Draft May 2002

Irrigation, Agricultural Performance and Poverty Reduction in China

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Paper to be presented at the Annual Meetings of the American Agricultural Economics Association, Long Beach, CA, July 26-29, 2002

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Abstract

The overall goal of our paper is to understand the impact that irrigation investments in China have had on incomes, in general, and income and poverty alleviation in poor areas, in particular. The paper seeks to meet three objectives. First, we describe the relationship among irrigation status, crop choice, yields and household crop revenue. Second, we seek to understand the magnitude and nature of the effect that irrigation has on yields and crop revenue. Finally, we seek to understand the impact that irrigation has on incomes in poor areas. Our analysis shows that irrigation contributes to increases in yields for almost all crops and in income for farmers in all areas. The importance of cropping income in poor areas and the strong relationship between cropping revenue and irrigation provides evidence of the importance of irrigation in past and future poverty alleviation in China.

Irrigation, Agricultural Performance and Poverty Reduction in China

China has made remarkable progress in increasing the standard of living in its rural areas since the onset of economic reform. Research has documented the rapid rise in rural incomes and reduction in poverty (Lardy, 1983; Putterman, 1992; World Bank, 2001). A number of studies have analyzed the impact of institutional changes and the increased use of inputs on production growth during the reform period as well as attempted to explain the success of China's poverty alleviation efforts (McMillan, Whalley and Zhu, 1989; Lin, 1992; Fan, 1991; Huang and Rozelle, 1996).

While several studies have established the links between rural growth and institutional change and input growth, few studies have established the link between policy effort and investments on one hand and poverty reduction on the other. For example, in a study of the effect of agricultural research on the productivity of farmers in poor areas, new technology is shown to have not benefited poor area farmers (Jin et al., 2002). Rozelle et al. (1998) show how that the billions of yuan that have been invested in poverty alleviation do not explain income per capita gains in poor areas. Most observers believe China's efforts to invest in micro-credit schemes have failed generally to produce any sustained, positive effect on poverty reduction (World Bank, 2001).

Perhaps most curiously, despite the large investment that China has made in water control, the most important form of investment in the agricultural sector in both rich and poor areas of the rural economy, previous studies have not been able to identify any strong impact of irrigation on the performance of any part of the rural economy.[1] China invests more than 10 times as much in irrigation (35 billion yuan in 2000) as it does in agricultural research (3.4 billion yuan). Investment in water control, more generally, also dominates all other forms of investment. For example, spending in 2000 on water control (83 billion yuan) far exceeds the annual budget that is targeted specifically at poverty reduction (22.4 billion).

Research, however, has not convincingly shown that the nation's massive spending on water control, and the irrigation infrastructure that it has spawned, have led to either increased performance in the agricultural sector or improvements in the livelihood of the poor. For example, Hu et al. (2000) find that irrigation did not contribute to the total factor productivity (TFP) growth of rice in China between 1981 and 1995. Jin et al. (2002) extend the work to other crops and can not find a link between irrigation and TFP growth of any major grain crop (rice, wheat or maize). Fan et al. (2000) illustrate that government expenditures on irrigation has the smallest returns to agriculture output compared to other investments, such as roads, agricultural research and development and education.

While such a finding may be surprising, a survey of the broader development literature shows that this finding is not unique to China. Studies in other countries frequently are unable to find a significant effect of irrigation on the performance of the rural economy. For example, Fan and Hazell (2000) show that despite levels of investment in water control that exceed those of seven other investment categories, irrigation ranks only sixth in terms of marginal impact on poverty alleviation in India behind investments such as rural roads, agricultural research, and education. Rosegrant and Evenson (1992) also find that irrigation does not have a significant impact on TFP in India.

The overall goal of our paper is to understand the impact that irrigation investments in China have had on incomes, in general, and income and poverty alleviation in poor areas, in particular. To meet this overall goal, we have three specific objectives. First, we describe the relationship between irrigation status, on one hand, and crop choice, yields and household crop revenue on the other. Second, we seek to measure the magnitude and nature of the effect that irrigation has on yields and crop revenue and if we find a positive effect to try to understand why previous studies often fail to do so. Finally, we seek to understand the impact that irrigation has on incomes in poor areas.

To meet these objectives, the rest of the paper will be organized as follows. In the first section, we introduce the data that are used for the analysis. The following section illustrates the proportion of cultivated area that is irrigated and the unconditional differences between irrigated and non-irrigated yields and per hectare crop revenues. To our knowledge, this is the first set of *by crop* estimates of sown area and yields for *irrigated and non-irrigated areas* in China, a statistic that, while commonly available in most other countries, heretofore has not been available in China. The third and fourth sections present the results of our multivariate analyses; we first seek to explain the impact of irrigation on yields and revenues, holding all other factors constant, and then examine the relationship between irrigation and crop income in China's poor areas. The final section concludes.

Data

The data for our study come from a randomly selected, almost nationally representative sample of 60 villages in 6 provinces of rural China (henceforth, the China National Rural Survey or CNRS).[2] To reflect accurately varying income distributions within each province, we selected randomly one county from within each income quintile for the province, as measured by the gross value of industrial output. The survey team selected randomly two villages within each county and used village rosters and our own counts to choose randomly twenty households, both those with their residency permits (*hukou*) in the village and those without. The survey included a total of 1199 households.

Enumerators collected a wide range of information on the household's production activities, and included a special block that focused on collecting by plot information on crop yields and plot-specific characteristics, including irrigation status. The household survey gathered detailed information on the household's total land holding, its demographics, labor allocation to farm and non-farm activities, investment, and other activities that allowed us to create measures of household per capita income and asset holdings. In our paper, we draw heavily on a part of the survey that provided a census of each household's cultivated plots. On average, each household cultivated four plots. For each plot, the respondent recounted the crop or crops that were grown during the sample year and the plot's irrigation status (was it irrigated by surface water, groundwater, both, or neither). In addition, enumerators collected a number of other plot attributes, including: land quality (a subjective measure whereby if the farmer ranked his plot as "good," a dummy variable was set equal to 1); topography (measured by two dummy variables that were each set equal to one if the plot was on a plain or hill); plot size (measured in *mu*, 1/15th hectare, and translated into hectares); cropping pattern (which is measured as a dummy variable that is set equal to 1 if the crop is not grown in conjunction with other crops during the year and is set equal to zero if it is cultivated in rotation with other crops); distance of the plot from the household (measured in kilometers); and a measure of any shock (e.g., flood or drought) that hit the plot during the year (measured one of two ways: either as a dummy variable set equal to 1 if there was a shock of any type, or as a continuous variable based on the farmer's subjective opinion about the percent by which yields were reduced by the shock). Descriptive statistics of these variables for all households in the sample and for those in rich and poor areas are included in Appendix A.

Irrigation, crop choice, and agricultural performance

Compared to other countries in the world, the proportion of China's cultivated area that is irrigated is high (Table 1). Data from our survey show that 52% of cultivated land is irrigated (row 1). Of the area that is irrigated, farmers irrigate 61% with surface water and the rest with groundwater. Although this figure is higher than the estimates published by CNSB (2001) in its annual yearbook (41%), both our estimates and those of the CNSB are higher than most of other countries in the world (for example, 33% of India's cultivated area is irrigated; 4.8% of Brazil; and 12% of the US).[3]

While a majority of China's cultivated area is irrigated, the proportion of area that is irrigated varies sharply by crop. For example, China's major food grains are mostly irrigated (Table 1, rows 2 and 3). Ninety-five percent of rice and 61% of wheat are irrigated, levels which in both cases are above the national average. In contrast, a majority of area for most feed grains and lower-valued staple crops is not irrigated (rows 4, 13, and 14). Despite the growing importance of maize in China's agricultural economy, only 45% of China's maize farmers irrigate their crop and even a lower proportion of coarse grain and tuber (white and sweet potatoes) farmers do. Although cash crops also vary among themselves, most farmers of the important cash crops in our sample irrigate their crops (e.g., 94% of cotton area and 69% of peanut area).

Examining unconditional differences between irrigated and non-irrigated yields, it is clear that for almost all crops, yields of irrigated plots are higher than those of non-irrigated ones, though there are differences among crops (Table 2). Positive differences and large t-statistics (for tests of differences between means) indicate that for almost all crops (except for rice and tubers) the average yields of irrigated plots exceed significantly those of non-irrigated ones (column 6).[4] For example, wheat yields of irrigated plots are 70.9% higher than those of non-irrigated plots (row 2). Irrigated maize yields are 16.4% higher and irrigated cotton yields are nearly 200% higher (rows 3 and 19).

The *annual output* of a particular plot of land also varies sharply due to irrigation's ability to increase the intensity of cultivation (Table 2).[5] When two crops are planted in rotation with one another (rows 5 to 7; rows 9 to 15 and row 17), the annual output per plot rises steeply when compared to the yields of a single season crop (rows 4, 8, and 16). For example, the annual yields of rice-rice (9,934), wheat-rice (9,266), and wheat-maize (8,263) rotations far exceed those of single season rice (6,195), single season wheat (1,931) and single season maize (2,876). And, although in some cases farmers can still produce two crops per year without irrigation, with the exception of rice, most single season crops are not irrigated (more than 80%) and most of those that produce two or more crops (more than 60%) are irrigated (Appendix B).

Even larger differences appear when examining *differences between the revenues* (price times yields) earned by farmers on their irrigated and non-irrigated plots (Table 3).[6] Overall revenue from irrigated plots is 79% higher than that of non-irrigated plots (row 1). While we can not pinpoint the source of these changes, three factors account for the higher crop revenues of a plot when irrigation is introduced: higher yields (of same crop), increasing intensity (producing more than one crop per season), and shifts to higher valued crops that are possible after irrigation.

Our results also provide evidence that to the extent that new irrigation becomes available, it will raise incomes in poor areas. Dividing villages by wealth level, farmers in rich and poor areas earn higher revenue from their irrigated crops (rows 2 to 3). In rich areas, farmer revenue per hectare from irrigated plots is 89% higher than that from non-irrigated plots. In poor areas, revenue in poor areas rises even more in relative terms. Revenue from irrigated plots in poor areas exceeds those from non-irrigated ones by 93%.

While the data show that irrigation is effective in both rich and poor areas, differences in the nature of rich and poor economies suggest that irrigation may have the largest impact on rural welfare in poor areas. Since people are poorer, and since we typically assume that utility functions are concave, if rich and poor areas enjoy equal income gains, the gains in the poorer areas will turn into larger increases in welfare. As seen above, cropping revenues in the poorest areas (93%) increase slightly more than those in richer areas (89%). Moreover, in our sample, the data show that cropping revenues make up the largest part of total income of those in poor area but not those in rich areas (column 2). In rich areas only 10% of total income comes from cropping activities; in the poorest area, cropping activities contribute more than 40%. If we multiply the percentage increase of cropping revenue by proportion of cropping revenue in total income, irrigation increases total income in rich areas only by 9%, while increasing it in poor areas by 38%. Since one characteristic of China's poverty is that the gap between the income of the poor and the poverty line is not overly wide (World Bank, 2000), raising the income of the poor by more than one-third would almost certainly have the effect of pulling a vast majority of those in newly irrigated areas out of poverty.

Framework for Examining the Effect of Irrigation on Supply

All the findings from our descriptive analysis support one fact: irrigation has substantial benefits for farmers. Yields of irrigated plots are significantly higher than those of non-irrigated plots for almost all the crops we study. Cropping revenue of irrigated plots also is higher than that of non-irrigated plots in rich and poor areas.

Such striking differences, however, are curious given the inability of previous studies to find significant effects of irrigation on agricultural performance. The differences may be due to several factors, some of which are due to problems with possible interpretations of our descriptive statistics (in the above section) and others of which may be due to weaknesses in the previous studies. First, our findings so far do not prove anything beyond correlation since we have only been comparing unconditional means of irrigated and non-irrigated plots. In fact, the observed differences may be partly (or could even fully be) due to other factors (such as land quality or management ability) that are correlated with irrigation. Second, due to a lack of data, most studies in the past have only used rough proxies for irrigation, such as government expenditure on irrigation. These proxies, however, may not be an accurate measure of irrigation because there is no guarantee that the allocation of funds to water control is ever turned into an effective irrigation system. Third, most analyses have been highly aggregated, both across states or provinces and across crops. This approach could cause omitted variable bias, a problem that would make the estimated relationship between irrigation and agricultural performance unreliable. For example, it is possible that we will underestimate the impact of irrigation in rich areas (such as, Zhejiang province, a rich east coast province near Shanghai). Although the proportion of land that is irrigated might be higher in Zhejiang than that in poorer provinces, households in richer areas have more opportunity to work off-farm and, ceteris paribus, they will almost certainly allocate less family labor to farming activities than households in poorer provinces that do not have as convenient of access to off-farm opportunities. In other words, an omitted variable – in this case, for example, it could be the inability to control for the household's employment opportunities -- could lead to an underestimation of the impact of irrigation on yield. In fact, after accounting for these factors, it is possible that the results about the direction of irrigation's impact on yields could be reversed.

In our analysis, we are going to take a different approach to explore the relationship between irrigation and agricultural performances that will attempt to address the three shortcomings. First, our strategy is to look directly at the relationship between irrigation and crop yield (and at the relationship between irrigation and cropping revenues) at the plot level, thereby avoiding the need to use a proxy for irrigation. In addition, by using a rich set of plot level data, we can hold constant many of the plot-specific factors that could be affecting yields and which could be potentially correlated with a plot's irrigation status. Finally, in our study, we have collected information on all of a household's major plots. Such data allow us to control for all of the non-plot varying factors that could be affecting yields by using household fixed effects approaches.

To explain the impact of irrigation on yields, holding other factors constant, we use a fixed effect model to explain the *supply response* of farmers that are producing a specific crop,

$$y_{ih} = \alpha + \gamma D_{ihj} + X_{ih}\beta + \mu_h + \varepsilon_{ih} \tag{1}$$

where y_{ih} denotes the yield (of a specific crop) or the revenue of the i^{th} plot of the h^{th} household. The term, X_{ih}, denotes plot-specific characteristics, including the plot's land quality, its topography, the size of the plot, the distance of the plot from the farmer's household, and the plot-specific shock suffered during 2000, and the parameter, β, represents a vector of parameters that corresponds to the effects of that these plot-specific variables have on yields. Holding X_{ih} constant, the parameter γ can be interpreted as our parameter of interest, measuring the effect of irrigation status on yields. The irrigation status variable, D_{ihj}, is written with a separate subscript, j, because in some of our specification we want to allow for a disaggregation of irrigation between surface (j=1) and groundwater (j=2). When the variable is written without a subscript, irrigation is a variable that represents irrigation regardless of the type of irrigation. Equation (1) also includes a term, μ_h, which represents all non-plot varying household and village fixed effects including management or the opportunity cost of the household.[7]

Estimating equation (1) has both strengths and weaknesses. The tradeoffs are seen most clearly by rewriting it as a fixed effects model,

$$y_{ih} - \overline{y}_i = \alpha + \gamma\left(D_{ihj} - \overline{D_i}\right) + \beta\left(X_{ih} - \overline{X}_i\right) + \left(\mu_h - \overline{\mu}\right) + \left(\varepsilon_{ih} - \overline{\varepsilon_i}\right) \quad (2)$$

where $\overline{y}_i$, $\overline{X}_i$, $\overline{\mu}$ and $\overline{\varepsilon}_i$ denote the average household level.

Since $\mu_h - \overline{\mu}$=0, Equation (2) can be simplified to

$$y_{ih} - \overline{y}_i = \alpha + \gamma\left(D_{ihj} - \overline{D_i}\right) + \beta\left(X_{ih} - \overline{X}_i\right) + \left(\varepsilon_{ih} - \overline{\varepsilon}_i\right), \quad (3)$$

and all household and village factors (e.g., management ability, opportunity cost of the household members, etc.) are accounted for.

Although prices are not included in equation (1), it should be noted that we are estimating a supply function and our regression is examining the economic efficiency that farmers gain when their plots are irrigated. The price variables, which are part of the μ_h term in equation (1), vary only by village and, hence, their effect also is captured by the household dummy variables. Because of the use of a supply-function framework, we do not include measures of other variable inputs (see endnote 5).

To use equation (3) to understand the effect of irrigation on agricultural performance, we adopt a four-step strategy. First, we examine the effect of irrigation on *yields for individual crops*. While interesting by itself, such a regression does not capture all of the dimensions of the irrigation effects, neither the impact of increased intensity nor the impact from crop switching. To do so, we estimate two additional models, one explaining *aggregate grain yields* (aggregating over all grains, including rice, wheat, maize and coarse grains) and one explaining *agricultural revenues*. If irrigation allows farmers to cultivate two crops per year and/or if it allows shifting into cash crops that generate higher revenues per hectare, the aggregate grain and agricultural revenue equations will capture the higher output from irrigation. Third, we decompose the effect of irrigation on agricultural output by regressing revenues per hectare on a series of interaction terms between irrigation and each major crop in our sample. In this way, the observed differences in revenues per hectare between irrigated and non-irrigated plots can be accounted for. Finally, we explain yields separately for better off and poorer areas in order to gauge the difference in irrigation effects in different parts of the economy. In all our analyses, we take the log form of yield or revenue so the coefficient will represent the percentage change in yield or revenue.

Multivariate Results

In most respects, our analyses perform well. More than half of the regressions have R-square goodness of fit statistics that exceed 0.4, levels that can be counted as high for cross-section yield regressions (Tables 4 to 6). Most of the coefficients in the models have the expected signs and in some cases are highly significant. For example, we find that the coefficient on the land quality variable positively affects yields in most equations and the coefficient on the variable measuring the plot-specific shock, as expected, reduces yields (e.g., Table 4, rows 4 and 9).

Most importantly, the findings of our study support the hypothesis that irrigation raises yields for most crops and show that the descriptive results hold up to multivariate analysis (Table 4). For example, irrigation increases the yields of wheat by 17.7%, those of maize by 29.4%, and those of cotton by 28.4% (row 1). Although the coefficients on the irrigation variables in the coarse grains and tuber equations are not significant, these findings are expected (column 6 and 7, row 1). The results of the tubers equations are consistent with the descriptive results. In the case of coarse grains, because there are so few households (only 9) that grow one plot of irrigated coarse grains and one plot of non-irrigated coarse grains, the findings reflect outcomes on less than 1% of the sample (and these are in only 3 villages). The effects of surface and groundwater are nearly the same for the case of wheat, the only crop that is grown widely in areas in which both surface (the Yangtse Valley) and groundwater (the North China Plain) are common.

The multivariate analysis results of crop-specific yields do differ from the descriptive results when examining the magnitude of the differences. With the exception of maize, the magnitude of impact of irrigation is lower in the regression results than in the descriptive statistics. Most likely this is because in the regression the irrigation impacts are being conditioned on the level of other variables, such as soil quality that is accounting part of the irrigation effect (since most irrigated land is "good").

Perhaps most significantly from a methodological point of view, when the regression is run with and without household fixed effects, the coefficients vary dramatically. In fact, in almost all of the equations without fixed effects, the coefficients are zero, a sure sign that omitted variables may be a problem. One interpretation is that without fixed effects, the family's opportunity cost of labor is not accounted for. If rural residents in irrigated areas, which tend to be in richer areas, have a higher opportunity cost, and hence tend to spend less effort on cropping activities, the insignificant coefficient in the equations that do not use fixed effects are mostly likely being biased downward to a point where there is no apparent effect of irrigation (when, in fact, once all household specific effects are accounted for they are positive and significant).

The impact of irrigation becomes even stronger obvious when we look at the impact of irrigation on plot cropping revenue (Table 5). Overall, irrigation will increase revenue by 76.1%, a figure that is only slightly less than the unconditional difference observed in the descriptive statistics (column 1). In other words, according to these results, most of the differences between revenues on irrigated and non-irrigated plots are due to the addition of water and not other plot characteristics. The magnitude of the coefficient drops (to 42.9 percent) when household dummy variables are replaced with four household variables and a set of village dummies, moving in the same direction as was observed in the yield equations when no fixed effects were used at all. Apparently, the use of village dummies and four household-level variable absorbs some, but not all, of the unobserved heterogeneity in the yield response behavioral equations in this analysis.

Decomposing revenue differences by crop illustrates differences among crops in the earnings potential that arise with irrigation (Table 5, column 3). When a plot is irrigated, rising yields and the ability to shift into new crops, such as rice and cash crops, facilitates the largest rises in revenue (88.7 percent higher for peanuts; 115.6 for rice; 136.5 for cotton). Although somewhat lower, when plots are irrigated rising yields also help increase revenues on wheat (57.3 percent), maize (61.9 percent), and coarse grains (31.7 percent). Of all of the major crops in the sample, tubers are the only ones that do not enjoy increased revenues. The results here are robust, though the size of the coefficients somewhat smaller, when village fixed effect are used in place of household effects (column 4).

Additionally, when the major grain crops, rice, wheat and maize, are disaggregated by rotation, the impact of increasing intensity can be seen (Table 5, column 5). For example, irrigated rice-rice increases yields by 147.3 percent, higher than single season rice (100.4 percent). When irrigation facilitates the shift to a wheat-maize rotation, revenues generated on a plot rise by 98.7 percent, higher than either the rise that accompanies single season wheat (20.6 percent) or single season maize (91.2 percent).[8]

When dividing the sample into better off and poorer areas, we find similar results (Table 6). In both rich and poor areas, irrigation has a significantly positive effect on cropping revenue, increasing by 132.8 percent in rich and 43.9 percent in poorer areas (columns 1 and 3). While the higher marginal effects of irrigation on cropping revenue in rich area may explain why more of the past investment in irrigation has gone into more favorable areas, it does not mean that the poor do not benefit. In fact, in terms of income effects, the poor may benefit more. From Table 3 it can be seen that the share of cropping revenue in total income is four times as high in poor areas (41 percent) as in rich areas (10 percent). Taking this into account, irrigation benefits farmers in poorest area one and half times it does farmers in rich area (18 percent in poor areas versus 13 percent in richer areas).

Conclusion

In this paper, we explore the relationship between irrigation status and yields, crop choices and household cropping revenue. Our paper provides evidence of irrigation's strong impact on yield and cropping revenue, both descriptively and in the multivariate analysis. Unlike some of the literature that used aggregate data, we find that irrigation increases yields and cropping revenue when we look at either different crops or examine grain or crops as whole. Moreover, we find that although the marginal impact of irrigation on revenue appears to be higher in richer areas, since the poor relies more on cropping revenue, our findings suggest that farmers in poor areas increase their incomes relatively more it do farmers in richer areas.

The strong findings in our paper of the effect of irrigation on agricultural performance relative to previous studies almost surely are in part a function of our data and methods. By using plot level data, we can control for many of the attributes in the natural environment that also affect yields as well as irrigation. By having more than one plot observations per household, we show that when we use household fixed effects (versus only controlling for some household effects and village effects or nothing) the effect of irrigation almost always rises. In fact, when we go from controlling from no supra-plot effects to the full model, the impact of irrigation goes from insignificant (zero) to highly significant and positive. Hence, it could be that omitted variable bias may be one reason why previous studies fail to find the strong effect of irrigation on agricultural performance.

If irrigation has such a great effect on agricultural performance it is no wonder why so much of the budget of many countries has gone towards irrigation in the past. Moreover, although the costs of the project must be considered, the disinterest that seems to be beginning to pervade the international community in irrigation may need to be questioned (Byerlee ,Heisey, and Pingali 1999). Our findings of the effect of irrigation on the income of those in poor areas mean the poverty alleviation programs, in particular, may want to consider increasing or at least not diminish the role of irrigation in their portfolio of activities.

Table 1. Proportion of Sown Area by Irrigation Type
(%)

	(1) Total (2)+(5)	(2) Irrigated Area [a]	(3) Surface Water Area	(4) Ground Water Area	(5) Non-irrigated Area
China	100	52	61	37	48
Major Grains -Aggregate					
Rice	100	95	95	3	5
Wheat	100	61	34	63	39
Maize	100	45	31	65	55
Major Grains – by Season					
Single Season Rice	100	94	94	4	6
Early Season Rice	100	99	99	0	1
Late Season Rice	100	99	99	0	1
Single Season Wheat	100	10	37	63	90
Wheat-Rice Rotation	100	98	96	2	2
Wheat-Maize Rotation	100	77	24	73	23
Wheat-Other Crop Rotation	100	63	23	76	37
Single Season Maize	100	15	23	71	85
Maize-Other Crop Rotation	100	49	72	27	51
Coarse Grains [b]	100	28	26	71	72
Tubers [c]	100	40	88	10	60
Cash Crops					
Cotton	100	94	13	87	6
Peanut	100	69	8	92	31

Source: Authors' survey
[a] Proportion of irrigated areas include areas irrigated by surface water, by groundwater and by both (conjunctively). Proportion of areas irrigated conjunctively is not reported here because it is less than 3%. Thus column (3) and column (4) does not sum up to 100%.
[b] Coarse grains includes sorghum, millet, pearl millet, buckwheat and others
[c] Tubers includes white potatoes and sweet potatoes.

Table 2. Crop Yield by Irrigation Type
(Unit: Kg/Ha)

	(1) Total Yield	(2) Irrigated Yield [a]	(3) Surface Water Yield	(4) Ground Water Yield	(5) Non-irrigated Yield	(6) Percentage Increase [b]
Major Grains - Aggregate						
Rice	5,947	5,942	5,919	6,663	6,002	-1.0
Wheat	3,305	3,853	3,302	4,518	2,255	70.9***
Maize	4,041	4,378	4,276	4,522	3,762	16.4***
Major Grains – by Season [c]						
Single Season Rice	6,195	6,207	6,202	6,367	6,087	2.0
Rice-Rice Rotation	9,934	9,949	9,943	11,250	9,000	10.5
Early Season Rice	4,516	4,516	4,513	5,250	4,500	0.4
Late Season Rice	5,418	5,433	5,431	6,000	4,500	20.7***
Single Season Wheat	1,931	3,624	4,025	3,223	1,698	113.4***
Wheat-Rice Rotation	9,266	9,284	9,251	11,357	7,513	23.6
Wheat	2,939	2,949	2,972	3,000	1,763	67.3***
Rice	6,327	6,334	6,279	8,357	5,750	10.2***
Wheat-Maize Rotation	8,263	9,174	8,309	9,617	6,271	46.3***
Wheat	3,877	4,439	3,796	4,746	2,642	68.0***
Maize	4,386	4,735	4,514	4,872	3,628	30.5***
Wheat-Other Crop Rotation	3,331	3,926	3,375	4,212	2,411	62.8***
Single Season Maize [d]	2,876	3,720	3,056	4,309	2,378	56.4***
Maize-Other Crop Rotation	3,941	3,984	4,181	2,883	3,893	2.3
Coarse Grains	1,457	1,996	1,836	2,115	1,119	78.3***
Tubers [a]	4,631	3,918	4,072	2,942	5,141	-23.8***
Cash Crops						
Cotton	2,357	2,561	1,190	2,790	924	177.3***
Peanut	2,538	2,758	2,731	2,770	2,143	28.7***

Source: Authors' survey
*** means significant at 99% level.
[a] We did not include yield of the plots irrigated by surface water and ground water conjunctively because there are few observations of them.
[b] Percentage increase means irrigated yield compared to non-irrigated yield.
[c] In this category, we divide rice into single season rice, double season rice(early season rice, late season rice). We divide wheat into single season wheat, wheat-rice rotation, wheat-maize rotation and wheat rotated with other crops than major grain. We divide maize into single season maize and wheat-maize rotation.
[d] We dropped Liao Ning province here because 80% are non-irrigated plots. 46% of the non-irrigated plots and 60% of the irrigated plots suffered from draught(lost of produce more than 50%).
[e] Tuber includes sweet potato and white potato.

Table 3. Gross Cropping Revenue by Irrigation Type and China's Regions.

	(1) Annual Income Per capita (Yuan/Person)	(2) Percentage of Cropping Income in Total Income (%)	(3) Cropping Revenue (Yuan/Ha)	(4) Cropping Revenue for Irrigated Plots (Yuan/Ha)	(5) Cropping Revenue for Non-irrigated Plots (Yuan/Ha)	(6) Percentage Increases of Cropping Revenue [a] (%)
China	2,107	23	3,940	4,585	2,568	79 [b]
By Wealth Level [c]						
Rich Area	3,652	10	4,060	4,603	2,439	89
Poor Area	907	41	3,318	4,385	2,268	93

Source: Authors' survey except for figures in columns (1) and (2) which are from China National Statistical Bureau (2001).

[a] Percentage increase is calculated as (column 4-column 5)/column 5.
[b] The national level is lower than both in Rich and Poor areas because we do not include middle-income area here which has 65% increase in cropping revenue when plots are irrigated.
[c] Rich area includes households whose incomes rank the first 20 percentile in every province and all the households from Zhejiang province. Poor area means households whose incomes rank the last 20 percentile in every province.

Table 4. The Impact of Irrigation on Crop Yield with Household Fixed Effect

	Dependent Variables: Crop Yield [b]						
	(1) Wheat		(2) Maize		(3) Cotton	(4) Coarse Grain	(5) Tuber
	Equation 1	Equation 2	Equation 1	Equation 2			
Irrigation Status							
Irrigated (by Surface Water or Ground Water)	0.177		0.294		0.284	-0.147	-0.097
	(2.81)***		(4.17)***		(5.28)***	(0.59)	(0.24)
Irrigated by Surface Water		0.171		0.039			
		(2.62)***		(0.38)			
Irrigated by Ground Water		0.203		0.418			
		(2.20)**		(5.18)***			
Land Characteristics							
Good Soil Quality	0.174	0.173	0.130	0.119	0.008	0.028	0.996
	(5.41)***	(5.34)***	(3.50)***	(3.21)***	(0.24)	(0.26)	(2.74)***
Topography-Plain	0.070	0.068	0.302	0.236	-0.001		-1.614
	(0.65)	(0.63)	(1.38)	(1.09)	(0.02)		(1.34)
Topography-Hill	0.132	0.129	0.181	0.112	0.083	0.013	-0.543
	(2.53)**	(2.44)**	(0.90)	(0.56)	(0.92)	(0.04)	(0.53)
Plot Size	0.041	0.041	0.204	0.197	0.010	0.281	-3.195
	(0.39)	(0.39)	(1.42)	(1.38)	(0.65)	(0.97)	(2.03)**
Distance from Home	0.003	0.003	-0.005	-0.001	0.008	0.061	-0.193
	(0.21)	(0.25)	(0.16)	(0.02)	(0.24)	(0.83)	(0.66)
Shock: Severity of Disaster [c]	-0.009	-0.009	-0.016	-0.015	-0.001	-0.030	0.005
	(6.22)***	(6.22)***	(12.78)***	(11.41)***	(1.65)	(6.38)***	(0.66)
Single Season Crop [d]	-0.040	-0.040	-0.106	-0.082	0.054	0.542	-0.370
	(0.87)	(0.86)	(2.06)**	(1.60)	(2.43)**	(2.96)***	(1.50)
Number of Plots	1027	1027	1116	1116	141	277	510
Number of Households	507	507	573	573	69	209	354
R-square	0.15	0.15	0.47	0.48	0.39	0.48	0.11

[a] Absolute value of t statistics in parentheses. * significant at 10%; ** significant at 5%; *** significant at 1%
[b] Dependent variable in log form. Estimate using fixed effect model at household level.
[c] Severity of Disaster means percentage reduction of production.
[d] A dummy variable that is 1 if the crop is not grown in conjunction with other crops during the year and is 0 if it is cultivated in rotation with other crops.

Table 5. Decomposed Impact of Irrigation on Household Cropping Revenue

	Dependent Variable: Total Cropping Revenue [b]					
	Household	Village	Household	Village [c]	Household	Village
Irrigation Dummy	0.761	0.429				
	(15.98)***	(13.83)***				
Interaction Dummies						
<u>**Major Grains**</u>						
Rice*Irrigation			1.156	0.947		
			(24.41)***	(27.34)***		
Wheat*Irrigation			0.573	0.421		
			(10.34)***	(10.62)***		
Maize*Irrigation			0.619	0.415		
			(10.85)***	(10.23)***		
Single Season Rice*Irrigation					1.004	0.807
					(18.36)***	(19.94)***
Single Season Wheat*Irrigation					0.206	-0.044
					(1.83)*	(0.53)
Single Season Maize*Irrigation					0.912	0.462
					(4.00)***	(2.78)***
Rice Rice*Irrigation					1.473	1.226
					(15.46)***	(18.31)***
Wheat-Rice Rotation*Irrigation					0.106	0.117
					(1.58)	(2.15)**
Wheat-Maize Rotation*Irrigation					0.989	0.818
					(12.32)***	(13.43)***
Wheat-Other Crop Rotation*Irrigation					0.863	0.750
					(9.02)***	(9.71)***
Maize-Other Crop Rotation*Irrigation					0.832	0.558
					(9.18)***	(7.80)***
<u>Coarse Grains</u>*Irrigation			0.317	0.109	0.532	0.298
			(3.78)***	(1.55)	(5.67)***	(3.97)***
<u>Cash Crops</u> - Cotton*Irrigation			1.365	1.104	1.541	1.241
			(15.14)***	(14.22)***	(14.79)***	(14.34)***
<u>Cash Crops</u> - Peanut*Irrigation			0.887	0.693	1.135	0.924
			(9.45)***	(8.19)***	(10.78)***	(10.10)***
<u>Tubers</u>*Irrigation			-1.226	-1.464	-1.120	-1.382
			(17.74)***	(27.77)***	(14.82)***	(24.72)***
Land Characteristics						
Good Quality	0.286	0.219	0.217	0.178	0.212	0.173
	(7.09)***	(7.83)***	(6.00)***	(7.07)***	(5.29)***	(6.25)***
Topography-Plain	0.098	-0.004	0.065	0.013	-0.046	-0.029
	(0.94)	(0.07)	(0.69)	(0.24)	(0.44)	(0.49)
Topography -Hill	-0.009	-0.104	-0.027	-0.072	-0.145	-0.113
	(0.11)	(2.02)**	(0.36)	(1.52)	(1.68)*	(2.11)**
Plot Size	0.095		0.011		-0.033	
	(1.02)		(0.12)		(0.33)	
Distance from Home	0.020	0.022	0.009	0.021	0.028	0.029
	(1.12)	(1.58)	(0.43)	(1.37)	(1.13)	(1.70)*
Shock: Severity of Disaster [d]	-0.009	-0.009	-0.009	-0.009	-0.010	-0.009
	(9.50)***	(11.93)***	(10.35)***	(13.97)***	(9.69)***	(12.70)***
Single Season Crop [e]	0.755	0.716	0.231	0.275	0.400	0.465
	(26.96)***	(28.48)***	(6.39)***	(9.60)***	(8.55)***	(12.29)***
Number of Plots	5352	5347	4858	4853	4166	4161
Number of Household/Village	1061	60	1058	60	1052	60
R-square	0.23	0.20	0.45	0.43	0.48	0.46

[a] Absolute value of t statistics in parentheses. * significant at 10%; ** significant at 5%; *** significant at 1%
[b] Dependent variable in log form. Estimate use fixed effect model at household level and village level.
[c] In Village Fixed Effect model, we use 4 household characteristic variables which are not reported here: Household size, Average Education Level, Total Wealth and Total Household Land.
[d] Severity of Disaster means percentage reduction of production.
[e] A dummy variable that is 1 if the crop is not grown in conjunction with other crops during the year and is 0 if it is cultivated in rotation with other crops.

Table 6. Regression Analysis of Impact of Irrigation on Cropping Revenue in Rich and Poor Area in China

	Dependent Variables: Plot Cropping Revenue with Fixed Effects			
	Rich Area		Poor Area	
	Equation1	**Equation2**	**Equation1**	**Equation2**
Irrigation Status				
Irrigated (by Surface Water Or Ground Water)	1.328		0.439	
	(14.11)***		(3.50)***	
Irrigated by Surface Water		1.470		0.296
		(14.30)***		(2.02)**
Irrigated by Ground Water		0.717		0.793
		(3.54)***		(3.55)***
Land Characteristics				
Good Soil Quality	0.147	0.167	0.143	0.139
	(1.90)*	(2.17)**	(1.50)	(1.47)
Topography-Plain	0.155	0.131	-0.327	-0.309
	(0.88)	(0.75)	(0.85)	(0.80)
Topography-Hill	-0.006	0.100	-0.280	-0.277
	(0.03)	(0.53)	(1.52)	(1.51)
Plot Size	0.048	0.066	-0.220	-0.236
	(0.25)	(0.34)	(1.43)	(1.54)
Distance from Home	0.134	0.111	-0.302	-0.284
	(2.96)***	(2.44)**	(3.39)***	(3.18)***
Shock: Severity of Disaster [c]	-0.010	-0.011	-0.011	-0.011
	(4.46)***	(4.70)***	(5.99)***	(5.52)***
Single Season Crop [d]	0.624	0.599	1.086	1.105
	(11.54)***	(11.05)***	(13.91)***	(14.06)***
Number of Plots	1542	1542	959	959
Number of Households	330	330	187	187
R-square	0.25	0.26	0.28	0.29

[a] Absolute value of t statistics in parentheses. * significant at 10%; ** significant at 5%; *** significant at 1%

[b] Dependent variable in log form. Estimate use fixed effect model at household level.

[c] Severity of Disaster means percentage reduction of production.

[d] A dummy variable that is 1 if the crop is not grown in conjunction with other crops during the year and is 0 if it is cultivated in rotation with other crops.

Appendix A. Comparison of Irrigated and Non-irrigated Land in Different Region

	China	Rich Area		Poor Area	
		Irrigated	Non-irrigated	Irrigated	Non-irrigated
Percentage of Sown Area	100	44	56	27	73
Percentage of Good Soil Quality Land	81	84	67	80	71
Percentage of Plain	45	50	37	11	41
Percentage of Hill	50	46	56	76	54
Average Plot Size (Ha)	0.10	0.06	0.15	0.08	0.15
Average Distance from Home (Km)	0.66	0.59	0.86	0.71	0.60
Average Severity	11.0	4.1	18.5	13.3	37.2
Percentage of Single-Season Crop	42	42	54	43	47

Source: Authors' survey
[a] Percentage Reduction of Production

Appendix B. Number of Plots by Irrigation Type

	(1) Total Plots (2)+(5)	(2) Irrigated Plots [a]	(3) Surface Water Plots	(4) Ground Water Plots	(5) Non-irrigated Plots
Major Grains -Aggregate					
Rice	1813	1688	1609	42	125
Wheat	1097	721	379	315	376
Maize	1218	552	257	274	666
Major Grains – by Season					
Single Season Rice	1169	1053	1000	33	116
Early Season Rice	197	194	192	1	3
Late Season Rice	197	194	192	1	3
Single Season Wheat	149	18	9	9	131
Wheat-Rice Rotation	239+239	237+237	215+215	6+6	2+2
Wheat-Maize Rotation	495+495	339+339	118+118	210+210	155+155
Wheat-Other Crop Rotation	224	136	46	89	88
Single Season Maize	486	87	34	48	399
Maize-Other Crop Rotation	237	126	105	16	111
Coarse Grains [b]	348	134	47	84	214
Tubers [c]	612	255	230	16	357
Cash Crops					
Cotton	152	133	19	114	19
Peanut	126	81	12	68	45

Source: Authors' survey

[a] Number of irrigated plots include plots irrigated by surface water, by groundwater and by both (conjunctively). Number of plots irrigated conjunctively is not reported here because it is less than 2% of total number of plots. Thus column (3) and column (4) does not sum up to column (2).

[b] Coarse grains includes sorghum, millet, pearl millet, buckwheat and others

[c] Tubers includes white potatoes and sweet potatoes.

Appendix C. The Impact of Irrigation on Crop Yield with Village fixed effect

	Dependent Variables: Crop Yield [b]											
	Wheat		Maize		Cotton		Coarse Grain		Tuber			
	Equation1	Equation2	Equation1	Equation2	Equation1	Equation2	Equation1	Equation2	Equation1	Equation2	Equation3	Equation4
Irrigation Status												
Irrigated (by Surface Water or Ground Water)	0.115		0.149		-0.080		0.145		-0.260		0.019	
	(2.97)***		(4.24)***		(0.56)		(1.05)		(2.50)**		(0.17)	
Irrigated by Surface Water		0.073		0.107		-0.084		0.395		-0.242		0.044
		(2.08)**		(2.77)***		(0.54)		(2.33)**		(2.31)**		(0.40)
Irrigated by Ground Water		0.057		0.172		-0.067		-0.198		-0.336		-0.202
		(1.11)		(3.55)***		(0.28)		(0.99)		(0.79)		(0.50)
Land Characteristics												
Good Soil Quality	0.138	0.140	0.125	0.123	0.560	0.561	-0.130	-0.113	0.171	0.171	0.172	0.173
	(4.88)***	(4.93)***	(3.91)***	(3.85)***	(4.59)***	(4.54)***	(1.31)	(1.12)	(1.61)	(1.61)	(1.69)*	(1.70)*
Topography-Plain	0.062	0.060	0.089	0.094		0.271	0.483	0.598	0.026	0.019	0.107	0.115
	(0.77)	(0.74)	(0.94)	(1.00)		(0.92)	(1.13)	(1.39)	(0.08)	(0.06)	(0.36)	(0.38)
Topography-Hill	0.035	0.031	0.114	0.114			0.593	0.684	-0.021	-0.015	0.056	0.064
	(0.71)	(0.62)	(1.38)	(1.38)			(1.45)	(1.66)*	(0.07)	(0.05)	(0.20)	(0.23)
Distance from Home	0.022	0.019	-0.024	-0.021	0.193	0.193	0.003	-0.024	-0.019	-0.019	-0.020	-0.021
	(1.57)	(1.37)	(1.11)	(0.98)	(2.71)***	(2.70)***	(0.05)	(0.35)	(0.33)	(0.32)	(0.37)	(0.37)
Shock: Severity of Disaster [c]	-0.008	-0.008	-0.012	-0.012	-0.003	-0.003	-0.013	-0.013	-0.003	-0.003	-0.003	-0.003
	(10.43)***	(10.32)***	(17.23)***	(16.91)***	(1.54)	(1.52)	(5.89)***	(5.76)***	(0.90)	(0.91)	(0.98)	(1.00)
Crop growing length [d]	0.093	0.091	-0.091	-0.086	0.062	0.062	-0.067	-0.075	0.216	0.221	0.288	0.288
	(1.71)*	(1.67)*	(2.12)**	(1.98)**	(0.54)	(0.53)	(0.47)	(0.54)	(1.85)*	(1.88)*	(2.55)**	(2.55)**
South Non-irrigated Potato											1.243	1.261
											(6.24)***	(6.32)***
Number of Plots	1027	1027	1112	1112	141	141	277	277	509	509	509	509
Number of Village	43		47	47	10	10	38	38	50	50	50	50
R-square	0.15	0.14	0.28	0.28	0.26	0.26	0.17	0.19	0.03	0.03	0.11	0.11

[a] Absolute value of t statistics in parentheses. * significant at 10%; ** significant at 5%; *** significant at 1%
[b] Dependent variable in log form. Estimate using fixed effect model at household level.
[c] Severity of Disaster means percentage reduction of production.
[d] A dummy variable that is 1 if the crop is not grown in conjunction with other crops during the year and is 0 if it is cultivated in rotation with other crops.

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[1] Information on investments are from a number of sources. Water control investment numbers are from the Ministry of Water Resources (2001). Agricultural research figures are from Huang and Hu (2001). Data on the investments for poverty alleviation are from China National Statistics Bureau (2001).

[2] The provinces are Hebei, Liaoning, Shaanxi, Zhejiang, Hubei, and Sichuan. The data collection effort involved students from the Center for Chinese Agricultural Policy, Renmin University, and China Agricultural University. It was led by Loren Brandt of the University of Toronto, Scott Rozelle of the University of California, and Linxiu Zhang of the Center for Chinese Agricultural Policy, Chinese Academy of Sciences. Households were paid 20 yuan and given a gift in compensation for the time that they spent with the survey team.

[3] Our figure may be higher than that used by official statisticians for two reasons. First, in our sample, we do not choose those villages that are more than 4 hours away from township so we are missing set of sample households that would be from an area in which the average proportion of cultivated area that was irrigated was lower than average. This would make our number biased upward. In addition, although almost a representative sample of China, our randomly selected sample did not choose some big provinces that happen to be less irrigated than the average national level. For example, only 17% of cultivated land in Heilongjiang province is irrigated, only 27% in Inner Mongolia and 19% in Gansu. Figures for other countries are from Table 8 in *Attacking Poverty* (World Bank, 2001).

[4] There are only two crops that have lower yield in irrigated plots, rice and tuber. If we further divide rice into single-season rice, rice-rice rotation (early season rice and late season rice) and wheat-rice rotation, we found for each of this subdivision, yield of irrigated plots is significantly higher than that of non-irrigated. The averaged yield of irrigated plots turns out lower is because yield of single-season rice is higher than other types of rice (rice-rice rotation and wheat-rice rotation) and so non-irrigated single-season rice is higher than irrigated yield of other rice. Moreover, 64% of rice is single-season so it weights more in the average. If we use the weighted average, irrigated yield is higher than non-irrigated yield. For tuber, we found out that only in south province(Zhejiang, Sichuan and Hubei) non-irrigated yield is higher than irrigated. As is known, in those provinces, tubers' growing time coincides with rain season and in our survey this effect is not included in irrigation although those plots are actually irrigated.

[5] Although there are two crops (rice and tubers) that have lower yields in irrigated plots when compared to non-irrigated plots, closer inspection shows that even in these cases, irrigation increases yields or at least does hurt them (Table 2, rows 1 and 19). If we divide rice into single-season rice, rice grown in a rice-rice rotation (early season rice and late season rice) and rice grown in a wheat-rice rotation, we find for each of this subdivision, the differences between the yields of irrigated and non-irrigated plots are all positive and significantly differently in several cases. The average yields of irrigated rice plots in the aggregate are lower because yields of single-season rice (both those that are irrigated and non irrigated) are 64% higher than those of other types of rice (rice grown in rice-rice or wheat-rice rotations). In the case of tubers, we find that the higher yields on non-irrigated plots can be accounted for by plots in sample's three southern provinces (Zhejiang, Sichuan and Hubei Provinces) since the main season for growing tubers coincides with the rainy season and tubers planted in irrigated areas that are typically more subjected to flooding do not do as well as those planted on non-irrigated plots.

[6] In table 3 in our regressions that explain cropping revenue we do not account for rising costs on irrigated plots due to data limitations (we did not collect inputs by plot). Since our regression analysis is based on supply analysis, this does not restrict our ability to examine efficiency gains from irrigation (since supply response is a function of prices and fixed factors). However, on the basis of another data set that we collected in 1995 in 2 northeastern provinces, Liaoning and Hebei, we can see that although costs rise when irrigation is introduced, the rise is restricted to only a subset of inputs and the total increase in the value of inputs is less than 61% and costs account only for about a half a plot's revenue.

[7] In some specifications (Appendix C) in which we want to use more of the intervillage variability of yields to understand the effect of irrigation by estimating

$$y_{ih} = \alpha + \gamma D_{ihj} + X_{ih}\beta + \mu_h + \mu_v' + \varepsilon_{ih}$$

where μ_h and μ_v' denote household and village fixed effect respectively. We include 4 household variables (land size, wealth ,household size, and average education level of household head) to control for differences among households and include a set of village dummies to control all village fixed effects. Although more variability is available for the regression estimates, there is a danger that unobserved household-level factors (e.g., management or the opportunity cost of the household) are biasing the estimates of the irrigation variable.

[8] Significantly, the wheat-rice rotation does not show any statistical difference between irrigated and non-irrigated areas. Most likely this is because in the case of only 4 households does a single household have both irrigated and non-irrigated plots (the requirement that needs to be met for the observations to be used).