Hybrid Rice Innovation in China: A Study of Market Demand Induced Technological Innovation in A Centrally-Planned Economy

by

Justin Yifu Lin

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Department of Economics
University of California, Los Angeles
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I. Introduction

The work presented in this paper is an attempt to analyze the innovation and diffusion of F_1 hybrid rice in China as a case study in the mechanism of agricultural technology innovation in a centrally-planned economy. It is a well-established hypothesis, first studied and empirically tested by Griliches (1957) and Schmookler (1966), that the rate of technological innovation of a given commodity in a market economy is responsive to the market demand for that commodity in the economy. Few attempts have ever been undertaken to examine the validity of this hypothesis in a centrally-planned economy, where market functions are restricted. The case of the innovation and diffusion of F_1 hybrid rice in China provides an opportunity to establish the degree to which rate of technological change is responsive to final market demand in a centrally-planned economy.

China is the only country in the world in which F_1 hybrid rice is commercially produced. The success achieved in the development of F_1 hybrids in China has been cited as one of the most significant technical achievements in rice breeding in the 1970s (Barker and Herdt 1985, p. 61). The large-scale dissemination of F_1 hybrids in China started in 1976, and the area devoted to hybrids reached 10.9 million hectare (34 percent of national rice acreage) in 1987. However, there exists a large regional variation in the adoption rate. In this paper I attempt to show that the regional variation can be explained by the Griliches-Schmookler hypothesis.

The organization of this paper is as follows: Section II consists of a brief historical review. Section III follows with a discussion of market demand and public-supported agricultural research in a centrally-planned economy. The data used to test the hypothesis are summarized in Section IV. Section V reports the empirical results. Some concluding remarks are presented in Section VI.

II. Research Institutions and F_1 Hybrid Rice Innovation in China

China's organized agricultural research system has had a decentralized character since its founding. In 1957, the Chinese Academy of Agricultural Sciences was organized in Beijing. Meanwhile, each of mainland China's 29 provinces established its own academy of agricultural sciences. While the national academy emphasizes basic and applied research with national significance, the provincial academies stress applied research in accordance with the ecological conditions of their provinces.

Despite the economy's many problems, China's agricultural research in the socialist period has been very remarkable. In 1964, China began to distribute in full-scale semi-dwarf rice varieties with high-yield potential, two years earlier than the International Rice Research Institute's release of IR-8, the variety which launched the Green Revolution in other parts of Asia. The commercial dissemination of F_1 hybrid rice in 1976 marked the second most important achievement of China's rice research. The yield advantage of F_1 hybrids over conventional modern semi-dwarf varieties has been found to be about 15 percent, without any significant difference in input use (He *et al* 1984 and 1987).

Like other types of improved seed, the F_1 hybrids proved to be sensitive to local ecological conditions. To obtain the yield potential, each region had to develop its own hybrids or screen hybrids developed in other regions to suit specific local conditions. Adaptation research on hybrid rice is thus conducted in the provincial and lower level research institutes in each rice-producing province.

Since 1976, the area devoted to hybrid rice has increased rapidly. However, there have been dramatic geographic differences in the adoption rates of F_1 hybrids. The adoption rates in Sichuan and Hunan Provinces were more than 50 percent in 1987, while the adoption rate in Heilongjiang and eight other provinces was zero in the same year (see table 1).

III. Market Size and Agricultural Research in a Centrally-planned Economy

According to the Griliches-Schmookler hypothesis, the rate of innovation for a commodity is a function of, among other things, the market demand for that commodity. The logic underlying the hypothesis is very simple: Take, for example, with any given yield advantage, the marginal returns to the innovation of a new rice variety are a positive function of the size of the rice-producing area and the price of rice. Therefore, the larger the rice area or the higher the rice price in a region, the more resources research institutes in that region will allocate to rice research, including research for F_1 hybrids. Consequently, the larger the rice area or the higher the rice price in a region, the more F_1 hybrid varieties will be available in that region. Since the availability of adaptable F_1 hybrids is a positive function of the size of rice area and the price of rice in a region, the adoption rate of F_1 hybrids will also be a positive function of the size of rice area and the price of rice in that region.

In a centrally-planned economy such as China's, prices are regulated by the state. Regional rice price variation, if exists at all, is negligible. Therefore, price cannot become a factor in determining regional discrepancies in the availability and adoption rate of hybrids. However, there are significant regional variations in rice-producing area. The resources devoted to hybrid rice research, the availability of hybrid varieties, and the adoption rate of hybrid rice in a region will thus depends on the rice-producing area in that region.[1]

IV. Data

In previous studies by Griliches and others, the validity of the Griliches-Schmookler hypothesis has been indirectly inferred from the variation in the date of first commercial availability obtained from fitting a logistic curve. This paper attempts to test the hypothesis directly. Two sets of data will be used in the study. The first set is composed of figures on the amount of project funds and number of scientists allocated to rice research at each provincial academy of agricultural sciences. The second set is province-level time-series data on total rice acreage and hybrid rice adoption rates.

The first data set was collected through a questionnaire survey mailed to the 29 provincial academies in November-December 1988. Three types of question were asked: (1) The number of scientists assigned to research on hybrid rice, conventional rice and other crops in 1975, 1980, 1985, and 1987; (2) the amount of funds allocated to research on hybrid rice, conventional rice and other crops in the fifth five-year plan (1976-1980), sixth five-year plan (1986-1980), and the actual expenditures in 1986-1987; (3) the number of newly-developed hybrids and conventional rice that met provincial or national standards for commercial release in 1976-1987. While this survey provides us with detailed information about rice research at the provincial academies, the data set has several limitations: (1) it does not include information about research on basic sciences; (2) the information on funds only covers project funds, omitting data on personnel salary and expenditures on equipment purchased in the past; (3) the information on research outputs only includes newly-developed varieties, omitting other research outputs, such as scientific publications, which were used by Evenson and Kislev (1973) in their celebrated paper on research and productivity.

The second data set contains information on the sown acreage of rice and hybrids, as well as the total rice output, labor, and cultivated land in each province from 1976 to 1987. The data on the area devoted to hybrids in each province from 1976 to 1987 were made available by the Science and Technology Bureau of the Ministry of Agriculture. The data on other variables for 1976-1979 were provided by the State Statistical Bureau, while data for 1980-1987 are available in published statistical yearbooks.

V. Empirical Analysis

To test the Griliches-Schmookler hypothesis, we will first estimate how the amount of rice acreage in a province affects research resource allocation in that province's academy of agricultural sciences, and then estimate the impact of the amount of rice acreage on the adoption rate of F_1 hybrids in that province.

(i) Rice Acreage and Rice Research Resource Allocation

Two sets of variables are used as indicators of the amount of resources invested by provincial academies in rice research: one set gives the amount of project funds spent on F_1 hybrids and conventional rice research in 1976-1987, and the other gives the total number of research scientists doing hybrid rice and conventional rice research averaged over the years 1975, 1980, 1985, and 1987. The area devoted to rice in a province (denoted as A_j) will be measured by that province's average rice acreage in the twelve years between 1976 and 1987. In addition to rice acreage, the allocation of resources to rice research in a provincial academy may also depend on how important rice is in that province's agriculture and on how much that province emphasizes agricultural research. As an indicator of the importance of rice in a province's agriculture, I use the proportion of rice area in total sown acreage in each province (denoted as S_j) averaged over the period from 1976 to 1987. As a measure of the degree of emphasis on agricultural research in a province, I use each provincial academy's total number of research scientists and total amount of research funds for all crops divided by the total cultivated land area in that province (denoted as P_j and F_j). The regression functions estimated are as follows:

(1) $X_{i,j} = \alpha_{i,0} + \alpha_{i,1} A_j + \alpha_{i,2} S_j + \alpha_{i,3} P_j + \mu_i$, if $X_{i,j} > 0$,

$X_{i,j} = 0$ otherwise;

and

(2) $Y_{i,j} = \beta_{i,0} + \beta_{i,1} A_j + \beta_{i,2} S_j + \beta_{i,3} F_j + \nu_i$, if $Y_{i,j} > 0$,

$Y_{i,j} = 0$ otherwise;

where X is the number of scientists averaged over 1975, 1980, 1985 and 1987; Y is the research funds in 1976-1987 (unit=1,000 yuan); μ and ν are residuals that are independently and normally distributed, with mean zero and variance σ^2_μ and σ^2_ν; and i and j indicate type of rice (hybrid or conventional) and province.

As specified, the dependent variables $X_{i,j}$ and $Y_{i,j}$ are censored. Therefore, the ordinary-least-squares regression will not produce consistent and unbiased parameter estimates. The appropriate method for estimating a censored normal regression model is the Tobit model.

Tables 2 and 3 report the Tobit estimates for number of research scientists and amount of research funds, respectively. The regressions were estimated in linear form and in double-log form (except $S_{i,j}$). In the double-log form, all variables, except $S_{i,j}$, were replaced by their natural logarithms, one being added to the variables to avoid zeros.

The estimates for coefficients of A in table 2 and 3 indicates that the rice acreage in a province has a significantly positive impact on the provincial academy's allocation of scientists and funds to research of both conventional rice and F_1 hybrids, as predicted by the Griliches-Schmookler hypothesis. Tables 2 and 3 also indicate that the importance of rice in a province (measured by S_j) and the degree of emphasis of agricultural research in a province (measured by P_j and F_j) have no significant effects on resource allocation to hybrid rice research. However, the estimates of conventional rice function indicate that the resource allocation to conventional rice research in a province is positively correlated with the degree of emphasis on agricultural research in that province. The estimated coefficients of P_j and F_j are positive and statistically significant at 0.1 percent level of confidence in both the linear and double-log models.

Scientific manpower and expenditure are inputs into the research system.

Because the allocation of manpower and expenditure to both hybrid and conventional rice research in a provincial academy depends on the rice-producing area in that province, we would expect that there should exist a positive significant relation between the number of new varieties of hybrid rice and conventional rice developed by a provincial academy and the area devoted to rice in that province. This prediction is confirmed by our data. However, for the sake of simplicity, the estimates are not reported.

(ii) Rice Acreage and the Adoption of Hybrid Rice

Table 1 indicates that the adoption rate of hybrid rice in a province is positively correlated to the size of rice-producing area in that province.[2] However, this does not necessarily reflect the effect of the size of rice-producing area on the adoption rate, as various other factors which affect adoption rate are not held constant.

Most previous studies, following the pioneering work by Griliches (1957), have described the diffusion of a new technology by a logistic function and then related indirectly the date of first commercial availability to market demand. A preferable procedure, however, would be to test the impact of market demand on the adoption rate directly, which is the method used in this paper.[3] The regression equation estimated is a reduced form of a complex and unspecified structural system involving the demand and supply factors. Since the main interest of this study is in the overall effect of the size of rice acreage on the adoption rate, the reduced form is sufficient. The data available for this study are the adoption rates of hybrids in 27 of the 29 provinces in China for the period 1976-1987.[4] The total number of observations is 324.

The adoption rate in a province during a given year is hypothesized to depend on the following variables:

1). Rice Acreage ($A_{j,t}$). This variable reflects the market size of rice in a province. It is expected to have a positive effect on the adoption rate.

2). Market density ($M_{j,t}$). Following the definition by Griliches (1957), market density for rice in a province is defined as the ratio of rice acreage over total sown acreage in that province. The higher the market density, the lower the marketing costs for seed companies. Therefore, a higher market density, *ceteris paribus*, implies a higher availability of hybrids. It is thus expected to have a positive impact on the adoption rate.

3). Output per hectare in the previous year ($Q_{j,t}$). The adoption rate of hybrids also depends on its expected profitability. Compared to conventional varieties, hybrid rice is a new innovation and therefore riskier. A farmer is required to invest time and other resources to learn new crop management and other information about hybrids. The higher the expected profits of hybrids, the more risk and expenditure a farmer will accept. Therefore, expected profits have a positive impact on the adoption rate. Since the only output data available to this study is total rice output, I will use output per hectare in the previous year in a province as an approximation of the expected yield advantage of hybrid rice in that province.[5]

4). Labor-land ratio ($L_{j,t}$). Hybrid rice, as an innovation that increases yield per unit of land, is a land-saving type of innovation. According to the factor-scarcity induced innovation hypothesis of Hick-Hayami-Ruttan (Hayami and Ruttan 1985), a land-saving technology will be favored by farmers in areas where land is relatively scarce. Therefore, $L_{j,t}$ is expected to be positively related to the adoption rate in that province.

5). <u>Year dummies</u> (Y_t's). Eleven year dummies are included in the regression function. Year dummies reflect time-dependent region-invariant changes in the supply of hybrids that may arise from the improvement of seed breeding and production technology, or changes in the demand for hybrid seeds that may arise from changes in output price, costs of inputs, and so on.

More specifically, the adoption rate of hybrid rice in a province can be expressed as the following function:

$$(3) \quad R_{j,t} = R\,(A_{j,t},\ M_{j,t},\ Q_{i,j},\ L_{j,t},\ Y_{77},\ \ldots\ Y_{87}) + \mu_{j,t},$$

$$\text{if } 0 < R_{j,t} < 1, \text{ otherwise}$$

$$R_{j,t} = 0 \text{ or } R_{j,t} = 1;$$

where $R_{j,t}$ is the adoption rate in the jth province in time t, and μ is the residual term with an identical and independent normal distribution over the population.

The above specification indicates that the appropriate method for estimation is the two-limit tobit model. The results of fitting the regression function are reported in table 4. Column 1 reports the estimation of equation (3) in a linear form, while column 2 with A, Q, L in their natural logarithm. In both columns, we find that all the explanatory variables have the expected sign and are significantly different from zero, with the exception of M, the proxy for market density.[6] Of all estimated coefficients, rice-producing area A has the largest asymptotic t-value. This result indicates that difference in market size is the most important factor in accounting for regional variations in the adoption rate.

V. Concluding Remarks

This paper uses the innovation of F_1 hybrid in China as a case study to test the validity of the Griliches-Schmookler hypothesis in a centrally-planned economy. The main argument is as follows: The invention of F_1 hybrid rice is the invention of a method of breeding superior rice varieties. Like hybrid corn and other new agricultural technologies, F_1 hybrid rice is region-specific -- it is not a single invention immediately applicable everywhere. The actual development of adaptable F_1 hybrids must be done separately for each area. Therefore, the availability of adaptable hybrids for a specific region depends on the amount of resources allocated to the innovation of adaptable hybrids in that region. Agricultural technological innovation in China is mainly undertaken by public research institutions. Social optimality requires that each region allocate more resources to commodities with larger market potential, and since the price of rice is regulated and has little regional variation, market potential in a region depends on the area devoted to rice in that region. Therefore, the larger a region's rice-producing area, the more resources will be allocated to rice variety improvement research in that region, and hence the more new varieties, including conventional varieties and hybrids, will be available for that region. Variations in the adoption rate of hybrid rice within China can thus be explained by variations in the availability of adaptable hybrid rice, induced by regional variations in rice acreage.

The empirical evidence indicates that the size of rice acreage in a province is the major factor in determining resource allocation for rice research in that province's academy of agricultural sciences and the aggregated adoption rate of hybrid rice in that province. This is consistent with the implications of the Griliches-Schmookler hypothesis. The empirical evidence also indicates that the adoption of hybrid rice in a province is affected by the profitability of hybrid rice and the labor-land ratio in that province. The last observation is consistent with the Hicks-Hayami-Ruttan hypothesis of factor-scarcity induced technological innovation. These results suggest that, in spite of a high degree of governmental interventions in economic decisions, research resource allocation for rice and the diffusion of F_1 hybrids in China's centrally-planned economy are amenable to economic analysis.

Finally, the limitations of the study should be noted. The available data are limited in quality and scope, and many important factors -- including resource allocation by seed companies, yield advantages of hybrids, farmer's age, level of education, willingness to take risk, and so on -- had to be omitted due to the unavailability of information. The results are only a first step toward understanding the factors which determine technological change in Chinese agriculture; but despite its many obvious limitations, this paper should be useful to economists concerned with the process of technological innovation in a centrally-planned economy.

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Notes

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1. A large proportion of new agricultural technology has the characteristics of a public good. To arrive at a general economic optimum, it is necessary to socialize this class of research. A socialized research institution may cease to be responsive to profits, which are implicitly assumed to be the motive for innovation in the Schmookler-Griliches hypothesis. Hayami and Ruttan (1985, pp. 88-89) have, however, argued that it is necessary only that there exist an effective incentive mechanism to reward scientists or administrators, materially or by prestige, for their contributions to the solution of significant problems in the society, and that under such conditions, research institutes in public sector research programs do respond to the needs of society. In the Chinese system, scientists and administrators who make important contributions are given high political honor and other material benefits. Therefore, it is reasonable to hypothesize that regional research institutes in China will allocate limited resources for rice research in accordance with the size of rice-producing area in their region.

2. The correlation coefficient is .66, which is significantly different from zero at a .1 percent level of confidence.

3. As acknowledged by Griliches (1957), before deciding to fit his data to

a simple logistic function, he had first attempted to fit a model in which year-to-year changes in the percentage devoted to hybrid seed were to be explained by year-to-year changes in the superiority of hybrids in the previous year or two, and other economic variables. Because the trend in his data was so strong, he failed to obtain significant estimates for any of the economic variables. Nevertheless, a direct estimation of the impact of economic variables on adoption behavior should be considered as a better method than an indirect estimation.

4. The data for Tibet and Qinghai Province are missing.

5. A better proxy for expected yield advantage is yield difference per hectare in the previous one or two years. Data on the output of hybrid rice in each province are not available. Therefore, we are unable to calculate the yield difference. However, the yield per hectare may give us some indication of the expected yield advantage. Farm level studies by He *et al* (1984 and 1987) in several provinces found that yield advantage of hybrids over conventional rice is about 15 percent, without any significant difference in input use.

6. This may arise from the fact that we use the ratio of rice acreage over the total sown acreage in a province as a measure for market density. However, in provinces with small rice-growing area, the area is likely to be concentrated in a small region. For local seed companies, the market density may be as high as that in provinces with a large rice-growing area. Therefore, M may underestimate the market density in provinces with small rice-producing area.

Table 1: Hybrid Rice Adoption Rate and Total Rice Acreage in 1987

Province	Hybrid Rice Adoption Rate (%)	Total Rice Sown Acreage (1,000 ha)
Sichuan	69.29	3031.5
Guizhou	22.18	721.3
Yunnan	14.83	1019.9
Shaanxi	60.66	156.1
Gansu	0.00	3.9
Qinghai	0.00	0.0
Ningxia	21.44	52.9
Xinjiang	0.00	77.4
Henan	4.19	414.1
Hubei	32.58	2557.5
Hunan	43.87	4255.1
Guangxi	35.94	2503.9
Guangdong	26.86	3554.4
Shanghai	0.53	276.2
Jiangsu	29.84	2399.5
Zhejiang	24.97	2376.0
Anhui	30.65	2207.9
Fujian	46.81	1493.7
Jiangxi	31.37	3268.7
Shandong	5.28	100.9
Beijing	12.13	38.5
Tianjin	0.00	40.6
Hebei	0.80	125.3
Shanxi	0.00	7.3
Neimong	0.00	27.5
Liaoning	19.25	533.3
Jilin	0.00	368.1
Heilongjiang	0.00	580.6

Sources: Hybrid Rice Adoption Rate - Ministry of Agriculture.

Total Rice Sown Acreage - China Agricultural Yearbook (1988, p. 231).

Tabes 2: Tobit Estimates for Number of Scientist

	Model I		Model II	
	Hybrid Rice	Conventional Rice	Hybrid Rice	Conventional Rice
Constant	.66	-.28	.54	7.45
	(.37)	(.13)	(.20)	(5.36)
A	.002	.006	.52	.53
	(2.50)	(4.28)	(2.00)	(4.57)
S	.03	-.02	-.004	-.01
	(.55)	(.21)	(.21)	(1.44)
P	-681.39	31906.2	.27	.90
	(.05)	(2.63)	(.68)	(4.78)
Log-Likelihood	-55.57	-68.96	-23.36	-8.61

Notes:

1. Model I is in linear form and model II in double-log form (except for S). A indicates the rice area in a province averaged over 1976-87; S indicates the percentage of sown area devoted to rice averaged over 1976-87; and P indicates the total number of scientists in a provincial academy averaged over 1975, 1980, 1985, and 1987 divided by the cultivated land area in that province averaged over 1976-87.
2. Figures in parentheses indicate absolute asymptotic t-values.
3. Number of observations = 26.

Tabes 3: Tobit Estimates for Research Funds

	Model I		Model II	
	Hybrid Rice	Conventional Rice	Hybrid Rice	Conventional Rice
Constant	-4.61	-68.86	-8.34	1.08
	(.60)	(1.47)	(1.47)	(1.77)
A	.008	.087	2.84	.91
	(2.24)	(3.29)	(2.06)	(5.99)
S	.46	-2.48	-.013	-.03
	(2.18)	(1.24)	(.09)	(1.36)
F	-38.56	735.33	1.30	1.50
	(.63)	(3.22)	(.80)	(6.63)
Log-Likelihood	-81.48	-136.77	-56.76	-8.61

Notes:

1. For the definitions of Model I, model II, A, and S, see the note 1 in table 2. F indicates the total research funds on rice and other crops in a provincial academy in 1976-87 divided by the cultivated land area averaged over 1976-87 in that province.
2. Figures in parentheses indicate absolute asymptotic t-values.
3. Number of observations = 26.

Table 4: Tobit Estimates for Hybrid Rice Adoption Rate

	(1)	(2)
Constant	-38.09	-1.62
	(5.45)	(4.73)
A	.0052	.054
	(5.08)	(5.49)
M	2.60	.021
	(.33)	(.27)
Q	.0059	.155
	(3.41)	(3.16)
L	3.76	.099
	(4.27)	(3.76)
Y77	5.10	5.09
	(.64)	(.47)
Y78	9.97	9.84
	(1.36)	(.95)
Y79	11.49	10.93
	(1.60)	(1.05)
Y80	17.15	16.67
	(2.51)	(1.67)
Y81	16.69	16.02
	(2.43)	(1.58)
Y82	17.08	16.41
	(2.47)	(1.63)
Y83	12.30	10.35
	(1.68)	(1.63)
Y84	24.06	22.29
	(3.57)	(2.22)
Y85	23.77	20.94
	(3.52)	(2.06)
Y86	1.29	-.57
	(.13)	(.04)
Y87	3.40	2.13
	(.32)	(.15)
Log-Likelihood	87.11	103.92

Notes to Table V:

1. A is the rice area, M is the market density (ratio of rice acreage to total sown acreage), Q is rice output per hectare in the previous year, L is labor-land ratio, Y_{77} to Y_{87} are year dummies. Column (1) is a linear model, and in column (2) A, Q, and L are in logarithm form.

2. Figures in the parentheses are absolute asymptotic t-values.

3. Number of observations = 324.