, is a residual. Except for the dummies, the dependent and independent variables are all in logarithmic form, as expression (2) has shown.

Table 7
Regression estimates of rice production functions ($N = 1062$)

	(1)	(2)
Constant	3.27	3.27
	(24.03) ***	(24.03) ***
Xiangxiang	0.21	0.21
	(5.98) ***	(5.93) ***
Nanxian	0.04	0.05
	(1.45)	(2.24) **
Anxiang	0.05	0.06
	(2.16) *	(2.53) **
Zhijiang	0.17	0.17
	(4.41) ***	(4.53) ***
Disaster dummy	−0.10	−0.10
	(5.85) ***	(5.86) ***
Middle-season rice dummy	−0.08	−0.08
	(2.24) *	(2.41) *
Late-season rice dummy	−0.04	−0.04
	(2.14) *	(2.11) *
Hybrid rice dummy	0.170	0.170
	(9.39) ***	(9.43) **
Ln labor	0.117	0.113
	(4.59) ***	(4.68) **
Ln land	0.806	0.806
	(33.56) ***	(33.94) ***
Ln fertilizer	0.097	0.095
	(6.25) ***	(6.18) ***
Ln machine service	0.002	
	(0.12)	
Ln draft animal service	−0.008	
	(0.58)	
Ln education	−0.012	
	(0.79)	
Ln age	−0.005	
	(0.17)	
Female	0.003	
	(0.08)	
Adjusted-R^2	0.901	0.902

Figures in parentheses are absolute values of t-statistics. *, ** and *** indicate, respectively, that the estimates are significantly different from zero at the 0.1, 0.01 and 0.001 levels of significance.

The results of fitting the production function by OLS are presented in Table 7. [7] From column (1), we see that, except for the coefficients of machine service and draft animal service and the three variables representing the household head's personal characteristics, all the other variables' coefficients are significantly different from zero. The *F*-statistic for the null hypothesis that the coefficients of the above five variables are jointly zero is 0.262. With degrees of freedom of 5 and 1045, the null hypothesis cannot be rejected. Therefore, these five variables can be excluded from the regression function. Column (2) reports the new estimation. The estimates for the coefficients of the remaining variables are basically unaffected.

The estimated coefficient of the hybrid rice dummy in column (2) measures the shift in the intercept of the production function, assuming the coefficients of the parameters in the production function are invariant for F_1 hybrid rice and conventional rice. The shift captures the impact of F_1 hybrid rice technology on total factor productivity. From the estimated coefficient of 0.17 for the hybrid rice dummy, we can infer that the total factor productivity of hybrid rice is about 19% higher than that of conventional rice. [8] That is, given the same level of inputs, the yield advantage of hybrid varieties over the conventional varieties is about 19%. [9]

The estimates in Table 7 also provide us with other valuable information about rice production in the study areas. Land is the predominant factor in rice production. A 10% increase in the sown acreage, holding other inputs constant, will result in a 8.06% increase in rice output. The sum of the coefficients of labor, land, and chemical fertilizers is 1.014, which is not significantly different from one. This implies that rice production has a constant return to scale. Therefore, the small farm size that resulted from the household-based farming system reform in rural China does not have an adverse effect on productivity in the rice production areas. The recent attempt to consolidate landholding by administrative methods in China may not be justifiable.

5. Concluding remarks

In this paper, I use an econometric approach to analyze the effects of F_1 hybrid rice on input demand and productivity. The major findings from

[7] The inputs are themselves endogenous variables, as discussed in the last section. However, OLS is an appropriate model for fitting the regression because the system is recursive (Johnston, 1984, p. 468). The inputs are determined before the production is completed. The input levels may not be correlated with the residual term.

[8] Since the dependent variable is in log form, to infer the effect of the dummy impact, one needs to convert the coefficient in the following way: [exp(estimated coefficient) − 1] × 100%.

[9] An anonymous referee suggests that the adoption of hybrid rice is endogenously determined. Therefore, he recommends taking some measures to deal with the simultaneity bias. However, as Table 2 shows, most households did not adopt hybrid rice in the early season. When most households adopted hybrid rice in the middle/late season, a substantial portion of these households adopted both hybrid and conventional rice. The absence of hybrid rice in the early season may reflect a climatic effect, which will not cause any trouble in a regression analysis. However, to deal with the simultaneity bias in the middle/late season, we need to run a three-stage regression. The first stage determines whether a household adopted hybrid rice or not. The second stage determines, among the adopting households, how much land is allocated to hybrid rice. The third stage estimates the production function. For the regression in the first stage, information on a household's characteristics and other economic variables is required. The regression in the second stage needs at least plot-specific information. The data set has information for the first stage regression but not for the second stage. Therefore, I encounter a dilemma in the analysis. If I include all households in the regression, a simultaneity bias may exist. If I only include those households that adopted either hybrid rice or conventional rice and exclude those households that adopted both types of rice, the simultaneity problem can be dealt with by a two-stage regression, but a selection bias may exist. From experiments, I find that the selection bias is more serious than the simultaneity bias. Moreover, the regression analysis reported in the paper shows that the household head's characteristics do not have significant effects on the output, and the *F*-statistic suggests that those variables can be deleted from the production function. The resulting production function, as shown in column 2 of Table 7, is an engineering relationship between outputs, inputs, and other dummies. Therefore, the estimation from the hybrid rice dummy may be interpreted as showing the engineering effect of hybrid rice on productivity.

the regressions are as follows: compared with conventional semi-dwarf varieties, F_1 hybrid rice uses 4% less labor inputs, 2% less draft animal power, and 6% more chemical fertilizers. Given the same level of inputs, the yield advantage of hybrid rice over the conventional modern varieties is about 19%. This figure is consistent with the 15% yield advantage estimated by He et al. (1987). In addition, the cross-tabulation indicates that the seed requirement for F_1 is only about one-third to one-fourth that of conventional rice. The lower seeding rate may contribute to the lesser requirements for labor and draft animal power in cultivation.

The introduction and rapid diffusion of semi-dwarf rice varieties throughout Asia in the late 1960s and the early 1970s resulted in amazing output growth. However, there is much concern within the research community that the growth in aggregate rice output and productivity has peaked and has started to decline (Rosegrant and Pingali, 1991; Herdt, 1988; Byerlee, 1987). The declining productivity phenomenon has also established itself in experiment stations, and the yield gap between experiment stations and farmers' fields is found to have diminished (Pingali, Moya and Velasco, 1990). One of the major reasons for the productivity decline is the lack of a significant breakthrough in the yield ceiling since the first modern varieties were released (Baker and Chapman, 1988). If the current yield ceiling does not shift upward, it is likely that the population growth rate may surpass the rice output growth rate in Asia. Due to its potential productivity advantage over conventional modern varieties, as shown in this paper, F_1 hybrid rice may be a candidate for the second-generation "Green Revolution" in other parts of Asia.

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