The Australian Journal of Agricultural and Resource Economics, 49, 159–175

Irrigation, poverty and inequality in rural China*

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This paper examines the impact of irrigation on rural incomes, poverty and the income distribution in rural China. The relationship between irrigation and income is examined using descriptive statistics and multivariate analysis. A simulation approach is used to explore the impact of irrigation on poverty incidence. To uncover the effect of irrigation on the income distribution, inequality is decomposed by source of income, by group according to access to irrigation and by estimated income flows as a result of specific household characteristics. The results show that irrigation increases income and reduces poverty and inequality.

Key words: income, inequality, irrigation, poverty, rural China.

1. Introduction

Although China has made remarkable progress in increasing the standard of living in its rural areas since the onset of economic reform, rural income growth has slowed in recent years and the distribution of income has deteriorated (Nyberg and Rozelle 1999; World Bank 2001). Based on the government's poverty line, the incidence of poverty declined from 30.7 to 3.4 per cent between 1978 and 2000 (Wang *et al*. 2002). Poverty reduction stalled in the late 1980s and early 1990s, recovered in the mid-1990s, but stalled again in the late 1990s (Ravallion and Chen 2004). Large discrepancies among households within regions and among sets of households in different regions have begun to appear. Rozelle (1996) shows that the interregional Gini ratio increased from 0.28 in the 1980s to 0.42 in the 1990s in rural China. Yang (2002) shows a similar rise in interhousehold measures of inequality. This widening of income inequality slowed the rate of China's poverty reduction (World Bank 2001).

* We would like to thank Frank Rijsberman, Mahabub Hossain, Bryan Lohmar, Siwa Msangi, Amelia Blanke and Yigang Zhang for comments on earlier versions of this manuscript. We also thank two anonymous reviewers for helpful comments. We want to acknowledge the financial support of the Ford Foundation, Beijing, the USDA National Research Initiative, the US National Science Foundation, International Water Management Institute and International Rice Research Institute. The authors also acknowledge the support of National Nature Science Foundation of China (70021001) and EC (INCO:ICA4-CT-2001-10085). Scott Rozelle is a member of the Giannini Foundation.

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As the expansion of the rural economy has driven a large part of China's past economic growth (Perkins 1994), the recent sluggish rural income expansion and increasing inequality have begun to command national attention. To reaccelerate growth, there is almost certainly a role for aggressive new investment in rural China. However, in an era of macroeconomic reforms and tight government budget constraints, efficient use of scarce resources has become increasingly important. Hence, in determining investment priorities, China's leaders need to understand which investments can best spur rural growth and reduce poverty and inequality.

One type of investment that China's leaders have traditionally relied on to increase rural livelihoods is investment in irrigation. China's success in achieving food self-sufficiency took place in the 1960s and 1970s when China's government made massive investments in irrigation infrastructure, suggesting that irrigation played a key role in rural development in the past. In 2000, government spending on irrigation (35 billion yuan) exceeded the annual budget targeted specifically at poverty reduction (22.4 billion yuan) and was more than 10 times the spending on agricultural research (3.4 billion yuan) (Huang and Hu 2001; Ministry of Water Resource 2001; National Statistical Bureau of China (CNSB) 2001a).

Despite such large investments, literature that examines the impact of irrigation on agricultural performance is mixed – both inside and outside of China. Often, studies of agricultural production, productivity and income growth cannot identify positive effects of irrigation investment. For example, Fan *et al*. (2000) illustrate that government expenditures on irrigation have only a modest impact on agricultural production growth and even less on rural poverty and inequality, even after accounting for trickle-down benefits. Jin *et al*. (2002) cannot find a link between irrigation and the total factor productivity (TFP) growth of any major grain crop (rice, wheat or maize) in China between 1981 and 1995. Outside China, Rosegrant and Evenson (1992) are also unable to establish a positive link between irrigation investment and productivity in India. Hossain (2000) is among the few studies that find a positive impact of irrigation on rural household income, in the Philippines and Bangladesh. However, the household survey-based analyses use small samples that are not nationally representative. To our knowledge, no household study has been used to examine these questions in China.

Despite the increasing seriousness of China's rural inequality problem, there has been little theoretical or empirical effort to study the effect of irrigation investment on inequality. Most studies of inequality in China do not examine the role of irrigation (e.g., Rozelle 1996; Kung and Lee 2001). The absence of research might be a result of the complicated nature of the linkages between irrigation and inequality; irrigation almost certainly leads to increased agricultural incomes (Rozelle 1996). However, irrigation has often been associated with rural households that reside in relatively favourable areas (David and Otsuka 1994). Hence, without an empirical study, it is impossible to predict whether increasing irrigation will help lower inequality.

The overall goal of our present paper is to examine the impact of irrigation on income, poverty and income distribution in rural China. To meet the overall goal, the paper pursues three specific objectives. First, we examine the relationship between irrigation and income using both descriptive statistics and multivariate analysis. Second, we use a simulation approach to explore the impact of irrigation on the incidence of poverty. Finally, in order to uncover the effect of irrigation on income distribution, we decompose inequality by source of income, by group according to access to irrigation and by estimated income flows as a result of specific household characteristics.

The rest of the paper is organised as follows. In the first section we introduce the data and variables used for the analysis. The second section describes the relationship between irrigation and income and presents the multivariate analysis of income determinants. The third section simulates changes in poverty incidence as a result of changes in irrigation status. Thereafter, we decompose income inequality using several different approaches, and present conclusions of the study.

2. Data

Our data come from a randomly selected, almost nationally representative sample of 60 rural villages in six provinces (Hebei, Liaoning, Shanxi, Zhejiang, Hubei, and Sichuan) (henceforth, the 2000 China National Rural Survey or 2000 CNRS). To accurately reflect varying income distributions within each province, we selected one county at random from within each provincial income quintile. The survey team randomly selected two villages within each county and used village rosters and our own counts to randomly choose 20 households. The village rosters included citizens with and without residency permits (*hukou*). The survey included a total of 1198 households.

The questionnaire included a special block that collected plot-level information. We asked whether a plot was irrigated and the area of the household's irrigated land. The block also recorded information on other plot-specific variables, such as the type of crop grown on a plot, crop yield, the degree of land fragmentation (measured as the number of plots per household), the proportion of good quality land (the proportion of one household's land that is rated as 'high quality' by the farmer) and the proportion of land that was affected by a negative shock during the cropping year (e.g., drought or flooding).

The survey collected data on rural household income that can be disaggregated into cropping, off-farm and other income sources. Cropping income includes proceeds from crop sales less expenses. Profits from processed crops (e.g., rice noodle) are also included in this category. Off-farm income includes all income from businesses run by households, wages from a household member's off-farm job and migrant remittances. Most of the households in the sample also had some other form of income, such as earnings from livestock, rent earnings, asset sales and pensions. This source of income is classified as 'other' in this study.

The household survey also gathered detailed information on other household characteristics. We have information on household size, average age and level of education of the household's labour force, total land holdings and asset holdings. Finally, a number of village level variables for our sample were constructed using data from a village leader questionnaire.

3. Irrigation and income

Compared to other countries, the proportion of China's cultivated area that is irrigated is high. Our data show approximately 49 per cent of total cultivated land is irrigated.

Table 1 Annual household income per capita and are of irrigated land per capita

Irrigated land per capita (ha)	No. household	Total household income per capita† (yuan)	Cropping income per capita (yuan)	Off-farm income per capita (yuan)	Total land per capita (ha)
1. China	1198‡	2257 (100%)§	460 (19%)	1462 (66%)	0.148
2. 0 (Non-irrigated)	186	1571 (100%)	211 (12%)	1120 (71%)	0.235
3. Between 0 and 0.067	554	2590 (100%)	296 (11%)	1914 (75%)	0.089
4. Between 0.067 and 0.2	378	1984 (100%)	654 (31%)	1005 (52%)	0.148
5. Above 0.2	80	2825 (100%)	1254 (43%)	1289 (46%)	0.407

Source of data: 2000 China National Rural Survey. †Other income is not reported here as it is not the focus of this paper. ‡Total number of households is 1198 instead of 1200 because information on two households is missing. §Shares of different income sources in total household income are reported in parentheses.

Although this figure is somewhat higher than the estimate published by the CNSB (2001b) in its yearbook (41 per cent), both our estimate and that of the CNSB are higher than for most other nations. For example, the comparable statistic for India is 33 per cent, for Brazil it is 1 per cent and for the USA it is 6 per cent (Food and Agriculture Organisation of the United Nations 2002).

Our data show that the amount of irrigated land per capita is strongly correlated with annual cropping income (Table 1, column 3). Compared to households without irrigated land (row 2), annual per capita cropping income is 40 per cent higher (296 vs 211) in households that have irrigated land holdings of up to 0.067 hectare per capita (row 3). This is true despite the fact that the average household's cultivated land per capita is only 0.089 hectare in the households with irrigated land, less than half that of households without irrigated land. Cropping income per capita continues to rise as irrigated land per capita increases (rows 4 and 5).

Our data also show that as irrigated land per capita increases, cropping income becomes a more important source of household income (Table 1, column 3 – see figures in parentheses). For example, cropping income accounts for only 12 per cent of total income for households without irrigated land. The share of income from cropping grows continuously as irrigated land per capita increases. For those with more than 0.2 hectare irrigated land per capita, cropping contributes to 43 per cent of total household income.

Total income per capita, however, does not show the same monotonically increasing relationship with irrigated land area as does per capita cropping income (Table 1, column 2). Households with irrigated land between 0 and 0.067 hectares per capita have a relatively high average annual income (2590 yuan per capita). By contrast, those with irrigated land between 0.067 and 0.2 hectares per capita have total incomes that reach, on average, only 1984 yuan per capita.

After examining column 2 of Table 1, we can draw one of two conclusions: (i), irrigation is not a significant factor in determining total income; or (ii), we are only observing two-way correlations and the true relationship between irrigation and total income could be masked by correlation between other factors. In order to answer the question of whether irrigation affects household income we need to hold other factors constant by using multivariate analysis.

3.1 Multivariate analysis

We follow the standard approach in the published literature on permanent income analysis (Paxson 1992; Datt 1998) and income inequality in rural China specifically (Benjamin *et al*. 2000; Morduch and Sicular 2002). In these studies, the determinants of income can be analysed by making income a function of a set of household and village characteristics, including household irrigated area. Because household income is treated in the same way as firm profit, income should also, theoretically, be a function of output and input prices and other factors.

Following this literature, our basic model is:

$$y_{hv} = \alpha + \gamma D_{hv} + \mathbf{X}_{hv}\beta + \mathrm{P}_{\mathbf{v}}\theta + \mathbf{Z}_{\mathbf{v}}\delta + \mu_v + \varepsilon_{hv}, \tag{1}$$

where y_{hv} denotes total income, cropping income, off-farm income or other income (in per capita terms) for household h in village v. $\mathbf{X}_{hv}$ is a matrix of household characteristics including household size, average age and education level of the household's labour force, degree of land fragmentation, proportion of good quality land and proportion of land affected by negative shocks. Cultivated land per capita is included to control for land as a fixed input. We have also included several variables, household agricultural assets, self-employed business assets, livestock assets and non-productive assets (in per capita terms), to control for factors including household access to credit markets or ability to adopt new technologies. The matrix $\boldsymbol{P}_v$ denotes the prices farmers face within each village, including both variable input prices and output prices. $\boldsymbol{Z}_v$ denotes the observable village characteristics including a village's topography, its distance from the county seat, the number of phones per capita in the village and the proportion of villagers that worked off-farm in 1990. Equation 1 also includes a term, μ_v, which represents all other village fixed effects that vary by village and are difficult to observe or measure (e.g., the economic environment of the village, certain climatic and/or agronomic factors that affect village-wide yields and prices, etc.). After holding $\boldsymbol{X}_{hv}$ and $\boldsymbol{Z}_v$ constant, γ can be interpreted as our parameter of interest, measuring the effect of area of irrigated land per capita denoted by D_{hv}.

It should be noted that a linear specification for the income equation is required to decompose the inequality by estimated income flows, one of the approaches we use in the third part of the paper to analyse the impact of irrigation on rural income distribution in China. This approach enables us to use the village-level data on employment, infrastructure and topography, increasing the degrees of freedom and allowing us to estimate the importance of these village characteristics. However, it is possible that we have omitted village-level variables that, although unobserved, may affect income and be correlated with irrigation. One such variable is weather variation in the village. In such a case, we could have an omitted variables problem and estimates of γ would be inconsistent.[1] If this were the case, one solution is to include a set of 60 village dummy variables that capture all of the observed and unobservable village effects. Casting the problem in this way (i.e., the fixed effects model), however, means that we cannot separate the effect of specific village characteristics ($\boldsymbol{Z_v}$ and μ_v) from other village fixed effects because all are captured by the village dummy variables. In addition, as input and output prices are almost surely the same within each village, the effect of prices on income is also grouped with other village fixed effects and cannot be separated out. If we adopt this approach, the fixed effects model that we estimate is:

$$y_{hv} - \bar{y}_{hv} = \gamma(D_{hv} - \bar{D}_{hv}) + (\mathbf{X_{hv}} - \bar{\mathbf{X}}_{\mathbf{hv}})\beta + (\varepsilon_{hv} - \bar{\varepsilon}_{hv}), \tag{2}$$

where $\bar{y}_{hv}$, $\bar{D}_{hv}$, $\bar{\mathbf{X}}_{\mathbf{hv}}$ and $\bar{\varepsilon}_{hv}$ are the averages of variables at the village level.

Alternative estimation methods are also used to inspect the robustness of our estimate. In our basic model, we estimate Equation 2 using ordinary least squares (OLS) with fixed-effects. In our sample, some households do not have a particular source of income (e.g., off-farm income). Other households have negative incomes because they have suffered from a large shock. In both cases, household income may not be perfectly observed and a censoring problem arises (only positive values are perfectly observed). Under such a circumstance, OLS estimators may be inconsistent and other estimators may be needed. A widely used censored regression model, the Tobit model, assumes the latent dependent variable $y^*{}_{hv}$ is normally distributed, while in practice income is usually assumed to be lognormal. Hence, we choose not to use a Tobit model to estimate the determinants of income. Alternatively, we use another type of estimator, Powell's (1984) censored least absolute deviation (CLAD), which estimates parameters by minimising the term, $\Sigma \mid y_{hv} - \max(0, \alpha + \gamma D_{h\mathrm{v}} + \mathbf{X_{hv}}\beta + \mathbf{P_v}\theta + \mathbf{Z_v}\delta + \mu_v) \mid$. Because the medians are preserved by the transformation of the data, the consistency of CLAD estimators does not require the knowledge of the error term, nor is it assumed the distribution of the error term is homoskedastic. Moreover, the outliers in observed incomes are given a much smaller weight. To inspect the robustness of our OLS estimator, we use OLS without any fixed effects to estimate Equation 1 and OLS with the fixed effects at the county level and CLAD to estimate Equation 2.

[1] We do not worry about the problem of the omitted variables at the household level in our analyses for three reasons. First, *a priori* there is not likely to be a high degree of correlation between unobserved household effects and irrigated area. Second, it is possible that, given our specification, we are missing important household-level determinants of income; in particular, measures of the ability of the household wage earners. To control for this, we add two measures of ability: the classroom grades of the household head during his/her last year in school; and the educational attainment of the mother. Although these are not perfect measures, they have been used in other analyses. When we include these variables, the coefficient on the irrigation variable does not change substantially (results not shown in the text). Third, as the only part of a household's irrigated area that might be related to ability is irrigated land that he/she rents (the rest is allocated to the household by the village based mostly on demographic factors), we have also included an alternative measure of irrigated land per capita that includes only irrigated land allocated from the village to the household, which would make it exogenous. When we run our regressions with this alternative measure, the results are robust (results not shown in the text).

Table 2 Determinants of income (Equation 2: ordinary least squares with fixed effects at the village level)

	Dependent variables (yuan per capita)			
	1. Total income	2. Cropping income	3. Off-farm income	4. Other income‡
1. Area of irrigated land	2628.459	3082.936	−28.624	−425.853
per capita (ha)	(2.37)**	(6.37)***	(0.03)	(1.52)
2. Household size (no. household	−67.308	−14.222	−69.120	16.034
members)	(0.57)	(1.26)	(0.60)	(0.90)
3. Average age of household labour	−1.748	−2.853	−13.664	14.769
(year)	(0.11)	(1.61)	(0.90)	(3.91)***
4. Level of education of	116.139	−7.385	86.184	37.340
household's labour force	(2.60)***	(1.09)	(2.06)**	(2.51)**
(attainment in years)				
5. Degree of land fragmentation	−184.540	13.531	−189.853	−8.218
(no. plots per household)	(2.96)***	(1.62)	(3.09)***	(0.64)
6. Proportion of good quality land	−0.502	0.762	−0.692	−0.572
(%)	(0.13)	(1.82)*	(0.19)	(0.62)
7. Proportion of land affected by	−0.811	−0.954	−0.636	0.779
negative shock (%)	(0.19)	(2.32)**	(0.15)	(0.99)
8. Cultivated land per capita (ha)	502.836	640.016	−134.822	−2.357
	(0.89)	(1.74)*	(0.27)	(0.01)
9. Non-land agricultural assets	−0.123	−0.004	−0.061	−0.058
per capita (yuan)	(0.44)	(0.21)	(0.22)	(1.53)
10. Self-business assets per capita	0.036	−0.008	0.036	0.008
(yuan)	(0.42)	(2.08)**	(0.42)	(0.79)
11. Livestock assets per capita	0.351	0.033	0.075	0.244
(yuan)	(2.53)**	(1.28)	(0.59)	(4.10)***
12. Non-productive assets	0.077	−0.000	0.071	0.006
per capita (yuan)	(2.35)**	(0.20)	(2.17)**	(1.18)
14. Constant	2115.979	279.794	2398.542	−562.357
	(1.68)*	(2.33)**	(1.93)*	(2.61)***
R-squared	0.18	0.54	0.18	0.17

Robust *t*-statistic in parentheses. *Significant at 10 per cent; **significant at 5 per cent; ***significant at 1 per cent. ‡Other income includes livestock income, income from gifts (non-remittances), rental income, income from subsidies and pensions, income from interest, income from asset sales, net value of commercial agricultural commodities (e.g., vegetable and fruit), value of crop subsidiaries (e.g., fodders), net value of processed crop products, and miscellaneous income.

3.2 Regression results

Our regression estimates of the effect of irrigation on income are listed in Table 2. The goodness of fit measure, R^2, is 0.18 for total income and 0.54 for the cropping income equation. These R^2 are sufficiently high for analyses that use cross-sectional household data. In addition, many of the coefficients associated with the control variables are statistically significant and of the expected sign. For example, the level of education of the household's labour force positively affects total income. Also, as expected, negative shocks significantly reduce cropping income and cultivated land per capita significantly increases cropping income.

Most importantly, the results allow us to reject the null hypothesis that irrigated land area has no effect on cropping income and indicate that the descriptive results are

Table 3 Comparison of the coefficient on area of irrigated land per capita in various income determination models

	Cropping income	Total income
1. OLS with variables on village characteristics	3698.692 (11.51)***	3156.934 (3.78)***
2. OLS with fixed effects at county level	3136.509 (6.26)***	2464.258 (2.27)**
3. Censored least absolute deviation (CLAD)	2746.484 (38.11)***	2195.031 (8.39)***

OLS, ordinary least squares. Robust t-statistic in parentheses. *Significant at 10 per cent; **significant at 5 per cent; ***significant at 1 per cent.

largely consistent with multivariate analysis (Table 2, column 2). Increasing irrigated land per capita by one hectare will lead to an increase of 3082 yuan in annual cropping income per capita, holding other household characteristics constant. Interestingly, unlike many of the studies using aggregate data (e.g., Rosegrant and Evenson 1992; Jin *et al*. 2002), when we use plot-level data, we find a strong relationship between irrigation and cropping income.

Results that compare estimates from different estimation methods show that the signs of most coefficients are close across models, although the magnitudes of coefficients differ somewhat for some variables (Table 3). Most importantly, the coefficients of the key variable, area of irrigated land per capita, are close for these three models in terms of sign, magnitude, and statistical significance. Therefore, our findings are robust to our choice of estimating method. Estimation using OLS, however, enables us to control for unobserved heterogeneity across villages using a fixed-effect framework.

Our multivariate analysis also reveals that, when we hold other factors constant, irrigation has a positive impact on total household income, mainly through its impact on cropping income. An additional hectare of irrigated land per capita is associated with an increase of 2628 yuan in total household income per capita. Thus, an increase of irrigated land per capita of one standard deviation (0.097 ha) leads to an increase in household per capita income of 255 yuan, which is about 10 per cent of average household per capita income. As there is no significant effect of irrigation on off-farm income and other income (column 3 and 4), it can be concluded that the positive impact that irrigation has on total income per capita comes largely from the impact of irrigation on cropping income.

4. Irrigation and poverty

The finding that irrigation has a positive impact on cropping income, coupled with the structural characteristics of household income, suggests that irrigation may have an important role in poverty reduction. Cropping income accounts for a much larger share of total income in poorer households than in rich ones. Households in the two poorest deciles earn almost 60 per cent of their income from cropping activities (Table 4). In contrast, households in the richest decile earn less than 10 per cent from cropping. Given such an income structure it is not surprising that the correlation coefficient between cropping income and total income (0.18) is much lower than that between off-farm income and total income (0.98). Hence, investment in irrigation, by increasing

Table 4 Share of cropping income in total income by percentiles of total income

Percentile of total income (%)	Share of cropping income in total income (%)
1–10	54.52
11–20	58.61
21–30	48.04
31–40	44.82
41–50	40.07
51–60	33.02
61–70	28.90
71–80	22.77
81–90	21.69
91–99	9.31

Source: 2000 China National Rural Survey.

cropping income, would increase the total income of poor households and lead to poverty reduction.

4.1 Methodology

To study more carefully the effects of irrigation on poverty, we use a simulation approach in order to assess the change in poverty incidence arising from a change in a specific factor. To do so, we follow Datt (1998) and Gibson and Rozelle (2003) and use parameters from a regression analysis of the determinants of total income to create a simulation framework. More specifically, the basic model is of (log) income per capita, y_{hv}, deflated by the poverty line, c, a ratio known as the 'welfare ratio' (Blackorby and Donaldson 1984):

$$\ln(y_{hv}/c) = \alpha' + \gamma' D_{hv} + \mathbf{X_{hv}}\beta' + \mathbf{P_v}\theta' + \mathbf{Z_v}\delta' + \mu'_v + \varepsilon'_{hv}, \quad (3)$$

where ε'_{hv} is independently and identically distributed normal random variables with zero means and constant variance, σ_v. Note that, although we use a semilog specification in Equation 3, Equations 1 and 3 are in essence the same equation except for the monotonic transformation of the dependent variable.

Normalising income per capita by the poverty line implies that $\ln(y_{hv}/c) < 0$ for poor households and the probability of the hth household being poor can be derived from:

$$\text{Prob}[\ln(y_{hv}/c) < 0] = \Phi[-(\alpha' + \gamma' D_{hv} + \mathbf{X_{hv}}\beta' + \mathbf{P_v}\theta' + \mathbf{Z_v}\delta' + \mu'_v)/\sigma_v]. \quad (4)$$

We adopt the same approach as in estimating Equation 1 and the fixed effects model we estimate is:

$$\ln(y_{hv}/c) - \overline{\ln(y_{hv}/c)} = \gamma'(D_{hv} - \bar{D}_{hv}) + (\mathbf{X_{hv}} - \bar{\mathbf{X}}_{\mathbf{hv}})\beta' + (\varepsilon'_{hv} - \bar{\varepsilon}'_{hv}), \quad (5)$$

where $\overline{\ln(y_{hv}/c)}$, $\bar{D}_{hv}$, $\bar{\mathbf{X}}_{\mathbf{hv}}$ and $\bar{\varepsilon}'_{hv}$ are the averages of variables at the village level. After we obtain consistent estimates of γ' and β' by estimating Equation 5, we then plug them back into Equation 3:

Table 5 Estimates of log welfare ratio for rural households (Equation 5: ordinary least squares with fixed effects at the village level)

	Dependent variable: Log welfare ratio
1. Area of irrigated land per capita (ha)	0.733 (1.77)*
2. Household size (no. household members)	0.007 (0.29)
3. Average age of household labour (year)	−0.001 (0.23)
4. Level of education of household's labour force (attainment in years)	0.061 (4.41)***
5. Degree of land fragmentation (no. household plots)	−0.018 (1.22)
6. Proportion of good quality land (%)	0.001 (1.42)
7. Proportion of land affected by negative shock (%)	−0.002 (2.29)**
8. Cultivated land per capita (ha)	0.161 (0.42)
9. Non-land agricultural asset per capita (yuan)	−0.000 (0.23)
10. Self-business asset per capita (yuan)	0.000 1.88*
11. Livestock asset per capita (yuan)	0.000 (3.58)***
12. Non-productive asset per capita (yuan)	0.000 (4.14)***
14. Constant	0.218 (0.88)
R-squared	0.34

Robust *t*-statistic in parentheses. *Significant at 10 per cent; **significant at 5 per cent; ***significant at 1 per cent.

$$\ln(\widehat{y_{hv}}/c) = \hat{\gamma}' D_{hv} + \mathbf{X_{hv}}\hat{\beta}' + \underbrace{[\alpha' + \mathbf{P_v}\theta' + \mathbf{Z_v}\delta' + \mu_v']}_{\hat{\alpha}_v'}, \tag{6}$$

where the term in brackets is estimated as one single parameter, $\hat{\alpha}'$, the village fixed effect, and is captured by the coefficients on the village dummy variables.

In the simulation, the probability of the hth household being poor is calculated as:

$$\text{Prob}\,[\ln(y_{hv}/c) < 0] = \Phi\left[\frac{\ln(\widehat{y_{hv}}/c)}{\hat{\sigma}_v}\right]. \tag{7}$$

A weighted average of the household probabilities of being poor gives the predicted incidence of poverty, where the weights are the household sampling weights in terms of household size.

4.2 Simulation results

The regression of log welfare ratio performs well (Table 5). The magnitude of the coefficients differs between Equations 2 and 5 because the dependent variable in Equation 2 is a non-linear (log) transformation of that in Equation 5. Nonetheless, the signs and statistical significance of the coefficients on most of the explanatory variables are consistent across Equations 2 and 5 (column 1, Table 2; Table 5). In particular, the coefficient on our variable of interest, area of irrigated land per capita, is positive and significant. In our calculation, we use the official government poverty line of 625 yuan/year per capita.

Table 6 Simulated effect of certain changes on incidence of poverty in rural China in 2000

	Poverty incidence
Baseline: Actual values	24.05%
Convert households' non-irrigated land into irrigated land	22.47%* (6.56%)†
Increase the level of education of household labour by one year	22.33%** (7.15%)

†Percentage change from the *predicted* baseline values is reported in parentheses. Simulated change of the amount of irrigated land is considered in isolation of the change of level of education. The model used to predict poverty is reported in Table 5. *Significant at 5%; **significant at 1%.

Using the simulation framework, the positive effects of increasing irrigated land on poverty reduction are clear (Table 6). According to the results, the incidence of poverty would fall by 1.6 per cent if all non-irrigated land were converted to irrigated land. Given China's rural population, this means that such irrigation investment would reduce the poverty head count by over 12 million. While increased irrigation can reduce poverty, our results also show the importance of alternative interventions. For example, increasing the level of education of the household's labour force by 1 year decreases the poverty incidence by 1.7 per cent. With our data, unfortunately, it is impossible to say which type of investment would be more cost-effective at eliminating poverty. Because we do not have information on the costs of increasing irrigation and education, our simulation analysis does not include the cost of new irrigation or the cost of education.

5. Irrigation and inequality

In addition to its positive impact on the incidence of poverty, given the structure of income in rural China, it is also possible that increased investment in irrigation could help lower income inequality. Because cropping income contributes heavily to the income of poor households, increases in irrigation should have a relatively larger impact on their income, which makes up the lower tail of the income distribution. Moreover, the regression results also showed that increases in irrigated land area do not contribute to higher off-farm incomes (Table 2, column 3), which has been shown by others to increase rural income inequality (Rozelle 1996; Kung and Lee 2001). In other words, irrigation might increase total income of households in the lower end of income distribution, while having a smaller impact on the income of those at the higher end, resulting overall in a lower inequality of total income.

5.1 Methodology

To analyse the impact of irrigation on inequality, we decompose inequality in three ways: by *source of income* (cropping income from irrigated plots, cropping income from non-irrigated plots, off-farm income and other income); by *group according to irrigation access* (those with some irrigated land and those without any irrigated land); and by estimated *income flows due to specific household characteristics* (e.g. irrigated land area per capita and the education level of the household's labour force). Our methodology is similar in all three cases. We decompose the Gini coefficient for total household income as a weighted sum of the inequality levels of incomes from different components, with the weights being functions of the importance of each component and the correlation of each component with total income. For example, if the income contributed by irrigated land accounts for a large share of total income and is itself highly unequally distributed, it is likely to increase the total income inequality. However, if income from a component is negatively correlated with total income (i.e., this component is more concentrated in the hands of poor farmers), then larger shares of that factor might help equalise total income.

We first decompose the total income Gini coefficient by income source. We begin by noting that if y_k is income from source k (e.g., irrigated plots), then total household income, y_0, is:

$$y_0 = \sum_{k=1}^{K} y_k, \quad k = 1, \ldots, K. \tag{8}$$

Note the subscripts h and v are suppressed here. Following the method suggested by Stuart (1954), Pyatt *et al.* (1980) and Lerman and Yitzhaki (1985), we can write the Gini coefficient for total household income per capita, G_0, as:

$$G_0 = \sum_{k=1}^{K} S_k G_k R_k, \tag{9}$$

where S_k is the share of y_k in y_0; G_k is the Gini coefficient of y_k; and R_k is the Gini correlation between y_k and the distribution of y_0 and is defined as:

$$R_k = \mathrm{cov}(y_k, F(y_0))/\mathrm{cov}(y_k, F(y_k)), \tag{10}$$

where $F(y_0)$ and $F(y_k)$ are the cumulative distributions of total household income and income from source k, respectively.

If income component j increases by a factor of e, such that $y_j(e) = (1 + e)y_j$ *for all households*, the marginal effect of this percentage change on total income inequality is

$$\partial G_0/\partial e_j = S_j(R_j G_j - G_0) \quad j = 1, 2, \ldots, K, \tag{11}$$

where S_j, R_j, G_j and G_0 are measured prior to the marginal income change. Dividing Equation 11 by G_0, we obtain:

$$(\partial G_0/\partial e_j)/G_0 = (S_j R_j G_j)/G_0 - S_j \quad j = 1, 2, \ldots, K. \tag{12}$$

The relative effect of a marginal percentage change in source-j income on the Gini coefficient for total income (elasticity of total income inequality with respect to income source j) equals the relative contribution of source j to overall income inequality minus the share of source j in total income.

Decomposing inequality by income sources, however, does not reflect the potential unequalising effects of irrigation as manifested in income differences between groups that have different irrigation. There may exist two distinct groups of farmers: those who have access to irrigation and earn relatively high incomes and those who cannot gain access to irrigation facilities, perhaps as a result of high cost, and therefore earn relatively low incomes. In such a situation, irrigation may widen income differences between these two groups and therefore increase inequality. Thus, following Pyatt (1976), we divide our sample into an irrigated group and a non-irrigated group according to their irrigated land holdings and then decompose total income inequality into contributions from the within-group inequality and the between-group inequality. While the within-group inequality is the level of income inequality within the irrigated group and within the non-irrigated group, the between-group inequality reflects partly the potentially unequalising effect of irrigation. One limitation of this approach is that it does not separate the effect of irrigation from other factors that might be correlated with irrigation. For example, the quality of land and irrigation status are likely correlated as farmers are more likely to adopt irrigation for plots that have better quality.

The limitation of decomposing inequality by group can be overcome by using a regression-based approach to decompose total income inequality by income flows attributable to specific household characteristics. This approach follows the work of Taylor (1997) and Morduch and Sicular (2002). In this approach, the estimated income flows contributed by characteristics, such as, area of irrigated land, level of education and age, are calculated using the estimated parameters ($\hat{\gamma}$ and $\hat{\beta}$) given by the regression results from Equation 2, and these flows constitute the various components of total income. By construction, total income is the sum of these flows:

$$y_{hv} = \hat{\gamma} D_{hv} + \mathbf{X_{hv}}\hat{\beta} + \hat{\alpha}_v + \hat{\varepsilon}_{hv}, \tag{13}$$

where $\hat{\alpha}_v$ is the estimated village fixed effect that is equivalent to the estimate of the term, $\alpha + \mathbf{P_v}\theta + \mathbf{Z_v}\delta + \mu_v$, in Equation 1. The shares of income flows from the area of irrigated land per capita and other household characteristics take the form $\frac{\hat{\gamma} D_{hv}}{y_{hv}}$ and $\frac{\mathbf{X_{hv}}\hat{\beta}}{y_{hv}}$, respectively. The decomposition by income flows uses the same approach as the decomposition by income sources except that each y_k is replaced by estimated income flows $\hat{\gamma} D_{hv}$, $\mathbf{X_{hv}}\hat{\beta}$, $\hat{\alpha}_v$ and $\hat{\varepsilon}_{hv}$.

5.2 Decomposition results

The overall Gini coefficient of per capita income from our sample is 0.541 (Equation 9, Table 7, row 1). Compared to Gini coefficients of 0.28 in 1983 and 0.42 in 1992 as calculated by Rozelle (1996), inequality has continued to rise in the 1990s. The Gini coefficient in rural China, however, is well within the range recorded for rural areas in other developing countries, albeit, on the high side. For instance, Adams (2001) shows the Gini coefficient in rural Egypt is 0.532 in 1997.

Decomposing the Gini coefficient by income source shows that irrigation could help to equalise income (Table 7). Cropping income from irrigated land is most equally distributed with a Gini coefficient approximately 0.1 to 0.2 points lower than those of

Table 7 Gini decomposition by income sources

Income sources	1. S_k	2. G_k	3. R_k	4. $S_kG_kR_k$	5. $\partial G_0/\partial e_j$	6. $(\partial G_0/\partial e_j)G_0$
1. Total income	1	0.5407	1	0.5407		
Cropping income						
2. From irrigated land	0.1692	0.6121	0.3478	0.0360	−0.0555	−0.1026
3. From non-irrigated land	0.0398	0.8433	0.1045	0.0035	−0.0180	−0.0333
4. Off-farm income	0.6208	0.7324	0.9070	0.4124	0.0768	0.1420
5. Other income	0.1778	0.7767	0.6452	0.0891	−0.0070	−0.0130

S_k, share of income source k in total income. G_k, Gini coefficient of income source k. R_k, Gini correlation between income source k and the distribution of total income. $S_kG_kR_k$, contribution of income source k to the Gini coefficient of total income. $S_kG_kR_k$ of cropping income, off-farm and other income sum to 0.5407. $\partial G_0/\partial e_j$, marginal effect on the Gini coefficient of total income due to a marginal percentage increase in income source j. $(\partial G_0/\partial e_j)G_0$, relative effect of a marginal percentage increase in income source j upon the Gini coefficient of total income.

other income sources (Table 7, column 2). Cropping income is not concentrated in rich households as the Gini correlation between cropping income and total income, R_k, is 0.35, much lower than that for off-farm income. More saliently, cropping income from irrigated land has the highest marginal effect on lowering inequality (column 6). A 1 per cent increase in cropping income from irrigated land for all households would decrease the Gini coefficient for total income by 0.1 per cent. Hence, just as Rozelle (1996) found that cropping income, in general, helped abate regional inequality, our results indicate that interhousehold inequality is attenuated by the presence of irrigation.

Our results from decomposing inequality by group show that while the income differences between the irrigated group and non-irrigated group have contributed to the overall income inequality, the between-group component is not dominant (Table 8, row 2). Only about 9 per cent of the total inequality level appears to arise from the presence of barriers to irrigation, reflecting the positive but small unequalising effect of irrigation. In contrast, 77 per cent of total inequality comes from the inequality within each group (row 2, column 4). The large within-group effect indicates that there is substantial inequality among farmers that have irrigated plots and among non-irrigated farmers.

Results from decomposing inequality by income flows as a result of specific household characteristics further confirm irrigation's propensity to equalise income (Table 9). After controlling for other factors, a 1 per cent increase of irrigated land per capita leads to a 0.05 per cent decrease in the Gini coefficient for total income. However, the results also show that irrigation is not the only factor that can decrease inequality. A 1 per cent increase of the education level of the labour force in a household will lead to a 0.23 per cent decrease in the inequality level of total income. Hence, education, like irrigation, can reduce poverty and lower income inequality.

6. Conclusion

In the present paper we explore the relationship between irrigation status, income, poverty and inequality using a nationally representative data set for rural areas in

Table 8 Gini decomposition by subgroups (the irrigated group and the non-irrigated group)

	1. Total Gini ratio	2. Between-group†	3. Overlap‡	4. Within-group§
1.	0.537¶	0.048	0.077	0.412
2.	(100)	(8.89)††	(14.31)††	(76.8)††
		Share of population (%)	Share of income (%)	Gini coefficients by groups
3. Irrigated group		84.81	89.34	0.534
4. Non-irrigated group		15.19	10.66	0.533
5. Total population		100	100	

†Between-group refers to inequality arising from income differences between irrigated group and the non-irrigated group. ‡Overlap refers to inequality arising from the fact the income ranges in different groups overlap. Some households could be relatively poor in the group with higher average income but rich in another group. §Within-group refers to inequality arising from income differences among households in the same group. ¶Gini coefficient of total population differs slightly from that in Table 7 because we did not include households without information on irrigation. ††Share of each source of inequality in total inequality level is in parentheses.

Table 9 Gini decomposition by income flows as a result of specific household characteristics

Income sources	1. S_k	2. G_k	3. R_k	4. $S_k G_k R_k$	5. $\partial G_0/\partial e_j$	6. $(\partial G_0/\partial e_j)/G_0$
1. Total income per capita (yuan)	1	0.5407	1	0.5407	0	
2. Area of irrigated land per capita (ha)	0.0649	0.5199	0.2122	0.0072	−0.0279	−0.0517
3. Level of education of household's labour force (attainment in years)	0.2597	0.2347	0.2567	0.0157	−0.1248	−0.2308
4. Proportion of good quality land (%)	0.0199	0.2342	0.1155	0.0005	−0.0102	−0.0189
5. Cultivated land per capita (ha)	0.0402	0.4676	0.0470	0.0009	−0.0209	−0.0386

This table uses results from Table 2. Not all variables are reported for the sake of brevity. S_k, share of income flow contributed by factor k in total household income. Column (1) does not sum to one because we did not list all explanatory variables in the regression or the residual. G_k, Gini coefficient of income flow contributed by factor k. R_k, Gini correlation between income flow contributed by factor k and the distribution of total income. $S_k G_k R_k$, contribution of income flow contributed by factor k to Gini coefficient of total income. The sum of the five $(S_k G_k R_k)s$ do not sum to 0.5572 because we did not list all explanatory variables in the regression or the residual. $\partial G_0/\partial e_j$, marginal effect on Gini coefficient of total income due to a marginal percentage increase in income flow contributed by factor j. $(\partial G_0/\partial e_j)G_0$, relative effect of a marginal percentage change in income flow contributed by factor j upon Gini coefficient of total income.

China. Using descriptive and multivariate analysis, we find evidence of the strong impact of irrigation on income and poverty. Using several alternative decomposition analyses of inequality, we find that irrigation also helps reduce income inequality. Hence, continued investment in new irrigation projects and maintenance of existing systems will help to attain the government's rural welfare improvement goals. Moreover, as reducing poverty and reducing inequality both have growth-enhancing effects (Deininger and Squire 1998), irrigation investment could have an added benefit. Irrigation investment in rural China appears to be an investment that can lead to both growth and equity.

While irrigation raises growth and attenuates poverty and inequality, it should not necessarily be the government's primary tool for development in all regions. Cost-benefit analysis is also necessary to justify new irrigation projects. With such a high share of cultivated area already under irrigation, the cost of installing new irrigation systems is likely to be high in much of China. In many cases, alternative investments, such as investment in education, should be considered. One of the implications of our work, however, is that when evaluating the benefits of irrigation, analysts may want to give extra weight to irrigation projects because of their potential poverty and inequality reducing effects. In short, although irrigation has many benefits for development, our policy recommendation does not mean that irrigation should be increased at any cost; however, irrigation can lead to higher incomes, lower poverty and reduced inequality in the areas where it is appropriate.

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