The Australian Journal of Agricultural and Resource Economics, 43:2, pp. 179–194

Technological change and agricultural household income distribution: theory and evidence from China[†]

Justin Yifu Lin*

This article applies a general equilibrium model to analyse the impact of new rice technology on household income and uses agricultural household survey data from China to test the implications of this model. It is shown that, when a new rice technology becomes available, the adopting household will reallocate resources to increase rice production and reduce the production of other goods. Meanwhile, the non-adopting households will do the opposite. Thus, the income from rice becomes increasingly concentrated in the adopting households and income from non-rice becomes increasingly concentrated in the non-adopting households. If only one source of income is examined, the introduction of new rice technology increases the inequality of income distribution in rural areas. But, if the total household income is examined, the distributional inequality is mitigated.

1. Introduction

The introduction of new rice technology since the 1960s, often referred to as the 'Green Revolution', has enabled the densely populated Asian countries to meet the food demand arising from both rapid population growth and increase in per capita income. Whereas the impact of modern rice technology on productivity is well recognised, its impact on income distribution is equivocal. Some studies found that the income from modern rice technology was unequally distributed, large farmers benefited more than small farmers did, and households in areas with assured irrigation profited more than

[†] I am indebted to Cristina C. David, Robert W. Herdt, Mahabub Hossain, Keijiro Otuska, Peter Warr, workshop participants at IRRI, IFPRI, Australian National University, and the University of Southern California for insightful comments. I would also like to thank two anonymous referees for helpful suggestions. Shen Minggao provided very capable assistance in data collection. The study was supported by the Rockefeller Foundation (Grant Number 880-0489).

* Justin Yifu Lin, China Center for Economic Research, Peking University, Haidian, Beijing 100871, China and Department of Economics, Hong Kong University of Science and Technology, Hong Kong.

households in areas without assured irrigation. Some studies showed that the technology was scale-neutral and its effect on a household's income depended on the household's access to necessary inputs, including credits. Some studies suggested that, although small farmers and tenant farmers might initially lag behind large farmers in the adoption process, they soon caught up, and eventually, a farm's size and a farmer's tenure status became irrelevant with respect to the technology's adoption and income distribution. Some studies argued that the Green Revolution might benefit the poor in the long run because of the fall of food prices (Grabowski 1979; Griffin 1974; Hayami and Herdt 1977; Lipton and Longhurst 1989; Mellor 1978; Pears 1980; Rao and Hanumanth 1976; Ruttan 1978).

Most studies mentioned above focused solely on the distribution of rice income between adopter and non-adopter and between labourer and landowner. However, one of the main characteristics of an agricultural household in the developing countries is its incomplete specialisation in production (Hymer and Resnick 1969). Most agricultural households in Asia obtain only part of their incomes from rice production, and earnings from non-rice agricultural activities and off-farm activities constitute a substantial portion of their income (Anderson and Leiserson 1980; Shand 1986). The article will use a two-sector framework to examine the impact of modern rice technology on household income distribution and show that the conclusion from a one-sector model may not be valid in a two-sector setting. The essence of the argument is as follows: the introduction of modern rice technology may result in a change in a household's production mix. A household with comparative advantages in adopting modern rice technology may adopt it and reallocate resources away from non-rice production in order to increase the production of rice, whereas a household without these comparative advantages may shift its production away from rice to other goods. Therefore, the introduction of modern rice technology increases the concentration of income, viewed from a single sector, be it in rice or other goods. However, if a household's total income is considered, the concentration will be reduced.

The organisation of the article is as follows: the next section presents a simple two-household-two-good model. The impact of technological change on household income distribution is examined in a general equilibrium context, and several testable hypotheses are derived. The model is followed by a description of the data set, collected from 500 households in Hunan Province, China. The modern rice technology in the data set refers to the F_1 hybrid rice seeds. The subsequent section presents the empirical analysis. The last section summarises the results and discusses their implications.

2. A model of technological innovation and household income distribution

Most analytical models of the distributional impact of a new technology attempt to analyse how the new technology affects the distribution of income among producers in a given region, between producers and consumers, or between landowners and workers (Binswanger 1980; Hayami and Herdt 1977; Quizon and Binswanger 1983). The analytical model presented in this section, however, will analyse the distributional impact by examining changes in a household's production mix. For analytical purposes, the article follows Evenson (1978) and considers a simple two-household-two-good model in a general equilibrium context.

The basic model is as follows: a household i (1 or 2) owns a vector of predetermined endowments E_i, including land, labour, human and physical capital. With this set of endowments, a household can produce two goods, non-rice (y_{i1}) and rice (y_{i2}), according to its production possibility curve.

$$y_{i1} = F_i(y_{i2} \mid E_i) \tag{1}$$

The input requirements for these two goods are assumed to be different. For example, rice is more land-intensive than non-rice, whereas non-rice is more labour-intensive than rice. Because the endowment structure is different between these two households, the comparative advantages in producing these two goods are different. For the purpose of exposition, household 1 is assumed to have comparative advantages in rice production and household 2 in non-rice production, as shown in figure 1.

To set forth the argument in the clearest way, it is assumed that no factor market exists but that the product markets are perfect. Therefore, all exchanges between these two households are made through the product markets. Without loss of generality, the price of non-rice is assumed unity, and the price of rice is p. Total income for household i is

$$I_i = y_{i1} + p\, y_{i2}. \tag{2}$$

Household i is assumed to derive utility u_i from consumption of non-rice (x_{i1}) and rice (x_{i2}) with the following budget constraint:

$$x_{i1} + p\, x_{i2} = I_i = y_{i1} + p\, y_{i2}. \tag{3}$$

Equation 3 can also be expressed in a different way,

$$(x_{i1} - y_{i1}) + p(x_{i2} - y_{i2}) = 0. \tag{3'}$$

Let us call the difference between household i's desired consumption x_{ij} and its production, y_{ij}, its excess demand for the jth good. If the excess demand is positive, the difference measures household i's market demand for the jth good; if it is negative, it measures household i's market supply. From the

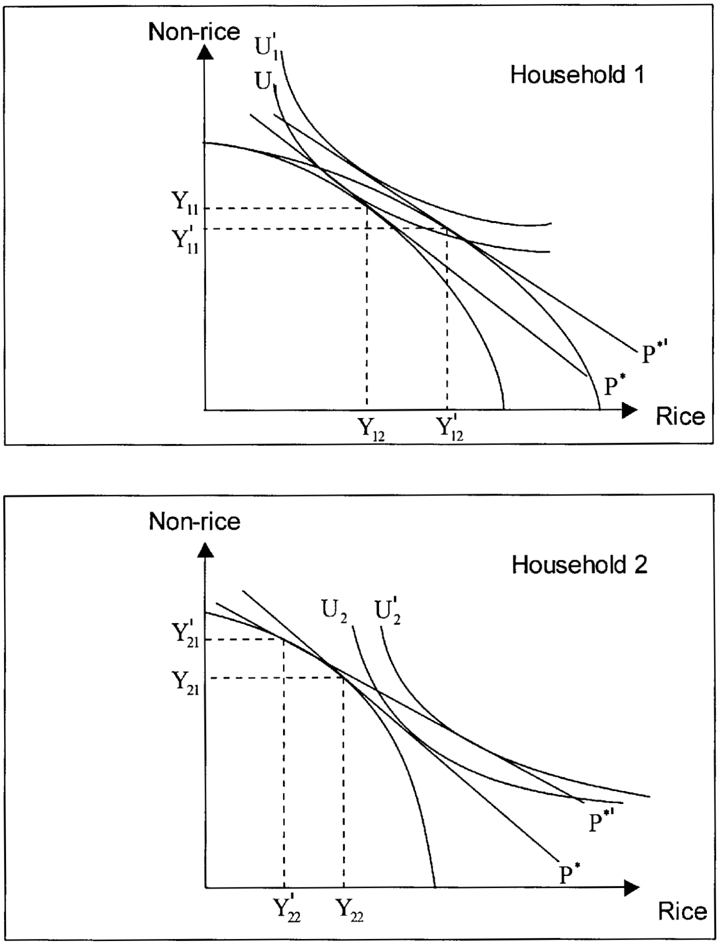

Figure 1 The impact of technological change on production mixes

budget equation 3′, the value of a household's market demands must equal the value of its market supplies.

Each household chooses a production mix and a consumption mix to maximise its own utility according to its preferences, endowments, production technology, and the prices it faces. From Walras's law, a market equilibrium p^* exists to clear the rice market and the non-rice market simultaneously.

The equilibrium is depicted in figure 1. At the equilibrium market price, p^*, household 1's production mix is (y_{11}, y_{12}) and household 1 is a net demander for non-rice and a net supplier of rice in the markets. Household 2's production mix is (y_{21}, y_{22}) and its market demand and supply are just the opposite to household 1. For simplicity, x_{ij}s are not indicated in figure 1.

Suppose, now, that a new rice technology becomes available. Like most new technologies, it has a higher yield than the original technology but is risky and requires certain costs to learn. The new technology is assumed to favour household 1 because of that household's endowment structure. As a result, household 1 adopts the new technology and expands its production possibility curve, as shown by the dotted curve, whereas household 2 does not adopt this new technology. The impact of this technological change on the income and welfare of these two households can be depicted diagrammatically.

First, at the original equilibrium price p^*, the total demand for both goods will be the same as usual, but the supply of rice from household 1 increases. The new equilibrium market price $p^{*\prime}$, which clears both markets, will be lower than p^*. How much the equilibrium price of rice falls depends on both households' marginal propensities to consume rice and non-rice. Under the new equilibrium price $p^{*\prime}$, the production mix for household 1 is (y'_{11}, y'_{12}) and for household 2 is (y'_{21}, y'_{22}).

Compared with the original production mixes, we can conclude that, for household 2, $y'_{21} > y_{21}$ and $y'_{22} < y_{22}$ and that, for household 1, definitely $y'_{12} > y_{12}$ but y'_{11} can be greater than, less than, or equal to y_{11}. However, if the fall in equilibrium price is moderate, it is likely that $y'_{11} < y_{11}$. Therefore, if only the rice income is considered, the technological innovation contributes to the increasing concentration of income in the adopting household, as claimed by many previous studies. However, the non-rice income is likely to concentrate increasingly in the non-adopting household due to adjustments in the production mixes by both households. Because of the offsetting effects of these two opposite adjustments, the claim — based solely on the distribution of rice income — that the new rice technology contributes to income inequality in the rural areas may not be warranted. It is likely that the new technology's impact on the relative income positions of these two households is negligible, even if only one household adopts the new rice technology. How much the new technology affects the income distribution between the adopting and non-adopting households is an empirical issue.

Two testable hypotheses concerning the impact of a new technology on household income distribution are in order:

Hypothesis 1: When a new rice technology becomes available, the agricultural households with comparative advantages in adopting this new technology will adopt it, and reallocate resources away from non-rice production to rice production. On the contrary, the non-adopting households will shift their production away from rice to non-rice production. Therefore, the income from rice becomes increasingly concentrated in the adopting households and the income from non-rice becomes increasingly concentrated in the non-adopting households.

Hypothesis 2: Due to the opposite directions of adjustments in the adopting and non-adopting households, the effect of a new technology on the distribution of total household income is more equal than its effect on the distribution of individual components of income.

3. Data

Agricultural household survey data from China is used to test the above hypotheses. Modern rice technology in this study refers to the hybrid rice seeds. Despite many problems in China's socialist economy, rice research and breeding in China have been very successful. In 1964, China began a full-scale distribution of fertiliser-responsive, lodging-resistant semi-dwarf rice varieties with high-yield potential, two years before the International Rice Research Institute released them. At the end of the 1970s, more than 80 per cent of the rice acreage in China had planted the semi-dwarf varieties. The full-scale dissemination of F_1 hybrid rice seeds in 1976 marked the beginning of a new stage of rice breeding and extension in China. Up to the early 1990s, China was the only country in the world where hybrid rice seeds were used in commercial production. In 1987, about 34 per cent of rice fields in China grew F_1 hybrid rice.[1] Under the same input application levels, F_1 hybrids are found to have a yield advantage of about 20 per cent over the conventional semi-dwarf varieties (He *et al.* 1984, 1987; Lin 1994).

The data that will be used to test the above hypotheses come from a cross-sectional survey of 500 households in five counties of Hunan Province conducted by the author during December 1988 and January 1989.[2] Hunan Province is at the middle reaches of the Yangtze River in South China. It has a semi-tropical climate. The province is divided administratively into 105 counties in three types of geographic setting — lake-plain, hill, and mountain. Among the five counties in the data set, two were selected from the lake-plain region, two from the hill region, and one from the mountain region. These five counties were selected from the provincial sample of 34 counties surveyed annually by the State Household Investigation Team. Samples of 100 households, selected randomly, from each of these five counties, were included in the data set. The main characteristics of the sample households are reported in table 1. Of the total 500 households, 495 devoted part of their land to rice. Detailed information on the number of

[1] For a detailed discussion of the invention, extension, and adoption of F_1 hybrid rice technology, see Lin (1991 a and b).

[2] See Lin (1991a) for a more detailed description of the data set.

Table 1 Characteristics of sample farm households

	Hill		Lake-plain		Mountain
	County 1 ($N = 100$)	County 2 ($N = 100$)	County 3 ($N = 100$)	County 4 ($N = 100$)	County 5 ($N = 100$)
Mean household size (person)	4.28 (.92)	4.26 (1.41)	4.59 (1.20)	4.60 (1.22)	4.20 (1.21)
Mean labour force (person)	3.11 (1.08)	3.32 (1.28)	3.40 (1.21)	3.61 (1.30)	3.26 (1.23)
Mean farm size (ha)	.33 (.15)	.31 (.11)	.54 (.20)	.56 (.20)	.40 (.17)
Percentage of paddy land	79.3	83.4	72.8	73.0	78.1
Hybrid rice					
Adopter	78	67	64	93	99
Non-adopter	22	33	36	7	1

Note: Figures in the parentheses are standard errors.

households adopting and not adopting hybrid seeds in each of the five counties in 1988 is reported in the last two rows of table 1.

Table 2 reports the average annual income per household in these five counties. Agricultural income in table 2 includes revenues from rice, cash crops, forestry, household sideline production, animal husbandry, and off-farm agricultural employment.[3] Non-farm income includes wages from non-farm employment, revenues from household non-farm business, and transfers. In the calculation of revenues, costs for material inputs and payments for hired services are deducted from the gross revenues; however, the costs for the family labour, capital service, and land rent are not deducted. Table 2 shows that rice was the single most important source of income in the sample households.[4] However, on average, about one-half to two-thirds of the household income was from non-rice production.

This data set represents an unusual opportunity to test the implications of the above model. This is because not only did households in the sample derive their income from rice and from other sources but also exchanges in

[3] The price that is used to calculate the revenue of rice is the average price received by the agricultural households. It is a weighted average of the state quota price and the above-quota price. In 1988, the average price was .611 yuan/kg.

[4] County 5 has the highest adoption rate of hybrid rice as shown in table 1. However, the contribution of rice income to total household income is smallest because the mountain climate dictates that the county can grow only one season of rice annually, whereas the other four counties grow two seasons of rice annually.

Table 2 Average annual farm household income (Yuan) by source

	Hill		Lake-plain		Mountain
	County 1	County 2	County 3	County 4	County 5
Total household income	3584.08 (1486.55)	3333.77 (1461.70)	3063.91 (1140.94)	3660.50 (1465.64)	2543.32 (1170.39)
Agricultural income:					
Rice income	1186.61 (491.50)	1484.88 (615.66)	1547.08 (1003.38)	1943.46 (891.61)	826.28 (515.94)
Non-rice agri. income:	1045.50 (617.15)	864.49 (462.83)	934.24 (484.78)	974.75 (508.40)	1073.99 (744.80)
Cash crop	271.87 (195.92)	191.16 (168.82)	565.35 (311.32)	503.96 (295.46)	435.85 (341.64)
Forestry	34.10 (55.93)	49.46 (113.50)	0 –	0 –	180.31 (218.31)
Husbandry + sidelines	735.90 (543.06)	608.37 (394.28)	345.82 (364.88)	470.79 (365.83)	447.68 (564.42)
Off-farm agr. employ.	3.62 (15.86)	15.50 (86.41)	23.07 (111.36)	0 –	10.15 (32.64)
Non-farm income:	1351.98 (1267.65)	984.40 (1202.96)	582.59 (596.28)	742.28 (1063.55)	643.05 (764.07)
Non-farm employment	153.88 (420.12)	94.23 (401.30)	63.82 (272.28)	72.73 (279.10)	89.55 (362.98)
Non-farm business	792.23 (834.56)	520.97 (698.53)	284.92 (353.13)	365.51 (594.56)	482.86 (633.57)
Transfer	405.87 (711.52)	369.20 (789.01)	233.85 (429.92)	304.04 (561.57)	70.64 (269.36)

Note: Figures in the parentheses are standard errors.

land and labour markets were inhibited in rural China. Before the reforms in the 1980s, such exchanges were outlawed for ideological reasons. There has been a relaxation in the regulation of land and labour markets. However, exchanges in land and labour markets are still very limited (Lin 1995). As shown in table 2, on average, a household obtains less than 1 per cent of its income from off-farm agricultural employment. The income from land rent is even more negligible. Therefore, the impact of hybrid rice technology on the distributional equity of household income can function only through the mechanism discussed in the previous section. This data set, however, also has a limitation: a household's adjustment in its production mix in response to the change in technology may take several years. The data has one year's observation only. Therefore, we are unable to trace the dynamic path of the adjustment. Although the hybrid rice technology has been available in the study area for more than a decade and thus the adjustment may have approached the new equilibrium point, caution needs to be exercised in drawing conclusions on the basis of only one year's observation.

4. Empirical analysis

Two approaches are used to examine the validity of hypotheses 1 and 2. The first approach compares a measure of the distribution equity of rice income with that of non-rice income, as well as with that of total household income. The second approach applies regression analyses to investigate how the hybrid rice technology affected various sources of income across adopting and non-adopting households. The first approach is indirect and suggestive of the distributional effect, whereas the second approach is a direct test. For the purpose of the present study, the total household income will be subdivided into three components: rice income, non-rice agricultural income, and non-farm income, as shown in table 2.

4.1 Approach 1

Most studies of the distributional effect of a new agricultural technology derive their conclusions from certain measures of income inequality. The most commonly used measure is the Gini coefficient. Table 3 reports the Gini coefficients of total household income, rice income, non-rice agricultural income, and non-farm income.

Column 5 of table 3 shows that the Gini coefficients of total household income in these five counties range from .21 to .25. Comparing column 5 with column 1, we find that the Gini coefficient of total household income is substantially lower than the Gini coefficients of rice income, non-rice agricultural income, and non-farm income in each of the five counties, except for the Gini coefficient of rice income in County 2. The same observation holds when data of these five counties are pooled together. This evidence is consistent with the implications of hypotheses 1 and 2.

4.2 Approach 2

While the evidence from the results of approach 1 is consistent with the implications of hypotheses 1 and 2, the results may arise from factors other than a household's adjustments in its production mix due to the adoption or

Table 3 Gini coefficients of the total household income and of the income components

	Component Gini (1)	Income Share (2)	Rank Correlation (3)	Gini Decomposition (1) × (2) × (3) = (4)	Total Household Income Gini* (5)
County 1:					
Rice income	.226	.331	.620	.046	
Non-rice agri. income	.317	.292	.509	.047	
Non-farm income	.456	.377	.721	.124	
Total income		1.000			.217
County 2:					
Rice income	.232	.445	.679	.070	
Non-rice agri. income	.299	.260	.455	.035	
Non-farm income	.558	.295	.772	.128	
Total income		1.000			.234
County 3:					
Rice income	.367	.505	.755	.140	
Non-rice agri. income	.283	.305	.335	.029	
Non-farm income	.516	.190	.419	.040	
Total income		1.000			.209
County 4:					
Rice income	.246	.531	.736	.096	
Non-rice agri. income	.275	.267	.512	.038	
Non-farm income	.570	.202	.617	.071	
Total income		1.000			.205
County 5:					
Rice income	.335	.325	.653	.071	
Non-rice agri. income	.326	.421	.609	.083	
Non-farm income	.574	.253	.688	.100	
Total income		1.000			.254
Aggregate:					
Rice income	.322	.432	.687	.096	
Non-rice agri. income	.304	.302	.455	.042	
Non-farm income	.552	.266	.656	.096	
Total income		1.000			.234

Note: *The Gini coefficient of total household income is a weighted sum of its individual components' Gini coefficients, using the product of each individual component's income share and rank correlation as the weight (Fei, Ranis, and Kuo, 1978, pp. 75–83).

non-adoption of the new technology. To separate the effect of technology from other influences, a regression analysis is applied. From the model, we see that a household's production of rice and non-rice is a function of the household's predetermined endowments. Therefore, a household's income from each source is also a function of the household's predetermined endowments. To examine the effect of hybrid rice technology on household income, we need to include a dummy in the income determination function indicating whether a household is an adopter of hybrid rice seeds. Aside from a household's predetermined endowments and the adoption dummy, in a cross-sectional data set a household's income may also depend on some region-specific variables that are not observable to an econometrician. Therefore, four county dummies will be included in the income determination functions to capture the region-specific effects. The resulting equations for the determination of a household's rice income, non-rice agricultural income, non-farm income, and total income can be expressed in a similar form as follows.

$$
\begin{aligned}
Ln\,\text{Income} = {} & a_0 + a_1 C_1 + \ldots + a_4 C_4 + a_5\,Ln\,\text{Land} + a_6\,Ln\,\text{Labour} \\
& + a_7\,\text{Capital} + a_8\,\text{Female Dummy} + a_9\,\text{Age} \\
& + a_{10}\,\text{Schooling} + a_{11}\,\text{Adoption Dummy} + u,
\end{aligned} \tag{4}
$$

where a_js are the coefficients to be estimated; a_0 is an intercept term; C_1 to C_4 are county dummies; regressors 5 to 7 are a household's production endowments, including the size of landholding, the size of the labour force, and the value of farm capital stock; regressors 8 to 10 represent a household head's personal characteristics, including the dummy for gender, age, and years of schooling of the household head; regressor 11 is a dummy variable indicating whether a household adopted hybrid rice; and the last term, u, is a residual. Both dependent and independent variables in the equation, except for the dummy variables, are in logarithm form.

The study uses one-time period, cross-section data to estimate equation 4, which in fact is a one-way fixed-effects model. If there is no heteroscedasticity in the data, Ordinary Least Squares is an unbiased, efficient estimation. However, groupwise heteroscedasticity is a potential problem in cross-section, time-series data. Greene (1993, pp. 395–6) suggests a likelihood ratio test to examine whether groupwise heteroscedasticity exists. Table 4 reports

Table 4 Likelihood ratio test for groupwise heteroscedasticity

	Rice Income Equation	Non-Rice Agri. Income Equation	Non-Farm Income Equation	Total Household Income Equation
H0: Homoscedasticity H1: Groupwise Heteroscedasticity				
Log likelihood Ratio	247.48	50.17	291.31	127.27
Chi-squared (.995, 4) = 14.86				

the results of the test. Under the null hypothesis of homoscedasticity, the likelihood-ratio statistic is asymptotically distributed as chi-squared with $G-1$ degrees of freedom, where G represents the number of groups. All likelihood-ratio statistics, shown in table 4, reject the null hypothesis of homoscedasticity and favour the alternative hypothesis of groupwise heteroscedasticity. Therefore, the heteroscedasticity-consistent FGLS procedure, instead of the OLS procedure, is used to fit the fixed-effects regressions. The results of fitting the regressions are reported in table 5. For simplicity, the coefficients of constant and county dummies have been omitted in table 5.

From hypothesis 1, we expect the sign of the coefficient of the adoption dummy to be positive in the rice income equation, and negative in both the non-rice and the non-farm income equations. According to hypothesis 2, the sign of the adoption dummy in the total income equation cannot be determined *a priori*. It can be significantly positive, significantly negative, or not significantly different from zero. However, the magnitude of the estimated coefficient should lie between the positive estimate in the rice

Table 5 FGLS estimates of the impact of hybrid rice adoption on income determination

	Rice income (*Ln*)	Non-rice Agri. Income (*Ln*)	Non-farm Income (*Ln*)	Total household Income (*Ln*)
Ln Landholding	.86 (15.06)***	.45 (5.99)***	−.57 (2.72)**	.44 (9.56)***
Ln Labour force	.12 (1.98)*	.16 (1.97)*	1.02 (4.36)***	.35 (6.93)***
Ln Capital stock	.006 (.42)	.05 (2.13)*	.08 (1.52)	.02 (2.10)*
Female dummy	.042 (.46)	.03 (.19)	.64 (1.73)*	.30 (3.66)***
Ln Age	−.13 (1.40)	−.05 (.42)	.63 (1.98)*	−.04 (.54)
Ln Schooling year	.03 (.59)	.006 (.11)	.46 (3.21)***	.10 (2.87)**
Hybrid rice adoption dummy	.26 (5.00)***	−.45 (.64)*	−.65 (3.58)***	.03 (.71)
County dummies	Yes	Yes	Yes	Yes
F-statistic	61.08	8.91	8.64	36.67
Adjusted R^2	.57	.15	.15	.44

Note: Figures in the parentheses are absolute values of t-statistics. *,**, and *** indicate that the estimates are significantly different from zero at the .1, .01, and .001 levels of confidence.

income equation and the negative estimates of the non-rice income equations. The results in table 5 confirm the predictions from these two hypotheses.

Holding other factors constant, we find that the adoption of hybrid rice technology had a positive and highly significant effect on a household's income from rice production. As expected, the adoption of hybrid technology had negative effects on both non-rice agricultural income and non-farm income. The negative effect on non-farm income was highly significant. Furthermore, the coefficient of the hybrid rice adoption dummy in the total household income equation, shown in the last column of table 5, has a positive sign but is not significantly different from zero. Its magnitude, .03, lies between .26, and −.45 and −.65. These results are consistent with the hypotheses derived from the theoretical model. Viewed from the income of rice production alone, the introduction of hybrid rice technology contributed to the concentration of rice income to the adopting households, and, consequently, increased the income inequality between the adopting and non-adopting households. However, from the viewpoint of total household income, the evidence shows that the introduction of hybrid rice technology did not contribute to any perceivable deterioration in distributional equity in the study areas.

It is interesting to note that a similar adjustment in the production mix in responding to a household's endowment structure can also be observed from the results in table 5. From column 1, we found that the size of a household's landholding is the most important factor determining a household's income from rice. The estimated coefficient of landholding indicates that a 10 per cent increase in the size of a household's landholding would result in an 8.6 per cent increase in the household's income from rice. However, the size of a household's landholding had a significantly negative effect on its non-farm income. The opposite signs suggest that households with small landholdings shift their labour and other resources from land-intensive rice cultivation to less land-intensive, non-farm activities. Consequently, the coefficient of landholding drops from .86 in the rice income determination equation to .44 in the total household income equation, while the coefficient of labour force increases from .12 to .38 in the same equations.

The signs and coefficients of other explanatory variables in table 5 also provide interesting information about the determination of agricultural household income. Capital contributed positively and significantly to total household income; the impact came mainly from the positive effect on non-rice agricultural income. The effect of capital stock on rice income was positive, but less significant. This finding is consistent with observations that tractors and other farm capital in rural China are used mainly for transportation and other non-farm purposes (Perkins and Yusuf 1984). The female dummy had a positive and significant impact on the total household income, mainly because a household with a female head received significantly more remittance — a component of non-farm income — than a household with a male head. On average, a female-head household received 838.67 yuan remittance annually, compared with 255.73 yuan for a male-head household. The age of a household head — a proxy for farming experience — did not have a significant effect on household income. However, it contributed positively and significantly to non-farm income. As in the case of the female dummy, the remittance that a household received was positively correlated with the age of the household head. The education of a household head was a significant variable in the determination of total household income. The positive impact mainly derived from its positive effect on non-farm income. The effects of education on non-rice agricultural income and rice income were insignificant. This evidence suggests that farmers with higher education had better job mobility. Education enabled them to utilise the opportunities arising from non-farm sectors.

5. Conclusion

This article uses a simple two-household-two-product general equilibrium model to analyse the impact of a new rice technology, which favours one household, on household income distribution. The implications of the model were tested with data collected from a sample of 500 households from five counties in Hunan Province, China. The empirical results are consistent with the implications of the theoretical model: when a new rice technology becomes available, the adopting households will reallocate resources away from non-rice production in order to increase the production of rice. Meanwhile, the non-adopting households do just the opposite. Due to adjustments in the production mixes, the income from rice becomes increasingly concentrated in the adopting households, whereas the income from non-rice becomes increasingly concentrated in the non-adopting households. Therefore, if only one source of income is examined, the introduction of new rice technology seems to increase the distributional inequality. However, due to the offsetting effect in production-mix adjustments, if the total household income is examined, the distributional inequality is mitigated. In the study areas of this article, hybrid rice's net effect on the distribution of total household income between adopting and non-adopting households is found to be negligible.

As mentioned in the introduction, up-to-date, theoretical and empirical studies on the distributional impact of the Green Revolution mostly focused on its effect on the distribution of rice income. The results shown in the article shed new light on this issue. The often-cited claim that the Green Revolution contributes to the inequality of income distribution in rural areas may be unfounded because even the poorest section of the rural population obtains a substantial portion of its income from non-rice and non-farm activities. Based on previous studies, some economists propose increasing research efforts on rice technologies that directly target unfavourable environments or underprivileged groups (Lipton and Longhurst 1989; Rao and Hanumanth 1976). The results in this study suggest such efforts may not be warranted.[5] Whether the distributional impacts of the Green Revolution are as negligible in other economies as in the areas studied here can only be determined by further empirical studies; such studies are warranted. The model in the article, nevertheless, suggests that a more efficient policy may be to improve education, transportation, and the infrastructure in rural areas, facilitating the expansion of product markets and offering opportunities for the poor to increase the production of non-rice crops or engage in non-farm activities.

References

Anderson, D. and Leiserson, M.W. 1980, 'Rural nonfarm employment in developing countries', *Economic Development and Cultural Change*, vol. 28, no. 2, pp. 227–48.

Binswanger, H.P. 1980, 'Income distribution effects of technological change: some analytical issues', *The Southeast Asian Economic Review,* vol. 1, December, pp. 179–218.

Evenson, R. 1978, 'Time allocation in rural Philippine households', *American Journal of Agricultural Economics*, vol. 60, no. 2, pp. 322–30.

Fei, J.C.H., Ranis, G. and Kuo, S.W.Y. 1978, 'Growth and the family distribution of income by factor components', *Quarterly Journal of Economics*, vol. 92, no. 1, pp. 17–53.

Grabowski, R. 1979, 'The implication of an induced innovation model', *Economic Development and Cultural Change*, vol. 27, no. 4, pp. 723–34.

Greene, W.H. 1993, *Econometric Analysis*, 2nd edn, Prentice-Hall, Englewood Cliffs, New Jersey.

Griffin, K. 1974, *The Political Economy of Agrarian Change: An Essay on the Green Revolution*, Harvard University Press, Cambridge, MA.

Hayami, Y. and Herdt, R.W. 1977, 'Market price effects of technological change on income distribution in semisubsistence agriculture', *American Journal of Agricultural Economics*, vol. 59, no. 2, pp. 245–56.

[5] To achieve a social optimum in allocating resources among breeding programs requires the following factors to be taken into consideration: a) the costs and time of the breeding program and its likelihood of successfully finding a new variety; b) the yield potential of the new variety and the size of the area in which the new variety is applicable; and c) the distributional impact of the new variety. According to the present study, a smaller weight should be given to the third consideration than that suggested by previous studies, for example Rao and Hanumanth (1976) and Lipton and Longhurst (1989).

He, Gui-ting, Te, A., Xigang, Zhu, Travers, S.L., Xiugan, Lai and Herdt, R.W. 1984, *The Economics of Hybrid Rice Production in China,* IRRI Research Paper Series, no. 101, December.

He, Gui-ting, Xigang, Zhu and Flinn, J.C. 1987, 'A comparative study of economic efficiency of hybrid and conventional rice production in Jiangsu Province, China', *Oryza*, vol. 24, no. 4, pp. 285–96.

Hymer, S. and Resnick, S. 1969, 'A model of an agrarian economy with nonagricultural activities', *American Economic Review*, vol. 59, no. 4, part I, pp. 493–506.

Lin, J.Y. 1991a, 'Education and innovation adoption in agriculture: evidence from hybrid rice in China', *American Journal of Agricultural Economics*, vol. 73, no. 3, pp. 713–24.

Lin, J.Y. 1991b, 'The household responsibility system reform and the adoption of hybrid rice in China', *Journal of Development Economics*, vol. 36, no. 2, pp. 353–72.

Lin, J.Y. 1994, 'The nature and impact of hybrid rice in China', in Otsuka, Keijiro and David, Cristina C. (eds), *Modern Rice Technology and Income Distribution in Asia*, Lynne Rienner, Boulder, Colorado, pp. 375–408.

Lin, J.Y. 1995, 'Endowments, technology and factor markets: a natural experiment of induced institutional innovation from China's rural institutional reform', *American Journal of Agricultural Economics*, vol. 77, no. 2, pp. 231–42.

Lipton, M. and Longhurst, R. 1989, *New Seeds and Poor People*, Unwin Hyman, London.

Mellor, J.W. 1978, 'Food price policy and income distribution in low-income countries', *Economic Development and Cultural Change*, vol. 27, no. 1, pp. 1–26.

Pears, A. 1980, *Seeds of Plenty, Seeds of Want: Social and Economic Implications of Green Revolution*, Clarendon Press, Oxford.

Perkins, D. and Yusuf, S. 1984, *Rural Development in China*, Johns Hopkins University Press, Baltimore.

Quizon, J.B. and Binswanger, H.P. 1983, 'Income distribution in agriculture: a unified approach', *American Journal of Agricultural Economics*, vol. 65, no. 3, pp. 526–38.

Rao, C. and Hanumanth, H. 1976, 'Factor endowments, technology and farm employment: comparison of East Uttar Pradesh with West Uttar Pradesh and Punjab', *Economic and Political Weekly*, vol. 11, September, pp. A117–A123.

Ruttan, V.W. 1978, 'The Green Revolution: seven generalizations', *International Development Review*, vol. 19, no. 4, pp. 16–23.

Shand, R.T. (ed.) 1986, *Off-Farm Employment in the Development of Rural Asia: papers presented at a conference held in Chiang Mai, Thailand, 23 to 26 August 1983*, National Centre for Development Studies, Australian National University, Canberra.