The impact of Irrigation on Agricultural Productivity: Evidence from India

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Using plot level production data from a nation-wide survey in India, we study the impact of irrigation on crop productivity, land prices and cropping intensities. Our main identification strategy is based on a sufficient number of households cultivating multiple plots of different irrigation status. After household fixed effects and plot characteristics are controlled for, our estimations show that irrigation has a strong and significant impact on all these outcomes with the dominant effects on cropping intensities. We find quality of irrigation also matters. Our results provide support for continuing investments to improve access and quality of irrigation in India.

Crop yields everywhere in the developing world are consistently higher in irrigated areas than in rainfed areas (Rosegrant and Perez 1997; Ringler et al. 2000; Hussain and Hanjra 2004; Lipton et al. 2005). About 17% of global agricultural land is irrigated contributing about 40% to the world's production of cereal crops (WCD 2000). A comprehensive review of World Bank-assisted irrigation projects during 1994-2004 (IEG 2006) and a review of irrigation projects in Asia that received assistance from the International Water Management Istitute (ADB/IWMI 2005) confirmed the significant role that irrigation plays in poverty reduction and economic growth. The impacts of irrigation on poverty reduction are both direct and indirect. Direct benefits of irrigation include higher farm productivity through crop yield increases and diversification of cropping patterns and crop technologies. These in turn result in higher household income, , consumption and employment. To the extent that irrigation results in higher marketed surpluses and increased employment opportunities, it also indirectly benefits the landless through higher wages). Finally irrigation may lead to lower food prices which is especially beneficial to the poor since they spend a disproportionally large share of their income on food.

Access to irrigation water is widely credited to be one of the major underlying factors for the substantial productivity gains obtained during the Green Revolution in Asia in the 1960s and 1970s (Pingali et al. 1997; Bhattarai et al. 2002).In light of the recent rises in food prices and increasing demand for non-agricultural use of land, raising agricultural productivity is more important than ever. Will improvements in irrigation be able to contribute to further gains in crop productivity? If so, to what extent and how can we maximize the potential of irrigation? Some recent studies based on regional or state-level data suggest that further investments in irrigation would make only a moderate contribution to agricultural production and agricultural GDP (Fan et al. 2000; Fan and Chan-Kang 2004). At the same time, however, others claim that the economic gains from further improvements in irrigation are potentially large (Datt and Ravallion 1997; Rosegrant et al. 1998; Barker et al. 2004; Hussain and Hanjra 2004; Huang et al. 2005). There exist a large number of reports and research papers that analyze the economic impact of irrigation. However, the issues being analyzed as well as the data and methods being used suffer from various limitations including aggregation bias, small sample problems and inability to establish the true causal relationship between irrigation and impact of irrigation.

In this paper we review some of the existing methods that have been used to evaluate the economic returns of access to irrigation water. Based on their advantages and disadvantages. we propose an improved method for analyzing the productivity impact of irrigation, usin a unique National Council of Applied Economic Research (NCAER) dataset that contains detailed plot level information on agricultural production and access to different types of irrigation services for 16 states in India.

Review of past studies regarding the economic impact of irrigation

While macro-level analyses can be useful for providing overall directions for public investment allocation, they cannot identify the heterogeneous impacts of infrastructure services. As demonstrated by Van de Walle and Gunewardena (2001), failing to take heterogeneous impacts of irrigation into account can lead to considerable bias. Understanding the different effects of public investments in different regions and on different households is crucial to ensure that public resources are most efficiently spent to achieve economic growth and poverty reduction. Micro-level analyses using household survey data are needed in this regard. A variety of empirical methods have been adopted to analyze the impact of access to irrigation at the level of the household. In recent years the literature in this area has expanded considerably - see Hussain (2007), Hussain et al. (2007) and Lipton (2007) for comprehensive reviews of the literature). Below we review some of the main methods used in these studies, especially in some of the more recent ones.

A series of recent studies funded by the Asian Development Bank (ADB) and the IWMI evaluate the poverty impact of irrigation systems that received assistance from IWMI in six Asia countries - Bangladesh, China, India, Indonesia, Pakistan and Vietnam (Hussain and Wijerathna 2004)[1]. Household level samples were drawn from a multistage sampling method. Poverty impact analyses was conducted for all the study countries using econometric models. Except for Bangladesh where a linear regression model was used to assess the impact of irrigation on household income, for all the other countries a logistic/probit model was used to estimate the impact of irrigation on poverty. In the logistic/probit models, the dependent variable is a dichotomous variable (=1 for poor households whose income is below the national poverty line, and 0 for non-poor households). Linear regression models were also used to analyze annual expenditure, gross value product, and yield in some countries. The explanatory variables included household demographic characteristics, farm productivity/income, asset holdings (such as land) and availability/access to irrigation. Irrigation variables included dummy variables for access to irrigation and location within the command area (i.e., head, middle, and tail). In the cases of Indonesia and Vietnam, sufficiency of water supply, time accuracy of water supply and distance to the water gate, 5 year incidence of drought and 5 year incidence of inundation were also included. And in the Pakistan study, ground water quality was also included as an explanatory variable. Among the 6 countries studied, the methods and data used in the China case were the broadest (Huang et al. 2005). Both econometric estimation and simulation based on the econometric results were used to assess the change in poverty incidence arising from a change in a specific factor (e.g., irrigation access). The impact on inequality was also evaluated by three different decomposition methods. The main innovation in the China study concerns the detailed input and output data at the plot level. The plot level production data were used to analyze the impact of irrigation on agricultural productivity. The availability of data regarding plot level characteristics allows to control for land quality in the productivity regression. Moreover, data from

[1] These countries together account for over 51 percent of global net irrigated area and over 73 percent of net irrigated area in Asia, with most of this area located in China, India and Pakistan.

multiple plots for the same household also allow to control for household fixed effects (i.e. any unobserved factors that are correlated with household access to irrigation and yield levels).

A strong correlation between irrigation and poverty was identified in almost all case studies. Poverty incidences are 20-30 percent less in settings with irrigation compared to those without irrigation. But the positive impact of irrigation on poverty reduction varies across irrigation systems, location of households within the system (head, tail and middle), quality of water supply (sufficiency and time accuracy), and size and distribution of land holdings. Moreover, in Indonesia the marginal poverty reduction effect is bigger in irrigated areas than in rainfed areas. These highly heterogeneous impacts of access to irrigation further highlight the need for these types of analyses to be conducted at the household level.

Van den Berg and Ruben (2006) used cross-sectional household level data from rural Ethiopia to analyze the distributional impacts on levels of household expenditure and labor demand, as well as the indirect effects of irrigation on expenditure levels of non-irrigation households. In this way these authors sought to determine whether the poor lose due to land consolidation or displacement of labor as a result of mechanization or increased use of agrochemicals caused by irrigation system improvement. In their econometric model, expenditures and labor use are a function of a set of household and community level variables. Owned area with irrigation and without irrigation are included in the model to test the effect of irrigation access on consumption and employment. The share of area irrigated in total agricultural area at the community level is also included to capture the spillover effects of irrigation on other households. The models were estimated using standard the OLS estimation approach. The findings suggest that irrigation is highly beneficial to those households directly involved, but the hypothesized positive spillover effects on other households were not significant. Given that farmers with irrigated land on average were poorer than farmers without irrigated land, the authors further argued that irrigation has stimulated growth without deepening inequality.[2]

[2] The finding of a positive effect of irrigation on equity is likely to be location specific. The results are beased on a sample from the (Tigray region in northern Ethiopia where livestock and other non-farm activities (rather than crops) are dominant activities and land holdings are negatively correlated with household income and wealth. The equity result has therefore limited relevance to other contexts.

Based on household data from the Philippines, a similar study by Shively (2001) showed that irrigation development in lowland agriculture increased the probability of employment for upland residents. However, the same study also showed that irrigated farms exhibited more intensive use of fertilizers and pesticides, leading to reductions in labor use. Simulations based on results from stochastic production function estimation indicate that labor use is likely to fall under the assumption of profit maximization.

A number other studies have examined the choice of irrigation services and the impact of different types of irrigation on productivity and income. Munir et al. (2002) estimated a stochastic frontier production function of wheat production using farm level data from Pakistan. Three irrigation dummies (canal, tubewell, and both canal and tubewell) were included in the model. Canal irrigation is the least reliable source of water, the combination of tubewell and canal is considered most reliable, and tubewell irrigation is in the middle. As expected, the estimation results showed productivity of farms with any of the three types of irrigation to be significantly higher than that of farms without any irrigation. Perhaps more interesting are the findings that productivity is highest on farms with access to the most reliable form of irrigation (i.e. access to both canal and tubewell), and second highest on farms with only access to tubewell, followed by those with only canal irrigation.

Based on household data from Pakistan, Meinzen-Dick and Sullins (1994) obtained similar results by assessing the yield difference among different types of water supply (public canal, public tubewell, purchased private tubewell, and own tubewell). Regression results based on a logit model suggested that young households with less land are more likely to purchase groundwater than older households with more land which are also more likely to own their own tubewell. Descriptive analysis shows that yields on land with access to water from an own tubewell are significantly higher than yields on land with any of the other three types of irrigation. Yield on irrigated land with access to water from a public canal only is the lowest among the four types of water supply. Productivity of land with access to purchased water from a private tubewell is similar to productivity of land with a public tubewell. The insignificant productivity difference between purchased tubewell and public tubewell is because the purchased water supply is almost as unreliable as the public tubewell (i.e. farmers are not guaranteed to have enough water to purchase). This finding is highly consistent across all three types of crops analyzed (i.e. wheat, maize and cotton) and was further supported by multivariate regression analysis using plot level production functions for wheat.[3]

The main drawback of the majority of existing household level analyses regarding the impact of irrigation on poverty reduction/income/consumption/inequality is the use of cross-sectional data (Hussain et al. 2007). Analysts who use cross-sectional data to analyze the impact of irrigation access face a number of econometric challenges – chiefly among them are heterogeneity and simultaneity. The estimation results will be biased if there are unobserved factors that are simultaneously correlated with access to irrigation (or improvement in irrigation services) and the outcome indicators/dependent variables (e.g., income/consumption/poverty/inequality). For example, households with access to irrigation might be also better farmers. In that case the estimated coefficients on access to irrigation based on cross sectional data are likely to be biased upward. Two common strategies to deal with the simultaneity problem includethe use of instrumental variables (IVs) or panel data. An IV is a variable that is correlated with the variable of interest (e.g. farmer access to irrigation) but uncorrelated with the outcome/dependent variable (or the error of the impact equation). The problem is that it is usually very difficult to find good IVs because most variables that are correlated with access to irrigation are also correlated with the outcome/depedent variable of interest. Kajisa et al. (2007) used an instrumental variables approach; however, their sample size was very small.

An alternative strategy to IVs is to use panel data. Panel data or plot level data that include indicators of access to and quality of irrigation services are rarely available and costly to obtain.[4] Meinzen-Dick and Sullins (1994) used plot level analysis, but the sample size again was very small. Huang et al. (2005) also used plot level information, but the input and output information was by crop rather than plot. As a result they had to rely on the extrapolation of data which potentially introduces bias to the data. In the next

[3] However, the number of observations for wheat was only 200 while maize and cotton had insufficient observations to allow multivariate regressions.
[4] A short panel may not be able to get enough variability in irrigation access.

section, we will describe how we were able to use the long panel of NCAER data to perform similar types of household analyses but with improved control of theseeconometrics problems.

Methods to analyze the NCAER data

Data

The household-level data used in our analysis are from three rounds of the ARIS/REDS[5] survey conducted by India's National Council for Applied Economic Research (NCAER) in respectively 1982, 1999 and 2006. The ARIS/REDS survey builds on a set of households who were first interviewed in 1968-1971 to evaluate the impact of an agricultural development program covering the relatively advantaged areas in most states. Even though the first round sample of 1968-1971 (which is stratified by farm size and wealth class) was limited to project areas, coverage of the survey was significantly expanded in 1982 to make it more representative at the national level while also increasing the sample size to slightly below 5,000 households (Foster and Rosenzweig 1996). The 1999 sample contains all of the households included in 1982 as well as replacements for households who were no longer present. If the original household had split, all of the households belonging to the same dynasty in the original village plus a sub-sample of successor households outside the village were interviewed, lifting the sample size total to about 7,500 households (Foster and Rosenzweig, 2004). To make sure the new households who split from the original 1999 households were also included in the 2006 round survey, a listing exercise of all the households in each of the surveyed communities was conducted. In this exercise information on income by source, consumption, irrigated and non-irrigated land in 2006 and 10 years before, for all the households in the community was collected.

The NCAER survey consists of two modules: a household module and a village module. In the village module, information regarding basic village characteristics including detailed information on land (e.g., total cultivated land area and land under different types of irrigation infrastructures - government

[5] ARIS is the acronym for 'Additional Rural Income Survey' whereas REDS stands for 'Rural Economic and Demographic Survey'.

canal, private tanks, wells, and other streams), village economic conditions and different economic activities, agricultural technology and level of production, governance, weather and other external shocks was collected.

The household module included not only most of the variables included in a standard multipurpose household survey (such as household characteristics, expenditure, assets, income sources etc.) but also detailed input-output information for all the plots under cultivation. In addition, the household survey also collected data regarding specific plot characteristics including soil quality, access to different types of irrigation services - surface water, ground water, pond, well, as well as information on the availability and reliability of water supply.

Plot level productivity analysis

The detailed plot level input and output data were used to estimate a production function to study the impact of irrigation on productivity. The model specification is similar to the one used in Huang et al. (2006). Specifically, we estimated the following model:

$$\ln Q_{ijk} = \alpha_i + \gamma_1^m D_{ijk}^m + \gamma_2 P_{ijk} + \gamma_3 \ln H_{ij} + \gamma_4 \ln Z_j + \varepsilon_{ijk} \qquad (1)$$

In equation (1) $\ln Q_{ijk}$ is the productivity of plot *k* of household *i* located in village *j*; α_i represents household fixed effects (e.g., household farming ability, access to credit, risk attitude of the households, etc.); D_{ijk}^m is a dummy variable for plot *i* with access to the m^{th} type of irrigation infrastructure (=1 if irrigation is type m, =0 otherwise); $\ln H_{ij}$ is a vector of other observable household characteristics (age, gender, education and off-farm experience of the household head, etc.); $\ln P_{ijk}$ is a vector of plot characteristics (land size, soil type, land quality, plot specific shocks, crop type, season type, etc.); Z_j is a vector of village *j*'s characteristics including village level technology, access to extension services, market development, local economic opportunities, weather, and other natural disasters (e.g., breakouts of diseases and insect infestation) etc.

It is well known that equation (1) cannot be estimated by OLS if α_i is correlated with D_{ijk}^m (or with any other variable on the right hand side). To purge α_i, we take advantage of the multiple plot data for each household and estimate equation (1) using a panel fixed effect estimation approach. This is equivalent to estimating the following equation:

$$\ln Q_{ijk} - \overline{\ln Q_{ij}} = \gamma_1^m (D_{ijk}^m - \overline{D_{ij}^m}) + \gamma_2 (\ln P_{ijk} - \overline{\ln P_{ij}}) + \varepsilon_{ijk} \qquad (2)$$

In equation (2), observed and unobserved household and village characteristics (α_i , $\ln H_{ij}$, $\ln Z_j$) have dropped out. Our main interest is the estimated parameter vector, γ_1^m .

Additional practical care is warranted when estimating equation (1). The fact that some plots are cultivated during only one season while others are cultivated during multiple seasons, combined with different plots being cultivated with different crops in a given season makes the estimation more difficult. We therefore tried a number of different estimation strategies: (1) estimating land productivity on an annual basis; (2) estimating land productivity on a seasonal basis; and (3) estimating productivity for those plots that are cultivated with the same crop in the same season.

Descriptive Analysis

Irrigation in India

Despite the enormous progress in India's irrigation system in the past, access to irrigation is still a big challenge for farmers in many parts of rural India. The NCAER data indicate that only about half of the agricultural plots in the sample are irrigated - 27% by public irrigation (i.e., canal irrigation), 18% by private irrigation schemes (e.g., ponds, wells, etc.) and about 4% by both public and private irrigation. The remaining half of the plots are rainfed (Table 1). However, access to irrigation varies sharply across states in India. While 94% of farm plots in Tamil Nadu are irrigated, almost all the plots in Himachal Pradesh are rainfed. Other states where the majority of plots have access to irrigation include Chhattisgarh (77% of plots), Gujarat (76%), and Punjab (73%). States besides Himachal Pradesh where the majority of plots remain rainfed include Bihar (67% of plots), Jharkhand (79%) and Karnataka (80%). Although on average public irrigation is more important than private irrigation (27% versus 18% of plots), the relative importance of the two irrigation systems varies from state to state. For example, while canal irrigation dominates in Chhattisgarh, Tamil Nadu, Orissa, and West Bengal, tubewells are the dominant irrigation source in Gujarat. On average, less than four percent of the plots in our sample have access to both private irrigation and public irrigation systems; on the other hand, 17% of plots in Punjab and 19% of sample plots in Tamil Nadu have access to both types of irrigation.

Irrigation and Land Productivity

A casual examination of the relationship between irrigation and land productivity using NCAER data tends to provide a justification for the huge investments made in public and private irrigation systems in India. Table 2 reports, for each state, annual gross revenue of crop production per acre of land and annual net revenue of crop production per acre of land by plots of different types with irrigation (e.g., plots with both public irrigation and private irrigation, plots with only public irrigation, plots with only private irrigation) and rainfed plots. The simple tabulation of annual gross revenue per acre and annual net revenue per acre of land by irrigation status and by states reveals a number of consistent and expected patterns.[6]

First, irrigation is positively correlated with agricultural productivity as both annual gross revenue per acre of land and annual net revenue per acre of land are lowest for rainfed plots in almost all states.[7] According to the NCAER data, the national average of annual gross revenue per acre of land is 15,415 Rupees for rainfed plots, significantly below the 22,376 Rupees, 21,143 Rupees and 24,960 Rupees, respectively for plots with private irrigation, plots with public irrigation and plots with both types of irrigation. In terms of percentage increases (columns 5-9), compared to rainfed plots, annual gross

[6] To address the concern that a comparison of the level of productivity between different types of plots may be influenced by extreme values in the data, we also calculated the logarithm of gross revenue and net revenue. The results are highly consistent with those based on the level of revenue.
[7] The difference between gross and net revenue is accounted for by production costs (excluding family labor).

revenues per acre for plots with access to public irrigation systems, for plots with private irrigation only, and for plots with both public and private irrigation, respectively are 51 percent, 56 per cent, and 69 percent higher than that for plots without any irrigation access. Similar trends also hold when outcome is measured by annual net revenue per acre of land.

Second, the impact of irrigation on agricultural productivity varies sharply across states. For example, while the difference in the log of gross revenue between irrigated plots and rainfed plots is substantial in Andhra Pradesh (ranging from 9.35 to 9.78 for irrigated plots depends on type of irrigation versus 8.77 for rainfed plots), Jharkhand (9.38-10.09 versus 8.64) and West Bengal (9.57-10.14 v.s. 9.26), the difference is almost negligible in the states of Haryana (9.92-10.20 versus 10.02) and Tamil Nadu (9.84-10.10 versus 9.84). Similar patterns are observed when productivity is measured by annual net revenue per acre. In the same way that the overall impact of irrigation on productivity varies across states, so does the relative importance between public irrigation and private irrigation. While private irrigation is much more important than public irrigation in Chhattisgarh and West Bengal, the opposite is true for the states of Gujarat, Kerala and Orissa.

Third, the data point toward significant complementarity between private irrigation and public irrigation, as illustrated by the fact that plots with access to both types of irrigation tend to have the highest annual revenue per acre. The national average of annual gross revenue per acre on plots with both types of irrigation is 24,960 Rs., 28 percent higher than that on plots with only public irrigation and 79 percent higher than that on rainfed plots. Again a similar pattern is observed when productivity is measured by annual net gross revenue instead of annual gross revenue.

There are two potential avenues through which irrigation increases annual crop revenues. First, irrigation increases annual revenue per acre of land through its direct positive effect on total crop production in a given cropping season. Second, irrigation may allow a plot to be planted for an extra crop season for a given year. The NCAER data allow us to investigate each of these two factors. Table 3 presents average gross and net revenue per acre per season for plots with different irrigation status by state. Like in the case of annual gross or net revenue per acre of land, average gross or net revenue per acre per season is also lowest among the rainfed plots, and the difference of season-based revenue per acre of land between public irrigation and private irrigation is again small. As in the case of annual gross or net revenue per acre, there exists substantial heterogeneity regarding the impact on season-based gross or net revenue across states. Differences in season-based revenues between irrigated plots and rainfed plots are much smaller than annual-based revenues. For example, while average gross revenues per acre for an average season from plots with public (or private) irrigation is 16 (or 20) percentage points higher than that of plots without any irrigation, the corresponding figures are 51 percent for public and 56 percent when annual revenue is used. Similarly, the impact of irrigation on net revenue per acre for an average season is also much smaller than the impact of irrigation on annual net revenue per acre of land. And the general results are largely consistent no matter whether all crops are included in the calculation of revenue of an average season (columns 2-9 in Table 3) or when only a selected set of crops (i.e., cereals, beans and oil crops) are included in the calculation (columns 10-17 in Table 3).

The NCAER data also indicate that the difference in gross or net revenue per acre for an average season between plots with both types of irrigation versus plots with only one type of irrigation (either public irrigation or private irrigation) is much smaller than that of gross or net revenue per acre per annum. There are even occasional cases where the average gross or net revenue per acre for an average season is smaller for plots with both types of irrigation than for plots with only one type of irrigation. This is in stark contrast to the large difference in annual gross or net revenue per acre between plots of two types of irrigation and plots with only one type of irrigation. The noticeable difference between the impact of irrigation on annual revenue and seasonal revenue suggests that irrigation also has considerable impact on land use intensity (i.e. number of cropping seasons).

Irrigation and land use intensity

Table 4 strongly supports our hypothesis that irrigation has a big impact on intensity of land use. Overall, plots with access to both types of irrigation have the highest number of cropping seasons (2.02) followed by plots with access to only private irrigation (1.82) or only public irrigation (1.75). On the other hand, rainfed plots are associated with the lowest land use intensity (1.5 cropping seasons). This pattern is consistent in most states. On the other hand the size of the impact of irrigation accesson plot use intensityvaries considerably from state to state. For example, the number of cropping seasons for irrigated plots is almost twice as high as that for rainfed plots in the Maharashtra (2.03 versus 1.17) and West Bengal (2.37 versus 1.11). On the other hand, the difference is negligible in Punjab (2.04 versus 1.98). The variation of the impact of irrigation on plot use intensity across states is not unexpected because land use intensity is likely to be influenced by agro-ecological factors besides irrigation access.

Irrigation and input use

It is widely argued that irrigation tends to increase the responsiveness of agricultural output to inputs and therefore is likely to be positively correlated with input use intensity. The descriptive evidence based on the NCAER data tends to support this argument (Table 5). At a national average of 5,186 Rs. (accounting for 1/3 of total revenue), the annual cost of production per acre for rainfed plots is the lowest among all the plots in most states. In spite of the higher annual cost of irrigated agriculture compared to rainfed agricultural production, the higher annual net revenue of irrigated plots implies that the more intensive input use yields net positive returns. The results are largely consistent even when the average cost of production is measured on a per season basis rather than per year.

Further analysis of the cost data by comparing input use between irrigated plots and rainfed plots for the major types of agricultural inputd provides additional insights (Table 6). Except for family labor use which shows little variation across irrigation status, irrigation generally increases of the use of all other inputs. Compared to rainfed plots, expenditures on fertilizers and other agrochemicals are almost double on irrigated plots. Even though the impact of irrigation on seed expenditure is less pronounced compared to expenditure on fertilizers and pesticides, the use of seed & seedlings on irrigated plots is also significantly higher than on rainfed plots (19% to 98% higher depending on the specific type of irrigation). Irrigation also stimulates labor use in agricultural production, with the largest increase in the use of hired labor.

Econometric results

The findings from our descriptive analysis suggest potentially large productivity gains of irrigation investments and point toward the potential avenues through which irrigation may affect productivity. Annual and seasonal gross and net revenues per acre, land prices, input use and number of cropping seasons are consistently higher on irrigated plots than on rainfed plots. However, the descriptive statistics do not help identification of the causal relationships between irrigation and outcome indicators. The observed differences in all these outcome indicators may be partially or fully due to differences in other factors such as observed plot or soil characteristics, or unobserved household characteristics such as farming ability etc. Regression analysis is therefore required to identify the causal relationships that underly the impacts of irrigation on productivity and to further quantify the magnitude of those impacts.

The key identification strategy of our regression analysis relies on variation of irrigation status within the same households. The strategy of using plot level production of multiple plots operated by the same households has been used in some of the most influential articles in the literature (e.g. Shaban 1987; Udry 1996). Taking advantage of the fact that the NCAER data contain a large number of households who cultivated multiple plots of different irrigation status (i.e., plots with only public irrigation, plots with only private irrigation, plots with both private and public irrigation, and plots without irrigation) in a given season or a given year, we were able to identify the impact of different irrigation status on land productivity, plot use intensity, input use intensity and land price using household fixed effect estimation.

To address the concern that the estimation results may be sensitive to of the way in which productivity is measured, we tried a number of different measures (i.e. gross revenue, net revenue, and yield) and based on annual production or seasonal production. If land markets are functioning reasonably well, the main characteristics of plots including irrigation status are supposed to be implicitly capitalized in the land price (Jacoby 2000). We estimated a fixed-effect price regression of land plots with varying irrigation status after controlling for a detailed set of plot and soil characteristics. We also estimated the impact of different types of irrigation on land use intensity (i.e., number of cropping seasons) and input use intensity.

Our econometric results strongly substantiate most of the descriptive evidence discussed above. The estimation results suggest that irrigation has a significant and large impact on annual gross and net revenues per acre of land. We also find that a large proportion of the impact of irrigation on annual productivity is realized through its impact on land use intensity. As expected, irrigation also has a positive and significant impact on land prices. The quality of irrigation also matters as plots with both private irrigation and public irrigation tend to generate the highest revenues among all plots. And among plots with public irrigation, those with continuous water always availability produce higher yields than plots with less frequent water availability.

Irrigation and Productivity

Revenue per acre per annum

We first explore the impact of irrigation on annual crop productivity (measured by annual gross revenues or net revenues per acre of land). Equation (2) was estimated using a household fixed-effect approach. In order for the household fixed-effect model to function, it is necessary for the sample to contain a sufficiently large number of households with multiple plots of different irrigation status. Among the 4,386 sample households which reported agricultural production in 2007, 998 households cultivated multiple plots of different irrigation status (3,135 plots in total). In light of the fact that the impact of different types of irrigation on productivity can only be identified by the 3,135 plots of 998 households, equation (2) was estimated using this subset of households. In addition equation (2) was also estimated using the entire sample in view of efficiency gains (Jacoby and Mansuri 2008).

Table 7 reports the estimation results regarding the impact of different types of irrigation on annual gross and net revenues per acre using the entire sample (columns 2-5) as well as the subsample of 998 households (columns 6-9). Given that the results are almost identical no matter whether the entire sample is used or only the subsample is used, our discussion will focus on the results based on the entire sample. The base model includes three irrigation dummies and size of the plot (columns 2 and 4). In the augmented model (columns 3 and 5) the base model was expanded by including the distance between the plot and the homestead, land price, and a set of soil and plot characteristics to control for the quality of each plot. The base category of irrigation dummies excluded from the equation is the rainfed plot dummy.

The most consistent results include a set of significant and positive coefficients of relatively large magnitude for all three irrigation dummies (i.e. private irrigation only, public irrigation only, both types of irrigation), implying a significant impact of irrigation on annual gross and net revenues per acre of land. The base model results (columns 2 and 4) suggest that private irrigation, public irrigation and both private and public irrigation increase annual gross (or net) revenue per acre of land by 39% (or 40%), 39% (or 43%), and 52% (or 53%), respectively (in comparison to rainfed plots). As expected, the coefficients of the irrigation dummies become somewhat smaller when a set of plot and soil characteristics are added (columns 3 and 5). But the magnitude of most coefficients remains large. For example, the coefficient for plots with both types of irrigation (or with private irrigation) dropped from 0.51 (0.40) to 0.46 (0.37). The results regarding distance between the plot and the homestead and land price are also as expected since the coefficient for the former is negative (though significant only in one case), and the latter is positive and statistically significant at the 1% level. A 10 percent increase in the land price is associated with a 1.5% increase in gross annual revenue per acre and a 1.7% increase in net annual revenue per acre, suggesting that land prices may be a good measure for land quality. On the other hand, variables regarding soil type and soil quality have only limited impact on gross and net revenues per acre. This result may have something to do with the small variation in soil types and soil quality within the same households (after land prices have been accounted for).

Rice and wheat yields

A potential concern is that revenue per acre may be subject to measurement errors. The price of a particular agricultural commodity is calculated as the ratio of the total sales value to total quantity sold.

Butsince many households did either not sell any or only part of their crops, prices often had to be extrapolated from data of other households in the sample – a procedure that may introduce measurement error. Crop yields on the other had are less subject to measurement error because both area and production can be directly obtained from the survey data. Rice and wheat are two most important crops cultivated in the two main cropping seasons in India. We therefore estimated equation (2) for wheat and rice using crop yield as the measure of productivity.

The results for the fixed effect regressions in Table 8 suggest that irrigation is more important for rice production than for wheat production - two of the three irrigation dummies are positive and significant in the rice regressions, but none of the irrigation dummies are significant in the wheat regressions. In the rice regression, access to both public and private irrigation increases yields by 15% and having access to private irrigation would lead to a 9% increase in yield. However, it is surprising to note that public irrigation alone is not significant in the yield regression. Again the results do not change much when plot and soil characteristics are added to the regressions.

Irrigation and plot use intensity

Both the descriptive evidence and the regression results suggest that irrigation has a substantially larger impact on annual productivity than on yield productivity. The descriptive data also suggest that irrigation has a significant impact on plot use intensity. To check whether this descriptive evidence holds up in the regression analysis, we estimated equation (2) using the number of cropping seasons for each plot as the dependent variable. The results based on the entire sample are reported in columns 2 and 3 of Table 9. Again, the results of the estimations based on respectively the entire sample and the sample with only households that have plots with differenty irrigation status are quite similar. Therefore we only report the results of the entire sample.

Our econometric results are highly consistent with the descriptive findings that irrigation access significantly increases the number of cropping seasons. In the base model, plots with both types of irrigation, plots with private irrigation and plots with public irrigation increase the number of crop seasons by respectively 0.37, 0.25 and 0.34. Adding plot and soil characteristics only slightly reduces the magnitude of the estimated coefficients of the irrigation dummies. In light of the fact that the average number of cropping seasons for rainfed plots is 1.5, irrigation access increases the number of seasons by 17% - 25% depending on the type of irrigation. The estimated coefficients of the distance between the plot and the homestead and the land price both have the expected signs - the number of cropping seasons decreases with the distance between the plot and the homestead but increases with the land price.

Land price regression

In an environment where land markets are functioning well, the price of land should reflect the present value of the land. Any factor that is likely to increase the present value of the land should therefore increase the price of land. If irrigation has a positive impact on land productivity, it should also have a positive impact on the land price – after controlling for plot and soil characteristics other than irrigation. Based on this argument, we can implicitly test the impact of irrigation on productivity by estimating a plot level land price regression using a household fixed-effect approach. This is equivalent to estimating equation (2) using the land price as the dependent variable. The estimation results are reported in the last two columns of Table 9. Only FE results are reported as OLS results are biased for the reasons discussed in the section III.2.

The positive and significant estimated coefficients of all three irrigation dummies suggest a strong impact of irrigation on the price of land. While access to both private and public irrigation and having access to public irrigation only increase land price by a similar magnitude (around 20%), access to private irrigation only increases land prices by about 10%.

Irrigation and input use intensity

The estimated results regarding the impact of irrigation on input use intensity (including fertilizers and pesticides, seed & seedlings, total labor use, use of family labor and hired labor, and other inputs) are reported in Columns 2-7 (annual data) and columns 8-13 (seasonal data) of Table 10. The regression results further substantiate the descriptive finding that input use intensity is higher on irrigated than rainfed plots. The results are robust across different types of inputs and consistent no matter whether annual data or seasonal data is used.

Besides crop productivity, land use intensity and land prices, input use intensity is also highest o plots that have access to both private and public irrigation. This is not surprising because economic returns to input use are generally higher (and more stable) under conditions of secure water availability. Compared to rainfed plots, fertilizer and pesticide use is almost double while use of other inputs is between 60% and 70% higher on plots with access to both private irrigation and public irrigation (as compared to rainfed plots). The impact of a single type of irrigation (either public irrigation or private irrigation) on input use intensity is also substantial (32% - 70% higher than on rainfed plots depending on the type of input and type of irrigation).

The magnitude of the estimated coefficients for all three irrigation dummies is reduced (though only by a small magnitude – approximately 2-5 percentage points) once plot and soil characteristics are controlled for – consisten with earlier findings. The estimated coefficients for the three irrigation dummies are significantly smaller when seasonal data instead of annual data are used. This is also not surprising as we have already shown that irrigation not only increases input use intensity in a given cropping season but has an even larger impact on the number of cropping seasons. Thus, the impact of irrigation on annual input use intensity is bound to be substantially larger than the impact on seasonal input use intensity.

The large and significant estimated coefficients of the irrigation dummies suggest that irrigation creates considerable employment opportunities in agriculture. Having access to both types of irrigation increases total labor use per acre by more than 60% on an annual basis (or by 17% for a given season). Public irrigation alone or private irrigation alone would lead to an increase in annual labor use by respectively 41% and 36%, and total labor use in a given season by 10%. The estimated coefficients for family labor use and hired labor use are rather similar.

Impact of Irrigation Quality

We already noted that irrigation quality (measured by whether or not a plot has access to both private and public irrigation) matters a lot in terms of the the impact of irrigation on various outcomes of interest. The 2007 NCAER survey also collected data on the frequency at which water is available on plots with public irrigation access. The three pre-coded answers included the following: 1=water always available; 2=water only available occasionally; and 3=water rarely available. We took advantage of this information to further explore the impact of irrigation quality. In particular, we created a public irrigation quality dummy variable which equals 1 if water is always available and zero otherwise. We estimated equation (2) by replacing the irrigation dummies with the public irrigation quality dummy and ran the regression based on a subsample composed of plots with only public irrigation access. The results are depicted in Tables 11 and 12. In order to estimate the fixed-effect regression, we relied on the variation of public irrigation quality status within households. In the entire sample, there are only 47 households with 99 plots of varying public irrigation status that meet this requirement, so we interpret the results with caution.

The estimated coefficient of the quality dummy variable is consistently positive and significant in all regressions presented in Table 11, suggesting that the quality of irrigation plays an important role in raising crop productivity, land use intensity and land price. The magnitude of the estimated coefficient of the quality dummy variable is also large, ranging from 0.46 to 0.67 in the revenue regressions and 0.31-0.32 in the land use intensity regressions. In fact, these estimates are comparable to those of the dummy variable for plots with both public and private irrigation in the previous regression using the entire sample. In light of the fact that the omitted comparison group in Table 11 is “other plots with public irrigation”, as opposed to rainfed plots which are the comparison group in the previous regressions (Tables 7, 9 and 10) , the actual impact of this quality variable (water always available for plots with public irrigation) is even more striking.

Unlike its highly significant effect on revenues, cropping intensity and land prices, the coefficient of the quality dummy variable is insignificant in most of the input use intensity regressions (Table 12).

The only statistically significant coefficient (even though only at the 10% level) is obtained in the labor use regression and then only when plot and soil characteristics are not controlled for. This is quite unexpected and in stark contrast to the input intensity use regression results reported earlier (see Table 10). One explanation could be that farmers reported the availability of water based on ex-post information. If farmers knew the availability of water beforehand, one would expect them to use more inputs on plots with more reliable irrigation access, similar to the case where both private and public irrigation are available.

Impact of Irrigation across States

Our econometrics analyses so far have focused on the average impact of irrigation on crop productivity at the national level. But the descriptive evidence suggests substantial inter-state variation in the impact of irrigation on crop productivity. To assess whether and to what extent the strong and significant effects of irrigation on productivity found at the national level also hold for each individual state, we augmented the set of explanatory variables in equation (2) by a set of interaction terms between state dummies and the irrigation dummies. To identify the average impact of different types of irrigation in a given state, we needed to have sufficient households that cultivated multiple plots with varying irrigation status in that state. In light of the fact that in most states the number of households with crop plots accessible to both private and public irrigation is quite limited, we did not interact state dummies with the dummy for access to both private and public irrigation. Instead we only included the other two irrigation dummies (i.e., public irrigation and private irrigation dummy) and all the state dummies. The regression results for, are shown in Tables 13. The results are broadly consistent with the state-wise descriptive evidence and those based on the regressions without the interaction terms between state dummies and the two irrigation dummies. The impact of irrigation on cropping seasons and land prices (Table 13, columns 2-5) is unambiguously positive and statistically significant in all other states. The magnitude of the impact is quite large though varying across states. For example, the elasticity of land prices ranges from 0.07 to 0.38 for public irrigation and from 0.81 to -0.003 for private irrigation . The impact of private irrigation relative to that of public irrigation also varies considerably from state to state. While the data show that private irrigation is more important than public irrigation in and to a lesser extent also in Tamil Nadu, the reverse is true in Madhya Pradesh, Rajastan, Haryana, Punjab, Uttar Pradesh, and Bihar.

Conclusions

The majority of existing studies that investigate the impact of irrigation either use macro analysis based on highly aggregated data, or household level data which tend to suffer from omitted variable bias. Moreover, the relatively few studies that use plot level data either suffer from small sample sizes or use inaccurate measures of output (e.g., output data recorded by crop rather than plot). In this paper, we take advantage of a large sample of plot level production data covering 16 states in India. Our identification strategy relies on considerable variation in irrigation status for multiple plots cultivated by the same households.

Both the descriptive and econometric analyses confirm that irrigation has a strong impact on land productivity. More importantly, the results show that the productivity impact tends to vary by type of irrigation as well as quality of irrigation. The results are robust across a number of different measures of productivity as well as across different subsamples. In particular our analysis highlights the importance of irrigation quality. Plots that have access to both private and public irrigation, or public irrigation with guaranteed water availability, have significantly higher land productivity. Finally, the main channel through which irrigation impacts on land productivity is via its effect on cropping intensity (number of cropping seasons). These findings are largely consistent across the majority of states in India even though the magnitudes of the impacts vary from state to state.

The results in this paper provide strong support for continuing investment in irrigation infrastructure in India. On the other hand the analyses in this paper do not identify the reasons why irrigation is more effective in some state than in others. Understanding the factors behind the hetereogenous impacts of irrigation across states is important for ensuring the optimal allocation of irrigation investment funds and is a topic for future research.

Table 1: Percentage of Plots by Irrigation Status and State

State	Both Public and Private Irrigation	Public Irrigation	Private Irrigation	Rainfed	Number of Observations
ANDHRA PRADESH	1.11%	20.67%	31.56%	46.67%	450
BIHAR	1.48%	15.76%	15.27%	67.49%	203
CHHATTISGARH	0.82%	69.49%	6.57%	23.12%	731
GUJARAT	3.22%	12.06%	60.59%	24.13%	373
HARYANA	7.57%	34.26%	21.38%	36.79%	753
HIMACHAL PRADESH	0.00%	0.56%	0.00%	99.44%	357
JHARKHAND	0.41%	16.33%	4.49%	78.78%	245
KARNATAKA	1.87%	10.41%	7.72%	80.00%	855
KERALA	0.00%	16.67%	19.44%	63.89%	36
MADHYA PRADESH	2.42%	23.21%	16.15%	58.22%	991
MAHARASHTRA	1.09%	22.74%	18.54%	57.63%	642
ORISSA	0.83%	34.16%	0.28%	64.74%	363
PUNJAB	16.89%	32.45%	33.44%	17.22%	302
RAJASTHAN	2.31%	14.55%	21.38%	61.76%	1,127
TAMIL NADU	19.03%	52.23%	22.67%	6.07%	247
UTTAR PRADESH	5.43%	32.97%	20.87%	40.72%	1,859
WEST BENGAL	4.13%	35.43%	13.91%	46.52%	460
Total	3.78%	27.42%	18.23%	50.57%	9994

Table 2: Annual Gross and Net Revenue* of Crop Production (Rps/Acre/Year) by Irrigation Status and State

	Gross Revenue				Logarithm of Gross Revenue				Logarithm of Net Revenue				Number of Observations
	Both Irrig.	Public Irrig.	Private Irrig.	Rainfed	Both Irrig.	Public Irrig.	Private Irrig.	Rainfed	Both Irrig.	Public Irrig.	Private Irrig.	Rainfed	
ANDHRA PRADESH	17915	17270	15395	8458	9.78	9.61	9.35	8.77	9.27	7.91	7.23	6.71	449
BIHAR	28955	21484	19706	17665	10.27	9.94	9.83	9.61	9.71	9.60	9.26	8.90	203
CHHATTISGARH	17155	16355	27518	16953	9.67	9.44	10.16	9.56	9.34	8.40	9.86	9.01	731
GUJARAT	25585	23754	22936	15731	10.07	10.04	9.85	9.48	9.12	9.40	9.30	9.08	373
HARYANA	26255	23782	29425	26162	10.11	9.92	10.20	10.02	9.52	9.42	9.75	9.54	753
HIMACHAL PRADESH		12725		24403		9.30		9.25		9.12		8.58	357
JHARKHAND	24200	14002	18875	9862	10.09	9.38	9.69	8.64	9.77	9.04	9.41	8.06	245
KARNATAKA	25668	25168	25262	13573	9.93	9.56	9.73	9.04	9.72	8.60	8.91	7.95	854
KERALA		34306	22816	21892		10.39	9.64	9.88		9.84	8.04	9.19	36
MADHYA PRADESH	12498	14932	13826	9992	9.30	9.33	8.82	8.60	8.81	8.71	7.66	7.21	991
MAHARASHTRA	16986	26974	20478	10856	9.70	9.99	9.66	9.03	7.66	8.30	8.76	7.63	641
ORISSA	17016	17852	7500	10129	9.65	9.37	8.92	9.01	8.93	8.70	8.37	8.09	363
PUNJAB	34098	32206	34878	27281	10.36	10.24	10.39	10.05	9.79	9.72	9.69	9.12	302
RAJASTHAN	18767	16628	17449	13315	9.73	9.52	9.61	9.05	8.91	8.84	8.87	8.20	1,127
TAMIL NADU	26879	19909	27864	21518	10.10	9.84	10.07	9.84	9.37	9.11	8.93	8.65	247
UTTAR PRADESH	20998	24159	23139	20646	9.88	9.91	9.84	9.65	8.79	9.18	8.07	8.41	1,856
WEST BENGAL	27852	22342	25705	13102	10.14	9.57	9.95	9.26	6.07	7.94	8.59	8.59	458
Total	24960	21143	22376	15415	9.98	9.70	9.75	9.19	9.04	8.82	8.66	8.17	9,986

* Net revenue is the difference between the gross revenue and the total cost of production (excluding family labor).

Table 3: Average Gross and Net Revenue (Rps/Acre/Season), by Irrigation Status

	All Crops								Cereal, Beans, and Oil Crop							
	Gross Revenue				Net Revenue				Gross Revenue				Net Revenue			
	Both Irrig.	Public Irrig.	Private Irrig.	Rainfed	Both Irrig.	Public Irrig.	Private Irrig.	Rainfed	Both Irrig.	Public Irrig.	Private Irrig.	Rainfed	Both Irrig.	Public Irrig.	Private Irrig.	Rainfed
ANDHRA PRADESH	8958	9808	9454	6842	5603	4346	4616	2214	8958	9589	9004	6629	5603	3759	4085	2088
BIHAR	11933	12223	10936	10408	7831	8012	7227	7073	11923	12225	10610	10451	7213	8808	7052	7170
CHHATTISGARH	10293	13951	15059	12088	7431	9717	11385	8113	9827	13802	15040	12088	6915	9452	11371	8113
GUJARAT	15443	13161	13298	12783	12294	7254	8555	8617	15277	13287	13238	13133	12178	7358	8479	8965
HARYANA	12810	11697	14356	13858	7677	7739	9786	9702	14059	13458	16194	15200	8356	9076	11379	10765
HIMACHAL PRADESH		6176		13199		4935		11517		6176		11151		4935		9649
JHARKHAND	12100	8751	11631	8243	8707	6709	9417	5790	12100	8540	11631	8243	8707	6511	9417	5790
KARNATAKA	13253	15302	13696	12238	11552	11643	10073	9560	9377	9926	8263	9537	7746	6933	5028	6988
KERALA		18712	12286	14386		11131	5464	8629		18712	12286	14559		11131	5464	8835
MADHYA PRADESH	9653	9333	9512	7085	6656	6094	6372	4456	6750	9338	8311	7112	4056	6095	5175	4476
MAHARASHTRA	9565	14163	15575	9862	4746	7344	10537	5827	10118	13397	11198	9690	5362	6385	6700	5701
ORISSA	10210	10326	7500	8148	5862	6423	4329	5228	10210	10103		7756	5862	6362		4780
PUNJAB	15769	15363	16705	14725	11566	10640	10854	9255	18447	17827	18045	17995	13594	12458	11009	10118
RAJASTHAN	10073	8743	9629	9083	3143	4434	6254	6203	9593	8880	8649	8514	2540	4324	5374	5638
TAMIL NADU	11122	10100	13672	14516	6727	6086	8495	6568	9736	9144	12915	14516	5436	5079	7536	6568
UTTAR PRADESH	11538	13342	14279	12298	6337	9211	6601	6943	10806	12315	11094	10352	6648	8853	7184	6655
WEST BENGAL	12605	12782	14816	12191	3274	5678	5907	8046	9027	10147	9960	11529	1715	4322	3168	7898
Total	12543	12592	13036	10849	7643	8147	7878	7317	12150	12154	11563	9839	7528	7881	7229	6654

Table 4: Average Number of Cropping Seasons per Year, by Irrigation Status and State

State	Entire sample	Public & Private Irrigation	Public Irrigation	Private irrigation	Rainfed
ANDHRA PRADESH	1.52	2.00	1.77	1.73	1.24
BIHAR	1.98	2.67	1.94	2.19	1.91
CHHATTISGARH	1.29	1.67	1.19	1.85	1.41
GUJARAT	1.62	1.92	1.89	1.72	1.21
HARYANA	2.02	2.14	2.05	2.01	1.96
HIMACHAL PRADESH	1.93	n.a.	1.50	n.a.	1.94
JHARKHAND	1.31	2.00	1.60	1.64	1.22
KARNATAKA	1.43	1.81	1.65	1.73	1.38
KERALA	1.64	n.a.	1.83	1.86	1.52
MADHYA PRADESH	1.57	1.75	1.63	1.80	1.47
MAHARASHTRA	1.49	2.00	2.03	1.80	1.17
ORISSA	1.58	1.67	1.89	1.00	1.39
PUNJAB	2.04	1.96	2.04	2.11	1.98
RAJASTHAN	1.64	1.81	1.87	1.86	1.48
TAMIL NADU	2.07	2.40	1.98	2.07	1.40
UTTAR PRADESH	1.78	1.90	1.89	1.72	1.71
WEST BENGAL	1.55	2.37	1.82	1.83	1.11
Total	1.65	2.02	1.75	1.82	1.50

Table 5: Annual Costs of Crop Production Inputs (Rps/Acre) by Irrigation Status and State

	Total cost of Production (Rps./Acre)				Log of Cost of Production			
	Public & Private Irrigated Plots	Public Irrigated Plots	Private Irrigated Plots	Rainfed Plots	Public & Private Irrigated Plots	Public Irrigated Plots	Private Irrigated Plots	Rainfed Plots
ANDHRA PRADESH	6709	9120	8285	5612	8.79	8.80	8.81	8.29
BIHAR	12238	6394	7896	6176	9.41	8.62	8.91	8.63
CHHATTISGARH	4771	5137	6716	5576	8.37	8.43	8.71	8.48
GUJARAT	6020	10125	8116	4826	8.66	8.90	8.88	8.29
HARYANA	10407	7885	9117	7909	9.20	8.86	9.05	8.79
HIMACHAL PRADESH		1838		3169		7.46		7.96
JHARKHAND	6785	3269	3761	3011	8.82	7.98	8.17	7.85
KARNATAKA	3695	5893	6506	3771	7.88	8.44	8.45	7.92
KERALA		13899	12668	8761		9.49	9.37	9.02
MADHYA PRADESH	4541	5248	5202	3641	8.29	8.37	8.23	7.84
MAHARASHTRA	9087	13410	7649	4638	9.04	9.33	8.75	8.23
ORISSA	7499	7117	3171	4029	8.88	8.72	8.06	8.17
PUNJAB	9492	10039	12778	10981	9.04	9.12	9.36	9.13
RAJASTHAN	14243	7012	6201	4250	8.69	8.41	8.57	8.06
TAMIL NADU	10413	8013	11702	10093	9.10	8.90	9.15	8.78
UTTAR PRADESH	9269	7579	12945	8889	8.96	8.73	9.06	8.66
WEST BENGAL	21610	12851	15297	4517	9.81	9.12	9.42	8.16
Total	9831	7605	9217	5186	8.94	8.70	8.85	8.21

Note: Family labor use is not included in the total cost.

Table 6: Annual Cost of Different Inputs by Irrigation Status and State

(Rps./Acre/Year for fertilizer & fungicide, seeds & seedling, and other production costs; Days/Acre/Year for family and hired labors)

	Both Public & Private Irrigation					Public Irrigation					Private Irrigation					Rainfed				
	Fertilizer & fungicide	Seeds & seedling	Other production cost	Total family labor	Total hired labor	Fertilizer & fungicide	Seeds & seedling	Other production cost	Total family labor	Total hired labor	Fertilizer & fungicide	Seeds & seedling	Other production cost	Total family labor	Total hired labor	Fertilizer & fungicide	Seeds & seedling	Other production cost	Total family labor	Total hired labor
AP	1908	157	1011	58	70	1928	104	1290	93	98	1761	251	1618	98	84	1193	126	1241	60	58
BIHAR	1643	3537	7571	128	68	1177	1955	3247	51	106	1476	1819	4140	72	77	1181	894	3259	54	19
CHHATTISGAR	862	519	2388	75	1	1096	705	2544	76	24	1986	614	2554	31	35	1490	816	2153	55	20
GUJARAT	2229	1030	1260	69	11	3262	2653	3358	23	13	3269	2130	1853	24	18	2516	755	899	14	12
HARYANA	3443	1303	4526	27	19	2151	918	3573	40	13	2378	825	4241	36	18	1937	723	3735	67	11
HP						42	336	756	137	0						215	2247	1196	118	26
JHARKHAND	2138	314	3840	11	20	1090	212	1240	56	3	1006	135	1855	36	26	1011	346	967	40	14
KARNATAKA	722	836	819	135	32	1537	443	1397	212	71	1555	698	2231	131	71	929	677	1338	78	34
KERALA						1429	9145	2206	70	70	1668	411	3368	42	50	1562	403	2274	57	40
MP	1120	828	1741	39	18	1699	1124	1794	35	17	1510	1218	1854	29	8	847	769	1605	20	7
MAHARASHTRA	1238	975	4296	86	34	2026	1791	5443	172	85	1106	1058	3087	120	55	769	677	1719	108	36
ORISSA	1835	1919	1901	72	40	1417	1053	2402	77	68	425	100	1427	78	23	797	885	1096	53	43
PUNJAB	4533	702	2901	18	18	4190	979	3421	28	18	4177	1393	5451	27	23	2984	1256	5070	45	13
RAJASTHAN	1455	1049	10811	22	13	1129	749	4246	30	12	1254	657	3144	28	16	780	461	2120	32	11
TAMIL NADU	2721	789	3236	158	87	1933	496	2535	117	69	3447	1675	3902	151	91	2291	765	2892	155	75
UP	1773	2597	3609	41	40	1694	2302	2648	68	40	1674	6729	3378	53	24	1353	3672	3370	65	20
WEST BENGAL	4153	3628	10766	231	61	3085	4182	4479	98	58	3737	3343	4986	52	67	1075	477	1623	58	31
Total	2519	1531	4127	66	36	1792	1427	2917	75	39	2095	2374	3071	54	33	1052	1201	2031	61	23

Table 7: Fixed-effect Estimation of Impact of Irrigation on Crop Productivity

Dependent variable: Logarithm of gross/net revenue (Rupees per acre per year)

	All households				Households with plots of different irrigation status			
	Gross revenue	Gross revenue	Net revenue	Net revenue	Gross revenue	Gross revenue	Net revenue	Net revenue
both public & private irrigation dummy	0.510	0.459	0.526	0.438	0.510	0.456	0.529	0.443
	(7.41)***	(6.58)***	(6.68)***	(5.51)***	(7.00)***	(6.14)***	(6.54)***	(5.39)***
private irrigation dummy	0.397	0.368	0.392	0.343	0.390	0.353	0.376	0.330
	(13.80)***	(12.48)***	(11.89)***	(10.20)***	(12.67)***	(10.99)***	(11.01)***	(9.28)***
public irrigation dummy	0.389	0.337	0.431	0.351	0.393	0.342	0.441	0.360
	(7.87)***	(6.65)***	(7.61)***	(6.06)***	(7.60)***	(6.35)***	(7.68)***	(6.05)***
log of area (acre)	-0.083	-0.084	-0.066	-0.061	-0.070	-0.068	-0.044	-0.044
	(7.76)***	(7.66)***	(5.41)***	(4.92)***	(4.10)***	(3.84)***	(2.30)**	(2.25)**
log of distance from fragment to home		-0.006		-0.033		-0.026		-0.026
(meter)		(0.48)		(2.20)**		(1.28)		(1.19)
log of land price per acre (Rps)		0.150		0.174		0.172		0.212
		(3.71)***		(3.78)***		(3.29)***		(3.67)***
Land quality and Soil type dummies	No	Yes	No	Yes	No	Yes	No	Yes
Observations	9214	9214	9214	9214	3135	3135	3135	3135
Number of Interview Number	4386	4386	4386	4386	998	998	998	998
R-squared	0.05	0.06	0.83	0.84	0.08	0.10	0.84	0.84

Robust t statistics in parentheses.

* statistically significant at 10% level; ** statistically significant at 5% level; *** statistically significant at 1% level.

Joint test for the coefficients for all the soil and land quality variables being zero rejected at 5% significance level.

Table 8: Fixed-Effect Estimation of Impact of irrigation on Rice and Wheat Yields
Dependent variable: Logarithm of yield (Kg per acre per season)

	Rice		Wheat	
both public & private irrigation dummy	0.153	0.154	0.099	0.098
	(2.96)***	(2.94)***	(1.41)	(1.37)
private irrigation dummy	0.087	0.088	0.037	0.042
	(3.07)***	(3.02)***	(1.30)	(1.43)
public irrigation dummy	0.011	0.001	-0.010	-0.018
	(0.31)	(0.04)	(0.17)	(0.30)
log of area (acre)	-0.168	-0.168	-0.177	-0.182
	(20.31)***	(20.04)***	(16.54)***	(16.40)***
Land quality and Soil type dummies	No	Yes	No	Yes
Observations	4840	4840	3600	3600
R-squared	0.14	0.15	0.14	0.15
Number of households	2282	2282	1941	1941

Absolute value of t statistics in parentheses.
* statistically significant at 10% level; ** statistically significant at 5% level; *** statistically significant at 1% level.
Joint test for the coefficients for all the soil and land quality variables being zero rejected at 5% significance level.

Table 9: FE Estimation of land use intensity (number of crop seasons per year per plot) and land price (rupees/acre)

	No. of crop seasons		Land Price	
both public & private irrigation dummy	0.371	0.331	0.216	0.209
	(9.28)***	(8.18)***	(16.39)***	(15.82)***
private irrigation dummy	0.250	0.225	0.197	0.189
	(14.96)***	(13.16)***	(19.11)***	(18.23)***
public irrigation dummy	0.337	0.300	0.100	0.097
	(11.70)***	(10.20)***	(18.24)***	(17.46)***
log of area (acre)	0.019	0.020	0.004	0.004
	(3.05)***	(3.18)***	(1.77)*	(1.74)*
squared of log of area(acre)			-0.001	-0.001
			(1.34)	(0.94)
Land quality and Soil type dummies	No	Yes	No	Yes
Observations	9214	9214	18385	18385
Number of households	4386	4386	4838	4838
R-squared	0.07	0.08	0.04	0.06

Robust t statistics in parentheses.

* statistically significant at 10% level; ** statistically significant at 5% level; *** statistically significant at 1% level.

The number of observations for the land price analysis is much larger than other for other regressions. In the land price analysis, subdivision (instead of plot) is the unit of analysis. Subdivisions of the same soil type located next to each other under the same cultivation system (planted with thesame crop) are treated as one plot during the data collection.

Table 10: Fixed Effect Estimation of Impact of Irrigation Facilities on Input Use Intensity

Dependent variable: Logarithm of value of input use per acre per year or per acre per season

	Annual (Rupees or Number of days per acre per year)						**Seasonal (Rupees or number of days per acre per crop season)**					
	Fertilizer & pesticide	Seed & Seedlings	All labor use	Family labor use	Hired labor use	Other inputs	Fertilizer & pesticide	Seed & Seedlings	All labor use	Family labor use	Hired labor use	Other inputs
both public & private irrigation dummy	0.924	0.581	0.583	0.579	0.583	0.561	0.276	-0.146	0.165	0.205	0.173	0.100
	(8.52)***	(4.04)***	(9.90)***	(9.63)***	(7.81)***	(9.43)***	(2.94)***	(1.03)	(4.05)***	(4.66)***	(2.96)***	(2.07)**
private irrigation dummy	0.491	0.647	0.361	0.347	0.316	0.368	0.148	-0.041	0.103	0.157	0.091	0.107
	(10.68)***	(10.64)***	(14.48)***	(13.66)***	(9.97)***	(14.60)***	(3.58)***	(0.66)	(5.73)***	(8.13)***	(3.56)***	(5.09)***
public irrigation dummy	0.667	0.244	0.406	0.428	0.262	0.436	0.248	-0.156	0.091	0.085	-0.021	0.031
	(8.43)***	(2.33)**	(9.47)***	(9.77)***	(4.81)***	(10.07)***	(3.49)***	(1.46)	(2.96)***	(2.55)**	(0.47)	(0.86)
log of area (acre)	0.031	-0.082	-0.460	-0.585	-0.133	-0.115	-0.116	-0.087	-0.321	-0.631	-0.144	-0.221
	(1.82)*	(3.62)***	(49.91)***	(62.09)***	(11.15)***	(12.31)***	(7.62)***	(3.80)***	(48.74)***	(88.69)***	(15.29)***	(28.39)***
Land quality & soil type dummies	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Observations	9214	9214	9214	9214	9214	9214	16316	16316	16316	16316	16316	16316
Number of Interview Number	4386	4386	4386	4386	4386	4386	4386	4386	4386	4386	4386	4386
R-squared	0.31	0.17	0.37	0.47	0.24	0.08	0.43	0.47	0.41	0.54	0.33	0.27

* statistically significant at 10% level; ** statistically significant at 5% level; *** statistically significant at 1% level.
Robust t statistics in parentheses.

Table 11: Fixed-effect estimation on impact of public irrigation quality on productivity, land use intensity and land price

	Log of annual gross revenue		Log of annual net revenue		Number of crop seasons		Long of land price	
Dummy for plot always has access to public irrigation	0.558	0.462	0.672	0.658	0.306	0.318	0.144	0.07
	(3.24)***	(2.56)**	(2.84)***	(2.68)***	(3.21)***	(3.20)***	(5.94)***	(2.61)***
Log of area (acre)	-0.032	-0.032	0.129	0.123	0.015	0.016	0.015	0.014
	(2.22)**	(2.17)**	(6.49)***	(6.07)***	(1.38)	(1.37)	(3.86)***	(3.57)***
Square of log of area (acre)	0.046	0.046	0.066	0.065	-0.006	-0.006	0.002	0.002
	(8.86)***	(8.84)***	(9.36)***	(9.19)***	(1.32)	(1.38)	(1.82)*	(1.58)
Land quality and soil dummies included	No	Yes	No	Yes	No	Yes	No	Yes
Observations	2180	2180	2198	2198	2670	2670	5621	5621
R-squared	910	910	915	915	1239	1239	1385	1385
Number of Interview Number	0.14	0.14	0.86	0.86	0.01	0.03	0.01	0.02

Absolute value of t statistics in parentheses.

* statistically significant at 10% level; ** statistically significant at 5% level; *** statistically significant at 1% level.

Table 12: Fixed-effect estimation on impact of public irrigation quality on input use intensity

	Fertilizer & pesticide	Seed & Seedlings	All labor use	Family labor use	Hired labor use	Other inputs	Fertilizer & pesticide	Seed & Seedlings	All labor use	Family labor use	Hired labor use	Other inputs
Dummy for plot always has access	0.036	-0.028	0.267	0.188	-0.182	-0.038	0.022	-0.062	0.233	0.128	-0.174	-0.053
to public irrigation	(0.22)	(0.25)	(1.89)*	(1.15)	(0.87)	(0.24)	(0.13)	(0.53)	(1.58)	(0.75)	(0.80)	(0.32)
Log of area (acre)	-0.09	-0.058	-0.289	-0.532	-0.16	-0.223	-0.092	-0.062	-0.284	-0.538	-0.157	-0.221
	(6.53)***	(6.22)***	(24.29)***	(38.76)***	(9.06)***	(16.84)***	(6.49)***	(6.47)***	(23.37)***	(38.44)***	(8.75)***	(16.28)***
Squared log of area (acre)	0.023	0.008	0.003	0.056	0.041	-0.02	0.024	0.007	0.004	0.055	0.043	-0.02
	(4.75)***	(2.47)**	(0.73)	(11.48)***	(6.65)***	(4.35)***	(4.77)***	(2.19)**	(0.90)	(11.26)***	(6.86)***	(4.16)***
Land quality and soil type dummies	No	No	No	No	No	No	Yes	Yes	Yes	Yes	Yes	Yes
Observations	2198	2198	2198	2198	2198	2198	2198	2198	2198	2198	2198	2198
No. of interviewers	915	915	915	915	915	915	915	915	915	915	915	915
R-squared	0.25	0.85	0.48	0.75	0.46	0.23	0.26	0.85	0.48	0.75	0.47	0.23

Absolute value of t statistics in parentheses.
* statistically significant at 10% level; ** statistically significant at 5% level; *** statistically significant at 1% level.

Table 13: FE Estimation of Impact of Irrigation on Cropping Seasons and Land Price across States

	Number of Cropping Seasons per annum		Land Price per acre (in logarithm)	
(1)	(2)	(3)	(4)	(5)
Both public & private irrigation dummy	0.339	0.33	0.189	0.177
	(7.52)***	(7.26)***	(12.64)***	(11.79)***
Public irrigation*Karnataka	0.12	0.103	0.325	0.31
	(1.45)	(1.23)	(10.24)***	(9.79)***
Public irrigation*Maharashtra	0.858	0.85	0.378	0.355
	(8.42)***	(8.31)***	(8.23)***	(7.76)***
Public irrigation*Madhya Pradesh	0.406	0.417	0.274	0.269
	(5.31)***	(5.43)***	(9.95)***	(9.76)***
Public irrigation*Rajasthan	0.354	0.358	0.139	0.143
	(4.28)***	(4.34)***	(4.26)***	(4.39)***
Public irrigation*Haryana	0.362	0.338	0.199	0.174
	(5.65)***	(5.18)***	(11.27)***	(9.77)***
Public irrigation*Punjab	0.261	0.256	0.103	0.095
	(3.07)***	(3.00)***	(4.26)***	(3.91)***
Public irrigation*Uttar Pradesh	0.203	0.197	0.091	0.088
	(3.23)***	(3.13)***	(3.92)***	(3.80)***
Public irrigation*Bihar	0.067	0.066	0.106	0.103
	(0.35)	(0.34)	(1.20)	(1.18)
Public irrigation*West Bengal	0.261	0.257	0.197	0.188
	(2.40)**	(2.36)**	(5.40)***	(5.20)***
Public irrigation*Jharkhand	0.538	0.538	0.227	0.22
	(3.25)***	(3.24)***	(2.95)***	(2.87)***
Public irrigation*Chattisgarh	0.055	0.043	0.155	0.156
	(0.50)	(0.39)	(3.55)***	(3.59)***
Public irrigation*Orissa	0.439	0.434	0.229	0.245
	(5.67)***	(5.59)***	(8.70)***	(9.31)***
Public irrigation*Andhra Pradesh	0.505	0.504	0.299	0.301
	(3.48)***	(3.48)***	(5.43)***	(5.50)***
Public irrigation*Tamil Nadu	0.342	0.343	0.07	0.078
	(2.41)**	(2.41)**	(1.44)	(1.62)
Private irrigation*Karnataka	0.352	0.339	0.393	0.384
	(4.58)***	(4.41)***	(12.42)***	(12.20)***
Private irrigation*Maharashtra	0.74	0.732	0.255	0.218
	(11.29)***	(11.03)***	(9.26)***	(7.88)***
Private irrigation*Guharat	0.74	0.724	0.744	0.808
	(7.20)***	(6.75)***	(16.23)***	(17.32)***
Private irrigation*Madhya Pradesh	0.342	0.333	0.171	0.168
	(7.74)***	(7.51)***	(11.27)***	(11.10)***
Private irrigation*Rajasthan	0.201	0.197	0.038	0.036
	(5.82)***	(5.71)***	(3.51)***	(3.36)***
Private irrigation*Haryana	-0.024	-0.035	0.042	0.038
	(0.49)	(0.73)	(3.56)***	(3.28)***
Private irrigation*Punjab	0.107	0.105	0.063	0.059
	(1.42)	(1.39)	(3.32)***	(3.12)***
Private irrigation*Uttar Pradesh	0.086	0.083	0.007	0.005
	(2.33)**	(2.25)**	(0.48)	(0.31)
Private irrigation*Bihar	-0.136	-0.136	0.076	0.086
	(1.21)	(1.21)	(2.67)***	(3.00)***
Private irrigation*West Bengal	0.453	0.445	0.173	0.163
	(4.60)***	(4.52)***	(5.32)***	(5.05)***
Private irrigation*Jharkhand	0.307	0.3	-0.003	-0.025
	(1.85)*	(1.81)*	(0.04)	(0.33)
Private irrigation*Chattisgarh	0.191	0.194	0.108	0.099
	(2.16)**	(2.18)**	(3.90)***	(3.57)***
Private irrigation*Orissa			0.791	0.796
	n.a.	n.a.	(4.47)***	(4.52)***
Private irrigation*Andhra Pradesh	0.566	0.563	0.257	0.258
	(8.60)***	(8.51)***	(9.62)***	(9.71)***
Private irrigation*Tamil Nadu	0.45	0.441	0.119	0.117
	(2.68)***	(2.63)***	(2.18)**	(2.16)**
Other control variables included	Yes	Yes	Yes	Yes
Soil type and soil quality	No	Yes	No	Yes
Observations	9214	9214	18385	18385
Number of Interview Number	4386	4386	4838	4838
R-squared	0.11	0.12	0.08	0.1

Absolute value of t statistics in parentheses.

* statistically significant at 10% level; ** statistically significant at 5% level; *** statistically significant at 1% level.

Kerala and HP are excluded from the regression due to two few observation for the former and no variation in irrigation type (99.5% of plots are rainfed) for the latter. Orissa has too few observations for plots with private irrigation, and therefore the coefficient for the private irrigation variable cannot be estimated.

The number of observations for the land price analysis and cropping intensity analysis is different. For the land price analysis, subdivision rather than plot is the unit of analysis. Subdivisions with thesame soil type and located next to each other under the same cultivation system (i.e. planted with thesame crop) are treated as one plot during the data collection.

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