# State-led or Market-led Green Revolution? Role of Private Irrigation Investment vis-a-vis Local Government Programs in West Bengal's Farm Productivity Growth[1]

Pranab Bardhan[2], Dilip Mookherjee[3] and Neha Kumar [4]

This version: March 1, 2011

**Abstract**

We estimate the role of private investments in irrigation in farm productivity growth in West Bengal, India between 1982-95. Using a state-wide farm panel, we find falling irrigation costs generated significant growth in value added per acre for farms. However, changes in irrigation capacity and costs were stimulated by tenancy registration programs implemented by local governments. This helps account for substantial spillover effects of the tenancy reform on non-tenant farms noted in an earlier study. Hence the West Bengal Green Revolution of the 1980s benefited from complementarity between private investment incentives and state-led institutional reforms.

Keywords: land reforms, tenancy, irrigation, agricultural development, public-private linkages; JEL Classification Numbers O12, O13, H44, H54

---

[1]For research support we are grateful to the MacArthur Foundation Inequality Network and the National Science Foundation (Grant No. SES-0418434). The paper has benefitted considerably from comments received from the Editor and two referees. We are grateful to Vikas Rawal for sharing district-level data on irrigation in West Bengal, and Bhaswar Moitra for many useful discussions. This paper is based on Chapter 3 of Neha Kumar's PhD dissertation submitted to Boston University, 2008.

[2]Department of Economics, University of California, Berkeley, CA 94720; bardhan@econ.berkeley.edu

[3]Corresponding Author; Department of Economics, Boston University, 270 Bay State Road, Boston MA 02215; dilipm@bu.edu, 617-3534392, 617-3534143 (f)

[4]International Food Policy Research Institute, 2033 K Street, NW Washington, DC 20006; n.kumar@cgiar.org

## 1 Introduction

A key issue in agricultural development in LDCs concerns the respective roles of public and private sectors. Does productivity growth and poverty reduction rely principally on public sector initiatives such as land reform and farm extension services? Or does private investment play the leading role? What is the nature of complementarity or substitutability between public policy and private investment? Answering this requires a proper understanding of the respective roles of these different factors in promoting rural development. This paper focuses on the experience of West Bengal, a state in eastern India, which witnessed a remarkable burst of productivity growth based on diffusion of high yielding varieties (HYV) of rice and increased cropping intensities during the 1980s and 90s. Rice yields increased two and half times between 1982 and 1995; acreage devoted to HYV rice rose from less than 10% or total rice acreage in 1982 to 66% in 1995. Wage rates for agricultural workers rose by 66% in real terms, and employment more than doubled.[5]

During this time, the West Bengal government vigorously implemented land reforms, combining tenancy registration and granting land titles to the poor. It also created a system of elected local governments, who were devolved responsibility for implementing farm extension and support services. Many attribute most of the credit for the West Bengal green revolution to these institutional reforms (e.g., see Banerjee, Gertler and Ghatak (2002), Lieten (1992) or Sengupta and Gazdar (1996)). Others (such as Harriss (1993) or Moitra and Das (2005)) have pointed out that this period also witnessed a significant increase in private groundwater investments, so the role of the land reforms and decentralization of farm extension services may have been exaggerated. However there are no estimates available concerning the role of irrigation investments in generating farm productivity growth in West Bengal, nor any analysis of determinants of such investments. In the absence of such estimates it is difficult to distinguish between the roles of the government reforms *vis-a-vis* private investments in irrigation.

[5]These numbers pertain to the sample of West Bengal villages drawn from 15 principal agricultural districts on which this paper is based. See Section 3 below for further details of the sample and data. For data pertaining to agricultural performance in major districts as a whole, see Banerjee, Gertler and Ghatak (2002) or Saha and Swaminathan (1994).

This paper uses a panel dataset of over 700 West Bengal farms drawn randomly from fifteen major agricultural districts of the state, covering the period 1982-95. This is complemented with an independent household survey of the evolution of irrigation status of agricultural land in these villages. Our purpose is to disentangle the respective roles of land reform, government supply of subsidized farm inputs and private irrigation investments in explaining farm productivity growth. This dataset has been used in previous studies by Bardhan and Mookherjee, BM hereafter (2010, 2011). It follows on BM (2011) in particular, a paper which estimated reduced form regressions for farm productivity on cumulative measures of tenancy registration, land titling and various farm support programs in the village, after controlling for farm fixed effects, common year effects, local rainfall, rice price and infrastructural support provided by local and state governments. BM found a statistically significant effect of the tenancy registration program, and a much larger effect of public distribution of agricultural minikits (containing subsidized seeds and fertilizers) on farm productivity. Somewhat surprisingly, the effects of the tenancy registration program were not confined to tenant farms alone: they exhibited substantial spillovers to non-tenant farms. While the nature of these spillover effects remained unexplained, their existence and significance implied that the effects of tenancy reforms could not be entirely understood in terms of the partial equilibrium effects of improving tenant's effort and investment incentives (owing to enhanced crop-shares and tenurial security). In this paper we will explore the role of private irrigation investments in accounting for a signifiant portion of these spillovers. This provides a novel dimension to the productivity benefits of tenancy reforms operating through induced general equilibrium impacts.

Section 2 sketches a theoretical model of such spillovers. Our hypothesis is that the tenancy registration program increased the demand for groundwater among tenant farms, as a consequence of reduced sharecropping distortions. In turn this induced sellers of groundwater to invest more in groundwater capacity which involve large fixed costs (tubewells, dugwells and submersible pumps), resulting in a fall in price of groundwater. Another possible channel with the same impact is that registered tenants became eligible for loans from formal credit institutions to invest in groundwater capacity themselves.[6] Consequently there

[6]There is a substantial literature in the context of other LDCs focusing on this channel of impact of land

was a significant fall in cost of groundwater for *all* farms in the village, including non-tenant farms. The model generates testable restrictions concerning (a) dependence of farm yields on expenditures on irrigation and other key inputs, and (b) how irrigation expenditures in turn depended on past land reforms, extension services and other programs administered by local governments.

Section 3 describes the nature of the data, relevant descriptive statistics and the institutional setting of West Bengal agriculture during this period. Section 4 presents the main empirical results.

One major problem with the cost of cultivation data we use is that while comprehensive information is available concerning all items of farm expenditure, the breakdown of these between factor prices and quantity is frequently missing. This prevents us from directly studying the evolution of prices paid (or imputed) by farmers for water. We study instead the corresponding expenditures on various inputs, which include both the cost of purchased inputs as well as the imputed value of self-supplied inputs. Changes in prices can be inferred from corresponding changes in expenditures, given assumptions concerning the elasticity or inelasticity of factor demands. Whether the demand for any factor is elastic or not can be inferred from observing how farm profits respond to changes in expenditures on that factor. For example, if farmers have inelastic demand for water, falling water expenditures will correspond to decreases in water prices, which in turn will raise farm profits. Hence regression (a) involves regressing farm profits on expenditures on various factors and examining the role of decreasing water expenditures in particular, controlling for expenditures on other inputs and the price of outputs. And regression (b) involves studying how water expenditures responded to various local government agricultural development programs. The combination of these two regressions then permits an assessment of the role of these programs in stimulating growth in farm profits, via their effect on irrigation investments in the village which lowered the price of water used by farmers.

reforms. For instance, Feder *et. al.* (1988) study the economic benefits of land registration in rural Thailand and find that farmers with legal land titles had greater access to institutional credit than those without it. They also find that titled farmers invested more in land and had higher output levels. Similar findings are reported for Honduras (Lopez (1998)) and Paraguay (Carter and Olinto (1996)).

The other major problem confronting the empirical analysis is potential endogeneity of irrigation expenditures in regression (a), and of local government programs in regression (b). To address this we use as instruments various higher-level (i.e., district, state or national) political and economic determinants of local government program implementation rates, interacted with lagged incumbency patterns in local government. This is based on earlier work of BM (2006, 2010) on the political economy of institutional reforms in West Bengal. Those papers argued that program implementation rates could be explained by political competition between the two principal political parties at the local level, in conjunction with political and economic factors at the national, state or regional level. Specifically, the presence of these parties in the national legislature, and economic performance of the locally incumbent party in the region in concern affect local competition in local government elections. These factors affected allocation of effort and resources of the state government devoted to these various programs across different local jurisdictions. The overall scale of various farm subsidy and village infrastructure programs at the level of the state government also varied from year to year according to macroeconomic conditions. Hence political and economic determinants at the national, state and regional level of the competitive strength of two rival political parties at the local level help predict temporal fluctuations in program implementation rates.

The associated exclusion restriction (in the case of regression (b)) is that these determinants of program implementation at the local village level had no direct impact on farm productivity or input expenditures, *after controlling for their effect on the various programs administered by local governments*. In regression (a), the identification assumption is that all effects of these programs on farm profits were incorporated through their effect on expenditures on various inputs. The plausibility of these assumptions derives from the comprehensiveness of local government programs included in the set of controls.[7] Our data set

[7]The exclusion restriction for the lagged incumbency rate is based on the assumption that village fixed effects absorb all the intertemporal correlations in the seat share of different parties in the local government council. In turn this is based on a Arellano-Bond specification for the dynamics of seat shares across successive elections to local government. In BM (2010) a test of this specification was not rejected. Note also that 'lagged' pertains to seat shares in the elected local government council in the previous administration, not the previous year.

includes surveys of local governments which includes all the major programs with a bearing on farm production: delivery of minikits, subsidized credit (in the form of IRDP (Integrated Rural Development Program) loans), spending on local roads, medium irrigation and other infrastructure, and generation of employment for the poor in public works programs (under the National Rural Labour Employment Generation Program (NRLEGP) and the Jawahar Rozgar Yojana (JRY)).

Our empirical findings turn out to be consistent with the theoretical hypothesis described above. Specifically:

1. Concerning results of regression (a), farm productivity (measured by value added per acre (VAA)) responded significantly to per acre expenditures on irrigation, seeds, fertilizers and hired labor. The demand for groundwater was price-inelastic: the IV estimate of the elasticity of VAA with respect to irrigation expenditure per acre is -0.24 (significant at 5%). Demand for other factors (chemical fertilizers, seeds, hired labor) were elastic, as one would expect owing to existence of substitutes for these factors.[8]

2. Concerning regression (b), per acre farm irrigation expenditures fell significantly in response to increases in tenancy registration in the village: both OLS and IV estimates are significant at the 1% level. This effect was particularly pronounced among large farms. These decreases occurred only with respect to expenditures on purchased water rather than self-supplied water, indicating that investments in own-irrigation capacity induced by enhanced access to credit was not a significant channel of impact. No other local government program had a significant effect on irrigation expenditures. The tenancy registration program also resulted in a statistically significant reduction in per acre expenditures on seeds, indicating an upward impact on seed prices.[9]

3. Next, we construct a measure of farm productivity net-of- irrigation (NOI) by subtracting irrigation expenditure weighted by its estimated IV elasticity from farm value added in regression (a). We then regress this NOI-productivity measure on the implementation

[8]All regressions controls for farm and year dummies, rainfall, the price of rice and state and local-government-provided irrigation. Robust standard errors were clustered at the village level.

[9]Farm profits respond positively to seed expenditures in regression (a), indicating that seed demand is price-elastic.

rates of the various programs at the village level. We find that the tenancy registration program no longer has a significant effect on NOI-productivity. But if irrigation is not netted out, the tenancy reform program has a significant effect on farm value added, as seen in BM (2011). Accordingly we infer that the effect on irrigation expenditures accounts for most of the impact of tenancy registration on farm productivity. In other words, the spillover effects to non-tenant farms are almost entirely accounted for by the effect of the tenancy registration program on irrigation costs. This implies that other possible channels such as effects on other factor prices or social learning were not significant sources of these spillovers .

4. We seek independent corroboration of the role of land reforms and extension services in stimulating the growth of minor irrigation, using an independent household survey of irrigation status of landholdings in these villages. This survey asked questions concerning the evolution of landholdings over the period 1967-2004 for a stratified random sample of households in these villages. The respondents provided details of the irrigation status of agricultural plots owned for each year between 1967 and 2004, indicating whether or not it was irrigated, and the source of irrigation. In line with other findings in the literature, the main source of growth in irrigation was private investment in shallow tubewells, followed by ponds and river-lift schemes implemented by local governments. In a regression run at the village level with village fixed effects, year dummies, price of rice and rainfall, we find that past tenancy registration in the village and minikits delivered were associated with significant increases in the proportion of cultivable land in the village that were irrigated by tubewells, river-lift schemes and ponds.

These results indicate that both institutional reforms, public and private investments in irrigation played a role in the growth of farm productivity in West Bengal. However, the growth in private investments were endogenously affected by the tenancy reforms. So the tenancy reforms had both a direct effect on tenant farms by enhancing their incentives, as well as a significant indirect spillover effect on all farms by stimulating private investment. The latter spillover effect accounted for most of the productivity effect of the tenancy reform at the village level. Tenancy reforms, public and private investment each played a role and complemented one another.

Our findings provide a perspective intermediate between pure state-led and market-led interpretations of the growth in farm productivity that occurred in West Bengal in the 1980s and 1990s. We confirm the importance of private irrigation, but emphasize its endogeneity, specifically the role of the state in stimulating it via institutional reforms. That the state may provide an indirect role by influencing incentives for private investment in irrigation has been argued by Rao (1995) in his critique of Harriss (1993) in the context of West Bengal's farm productivity growth of the 1980s. This paper thus provides concrete empirical evidence for this view.

The state also played other important roles: the delivery of farm extension services (subsidized minikits, credit and public employment programs), and investment in minor irrigation (river-lift schemes and ponds). Indeed the results in BM (2011) show that their quantitative significance far exceeded that of the tenancy reforms. We find here that these had a significant role even after accounting for private irrigation expenditures (i.e., as measured by their impact on NOI-productivity). Hence the West Bengal Green Revolution should not be thought of as the result of the tenancy registration program or private irrigation investments alone.

# 2 Theory

## 2.1 Farm Production Decisions

Consider a farm of a given size (acreage), which is cultivated either by a tenant or the owner. We abstract from possible effects of various public programs on land leasing or purchase decisions. The productivity of the farm is described by a production function

$$Y = A(e)G(x, z) \tag{1}$$

where $Y$ denotes productivity, $e$ denotes a level of effort chosen by the cultivator, $x, z$ denote irrigation and other inputs. $A$ and $G$ are both strictly increasing, strictly concave, smooth functions satisfying Inada conditions. Moreover, all inputs are complementary, so the marginal product of any input is increasing in application of any other input.

The cultivator takes $p$ the price of output and $q, r$ the prices of irrigation and other inputs as given. An owner-cultivator then decides on effort $e$ and input applications $x, z$ to maximize

$$\alpha p A(e) G(x, z) - qx - rz - D(e) \tag{2}$$

where $\alpha \leq 1$ and $D(.)$ is a strictly increasing, strictly convex smooth function representing effort disutility. The value of $\alpha$ is less than one for a tenant cultivator, representing the share of output accruing to the cultivator.

Optimal effort and input decisions are denoted by $e(p, q, r; \alpha), x(p, q, r; \alpha), z(p, q, r; \alpha)$, which result in farm productivity $Y(p, q, r; \alpha)$. Owing to the supermodularity of the production function, effort and inputs move in the same direction in response to changes in farm parameters: rising in $p$ and $\alpha$, falling in $q$ and $r$.

Tenancy registration results in an increase in $\alpha$ for tenant cultivators.[10] There is a direct effect on productivity of tenant farms alone, for given factor prices.

## 2.2 Factor Price Effects

The tenancy reform can have a general equilibrium (GE) effect on factor prices in the village. We focus now on the determination of $q$, the price of irrigation. We formulate the market for groundwater in a representative village as the result of an oligopoly among a given number of sellers. Moitra and Das (2005) argue this is a reasonable representation of groundwater markets in West Bengal villages, based on field studies. As we shall see, over 90% of observed irrigation expenditures in our sample is accounted by water purchases rather than self-provision. Selling groundwater requires substantial investments, which only a few wealthy agents in the village can afford to undertake. We take the number of such agents as given, and suppose all other farmers in the village purchase water from the given set of sellers.

Water sellers make costly investments in groundwater capacity. A major simplifying

[10] Land redistribution tends to have the same effect if it causes land to be redistributed from landlords who lease out their land to those who cultivate it themselves. On the other hand, land may be redistributed also from landowners who cultivate it themselves with or without hired labor. In that case the effect on productivity is not so clear, corresponding to a change in the size of the farm and the wealth of the owner cultivator, effects we abstract from here.

assumption we make here for the sake of analytical tractability is that investments reduce marginal cost of supply, which is independent of the amount of water supplied. As in R&D models (Dasgupta-Stiglitz (1980)) or the capacity investment model in Banerjee *et al* (2001), a marginal cost $c$ of delivering groundwater necessitates a fixed upfront investment of $F(c)$, where $F$ is a strictly decreasing, convex and smooth function. A more realistic scenario is one where marginal supply is a function both of the amount of water supplied, and investments in capacity (rising in the former, falling in the latter). This would complicate the model of oligopolistic interaction among water-sellers (e.g., necessitating mixed strategy equilibria), while the basic mechanism we are focusing on would continue to apply.

Also suppose (owing to a given wealth distribution in the village) there is a given number $n$ of identical sellers of groundwater, so as to abstract from considerations of endogenous entry and exit. At the first stage, each of these sellers decide independently on a level of investment (equivalently, a level of marginal cost of water delivery). At the second stage, they play a Cournot game and independently decide how much water to deliver. Here they take the demand function for water in the village, which is obtained from aggregating the input decisions of various buyers who take the water price as given. Let the inverse demand function be denoted $q(X|p, r, \tau)$, where $X$ is the aggregate supply of water, $\tau$ is the fraction of farms in the village which are cultivated by tenants that are registered. Water sellers take prices of farm output and other inputs $p, r$ as given.

We focus on a symmetric equilibrium of this game. If all sellers have selected the same marginal cost $c$, the second stage symmetric Cournot equilibrium results in the familiar expression for the price-cost margin:

$$1 - \frac{c}{q} = \frac{1}{n\epsilon} \tag{3}$$

where $\epsilon$ denotes the price elasticity of demand for water. Considering the case where this elasticity is constant, the second-stage equilibrium price for water can be expressed simply as

$$q^* = c[1 - \frac{1}{n\epsilon}]^{-1} \tag{4}$$

i.e., is proportional to the level of marginal cost chosen by sellers at the first stage. Use $q^*(c)$ to denote the second stage price.

Moving back to the first stage, a symmetric equilibrium choice of capacity by sellers will maximize

$$\frac{1}{n}[q^*(c) - c]X(q^*(c)|p, r, \tau) - F(c) \tag{5}$$

where $X(q|p, r, \tau)$ denotes the demand function for water. Applying the Envelope Theorem to the maximization exercise implicit in the second-stage equilibrium choice of water delivery, equilibrium capacity investments will satisfy the first-order condition

$$-F'(c^*) = \frac{X(q^*(c^*)|p, r, \tau)}{n} \tag{6}$$

Owing to the nonconvexity of the capacity decision, this first-order condition is not sufficient, and there may be multiple solutions to the first order condition.

The local second-order condition for equilibrium capacity choice is easily shown to imply that a small outward shift of the demand for water results in increased capacity investments, and thus a fall in the marginal cost and price of groundwater. Hence an increase in $\tau$ the tenancy registration rate will cause a fall in the cost of groundwater, owing to its induced effect on investment in irrigation capacity. Dasgupta and Stiglitz (1980) provide closed form expressions for the equilibrium investment levels in the case of constant elasticity demand and capacity cost functions, which explicitly show the 'induced innovation' effect of an expansion in market demand.

The preceding discussion took the prices $r$ of other inputs as given. A full-blown general equilibrium analysis of the effects of the tenancy reform would incorporate effects on these prices as well. Without going into a formal and explicit analysis of equilibrium factor prices for the village as a whole, it is useful to keep in mind that additional interdependencies could arise across prices of different inputs. An increase in supply of subsidized seeds and fertilizers will lower the price of these inputs, which will raise the demand for groundwater, thus stimulating private investment in irrigation. The reduced form for equilibrium prices of various inputs will thus express them as a function of tenancy reforms as well as farm extension programs:

$$q = q^*(\tau, \kappa|p); r = r^*(\tau, \kappa|p) \tag{7}$$

where $\kappa$ denotes supplies of subsidized inputs as well as demonstration programs which help farmers learn about new technologies. The presence of dynamic learning effects implies that both current and lagged implementation rates of tenancy registration and farm extension programs will matter. As in standard formulations of learning-by-doing effects, our empirical analysis will use cumulative past levels of implementation of these various programs.

It should be mentioned that the model sketched above need not be the only channel by which the tenancy registration program affect investments in groundwater capacity. An alternative channel may arise from access to institutional credit to registered tenants, which may have allowed farmers to invest more easily in tubewells and pumps and thus self-provide irrigation rather than purchase from oligopolistic sellers. Local governments implementing the tenancy program more vigorously may also have facilitated access of local farmers to credit from state-owned banks for purposes of investing in irrigation. Accounts of both kinds of stories were reported in our interviews with state government and bank officials. In the empirical analysis we shall explore the relevance of this channel, by breaking down effects on self-supplied water expenditures *vis-a-vis* purchased water.

The main aim of our empirical analysis is to obtain quantitative estimates of the significance of the factor price effects of tenancy reforms in explaining the spillover effect on non-tenant farms. This will involve estimating regressions corresponding to (a) the farm profit function which shows the extent to which farm productivity rose in response to a fall in factor prices, and (b) the function $q^*(\tau, \kappa|p)$ representing the effect of tenancy reforms on factor prices.

# 3 Background, Data and Descriptive Statistics

## 3.1 Land Reforms and Local Government Farm Development Programs

There were two kinds of land reforms implemented in West Bengal. One was a tenancy reform, called *Operation Barga (OB)*, in which tenants were encouraged to register their lease. Such registration protected them from eviction and guaranteed them a larger fraction of the output. The other was a land redistribution policy in which new land titles, called *pattas*, were distributed (from land previously appropriated from those with landholdings exceeding legal ceilings). Table 1 shows the extent of land reforms implemented across all the sample villages in 1978 and 1998. By 1998 about 6.1% of operational land was registered under OB, with close to 5% of the households registered as tenants. The land redistribution affected a much larger fraction of the population. Almost 15% of the households in our sample got land in form of *pattas* amounting to 5.4% of operational land.

The average size of land parcels distributed in the titling program was approximately half an acre, compared with an average size of 1.5 acres for plots registered under the tenancy registration program. While the latter were cultivable by their very nature, approximately half of all titles distributed consisted of non-cultivable land. Interviews with bank officials and farmers indicated that farmers were not eligible for bank loans on the basis of collateral representing titles received in the land reform program, owing to the uneconomically small size and poor quality of the land parcels concerned. Therefore the productivity impact of the land titling program could be expected to be less significant than the effects of tenancy registration, and we focus principally on the latter.

The local governments, *gram panchayats*(GP), played a significant role in the implementation of these land reforms. Their role included identification of beneficiaries and working with state government and court officials to further the legal process. The GPs occupied the bottom tier of three tier system of *panchayats*, with higher tiers corresponding to blocks and districts. This system of local government was created in 1977, with officials at each tier selected via direct elections once every five years. Each GP oversees 10–15 villages, with each village electing a representative to the GP council which votes on significant initiatives affecting its jurisdiction. Elections have typically been dominated by the Left Front coalition and its principal opposition party, the Indian National Congress (INC) or its offshoot the Trinamool Congress: these two parties accounted for over 90% of all elected positions in the panchayats.

Apart from the land reforms the *panchayats* were responsible for allocation and selection of beneficiaries under various centrally sponsored poverty alleviation schemes. These were: (a) the Integrated Rural Development Program (IRDP) that provided credit at highly subsidized rates; (b) the distribution of subsidized agricultural kits that contained seeds, fertilizers and pesticides, and (c) several programs creating local infrastructure and employing local people. The *panchayats* allocated budgets received from higher levels of government between local roads, medium-scale irrigation projects (such as ponds and river-lift schemes) and other local buildings (such as schools). They supervised construction and selected those from the local area employed on the projects. Part of the purpose was to provide a safety net for poor households by providing them employment opportunities.

The allocation of funds across panchayats was the result of percolation of resource budgets downwards through district, block and village panchayats, a process subject to considerable political discretion and lobbying. BM (2006) found inter-GP and inter-village allocation of these programs subject to anti-poor and anti-low-caste biases, whilst intra-village allocations were remarkably egalitarian. Hence political composition of GPs had a significant impact on the delivery of various programs to villages, owing to considerations of political competition as well as collective action problems within GPs in lobbying higher-level panchayats for resources. Implementation of the land reforms were similarly affected by considerations of political competition, as studied in BM (2010). Hence village-year fluctuations in land reforms, and supply of various programs of farm support depended on variations in competitive strength of the Left Front and the Congress in GP elections. This will form the basis of our identification strategy of the effect of these various programs on farm outcomes.

### 3.2 Data

We use the same data-set as B-M (2011), consisting of over 500 farms spread across 89 villages located in 15 major agricultural districts in West Bengal. This data-set includes two principal components: (i) annual farm-level cost-of-cultivation surveys conducted by the government of West Bengal and (ii) village surveys. We now describe each of these in detail.

The cost of cultivation surveys were conducted using a stratified random sampling frame that give three to five year panels of farm production data for a sample of eight farms per village. Villages were selected in pairs from within randomly selected blocks within each district, with the first village selected randomly and the other one selected from those with a different irrigation status within a 8 kilometer radius of the first. If the first village was irrigated to a significant degree, the second one would be more likely to be chosen from non-irrigated villages in the neighborhood, and vice versa. Eight farms were selected randomly within each village, stratifying by farm size (across four classes, with thresholds of 2.5, 5 and 10 acres).

Investigators were responsible for collecting data on all items of farm expenditures on a bi-weekly basis for five successive years, though the data available to us is aggregated by year and ranges between three to five years per farm. Data includes the following items: (i) use of human labor, broken down by family and hired labor, and wages paid to the latter; (ii) seeds and plants; (iii) manures, fertilizer and pesticides; (iv) main products and by-products harvested, marketing and sale of these, and associated marketing costs; (v) irrigation; (vi) purchase, sale or repair of all articles used in farming; of land; (vii) maintenance costs and incomes earned from bullocks. The investigators also collected market prices for different agricultural products twice a month. With regard to fixed assets such as pumps, power tillers or tractors, fixed costs were amortized and record of annual maintenance, operating and depreciation costs kept to estimate the costs of self-supply of the relevant input. Hence costs of self-supplied irrigation are included along with purchased water inputs to estimate total irrigation expenditures. The breakdown between self-supplied and purchased expenditures is also available, permitting us to examine whether the reforms affected farmers' own investments in irrigation.

We use the farm-level data to compute farm value added on an annual basis, subtracting the costs of all expenditures (excluding application of family labor) from all revenues for each crop planted, and then aggregating across all crops. We use value added per acre as a measure of farm profits, since it is not clear how to impute the cost of family labor (which has traditionally been argued to frequently lie below the market wage rate, owing to various transaction costs and labor market imperfections). This measure of productivity includes effects on yields, cost reductions on various inputs, as well as induced effects on cropping patterns and cropped areas.

The village surveys give data on local government composition, budgets, expenditure on major schemes administered by local governments. This is further supplemented by: (a) data concerning land reforms implemented in the village between 1971-98 collected from the local Land Records Office, (b) minikits distributed by block offices of the state agriculture department, and subsidized loans given to farmers in each village under the

IRDP Program by local lead banks, both in consultation with local government officials, (c) household surveys of landholding, occupation, caste and education for 1978 and 1998, (d) a household survey of landholdings and their irrigation status and source on a recall basis since 1967, (e) population census data on villages, (f) district-year data concerning number of electrified tubewells from the State Electricity Board, besides the Census of Minor Irrigation; (g) monthly rainfall records in the nearest recording center, (h) district level allocations to major development programs and (i) results from national, state and local government elections from 1977 to 1998. [11]

### 3.3 Descriptive Statistics

Table 2 gives the trends for some of these programs. The cumulative measures of these programs indicate that the proportion of minikits per household and amount of credit per household consistently increased during this period. However, their annual flows declined over time. The same is true for number of mandays of employment- the annual flow fell from about 4 days per household in 1982 to 2 days per household in 1995. Much of the GP expenditure on roads and irrigation was concentrated in the 1980s which consistently decreased until 1990 and then increased again in 1995. But they never returned to the levels of 1982/1983. The Table also shows area irrigated by state canals increased (except for a decline in 1985).

The separate contribution of the different programs can be estimated precisely only if they were not highly inter-correlated with one another. The partial correlations were low and statistically insignificant at the 10% level. A regression of the coverage of the tenancy registration program on the other programs, yielded a coefficient of -.145 with respect to the minikit program (p-value of 0.25), -0.100 with respect to the credit program (p-value of 0.32), and 0.065 with respect to the land title distribution program (p-value of 0.27), after controlling for village fixed effects, year dummies and other controls used in the main regressions in this paper.

Table 3 shows trends in cropping patterns, value added, wages and employment. These

[11] Greater detail on the various datasets is provided in BM (2006, 2010, 2011)

are weighted averages across farms in three separate farm panels based on the cost of cultivation surveys (1982-85, 1986-90 and 1991-96). Total cropped area increased by about 9% in the first two panels and stayed constant in the last panel. Area under high yielding varieties (HYV) of rice increased consistently in all three panels. The same is true for value added per acre and value added per farm. The wage rate (adjusted for changes in cost of living of agricultural workers) did not change much in the 1980s but increased between 1990-95 which was accompanied by a fall in hired labor hours per acre.

Table 4 shows the expansion of various types of minor irrigation schemes in the state as a whole, based on the Census of Minor Irrigation. Between 1987-1994 there was a 340% and 161% increase in the number of shallow tubewells and dugwells, respectively. As Moitra and Das (2005) indicate, these were mainly the result of private investment. The expansion was most marked in the 1980s and tapered off in the 1990s. By 1993-94, 23 per cent of net sown area was irrigated by ground water which amounted to approximately 50 per cent of net irrigated area in the state[12].

Table 5 indicates the relative importance of different sources of irrigation in our sample villages, based on our household landownership survey. This was based on a stratified random sample of approximately 25 households in the same villages involved in the cost-of-cultivation surveys, carried out in 2004. The questionnaire asked each household to list all plots they owned since 1967, including whether or not it was irrigated and the source of irrigation in any given year.[13] We use these responses to estimate the average proportion of cultivable land in each village irrigated by alternate sources, weighted by land area sizes. Table 5 provides the average of these across different villages in the sample for each year between 1981 and 1995. It indicates more than a four-fold expansion of land irrigated by shallow tubewells, from 7.6% to 31.4% of operational land between 1981-95. River-lift/ponds (the main responsibility for which rested with local governments) represented the second most important source, which rose from 7.5% to 14.9% during this period. State canals in contrast provided only 5.2% of operational area in 1981, which grew slightly to only 5.9% in 1995. Hence the most important source of growth in irrigation was private investment

[12]Census of Minor Irrigation 1993-94

[13]Further details of the survey are provided in Bardhan, Mitra, Mookherjee and Sarkar (2009).

in shallow tubewells and dugwells, followed by medium irrigation schemes administered by local governments. This assessment is consistent with that provided by Rawal (2001).

Table 6 gives the percentage of irrigation expenditure accounted for by purchased water among farms in our sample that incurred positive irrigation expenditures. The vast majority of irrigation expenditures were purchased rather than self provided. In the first and second panels spanning the 1980s, all irrigation expenditures were purchased. In the third panel the proportion of purchased irrigation ranged between 84 and 90%, with no visible trend.

# 4 Empirical Results

## 4.1 Factor Price Effects on Farm Productivity

We first consider the impact of changes in factor prices of various inputs on farm productivity. Following the discussion in Section 2.1, farm productivity can be expressed as a function of output and factor prices, and on tenancy status. The first main problem we run into is that data on factor prices from the cost of cultivation surveys is available for only one quarter of farms in the sample. We do however observe expenditure on various inputs for almost all farm-years. So we use variations in expenditures on various inputs as a proxy for changes in their prices.

If we use farm profits or value added per acre as the measure of productivity (denoted by $\pi$), and assume that water-buyers are price-takers, Shepards Lemma implies that

$$d \log \pi = -\sum_i \frac{E_i}{\pi} d \log s_i \tag{8}$$

where $s$ denotes the factor price vector, $z_i(s)$ the factor demand for input $i$, and $E_i \equiv s_i z_i(s)$ the expenditure on input $i$. Here we suppress output price and tenancy status in order to conserve notation among the arguments of the factor demand functions.

If there are no cross-price effects across different factors,

$$d \log E_i = (1 - \epsilon_{ii}) d \log s_i \tag{9}$$

where $\epsilon_{ii}$ denotes the own price-elasticity of demand for factor $i$. Inserting this into (8) we obtain the relationship between changes in farm productivity and expenditures on various inputs:

$$d\log\pi = -\sum_i \frac{E_i}{\pi(1-\epsilon_{ii})} d\log E_i \tag{10}$$

Increased expenditures on a factor correspond to increased prices if its demand is inelastic, and to decreased prices if it is elastic. Hence expenditure changes proxy price changes for inelastic factors, and in the opposite direction for elastic factors. Whether a factor is inelastic or elastic can thus be inferred from the sign of the coefficient of farm productivity on expenditure of the corresponding input. If it is negative for factor $i$, we should infer it is an inelastic factor, and should interpret reductions in expenditure on that input as indicating reductions in its price.

This interpretation needs to be qualified, of course, in the presence of cross-price effects. One can still express changes in farm productivity as a function of changes in factor expenditures. In the case of two factors for instance, it is easily checked that

$$d\log\pi = -[\frac{E_1 + \frac{\epsilon_{12}}{1-\epsilon_{22}}E_2}{\pi[(1-\epsilon_{11}) - \epsilon_{21}\frac{\epsilon_{12}}{1-\epsilon_{22}}]}]d\log E_1 - [\frac{E_2 + \frac{\epsilon_{21}}{1-\epsilon_{11}}E_1}{\pi[(1-\epsilon_{22}) - \epsilon_{12}\frac{\epsilon_{21}}{1-\epsilon_{11}}]}]d\log E_2 \tag{11}$$

At the same time one can express price changes as a function of expenditure changes as follows:

$$d\log s_i = \frac{d\log E_i}{(1-\epsilon_{ii}) - \epsilon_{ij}\frac{\epsilon_{ji}}{1-\epsilon_{jj}}} + \frac{\frac{\epsilon_{ji}}{1-\epsilon_{jj}}d\log E_j}{(1-\epsilon_{ii}) - \epsilon_{ij}\frac{\epsilon_{ji}}{1-\epsilon_{jj}}} \tag{12}$$

so prices and expenditures move in the same direction if factors are own-price-inelastic, and cross-price effects are either small relative to own-price effects, or if factors are complementary (i.e., $\epsilon_{ij} > 0$). Moreover, under this condition, profits are decreasing in factor expenditures if the latter are moving in the same direction as their prices.[14]

In any case, viewing expenditure changes as induced by underlying factor price changes, we can estimate regressions corresponding to (10, 11). Assumptions about cross-price effects matter only in the way we interpret the direction in which factor prices must have changed for a certain observed change in expenditures to have come about.

Our regression specification is thus the following:

$$\log y_{kvt} = \alpha_k + \delta_t + \gamma\log p_{vt} + \beta\log E_{kvt} + \epsilon_{kvt} \tag{13}$$

[14]Under the latter condition, $\frac{\epsilon_{ji}}{1-\epsilon_{jj}}$ is positive. So $\frac{d\log\pi}{d\log E_i}$ is negative if and only if $[(1-\epsilon_{ii}) - \epsilon_{ji}\frac{\epsilon_{ij}}{1-\epsilon_{jj}}] > 0$, i.e., if and only if $\frac{d\log s_i}{d\log E_i} > 0$.

where $y_{kvt}$ denotes value added per acre for farmer $k$ in village $v$ in year $t$, $p_{vt}$ is the price of rice (the principal crop) in village $v$ in year $t$ and $E_{kvt}$ is the vector of expenditure on various inputs by farmer $k$ in village $v$ in year $t$. If we observe the $\beta$'s to be negative (positive) we infer that expenditures on the corresponding factor move in the same (opposite) direction as its price.

A problem in estimating (13) is that expenditure on inputs are endogenous, being jointly determined with farm productivity. OLS estimates of the elasticities $\beta$ are likely to be biased for various reasons. First, expenditure on inputs would be correlated with farmer characteristics that also affect yields. We can control for fixed farmer characteristics with farmer fixed effects, but time-varying unobserved characteristics (such as wealth or household labor stock) would still represent a source of bias. Second, expenditures could be correlated with time-varying village-specific variables affecting productivity such as other (unmeasured) inputs, infrastructure, or shared information about planting or harvesting.

We therefore need instruments for input expenditures. Temporal variations in these arise from temporal variations in input prices, which in turn were driven by various programs implemented by local governments: land reform, farm extension programs, infrastructure and employment generation by GPs. We therefore seek predictors of temporal fluctuations in program implementation rates at the village level. As explained above, we rely on earlier work of BM (2006, 2010) on the political economy of program implementation rates.

We predict land reform implementation rates by variables affecting political competition between the two rival political parties – the Left Front alliance and the Congress or its Trinamool offshoot – at the level of the local government. BM (2010) showed that land reform implementation rates displayed an inverted-U relation with the Left share, after controlling for village fixed effects and changes in the land distribution — which can be interpreted as representing the effect of political competition on implementation rates. Hence predictors of the Left share and their squares represent predictors of land reform implementation rates. Left shares in the current GP cannot be used as instruments as temporal fluctuations in these may be correlated with shocks to farm outcomes. So we predict the current Left share in the GP in terms of the Left share in the preceding GP administration, and recent shocks to the popularity of the Left and the Congress at the national and district levels.[15] We specifically use the presence of the Congress in the national Parliament (INC), and average vote share difference (AVSD) between the two rivals in the preceding elections to the state legislature averaged at the district level. Note that a district contains an average of 200 GPs and 2000 villages, so AVSD is a measure of competitive strength of the two parties at a much higher level of aggregation than the individual village. Village-year variations in land reform implementation is then ultimately predicted by lagged Left share in the GP and its square, plus interactions with AVSD and INC. The square of Left share is included to incorporate non-linearities arising from non-linear variations in control associated with share of seats in the council, as well as effects of political competition. BM(2010) found an inverted-U shape in the relationship of land reform implementation with seat share, besides effects of shocks to popularity and election-year-timing which indicate the role of political competition.

In the case of minikits, IRDP credit and local employment generation programs, the delivery of these in any given village is predicted by the determinants of political competition described above, additionally interacted with the scale of the corresponding program in the state as a whole. The IV regressions in Table 7 use as instruments AVSD, INC, the scale of the kits, IRDP credit, employment programs at the state level interacted with lagged Left share in the GP and its square. In order to be valid instruments, these predictors of the Left share should have no residual effect on farm productivity after incorporating their effect on input expenditures or other controls in the regression. It is plausible that they are uncorrelated with time-varying farmer-specific unobservables that may affect productivity, though less so with regard to time-varying village specific factors (such as infrastructure or social learning) that affect farm productivity. The second-stage regressions therefore additionally control for state-provided irrigation, including electrified tubewells (at the district-year level), and GP spending on irrigation programs (at the village-year level).

The OLS and IV regression results are shown in Table 7, for log of total value added

[15] Specification tests of an Arellano-Bond specification of the Left share regression at the GP level were not rejected. Hence controlling for village effects, lagged Left shares at the GP level are valid instruments for the current Left share and therefore for programs implemented by the currently elected GP.

per acre. We present two versions of the IV estimates, one in which we instrument all the expenditure variables (shown in columns 2 and 5), and another in which we only instrument for expenditure on irrigation(shown in columns 3 and 6). The relevant first-stage results are presented in the bottom panel of Table 7. The low values of the Kleibergen-Paap Wald F-statistic in columns 2 and 5 indicate a weak instrument problem, so we focus mainly on columns 3 and 6 where the maximal bias of the IV estimate is within 20% relative to that of the OLS estimate.

We find both the OLS and IV estimates of the elasticity with respect to irrigation expenditures are negative. While the OLS coefficient is close to zero and statistically insignificant, the IV estimate is approximately -0.24, and statistically significant. Since both are negative we shall interpret irrigation expenditure changes as proxying groundwater price changes in the same direction, i.e., that its demand is price-inelastic.

The fact that the IV estimate of the elasticity is larger in magnitude than the OLS estimate is consistent with the removal of bias associated with time-varying farmer unobservables. For instance, a farmer with more family members to help on the farm in some given year may decide to crop more intensively and thus spend more on groundwater. The result will be a higher productivity. The bias is therefore likely to be positive. The IV estimate filters out farmer-specific unobservables likely to affect both farm productivity and irrigation expenditures in the same direction. It will also filter out similar village-level factors that affect both irrigation and productivity: e.g., peer effects that promote increases in cropping intensity. Moreover, it may reflect removal of attenuation bias resulting from measurement error in irrigation expenditures.

The IV elasticity of value added per acre with respect to expenditures on bullock is also negative in columns 3 and 6, though not significant. In contrast, the coefficient on expenditure on labor, fertilizers and seeds is always positive and significant. These results seem intuitively reasonable. Ploughing and irrigation represent inputs indispensable for farming, with few substitutes available; unit-factor requirements are dictated largely by the technology as in a Leontief technology. Therefore, their demands are unlikely to be price elastic. Fertilizers and hired labor, on the other hand, can be substituted for by manure and household labor respectively. In the case of seeds, these were found in the minikits that were supplied to households. So their demands are more likely to be price elastic.

The first three columns in Table 7 is based on all farms in the sample, including tenant farms. One objection to these results concerns the lack of any controls for tenant farms, being based on the implicit assumption that the same production relationship is exhibited for tenant and non-tenant farms. A related problem is that this creates some endogeneity bias: Marshallian distortions (or inferior soil quality on leased lands) may cause tenants to spend less on irrigation and on other inputs, and apply less effort, which would lower productivity. This would impart a positive bias to the estimated elasticities. However, this problem is unlikely to be acute as the proportion of tenant farms in our sample is low (less than 10%), so the results in columns 1-3 in Table 7 pertain mainly to non-tenant farms. To check this, columns 3-6 in Table 7 shows the value added regression estimated for non-tenant farms alone. The elasticity estimate with respect to irrigation, seeds and hired labor are reduced somewhat, but they continue to be significant and have the same signs.

## 4.2 Effects of Land Reforms and Other Government Programs on Factor Prices

We now turn to the key prediction of our model: that the tenancy reforms induced a significant expansion of groundwater capacity which lowered the price of groundwater. Ideally, we would estimate a regression corresponding to equation (7), but the non-availability of factor price data does not allow this. We therefore treat expenditures on various inputs as proxies of their respective prices. We use the signs of the coefficients of the corresponding factor expenditure in the productivity regression to interpret the results in terms of induced price effects. We saw that irrigation exhibited a negative coefficient, so we can interpret movements in irrigation expenditures as reflecting price movements in the same direction.

The regression specification is the following:

$$log(E_{jkvt}) = \alpha_k + \delta_t + \beta_1 TR_{vt} + \beta_2 LT_{vt} + \beta_3 Kits_{vt} + \beta_4 Cred_{vt} + \beta_5 Emp_{vt} + \epsilon_{jkvt} \quad (14)$$

where $E_{jivt}$ denotes the expenditure per acre on input $j$ by farmer $k$ in village $v$ in year $t$. ($TR_{vt}$, $LT_{vt}$, $Kits_{vt}$, $Cred_{vt}$, $Emp_{vt}$) are measures of the cumulative extent of tenancy reforms, land titling, minikits, credit subsidy distributed and mandays of employment per household implemented or generated in village $v$ until year $t$. We run these for different inputs separately.

In the IV estimation, the instruments are the predictors of Left share in GP seats (and its square) described above, interacted with the aggregate scale of various reforms in the state as a whole. Year-to-year fluctuations in the latter reflect changing macroeconomic circumstances, which are unlikely to be significantly correlated with temporal fluctuations in village-specific unobservables. The underlying identification assumption is that these external factors (interacted with lagged incumbency rates at the local level) affected farm input expenditures only via their impact on the programs and other controls included on the right-hand-side of the regression. The basis for this assumption is that we incorporate the effect of practically all programs administered by local and state governments with a bearing on farmers decisions concerning input expenditures — land reform, credit, kits, employment and infrastructure programs. In particular we include local GP spending on minor irrigation programs, and the number of electrified deep and shallow tubewells at the district-year level. The latter is included to address possible concerns that the estimated impact of the the local tenancy reforms may be biased owing to its correlation with with subsidized provision of electrically powered tubewells by the State Electricity Board of the West Bengal government.

Table 8 shows the OLS and IV regression results for the effect of various programs on farm irrigation expenditures.[16] The tenancy program had a negative effect on per acre irrigation cost which is significant at the 1% level. This is irrespective of whether we focus on the OLS or IV estimates. The IV estimates are larger in magnitude than the OLS estimate, indicating a positive endogeneity bias. The sign of the bias is what we would intuitively expect: as farmers and local governments become more 'progressive', we would expect greater spending by farmers on irrigation and more vigorous implementation of

[16]Tenancy registration and the kits program are instrumented here, just as in BM (2011), because these are the two most important programs and for which the instruments have enough power. The F-statistics when we try to predict the other programs are below the standard benchmark of 10, and the p-value of the identification rank test is substantially above 0.1.

institutional reforms and farm extension programs. The fixed effects IV estimate eliminates this source of bias, revealing a stronger effect of programs implemented (owing to external and historical factors) on the cost of irrigation.

We do not observe significant effects of the land titles, the minikits, the IRDP credit or the employment program on irrigation expenditures. Columns 3–6 examine corresponding effects on self-supplied and purchased irrigation services. Almost all the effects of tenancy registration operated through irrigation purchases, which is to be expected since they formed most of total expenditures. The estimated effects on self-supplied irrigation expenses are negative but statistically insignificant. Hence the observed effect of the program is unlikely to have operated through enhanced access of registered tenants to credit which may have induced them to invest in their own irrigation capacity (and reduce irrigaion costs by avoiding the oligopolistic markups charged by water-sellers).

In order to examine the differential effect of the tenancy program on the tenant and non-tenant farms, we include a dummy for whether the farmer in question leased in any land in the year in question, and an interaction between this dummy and the extent of tenancy registration within the village. We find that as might be expected, *ceteris paribus* tenant farms spend less on irrigation. The impact of tenancy registration on tenant farms is lower than on the average farm in the village, but the IV estimate of this difference is not statistically significant in the IV regressions.

Table 9 examines heterogeneity of impact by farm size: we divide the sample into small, medium and large farms on the basis of total land holding tertiles and examine the impact of reforms for each group separately. We find most of the impact of tenancy registration is driven by its impact on the medium and large farms, who spend more on irrigation. Within large farms, the impact on tenant farms is substantially greater than on non-tenant farms.

Table 10 shows analogous results for the effect of the reforms on expenditure on other inputs. The IV coefficients of tenancy reform is not significant for any of the input expenditures. The kits program did not affect expenditures on any of the inputs. The land titling program had a significant effect on spending on seeds, indicating an upward impact on their prices. The credit program had a marginal positive effect on bullock expenditure indicating a downward impact on prices; however Table 7 showed the elasticity of value added with respect to bullock expenditure was not statistically significant.

### 4.3 Does the Effect on Irrigation Account for the Entire Spillover Effect of Tenancy Reforms on Non-tenant Farms?

We have found evidence suggesting that irrigation prices represented an important source of spillover from the tenancy registration program to productivity in non-tenant farms. Farm productivity was decreasing significantly in irrigation cost for both non-tenant and tenant farms. And irrigation cost fell in response to the tenancy registration program. We now ask whether this channel accounted for the entire spillover. In order to do so, we construct a measure of productivity which nets out the irrigation effect, by subtracting from value added the term involving irrigation expenditures, weighted by the IV-estimate of its elasticity (from Table 8). We then regress this on implementation rates of the various programs:

$$log\ y_{kvt} - \hat{\beta}_i logE_{ikvt} = \mu logp + \gamma_1 TR_{vt} + \gamma_2 LT_{vt} + \gamma_3 Kits_{vt} + \gamma_4 Credit_{vt} + \gamma_5 Mandays_{vt} + \epsilon_{ikvt} \tag{15}$$

where $\gamma_l$ denotes the reduced form effect of policy $l$ on productivity net-of-irrigation (NOI-productivity) and $\hat{\beta}_i$ is the IV estimate of the elasticity of productivity with respect to irrigation cost (from Table 7). As in Table 8, we instrument tenancy registration and kits supply with lagged Left share, its square, the scale of the kits, credit and employment programs in the state, shocks to popularity of the two principal parties, and interactions amongst these.

The results are shown in the third and fourth columns of Table 11: the tenancy registration program had no significant impact on total value added, net of the irrigation impact. For purpose of comparison, columns 1 and 2 of Table 11 provides the same reduced form regressions for productivity without netting out the irrigation impact (this is essentially the same as the main regression reported in BM (2011)).[17] Without accounting for the irrigation impact, tenancy registration has a large positive and statistically significant impact

[17] The IV estimate of tenancy registration is significant here, while it was not significant in BM (2011). The reason is that we have used a larger instrument set here, including instruments such as the scales of the credit program and employment program, which have increased the power of the instrument set.

on productivity. As shown in BM (2011), most of this represented the effect on non-tenant farms in the village, as the coefficient on the lease dummy is not statistically significant. Columns 3 and 4 of Table 11 show that this effect vanishes when the irrigation impact is netted out. These results also suggest the absence of spillovers due to social learning: if owner-cultivators were learning from their tenant neighbors, this should have led to a positive and significant effect of tenancy registration on NOI-productivity.

We saw in Table 8 that the minikit program had no significant impact on irrigation costs. Consistent with this, the effect of the minikit program is not much affected by netting out irrigation costs from value added. The same is true for the other programs. The credit effect is positive and significant in NOI-productivity. Employment programs also had a positive effect on NOI-productivity. As shown in BM (2006), these programs increased the wage rate for hired labor. This may have caused farmers to substitute away from hired labor and increase application of family labor, which would raise farm yields and value added. Hence the credit and employment programs had an independent impact on farm productivity, over and above the tenancy program and its induced impact on irrigation cost. Finally the land titling program had a negative impact on value added, possibly because of its positive impact on seed prices, combined with the lack of any direct impact on average productivity in the village owing to the low quality and size of plots distributed.

### 4.4 Household Survey Evidence

Finally, Table 12 reports corresponding IV regression results for proportion of cultivated land in the village irrigated by various sources, and the extent to which this is explained by cumulative implementation of various local government programs in the village. Table 13 provides the corresponding OLS estimates. These regressions are therefore run at the village rather than farm level. As with previous regressions, the independent variables are percent land registered in the tenancy program, distributed in the titling program, and level of minikits, credit subsidy and mandays employment generated per household. Controls include village fixed effects, the price of rice, rainfall, and irrigation provided by state canals and year dummies. We use the same instruments for tenancy reform as in earlier regressions.

Column 1 provides estimates for the proportion of land under minor and medium irrigation which Table 5 showed were the most important sources of growth in irrigation: the proportion of cultivable land irrigated by tubewells, river-lift and ponds. We see this is stimulated particularly by tenancy registration, whose effect is large and significant at 1%. Employment programs on the other hand exerted a significant negative effect. Column 2 provides the corresponding regression for total proportion irrigated by shallow and deep tubewells combined, while columns 3, 4 and 5 break it down into the effects on shallow tubewells, deep tubewells and river-lift/ponds respectively. The effect is accounted for mainly by shallow tubewells, followed by river-lift and ponds, though the former is imprecisely estimated.

Being based on an entirely different source of data, these results thus provide independent corroboration of the main hypothesis of this paper, that investment in minor irrigation was stimulated by the tenancy reform program. Part of this was in the form of river-lift and ponds, which were partly carried out by local governments.[18] The remainder was in shallow tubewells, which was essentially private.

## 5 Concluding Comments

We have found evidence of pecuniary externalities operating through effects of the tenancy reforms on the cost of irrigation. These help explain the significant spillover effects of the tenancy reforms on farm productivity in non-tenant farms found in earlier work on West Bengal agriculture by BM (2011).[19]

There are at least two possible channels by which tenancy reforms reduced irrigation costs: induced effects on investment in groundwater capacity by water sellers, and enhanced availability of cheap institutional credit to registered tenants which facilitated investments by these farmers in irrigation. We did not find any evidence for the latter channel: almost the entire effect was accounted for by reduction in puchased irrigation, rather than a sub-

[18]Note, however, that the direct effect of GP spending on irrigation itself on river-lift and pond irrigation is negative, as is the effect on shallow tubewells, suggesting some crowding out of private spending by local government spending.

[19]Our estimates imply a predicted impact of the tenancy program on value added through this channel of 2.4%, out of a total predicted impact of approximately 3.9%.

stitution of self-provided irrigation for purchased irrigation. Moreover, owner-cultivators experienced larger reductions in purchased irrigation expenses than tenant farms. Hence we infer that the former channel accounted for the observed impact. Independent corroboration was obtained from an alternative dataset drawn from a household landholding survey, which shows impacts of the tenancy program on proportion of land irrigated by shallow tubewells, ponds and river-lift schemes.

Our results complement the detailed studies carried out by Moitra and Das (2005) of the extensive groundwater markets in West Bengal. They find that in the early 1980s there was substantial growth in investment in tubewells, later shifting to submersible pumps. They also find that owners of tubewells sell water (as tubewell owners irrigate a larger area than they own), and water sellers behave oligopolistically with regard to pricing of water. These observations are consistent with the simple model sketched in Section 2.

The general picture suggested by our study is that institutional reforms implemented by local governments stimulated investments in minor irrigation, which in turn increased farm productivity. Complementarity between state-led institutional reforms and irrigation investments by local governments and private water-sellers contributed to the West Bengal green revolution of the 1980s and 1990s. This supplemented the direct effects of the tenancy reforms and subsidized provision of minikits.

## References


[1] Banerjee A., P. Gertler, and M. Ghatak (2002), "Empowerment and Efficiency: Tenancy Reform in West Bengal," *Journal of Political Economy*, 110(2), 239-280.

[2] Bardhan P. and D. Mookherjee (2006), "Pro-Poor Targeting and Accountability of Local Governments in West Bengal," *Journal of Development Economics*, 79, 303-327.

[3] ———— (2010), "Determinants of Redistributive Politics: An Empirical Analysis of Land Reforms in West Bengal, India," *American Economic Review*, 100(4), 1572-1600.

[4] ———— (2011), "Subsidized Farm Input Programs and Agricultural Performance: A Farm-Level Analysis of West Bengal's Green Revolution 1982-95," forthcoming, *American Economic Journal: Applied Microeconomics*.

[5] Bardhan P., S. Mitra, D. Mookherjee and A. Sarkar (2009), "Local Democracy and Clientelism: Implications for Political Stability in Rural West Bengal," *Economic and Political Weekly*, February 28 2009.

[6] Besley T. and R.Burgess (2000), "Land Reform, Poverty Reduction, and Growth: Evidence From India", *Quarterly Journal of Economics*, May, 389–430.

[7] Carter, M. R. and P. Olinto, (1996), " Decomposition and Identification of the Impact of Land Titling on Agricultural Productivity in Paraguay". Madison, WI: Department of Agricultural Economics, University of Wisconsin.

[8] Dasgupta P. and Stiglitz J. (1980), "Industrial Structure and the Nature of Innovative Activity," *Economic Journal*, 90, June 1980, 266-293.

[9] Harriss J. (1993), “What is Happening in Rural West Bengal? Agrarian Reform, Growth and Distribution,” *Economic and Political Weekly*, June 12 1993, 1237–1247.

[10] Feder G., T.Onchan, Y. Chamlamwong and C. Hongladarom, (1988), “Land Policies and Farm Productivity in Thailand”. Baltimore, Md. : Johns Hopkins University Press.

[11] Feder G. abd A. Nishio (1997), “ The Benefits of Land Registration and Titling: Economic and Social Perspectives”, The World Bank, Washington DC.

[12] Foster A and M Rosenzweig, (1995), “ Learning by Doing and Learning from Others: Human Capital and Technical Change in Agriculture”, *The Journal of Political Economy*, Vol. 103, No. 6.

[13] Lopez, R, (1996), “Land Titles and Farm Productivity in Honduras”, College Park, Md.: Department of Agricultural and Resouce Economics, University of Maryland.

[14] Moitra B. and Das, P.K, (2005),“Ground Water Markets in West Bengal, India: Emergence, Evolution and Market Structure,” South Asia Networks of Economic Research Institutes (SANEI) Report, and mimeo, Deparment of Economics, Jadavpur University.

[15] Pender, John L. and John M. Kerr, (1994), “The Effect of Transferable Land Rights on Credit, Land Investment and Use: Evidence from South India.” Provo, Utah: Brigham Young University, Department of Economics.

[16] Rao, Mohan J. (1995), “Agrarian Forces and Relations in West Bengal,” *Economic and Political Weekly*, July 29 1995, 1939-1941.

[17] Sekhri, S,(2007),“Public Provision and Protection of Natural Resources: Groundwater Irrigation in Rural India”, RI: Department of Economics, Brown University

[18] Shaban R. (1987), 'Testing Between Competing Models of Sharecropping,' *Journal of Political Economy*, 95(5), 893–920.

[19] Wade, R., [1988], Village Republics, Cambridge University Press.

# 6 Appendix : Tables and Figures

Table 1: Extent of Land Reforms

| | 1978 Average | 1998 Average |
|---|---|---|
| % operational land titles distributed | 1.4 | 5.4 |
| % hh's receiving land titles | 4.9 | 14.9 |
| % operational land with registered tenants | 2.4 | 6.1 |
| % hh's registered tenants | 3.1 | 4.4 |
| % tenants registered | 43.4 | 51.2 |

Average across sample villages, weighted by operational land areas

Source: Bardhan and Mookherjee (2011), Table 1

Table 2: Trends in Public Supplies of Agricultural Inputs

| | 1982 | 1985 | 1990 | 1995 |
|---|---|---|---|---|
| Minikits per household | 0.13 | 0.14 | 0.10 | 0.07 |
| Minikits per hh cumulative | 0.67 | 1.03 | 1.46 | 1.68 |
| IRDP[a] per household | 63 | 43 | 35 | 22 |
| IRDP[a] per hh cumulative | 288 | 507 | 608 | 662 |
| GP Irrigation Expenditure[b] | 5741 | 3734 | 1872 | 3085 |
| GP Road Expenditure[c] | 5831[d] | 3903 | 2859 | 4025 |
| GP Employment Mandays per household | 3.9 | 3.2 | 2.5 | 2.2 |
| Area Irrigated by State Canals (hectares) | 73691 | 70416 | 77552 | 82721 |
| State Road Length (Km) | 1276 | 1288 | 1316 | 1331 |

Average of yearly flows across sample villages, weighted by operational land areas

a: IRDP Credit Subsidy, 1980 prices;

b,c: Expenditure out of Employment Program Funds, 1980 prices; d: for year 1983

Source: Bardhan and Mookherjee (2011), Table 2

Table 3: Trends in Farm Productivity, Incomes and Wages

| | 1982 | 1985 | 1986 | 1990 | 1991 | 1995 |
|---|---|---|---|---|---|---|
| Cropped Area (acres)* | 1.04 | 0.71 | 1.16 | 1.19 | 0.86 | 1.74 |
| Fraction Rice area HYV | 0.06 | 0.06 | 0.26 | 0.40 | 0.58 | 0.67 |
| Rice Value Added per acre | 936 | 1492 | 1557 | 2903 | 4191 | 5444 |
| Value Added per acre | 635 | 777 | 875 | 1232 | 1309 | 1368 |
| Value Added per farm | 3027 | 3831 | 4007 | 5365 | 5181 | 5642 |
| Hired Labor Wage Rate | .62 | .66 | .92 | .88 | .88 | 1.01 |
| Hired Labor Annual Hrs/Acre | 153 | 176 | 235 | 251 | 317 | 371 |

Unweighted average across farms

All rupee figures deflated by cost of living index, 1974=100

Source: Bardhan and Mookherjee (2011), Table 5

Table 4: Expansion of Minor Irrigation in West Bengal: Annual growth rates

| Year | 1987-1994 | 1987-88 | 1988-89 | 1989-90 | 1990-91 | 1991-92 | 1992-93 | 1993-94 |
|---|---|---|---|---|---|---|---|---|
| Shallow Tubewells | 340% | 49% | 32% | 27% | 23% | 15% | 11% | 12% |
| Deep Tubewells | 45% | 4% | 3% | 3% | 4% | 6% | 7% | 11% |
| Dugwells | 161% | 22% | 16% | 14% | 13% | 10% | 9% | 18% |
| Surface Flow Schemes | 13% | 2% | 2% | 1% | 1% | 1% | 1% | 4% |
| Surface Lift Schemes | 49% | 6% | 5% | 7% | 5% | 4% | 4% | 10% |

Source: Census of Minor Irrigation 1993-94

Table 5: Percentage of Cultivated Area in Sample Villages Irrigated by Source

| Year | Canals | Deep Tubewells | River lift/pond | Shallow Tubewell | Others |
|---|---|---|---|---|---|
| 1981 | 5.20 | 2.81 | 7.5 | 7.62 | 0.45 |
| 1982 | 5.20 | 2.81 | 7.45 | 8.79 | 0.46 |
| 1983 | 5.21 | 2.92 | 7.54 | 9.03 | 0.46 |
| 1984 | 5.22 | 3.08 | 8.17 | 10.97 | 0.46 |
| 1985 | 5.22 | 3.22 | 8.67 | 13.18 | 0.46 |
| 1986 | 5.27 | 3.30 | 9.08 | 14.09 | 0.48 |
| 1987 | 5.28 | 3.42 | 9.32 | 14.81 | 0.48 |
| 1988 | 5.35 | 3.55 | 9.43 | 15.56 | 0.54 |
| 1989 | 5.4 | 3.66 | 9.97 | 17.01 | 0.54 |
| 1990 | 5.41 | 4.05 | 11.9 | 19.43 | 0.55 |
| 1991 | 5.42 | 4.10 | 12.09 | 20.85 | 0.55 |
| 1992 | 5.45 | 4.3 | 12.43 | 23.22 | 0.55 |
| 1993 | 5.45 | 4.35 | 12.52 | 24.27 | 0.56 |
| 1994 | 5.47 | 4.41 | 13.44 | 29.29 | 0.68 |
| 1995 | 5.82 | 4.51 | 14.85 | 31.39 | 0.68 |

Average across sample villages, weighted by operational land area

Source: Household Survey

Table 6: Composition of Irrigation Expenditures

| Year | Percent of Irrigation Expenditure accounted for by purchased water |
|---|---|
| 1982 | 100 |
| 1983 | 100 |
| 1984 | 100 |
| 1985 | 100 |
| 1986 | 100 |
| 1987 | 100 |
| 1988 | 100 |
| 1989 | 100 |
| 1990 | 99 |
| 1991 | 90 |
| 1992 | 84 |
| 1993 | 89 |
| 1994 | 89 |
| 1995 | 90 |

Source: Cost of Cultivation Survey

Table 7: Relation between Farm Yields and Per Acre Input Expenditures

| | Log of Total Value Added per Acre | | | | | |
|---|---|---|---|---|---|---|
| | All Farms | | | Non-Tenant Farms | | |
| | OLS | IV | IV | OLS | IV | IV |
| Log Expenditure on Irrigation | -0.010 | -0.234* | -0.242** | -0.009 | -0.221* | -0.213** |
| per acre | (0.009) | (0.141) | (0.113) | (0.009) | (0.131) | (0.090) |
| Log Expenditure on Fertilizers | 0.017 | 0.037 | 0.063** | 0.026 | 0.117 | 0.075** |
| per acre | (0.019) | (0.160) | (0.032) | (0.019) | (0.170) | (0.030) |
| Log Expenditure on Seeds | 0.059** | -0.071 | 0.144** | 0.045* | -0.141 | 0.122** |
| per acre | (0.028) | (0.187) | (0.060) | (0.027) | (0.173) | (0.054) |
| Log Expenditure on Labor | 0.305*** | 0.556** | 0.343*** | 0.281*** | 0.512** | 0.306*** |
| per acre | (0.064) | (0.241) | (0.080) | (0.061) | (0.240) | (0.075) |
| Log Expenditure on Bullock | -0.009 | 0.016 | -0.054 | -0.008 | 0.024 | -0.046 |
| per acre | (0.017) | (0.062) | (0.033) | (0.016) | (0.067) | (0.030) |
| No. of Electrified Deep | 0.001 | 0.000 | 0.000 | 0.001 | 0.000 | 0.000 |
| Tubewells in district | (0.001) | (0.001) | (0.001) | (0.001) | (0.001) | (0.001) |
| No. of Electrified Shallow | -0.000 | -0.000 | -0.000 | -0.000 | -0.000 | -0.000 |
| Tubewells in district | (0.000) | (0.000) | (0.000) | (0.000) | (0.000) | (0.000) |
| Log price of rice | 0.337*** | 0.356*** | 0.427*** | 0.341*** | 0.409*** | 0.456*** |
| | (0.082) | (0.121) | (0.105) | (0.102) | (0.146) | (0.123) |
| Observations | 2005 | 1856 | 1856 | 1874 | 1750 | 1750 |
| $R^2$ | 0.158 | -0.543 | -0.437 | 0.142 | -0.556 | -0.334 |
| First stage F-stat[a] | | | | | | |
| Log Expenditure on Irrigation | | 8.65 | 9.77 | | 9.15 | 9.58 |
| Log Expenditure on Fertilizers | | 6.52 | | | 4.95 | |
| Log Expenditure on Seeds | | 14.90 | | | 13.64 | |
| Log Expenditure on Labor | | 4.72 | | | 5.23 | |
| Log Expenditure on Bullock | | 72.87 | | | 59.56 | |
| Hansen's J Statistic | | 14.55 | 23.01 | | 13.75 | 23.05 |
| Hansen's J, p-value | | 0.48 | 0.23 | | 0.54 | 0.23 |
| Kleibergen-Paap rk LM stat | | 13.64 | 18.09 | | 12.77 | 21.03 |
| Underidentification Test, p-value | | 0.62 | 0.68 | | 0.53 | 0.39 |
| Kleibergen-Paap rk Wald F-stat | | 1.2 | 9.77 | | 0.78 | 9.58 |
| Maximal Relative Bias | | (n.a.) | (10%,20%) | | (n.a.) | (10%,20%) |

All regressions include annual rainfall, farm and year dummies; and controls for state and GP level irrigation and roads

The state measure of irrigation is state-canal-provided irrigation which varies from district to district in any given year.

Columns 2 and 5 all expenditure variables instrumented, Columns 3 and 6 only irrigation expenditure instrumented.

a. p-values on all First stage F-stats is 0.000.

Set of excluded instruments: Congress seats in Parliament, average vote share difference, state average for kits, credit and empl share and its square, and interactions among these

Robust standard errors in parentheses clustered at village level. *** p<0.01, ** p<0.05, * p<0.1

Table 8: Impact of Policy Interventions on Log of Per Acre Irrigation Expenditure on All Crops

| | Log Total Irrigation Expenditure per Acre | | Log Own Irrigation Expenditure per acre | | Log Purchased Irrigation Expenditure per acre | |
|---|---|---|---|---|---|---|
| | OLS | IV | OLS | IV | OLS | IV |
| Tenancy Registration[a] | -1.151*** | -1.614*** | -0.056 | -0.303 | -1.075*** | -1.294** |
| | (0.212) | (0.566) | (0.173) | (0.417) | (0.279) | (0.648) |
| Minikits/HH | 0.321 | -0.105 | -0.089 | -0.268 | 0.400 | 0.139 |
| | (0.262) | (0.539) | (0.176) | (0.438) | (0.290) | (0.567) |
| IRDP Credit/HH | 0.001 | 0.002 | -0.001 | -0.001 | 0.002 | 0.003 |
| | (0.001) | (0.001) | (0.001) | (0.001) | (0.001) | (0.002) |
| Mandays/HH | 0.020 | 0.021 | 0.073** | 0.085** | -0.078 | -0.092 |
| | (0.055) | (0.059) | (0.037) | (0.043) | (0.070) | (0.081) |
| Land Titles[b] | -0.019 | -0.880 | 0.174 | 0.565 | -0.234 | -1.542 |
| | (0.204) | (1.559) | (0.127) | (0.749) | (0.214) | (1.444) |
| Lease Dummy | -0.296* | -0.193 | -0.109 | -0.147* | -0.207 | -0.064 |
| | (0.162) | (0.177) | (0.074) | (0.087) | (0.165) | (0.182) |
| Lease Dummy* | 0.840** | 0.383 | 0.472 | 0.524 | 0.436 | -0.096 |
| Tenancy Registration | (0.421) | (0.516) | (0.437) | (0.406) | (0.493) | (0.496) |
| Observations | 1906 | 1780 | 1906 | 1780 | 1906 | 1780 |
| $R^2$ | 0.039 | 0.035 | 0.028 | 0.029 | 0.040 | 0.041 |
| Hansen's J Statistic | | 10.97 | | 17.24 | | 13.01 |
| Hansen's J, p-value | | 0.89 | | 0.50 | | 0.79 |
| Kleibergen-Paap LM Stat | | 23.92 | | 23.92 | | 23.92 |
| Underidentification test, p-value | | 0.19 | | 0.19 | | 0.19 |
| Kleibergen-Paap Wald F-stat | | 9.48 | | 9.48 | | 9.48 |
| Maximal Relative Bias | | (10%, 20%) | | (10%, 20%) | | (10%, 20%) |

All regressions include annual rainfall, farm and time dummies; and controls for state and GP level irrigation, total cropped area and its square, number of electrified deep and shallow tubewells at district level for each year.
a. Lagged cumulative proportion of operational land registered under Operation Barga
b. Lagged cumulative proportion of operational land distributed as *pattas*.
Credit and Kits are cumulative past provision
Tenancy registration and Minikits are instrumented in the IV regressions. Set of excluded instruments same as Table 7.
First Stage F-stat(p-value) for Tenancy Registration is 260.92 (0.000) and for Minikits/HH is 30.56(0.000)
Robust standard errors in parentheses clustered at village level. *** p<0.01, ** p<0.05, * p<0.1

Table 9: Impact of Policy Interventions on Log of Per Acre Irrigation Expenditure on All Crops by Farm Size

| | Small Farms IV | Medium Farms IV | Large Farms IV |
|---|---|---|---|
| Tenancy Registration | 2.136 | -1.560* | -3.140*** |
| | (3.094) | (0.849) | (0.807) |
| Minikits/HH | 0.928 | 0.685 | -1.289 |
| | (0.763) | (0.646) | (0.861) |
| IRDP Credit/HH | 0.003 | 0.002 | -0.001 |
| | (0.002) | (0.003) | (0.003) |
| Mandays/HH | 0.006 | -0.246*** | 0.149* |
| | (0.125) | (0.093) | (0.077) |
| Land Titles | 0.454 | -1.244 | -0.284 |
| | (2.289) | (1.121) | (3.414) |
| Lease Dummy | -0.335 | 0.136 | 0.324 |
| | (0.424) | (0.460) | (0.674) |
| Lease Dummy* | 8.165 | 0.489 | -22.493*** |
| Tenancy Registration | (16.660) | (0.970) | (7.227) |
| Observations | 525 | 545 | 568 |
| $R^2$ | 0.053 | 0.086 | 0.082 |

All other comments as in Table 8.

Robust standard errors in parentheses clustered at village level.

*** p<0.01, ** p<0.05, * p<0.1

Table 10: Impact on Log Per Acre Expenditures on Other Inputs, All Crops

| | Fertilizers | | Bullock | | Seeds | | Labor | |
|---|---|---|---|---|---|---|---|---|
| | OLS | IV | OLS | IV | OLS | IV | OLS | IV |
| Tenancy Registration | 0.061 | 0.217 | -0.126 | 0.477 | -0.476*** | -0.386 | -0.015 | 0.014 |
| | (0.187) | (0.557) | (0.189) | (0.717) | (0.094) | (0.257) | (0.077) | (0.183) |
| Minikits/HH | 0.172 | 0.273 | 0.085 | 0.634 | -0.015 | 0.147 | 0.169 | 0.200 |
| | (0.169) | (0.513) | (0.281) | (0.925) | (0.103) | (0.260) | (0.108) | (0.237) |
| IRDP Credit/HH | 0.001 | 0.000 | 0.001 | 0.003* | -0.001*** | -0.001 | 0.000 | 0.000 |
| | (0.001) | (0.001) | (0.001) | (0.002) | (0.000) | (0.001) | (0.000) | (0.000) |
| Mandays/HH | -0.044 | -0.006 | -0.066 | -0.105* | -0.023 | -0.021 | -0.009 | -0.014 |
| | (0.037) | (0.046) | (0.048) | (0.059) | (0.026) | (0.030) | (0.022) | (0.026) |
| Land Titles | -0.332*** | -0.210 | -0.394** | -0.626 | -0.013 | -1.158*** | 0.122** | -0.316 |
| | (0.106) | (0.941) | (0.160) | (2.892) | (0.054) | (0.427) | (0.058) | (0.444) |
| Observations | 2091 | 1926 | 2091 | 1926 | 2091 | 1926 | 2091 | 1926 |
| $R^2$ | 0.020 | 0.013 | 0.029 | 0.039 | 0.022 | 0.015 | 0.040 | 0.032 |
| Hansen's J Statistic | | 20.89 | | 17.62 | | 27.26 | | 27.86 |
| Hansen's J, p-value | | 0.28 | | 0.48 | | 0.07 | | 0.06 |
| Kleibergen-Paap LM Stat | | 27.39 | | 27.39 | | 27.39 | | 27.39 |
| Underidentification Test, p-value | | 0.09 | | 0.09 | | 0.09 | | 0.09 |
| Kleibergen-Paap Wald F-stat | | 4.75 | | 4.75 | | 4.75 | | 4.75 |
| Maximal Relative Bias | | (20%,30%) | | (20%,30%) | | (20%,30%) | | (20%,30%) |

All other comments as in Table 8.

Robust standard errors in parentheses clustered at village level. *** p<0.01, ** p<0.05, * p<0.1

Table 11: Effects of Land Reforms and Other Development Programs on Total Value Added

| | Total | | Net of Irrigation[a] | |
|---|---|---|---|---|
| | OLS | IV | OLS | IV |
| Tenancy Registration | 0.423*** | 0.404** | 0.007 | -0.067 |
| | (0.127) | (0.178) | (0.117) | (0.188) |
| Minikits/HH | 0.494*** | 0.404* | 0.454*** | 0.353 |
| | (0.165) | (0.212) | (0.148) | (0.227) |
| IRDP Credit/HH | 0.001** | 0.001 | 0.001** | 0.001** |
| | (0.000) | (0.000) | (0.000) | (0.000) |
| Mandays/HH | 0.048 | 0.060*** | 0.059* | 0.064*** |
| | (0.031) | (0.021) | (0.030) | (0.023) |
| Land Titles | 0.187 | -0.822* | 0.212* | -1.116 |
| | (0.119) | (0.453) | (0.110) | (0.728) |
| Lease Dummy | -0.053 | -0.033 | -0.169** | -0.131 |
| | (0.056) | (0.056) | (0.073) | (0.087) |
| Lease Dummy* | 0.254 | 0.183 | 0.443** | 0.302 |
| Tenancy Registration | (0.155) | (0.147) | (0.181) | (0.206) |
| Observations | 2083 | 1919 | 2083 | 1919 |
| $R^2$ | 0.135 | 0.106 | 0.099 | 0.080 |
| Hansen's J Statistic | | 21.84 | | 13.52 |
| Hansen's J, p-value | | 0.23 | | 0.75 |
| Kleibergen-Paap LM Stat | | 27.63 | | 27.86 |
| Underidentification Test, p-value | | 0.09 | | 0.08 |
| Kleibergen-Paap Wald F-stat | | 4.9 | | 4.87 |
| Maximal Relative Bias | | (20%,30%) | | (20%,30%) |

a. The dependent variable is value added per acre net of the effect of irrigation/seeds expenditure.

i.e.$log(va) - \hat{\beta} logExp_i rri$,where $\hat{\beta}$ is estimated from Table 7.

All other comments as in Table 8.

Robust standard errors in parentheses clustered at village level.

*, **, *** significant at 10%, 5%, 1%,respectively.

Table 12: Effects of Local Govt. Programs on Medium and Minor Irrigation, IV

| | Shallow+Deep Tubewell +Riverlift | Shallow+Deep Tubewell | Shallow Tubewell | Deep Tubewell | River-lift +Ponds | Canals |
|---|---|---|---|---|---|---|
| Tenancy Registration | 18.784** | 12.706* | 10.894 | 0.030 | 6.018* | 0.002 |
| | (7.323) | (7.323) | (6.882) | (0.029) | (3.329) | (0.024) |
| Minikits/HH | 11.431 | 10.835 | 8.399 | 0.029 | 0.462 | 0.013 |
| | (8.029) | (8.320) | (7.632) | (0.029) | (3.260) | (0.031) |
| IRDP Credit/HH | 0.011 | 0.009 | 0.010 | 0.000 | 0.002 | 0.000 |
| | (0.013) | (0.012) | (0.011) | (0.000) | (0.005) | (0.000) |
| Mandays/HH | -1.105* | -1.141** | -1.474*** | 0.004 | 0.004 | -0.016 |
| | (0.596) | (0.541) | (0.570) | (0.003) | (0.327) | (0.012) |
| Land Titles | 11.484 | 27.799 | 26.799 | -0.008 | -16.326 | 0.079 |
| | (26.826) | (30.831) | (32.134) | (0.039) | (12.031) | (0.126) |
| GP Irrigation | -0.325** | -0.226 | -0.240* | 0.000 | -0.100 | -0.001 |
| Expenditure | (0.165) | (0.145) | (0.144) | (0.001) | (0.074) | (0.001) |
| Area irrigated by | 0.107 | 0.005 | -0.051 | 0.000 | 0.098 | -0.001 |
| State canals | (0.206) | (0.172) | (0.164) | (0.000) | (0.108) | (0.001) |
| Observations | 232 | 232 | 227 | 227 | 227 | 245 |
| $R^2$ | 0.063 | 0.059 | 0.092 | 0.007 | 0.057 | 0.064 |
| Hansen's J Statistic | 26.81 | 30.63 | 35.05 | 1.30 | 16.63 | 1.54 |
| Hansen's J, p-value | 0.08 | 0.03 | 0.01 | 1.00 | 0.54 | 0.90 |
| Kleibergen-Paap LM Stat | 31.52 | 31.52 | 34.42 | 31.52 | 34.42 | 31.52 |
| Underidentification Test, p-value | 0.03 | 0.03 | 0.01 | 0.01 | 0.01 | 0.03 |
| Kleibergen-Paap Wald F-stat | 3.5 | 3.5 | 4.43 | 4.32 | 4.32 | 3.5 |
| Maximal Relative Bias | <30% | <30% | <30% | <30% | <30% | <30% |

Dependent variables are proportion of village cultivable land irrigated by corresponding source;

All regressions include village dummies. All other comments as in Table 8

Robust standard errors in parentheses clustered at village level.*, **, *** significant at 10%, 5%, 1%, respectively.

Table 13: Effects of Local Govt. Programs on Medium and Minor Irrigation, OLS

| | Shallow+Deep Tubewell +Riverlift | Shallow+Deep Tubewell | Shallow Tubewell | Deep Tubewell | River-lift +Ponds | Canals |
|---|---|---|---|---|---|---|
| Tenancy Registration | 10.930*** | 8.018*** | 7.895*** | 0.004 | 2.899*** | 0.018 |
| | (2.804) | (2.760) | (2.719) | (0.005) | (1.083) | (0.017) |
| Land Titles | -3.452 | 7.982 | 8.415 | -0.006 | -11.392 | 0.076 |
| | (14.677) | (17.138) | (17.821) | (0.022) | (7.814) | (0.123) |
| MInikits/HH | 1.644 | 2.620 | 2.518 | 0.008 | -0.986 | 0.012 |
| | (2.482) | (2.689) | (2.631) | (0.008) | (1.125) | (0.013) |
| IRDP Credit/HH | 0.004 | 0.002 | 0.003 | 0.000 | 0.002 | 0.000 |
| | (0.006) | (0.005) | (0.005) | (0.000) | (0.003) | (0.000) |
| Mandays/HH | -1.100** | -1.125** | -1.342*** | 0.002 | 0.001 | -0.016 |
| | (0.528) | (0.497) | (0.516) | (0.002) | (0.250) | (0.012) |
| GP Irrigation | -0.345** | -0.233 | -0.251 | 0.001 | -0.114 | -0.001 |
| Expenditure | (0.163) | (0.149) | (0.156) | (0.001) | (0.073) | (0.001) |
| Area Irrigated by | -0.004 | -0.097 | -0.119 | -0.000 | 0.090 | -0.001 |
| State Canals | (0.193) | (0.156) | (0.153) | (0.000) | (0.111) | (0.001) |
| Observations | 252 | 252 | 247 | 247 | 247 | 247 |
| $R^2$ | 0.097 | 0.085 | 0.097 | 0.011 | 0.071 | 0.064 |

Dependent variables are proportion of village cultivable land irrigated by corresponding source;

All regressions include village dummies. All other comments as in Table 8

Robust standard errors in parentheses clustered at village level.

*, **, *** significant at 10%, 5%, 1%, respectively.