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

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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]

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Abstract

This paper estimates respective roles of private investments in irrigation and local government programs (land reforms, extension services, and infrastructure investments) in the growth of farm productivity in West Bengal, India between 1981-95. Using a farm panel from a stratified random sample of farms from major agricultural districts of West Bengal, we find evidence that private investment in irrigation which reduced irrigation costs for farms played an important role in the growth process. However, the growth in private investment was itself stimulated by tenancy registration and minikit distribution programs implemented by local governments. This channel helps account for the substantial spillover effects of the tenancy reform on non-tenant farms noted in an earlier study. Hence the observed productivity growth was a result of 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

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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, and devolved to them 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.

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

[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).

reform, farm extension services and private irrigation investments in explaining farm productivity growth. This dataset has been used in previous studies by Bardhan and Mookherjee, BM hereafter (2008a,b,c). It follows on BM (2008b) in particular, a paper which estimated reduced form regressions for farm productivity on cumulative measures of tenancy registration, land titling and various farm extension 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 farm extension services 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 a reduction in Marshallian sharecropping distortions. In this paper we will explore the role of private irrigation investments in explaining the nature of these spillovers. This provides a novel dimension to the productivity benefits of tenancy reforms operating through their 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 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 was a significant fall in cost of groundwater for *all* farms in the village, including non-tenant farms. Since HYV rice varieties have higher groundwater requirements than traditional varieties, the net result was a faster diffusion of HYV rice varieties in the village. The model generates

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

testable restrictions concerning (a) the 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, as well as broad descriptive statistics. Section 4 then presents the main empirical results. A key 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 political incumbency patterns in local government. This is based on earlier work of BM (2006, 2008a) 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 extension 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 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.*[7] The plausibility of this assumption derives from the comprehensiveness of

[7] This applies to regression (b). In regression (a), the identification assumption is more stringent, as controls for extension services or employment programs were not included. However, we did include controls for local government expenditures on irrigation and state-provided irrigation. See the discussion in Section 4 concerning the identification of regression (a).

local government programs included in the set of controls.[8] Our data set includes surveys of local governments which includes all the major programs with a bearing on farm production: delivery of subsidized seeds and fertilizers (in the form of *agricultural 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 results concerning the effect of land reforms and extension services on irrigation costs appear in both OLS and IV regressions. The IV estimates systematically exceed the OLS estimates in size and statistical significance. This indicates endogeneity bias in the OLS estimates, and that the direction of this bias causes an underestimation of the strength of the effects that we do find.

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

1. Concerning results of regression (a), farm yields (measured either by rice yields or farm value added per acre (FVAA)) responded significantly to per acre expenditures on irrigation, seeds, fertilizers, bullocks and labor. The demand for groundwater was price-inelastic: the IV estimate of the elasticity of FVAA with respect to irrigation expenditure per acre is -0.25 (significant at 1%), while the OLS estimate is -0.02 (significant at the 5% level).[9]

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 impact did not vary significantly between tenant and non-

[8] 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 (2008a) a test of this specification was not rejected. Note also that 'lagged' pertains to seat shares in the previous elections to the local government council, not the previous year.

[9] 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.

tenant farms. The only other program which reduced irrigation expenditures significantly was delivery of minikits. The tenancy registration program also resulted in a statistically significant reduction in per acre expenditures on seeds, while the effect on other inputs (fertilizers, labor and bullocks) was insignificant.

3. Next, we construct a measure of farm productivity net-of- irrigation (NOI) by subtracting per acre irrigation expenditure weighted by its estimated IV elasticity from regression (a). We then regress this NOI-productivity measure on the implementation 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. Comparing this with the significant reduced form effects of the program on productivity found by BM (2008b), 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 found in BM (2008b) 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 seed costs, or social learning were not significant sources of spillover.

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 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 reducing Marshallian distortions, 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. Both tenancy reforms and private investment were thus important, and were complementary with one another.

Our findings provide a perspective intermediate between a state-led and market-led interpretation 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.[10]

The state also played another important role: the delivery of farm extension services (subsidized minikits, credit and public employment programs). Indeed the results in BM (2008b) show that their quantitative significance far exceeded that of the tenancy reforms. We find here that they 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

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

[10]That the state may provide an indirect role by influencing incentives for private investment in irrigation is argued by Rao (1995) in his critique of Harriss (1993). This paper thus provides concrete empirical evidence for this view.

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 $\alpha \equiv 1$ and $D(.)$ is a strictly increasing, strictly convex smooth function representing effort disutility. The value of α 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 functions, effort and inputs move in the same direction in response to changes in farm parameters: rising in p and α, falling in q and r.

Tenancy registration results in an increase in α for tenant cultivators.[11] There is a direct effect on productivity of tenant farms alone, conditional on given 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. Selling groundwater requires substantial investments, which only a few wealthy agents in the village can afford

[11] 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.

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.

The key assumption is that irrigation groundwater flows out of costly investments in groundwater capacity. There is a given number n of identical sellers of groundwater, each of whom make endogenous capacity investment decisions. Capacity choices are variable: a larger capacity investment yields a supply of water at a lower marginal cost (which we assume 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.

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, τ 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:

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

where ϵ 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

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

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 τ 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 κ 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 may 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. 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. It should be noted that we will not be able to distinguish such a channel from the one sketched above. So in the empirical section both possible channels should be kept in mind as representing the hypothesis that we are seeking to test.

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 Data and Descriptive Statistics

We use the same dataset as B-M (2008b), consisting of 743 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. 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. This survey collected crop-wise information on acreage, amount and value of output and the expenditure on various inputs. 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) subsidized loans given to farmers in each village under the IRDP Program by local lead banks, in consultation with local government officials, (c) household surveys of landholding, occupation, caste and education for 1978 and 1998, (d) population census data on villages, (e) Census of Minor Irrigation, (f) monthly rainfall records in the nearest recording center, (g) district level allocations to major development programs and (h) results from national, state and local government elections from 1977 to 1998. [12]

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. Moreover, 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, *panchayats*(GP), played a significant role in the implementation of these land reforms. Their role included identification of beneficiaries and working

[12] Greater detail on the various datasets is provided in BM (2006, 2008b)

with state government and court officials to further the legal process. 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.

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 these never returned to the levels of 1982/1983. The Table also shows area irrigated by state canals increased (except for a decline in 1985).

Table 3 shows trends in cropping patterns, value added, wages and employment. These 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 close to 50 per cent of net irrigated area in the state[13].

Table 5 indicates the relative importance of different sources of irrigation in our sample villages, based on our household 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.[14] 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 in shallow tubewells and dugwells, followed by medium irrigation schemes administered by local governments.

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

[13]Census of Minor Irrigation 1993-94

[14]Further details of the survey are provided in Bardhan, Mitra, Mookherjee and Sarkar (2008).

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 π), Shephards 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 ϵ_{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.[15]

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:

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

where y_{kvt} is a measure of farm productivity (rice yield per acre or total 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 β's to be negative (positive) we infer that expenditures on the corresponding factor move in the same (opposite) direction as its price.

A typical problem with estimating (13) is that expenditure on inputs are endogenous, being jointly determined with farm productivity. OLS estimates of the elasticities β 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.

[15] 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 $\frac{d \log s_i}{d \log E_i} > 0$.

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 in the Introduction, we rely on earlier work of BM (2006, 2008a) 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 (2008a) 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. These include variables affecting relative popularity of the two parties with local voters, such as: (a) the presence of the Congress in national Parliament, (b) inflation rate of the cost of living index for agricultural workers in the region, (c) generation of employment in small factories in the district in question, and (d) interactions of these with the lagged (i.e., from the previous GP election) Left share. The cost of living index pertains to each of four regions of the state. Small factory employment pertains to the district. Each district contains of the order of 200 GPs, and each region is composed of a number of districts. Each GP in turn is composed of 10–15 villages (called *mouzas*). Hence these pertain to areas at a much higher order of aggregation than the village in question. In addition, 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 programs implemented by the currently elected GP.

Recall that our theory is that land reform implementation rates in turn predict changes in input prices and hence input expenditures in local farms, as explained in Section 2. So these predictors of land reforms are potential predictors of farm input expenditures. The relevant first-stage regressions are presented in Table 7; these show that the corresponding F-statistics are significant at 1%.

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. Hence the IV estimates ought to remove at least one important source of bias in the OLS estimates. The direction of the endogeneity bias can be inferred from comparing the IV with the OLS estimates.

The OLS and IV regression results are shown in Table 6, for the two different measures of productivity. Focusing on the value added per acre measure of productivity, we find both the OLS and IV estimates of the elasticity with respect to irrigation expenditures are negative and statistically significant. The IV estimates is substantially larger in magnitude: -0.25 as against -0.02, the OLS estimate. Since both are negative we shall interpret irrigation expenditure changes as proxying groundwater price changes in the same direction. In the case of rice yields, the IV estimate is negative significant, while the OLS estimate is positive and significant at 5%.

The fact that the IV estimate of the elasticity is more negative 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 per acre. 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 may not be able to filter out similar village-level factors that affect both irrigation and productivity: e.g., peer effects that promote increases in cropping intensity. Hence the true elasticity of productivity with respect to irrigation expenditures (resulting from changes in groundwater prices) is likely to be even more negative and larger in magnitude than indicated by our IV estimates.

The IV elasticity of value added per acre with respect to expenditures on bullock and seeds are also negative, though only the former is significant. In contrast, the coefficient on expenditure on labor and fertilizers is always positive and significant. These results seem intuitively reasonable. Seeds, ploughing and irrigation represent inputs indispensable for farming, with few substitutes available, and unit-factor requirements dictated largely by the 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. So their demands are more likely to be price elastic.

Table 6 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 should be 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 very acute as the proportion of tenant farms in our sample is low (less than 10%), so the results in Table 6 pertain mainly to non-tenant farms. To reassure that this is indeed the case, Table 8 shows the value added regression estimated for non-tenant farms alone. It shows that the results are practically unaltered.

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, both for rice crops alone, as well as for all crops. In the IV estimation, we use the same set of instruments for land reforms as in the farm productivity regressions in the previous section. For local credit, kits and employment programs, we use the same predictors of local political competition (i.e, the Left share in GP seats) interacted with the aggregate scale of each program 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. Since we incorporate the effect of practically all programs administered by local and state governments with a bearing on farmers decisions concerning irrigation expenditures — land reform, credit, kits, infrastructure, employment programs — this assumption seems plausible.

Table 9 shows the regression results for per acre irrigation expenditures in rice cultivation, with the corresponding statistics for the first stage regression corresponding to the IV estimates reported in Table 10. These are followed by the corresponding results for irrigation expenditures aggregated across all crops in Table 11, with the corresponding first stage statistics in Table 12.

These tables contain the main finding of this paper: the tenancy program had a significant (at 1%), negative effect on per acre irrigation cost. This is irrespective of whether we focus on the OLS or IV estimates. The same results apply to irrigation expenditures in rice cultivation, and across all crops. 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 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 also observe, as expected, complementary effects of extension programs on irrigation costs. An expansion of kits provided by local governments would be expected to increase the demand for groundwater, also stimulating investment in groundwater capacity and driving down the price. Credit or employment programs do not have a significant effect, while the land titling program yields a significant positive IV estimate (and an insignificant OLS estimate).

One possible explanation of a positive effect of the land titling program is that it raised the demand for groundwater from those receiving the titles, without a countervailing effect on the supply of groundwater. This could owe to the fact that land titles did not entitle holders to institutional credit for irrigation loans, in contrast to the tenancy registration program. Hence the linkage between tenancy registration and access to institutional credit may have been an important source of the significant productivity effects of this program.

Table 13 checks whether the impact of the tenancy program or irrigation cost differed between 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 effect 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, but this difference is not statistically significant. The impact of tenancy registration in the village also does not differ significantly between tenants and non-tenant farms, confirming that the effect being estimated here is indeed a spillover effect from the tenancy program to non-tenant farms. The impact on tenant farms is quantitatively smaller than for non-tenant farms, which could result from the fact that tenants spend less on irrigation to start with.

Tables 14 and 15 show analogous results for the effect of the reforms on expenditure on other inputs. For expenditure on bullock and seeds, IV coefficients of tenancy reform are negative and significant. Given the (weak) evidence in Table 6 of inelasticity of these factors, this suggests the tenancy program also had a supplementary negative effect on the price of seeds and bullock labor. Given the weak effect of these expenditures on farm productivity seen in Table 6 it is doubtful if this channel would be quantitatively important. Note that the evidence also shows that the cost of rice seeds fell as a consequence of the expansion in minikits provided. This corresponds to the fact that rice seeds were one of the most important ingredients in minikits supplied.

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

We have found evidence that irrigation costs represented an important source of spillover from the tenancy 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 all of the spillover effect. In order to do so, we construct a measure of productivity which nets out the irrigation effect, by subtracting from productivity the term involving irrigation expenditures, weighted by its estimated elasticity. We then regress this on implementation rates of the various programs:

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

where γ_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 6). The results are shown in Tables 16, 17.

The results show that tenancy registration and kits have no significant impact on rice yields or total value added net of the irrigation impact. For purpose of comparison, Table 19 provides the same reduced form regressions for productivity without netting out the irrigation impact (this is the same as the main regression reported in BM (2008b)). Without accounting for the irrigation impact, tenancy registration has a large positive and statistically significant impact on productivity. As shown in BM(2008b), most of this represented the effect on non-tenant farms in the village, as the effect did not vary significantly between tenant and non-tenant farms. Tables 16, 17 show that this effect vanishes when the irrigation impact is netted out. These results also suggest the absence of spillovers due to social learning.[16]

The coefficient of land titles distributed remains significant and positive. Hence land titling affected factors other than irrigation that increased farm productivity. Somewhat surprisingly, the irrigation impact also seems to account for a large part of the reduced form impact of the minikit program on value added per acre across all crops. This is not true for the supply of credit, or employment programs. The distribution of kits stimulated demand for groundwater, since the kits contained HYV seeds planted during the *boro* season, which are well known to be very water-intensive. Hence it is natural to expect a strong positive effect of minikit distribution on irrigation.

The credit effect is positive and significant in all specifications. 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.

4.4 Household Survey Evidence

Finally, Table 19 reports 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. 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 the local government programs as in earlier regressions.

[16]If owner-cultivators were learning from their tenant neighbors and adopting HYV of rice etc, this should have led to a positive and significant effect of tenancy registration on NOI-productivity.

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%. A secondary positive effect was exerted by minikits delivered. 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. Finally, column 6 regresses the proportion irrigated by canals. We see that the bulk of the positive effect of tenancy registration on medium and minor irrigation was accounted by its effect on area irrigated by shallow tubewells. There were no noticeable effects on areas irrigated by deep tubewells, river-lift/ponds or canals.

These results provide independent corroboration of the main hypothesis of this paper, that private investment in minor irrigation was stimulated by the tenancy reform program and extension programs implemented by local governments. It is based on a survey of a different sample of households carried out in 2004, whereas the evidence in earlier sections were based on yearly farm cost-of-cultivation surveys carried out between 1982 and 1995.

5 Concluding Comments

We have found evidence of pecuniary externalities operating through effects of the tenancy reforms and other development programs on the cost of irrigation. These help explain the large spillover effects of the tenancy reforms on farm productivity in non-tenant farms found in earlier work.

There were 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 irrigation investment. A tenant with access to cheap credit could then invest in a tubewell, but the water-delivery capacity of a tubewell is typically much larger than what the tenant would himself need. So the tenant would have to sell some of the water, lowering water costs for other non-tenant farms. The credit channel can explain why the land titling program did not have the same effect on irrigation investments (as land titles did not create the same credit access as a registered tenancy).

However it is unlikely the credit channel can account for all of the observed effect, since rising supply of minikits also had a significant impact on irrigation cost. This can be rationalized by complementarity between minikits and groundwater in the cultivation process: rising supplies of the former raised the demand for water, which induced higher investments in groundwater capacity by oligopolistic water sellers, lowering irrigation costs for farmers.

Our results indicate that irrigation and roads provided by local governments had a positive effect on productivity. But these were by no means sufficient to explain the growth in farm productivity. Our results complement the detailed studies carried out by Moitra and Das (2005) of the emergence and evolution of 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 private investment in irrigation, which in turn increased farm productivity. Both tenancy reforms and delivery of minikits played a key role in this respect. Complementarity between state-led institutional reforms and market-based investment incentives drove a large part of the West Bengal green revolution of the 1980s and 1990s.

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6 Appendix: Tables

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 leased	2.7	4.2
% 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 (2008b), Table 3

Table 2: Trends in Public Supplies of Agricultural Inputs

	1982	1985	1990	1995
Minikits per household	0.11	0.11	0.08	0.06
Minikits per hh cumulative	0.67	1.03	1.46	1.68
IRDP[a] per household	36	29	25	18
IRDP[a] per hh cumulative	288	507	608	662
GP Irrigation Expenditure[b]	5233	4265	1485	2627
GP Road Expenditure[c]	6470[d]	4501	2501	4572
GP Employment Mandays per household	3.9	3.0	2.2	1.9
Area Irrigated by State Canals (hectares)	72793	72168	79774	84672
State Road Length (Km)	1271	1282	1309	1320

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 (2008b), Table 4

Table 3: Trends in Farm Productivity, Incomes and Wages

	1982	1985	1986	1990	1991	1995
Cropped Area (acres)*	.99	1.07	.97	1.06	.98	.98
% Rice area HYV	1.24	7.63	16.54	32.92	45.87	52.70
Rice Value Added per acre	1055	1565	1624	2983	4135	5546
Value Added per acre	703	854	913	1272	1293	1454
Value Added per farm	7613	10915	11223	19070	20553	27349
Hired Labor Wage Rate	.57	.54	.83	.76	.81	.99
Hired Labor Annual Hrs/Acre	180	188	242	279	319	265

Average across farms, weighted by cropped areas, excepting*

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

Source: Bardhan and Mookherjee (2008b), Table 5B

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: Relation between Farm Yields and Per Acre Input Expenditures: All Farms

	Log of Rice Output per acre		Log of Total Value Added per acre	
	OLS	IV	OLS	IV
Log Expenditure on Irrigation	0.014**	-0.076**	-0.021**	-0.255***
per acre	(0.006)	(0.033)	(0.008)	(0.056)
Log Expenditure on Fertilizers	0.108***	0.399***	0.020*	0.484***
per acre	(0.016)	(0.065)	(0.012)	(0.100)
Log Expenditure on Seeds	0.120***	-0.260**	0.067***	-0.051
per acre	(0.026)	(0.111)	(0.023)	(0.154)
Log Expenditure on Labor	0.469***	0.814***	0.333***	1.112***
per acre	(0.036)	(0.133)	(0.027)	(0.195)
Log Expenditure on Bullock	-0.006	-0.031	-0.012	-0.120**
per acre	(0.017)	(0.056)	(0.014)	(0.056)
Log Price of Rice	-0.264***	-0.241***	0.331***	0.331***
	(0.056)	(0.077)	(0.059)	(0.112)
Observations	1590	1572	2221	2203
w-R-squared	0.35	-0.08	0.21	-1.27

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

Instruments included Congress share in Parliament, inflation and small factory employment in region/district interacted with lagged GP left share, and squares of these

Robust standard errors in parentheses clustered at village level

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

Table 7: First Stage Results for IV Regressions in Table 6

	Log of Rice Output per acre			Log of Total Value Added per acre		
	Partial R^2	F-stat	P-value	Partial R^2	F-stat	P-value
Log Expenditure on Irrigation per acre	.08	3.14	0.00	.05	2.85	0.00
Log Expenditure on Fertilizers per acre	.12	4.89	0.00	.05	2.64	0.00
Log Expenditure on Seeds per acre	.15	6.05	0.00	.09	5.15	0.00
Log Expenditure on Labor per acre	.11	4.35	0.00	.05	3.02	0.00
Log Expenditure on Bullock per acre	.15	6.02	0.00	.19	11.79	0.00

Table 8: Relation between Farm Yields and Per Acre Input Expenditures: Non-Tenant Farms

	Log of Total Value Added per acre	
	OLS	IV
Log Expenditure on Irrigation per acre	-0.021**	-0.229***
	(0.008)	(0.057)
Log Expenditure on Fertilizers per acre	0.030**	0.523***
	(0.012)	(0.105)
Log Expenditure on Seeds per acre	0.054**	-0.028
	(0.024)	(0.162)
Log Expenditure on Labor per acre	0.314***	1.131***
	(0.028)	(0.200)
Log Expenditure on Bullock per acre	-0.012	-0.103*
	(0.015)	(0.057)
Log Price of Rice	0.315***	0.350***
	(0.066)	(0.129)
Observations	2090	2078
w-R-squared	0.20	-1.36

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

Instruments included Congress share in Parliament, inflation and small factory employment in region/district interacted with lagged GP left share, and squares of these

Robust standard errors in parentheses clustered at village level

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

Table 9: Impact of Policy Interventions on Log of Per Acre Irrigation Expenditure in Rice Cultivation

	OLS	IV
Tenancy Registration[a]	-2.210***	-3.583***
	(.485)	(.586)
Land Titles[b]	0.236	2.507***
	(.443)	(.649)
Minikits/HH	-0.469*	-1.993***
	(.224)	(.427)
IRDP Credit/HH	0.000	0.001
	(.001)	(.001)
Mandays/HH	0.005	-0.143
	(.051)	(.087)
Obs., w-R-squared	2099, .06	2089, .01

All regressions include farm, year dummies; rice price; annual rainfall;

controls for state-provided canals, GP expenditures on irrigation, roads

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

Robust standard errors in parentheses clustered at village level

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

Table 10: First Stage Results for IV Regressions in Table 9

	Partial R^2	F-stat	P-value
Tenancy Registration	.95	947.36	0.00
Land Titles	.58	66.19	0.00
Minikits	.50	47.18	0.00
Credit	.60	73.66	0.00
Mandays	.35	25.91	0.00

Table 11: Impact of Policy Interventions on Log of Per Acre Total Irrigation Expenditure on All Crops

	OLS	IV
Tenancy Registration[a]	-1.696***	-2.534***
	(.435)	(.533)
Land Titles[b]	0.283	1.600***
	(.355)	(.497)
Minikits/HH	-0.379*	-1.295***
	(.214)	(.388)
IRDP Credit/HH	0.000	0.001
	(.001)	(.001)
Mandays/HH	0.031	-0.076
	(.046)	(.078)
Obs., w-R-squared	2152, .06	2142, .03

All other comments as in Table 9

Robust standard errors in parentheses clustered at village level.

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

Table 12: First Stage Results for IV Regressions in Table 11

	Partial R^2	F-stat	P-value
Tenancy Registration	.94	900.876	0.00
Land Titles	.64	89.01	0.00
Minikits	.47	44.5	0.00
Credit	.60	74.79	0.00
Mandays	.35	26.78	0.00

Table 13: Impact on Log of Per Acre Irrigation Expenditure in Cultivation of Rice and All Crops: Tenant vs. Non-tenant Farms

	Rice		All Crops	
	OLS	IV	OLS	IV
Lease Dummy	-0.516	-0.525	-0.296	-0.331
	(.345)	(.352)	(0.215)	(0.220)
Lease Dummy*	5.393	1.296	0.534	0.369
Tenancy Registration	(9.640)	(9.894)	(1.676)	(1.713)
Tenancy Registration[a]	-2.209***	-3.615***	-1.699***	-2.549***
	(.485)	(.587)	(0.435)	(0.533)
Land Titles[b]	0.264	2.588***	0.301	1.634***
	(.443)	(.653)	(0.355)	(0.499)
Minikits/HH	-0.471*	-2.036***	-0.389*	-1.323***
	(.245)	(.429)	(0.214)	(0.390)
IRDP Credit/HH	0.000	0.001	0.000	0.001
	(.001)	(.001)	(0.001)	(0.001)
Mandays/HH	0.003	-0.142	0.031	-0.071
	(.051)	(.087)	(0.046)	(0.078)
Obs., w-R-squared	2099, .06	2089, .01	2152, .07	2142, .03

All other comments as in Table 9

Robust standard errors in parentheses clustered at village level

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

Table 14: Impact on Log Per Acre Expenditures on other Inputs in Rice

	Fertilizers		Bullock		Seeds		Labor	
	OLS	IV	OLS	IV	OLS	IV	OLS	IV
Tenancy Registration[a]	-0.082	0.099	-0.070	-0.384*	0.003	-0.327**	0.032	0.154
	(0.246)	(0.317)	(0.185)	(0.221)	(0.126)	(0.152)	(0.104)	(0.124)
Land Titles[b]	0.847	5.747*	-0.393**	-0.191	-0.011	0.342**	0.201**	0.011
	(1.934)	(2.933)	(0.169)	(0.244)	(0.115)	(0.168)	(0.095)	(0.137)
Minikits/HH	-0.150	0.002	0.074	-0.294*	-0.098	-0.407***	0.054	0.091
	(0.161)	(0.280)	(0.093)	(0.162)	(0.063)	(0.111)	(0.052)	(0.090)
IRDP credit/HH	0.001***	0.001	0.001**	-0.000	-0.000	-0.000**	0.000	0.000
	(0.000)	(0.001)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
Mandays/HH	-0.009	0.130***	-0.036*	-0.032	-0.037***	-0.062***	0.006	0.024
	(0.029)	(0.049)	(0.020)	(0.033)	(0.013)	(0.023)	(0.011)	(0.018)
Observations	1551	1541	2054	2044	2092	2082	2094	2084
w-R-squared	0.07	0.05	0.18	0.16	0.12	0.08	0.09	0.09

All other comments as in Table 9

Robust standard errors in parentheses clustered at village level.

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

Table 15: 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[a]	-0.003	0.199	-0.119	-0.350	-0.438**	-0.765***	-0.099	-0.013
	(0.309)	(0.374)	(0.255)	(0.308)	(0.181)	(0.219)	(0.152)	(0.184)
Land Titles[b]	-0.733***	-0.333	-0.595***	-0.620**	0.005	0.222	0.099	-0.048
	(0.252)	(0.349)	(0.207)	(0.288)	(0.148)	(0.204)	(0.124)	(0.172)
Minikits/HH	0.010	-0.046	0.114	-0.239	-0.026	-0.259	0.097	0.124
	(0.152)	(0.272)	(0.125)	(0.225)	(0.089)	(0.159)	(0.075)	(0.134)
IRDP Credit/HH	0.001**	0.001**	0.001***	-0.000	-0.001***	-0.001***	0.000	0.000
	(0.000)	(0.001)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
Mandays	-0.060*	0.038	-0.072***	-0.044	-0.023	-0.026	-0.008	0.023
	(0.033)	(0.055)	(0.027)	(0.045)	(0.019)	(0.032)	(0.016)	(0.027)
Observations	2152	2142	2152	2142	2152	2142	2152	2142
w-R-squared	0.04	0.03	0.15	0.14	0.09	0.08	0.08	0.07

All other comments as in Table 9

Robust standard errors in parentheses clustered at village level.

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

Table 16: Effect of Land Reforms and Other Development Programs on Rice Yields, Net of Irrigation Effect[a]

	OLS	IV	OLS	IV
Tenancy Registration	0.210	0.350	0.078	0.175
	(0.204)	(0.250)	(0.140)	(0.174)
Land Titles	0.371**	1.037***	0.327***	0.910***
	(0.184)	(0.266)	(0.126)	(0.184)
Minikits/HH	0.059	-0.238	0.180**	0.032
	(0.100)	(0.182)	(0.070)	(0.133)
IRDP Credit/HH	0.001**	0.002***	0.000***	0.001***
	(0.000)	(0.000)	(0.000)	(0.000)
Mandays/HH	0.083***	0.186***	0.017	0.072***
	(0.021)	(0.035)	(0.015)	(0.025)
Other State/District Controls Included	No	No	Yes	Yes
Observations	2099	2089	2091	2081
w-R-squared	0.12	0.08	0.14	0.10

a. The dependent variable is rice yield net of the effect of irrigation expenditure in rice. i.e. $log\ y - \hat{\beta} logExp_{irririce}$, where $\hat{\beta}$ is estimated from Table 6

All other comments as in Table 9

Robust standard errors in parentheses clustered at village level.

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

Table 17: Effects of Land Reforms and Other Development Programs on Total Value Added, Net of Irrigation Effect[a]

	OLS	IV	OLS	IV
Tenancy Registration	-0.102	-0.048	-0.120	-0.149
	(0.183)	(0.225)	(0.181)	(0.224)
Land Titles	0.112	0.625***	0.183	0.737***
	(0.146)	(0.201)	(0.145)	(0.201)
Minikits/HH	0.329***	0.208	0.286***	0.057
	(0.088)	(0.166)	(0.087)	(0.171)
IRDP Credit/HH	0.001***	0.002***	0.001***	0.002***
	(0.000)	(0.000)	(0.000)	(0.000)
Mandays/HH	0.061***	0.092***	0.052***	0.097***
	(0.019)	(0.032)	(0.019)	(0.032)
Other State/District Controls Included	No	No	Yes	Yes
Observations	2138	2128	2138	2128
w-R-squared	0.12	0.09	0.14	0.11

a. The dependent variable is value added per acre net of the effect of irrigation expenditure. i.e.$log(va) - \hat{\beta} logExp_{irri}$,

where $\hat{\beta}$ is estimated from Table 6

All other comments as in Table 9

Robust standard errors in parentheses clustered at village level.

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

Table 18: Effects of Land Reforms and Other Development Programs on Farm Productivity, Including Irrigation Effect

	Log of Rice Output per acre		Log of total Value per acre	
	OLS	IV	OLS	IV
Tenancy Registration[a]	0.394**	0.835***	0.369**	0.774***
	(0.197)	(0.238)	(0.146)	(0.179)
Land Titles[b]	0.275	0.535**	-0.032	-0.052
	(0.180)	(0.263)	(0.119)	(0.167)
Minikits/HH	0.030	0.141	0.434***	0.709***
	(0.099)	(0.173)	(0.072)	(0.132)
IRDP Credit/HH	0.001**	0.001***	0.001***	0.001***
	(0.000)	(0.000)	(0.000)	(0.000)
Mandays/HH	0.063***	0.178***	0.053***	0.112***
	(0.021)	(0.035)	(0.016)	(0.026)
Other State/District Controls Included	Yes	Yes	Yes	Yes
Observations	2099	2089	2138	2128
R-squared	0.13	0.10	0.16	0.13

All other comments as in Table 9

Robust standard errors in parentheses clustered at village level.

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

Table 19: Effects of Local Govt. Programs on Medium and Minor Irrigation

	Shallow+Deep Tubewell +Riverlift IV	Shallow+Deep Tubewell IV	Shallow Tubewell IV	Deep Tubewell IV	River-lift +Ponds IV	Canals
Tenancy Registration	18.06***	13.83**	11.21*	.009	4.56	0.0638
	(6.925)	(6.24)	(6.122)	(0.038)	(3.54)	(0.072)
Land Titles	-8.255	-4.383	9.661	.306	-5.33	0.160
	(49.37)	(44.51)	(43.98)	(0.274)	(25.47)	(0.520)
Minikits/HH	10.60*	10.70**	7.57	0.008	0.338	0.065
	(5.475)	(4.937)	(4.748)	(0.029)	(2.750)	(0.056)
IRDP Credit/HH	0.010	0.003	0.003	0.000	0.006	0.0004***
	(0.009)	(0.008)	(0.008)	(0.005)	(0.005)	(0.0001)
Mandays/HH	-2.043**	-2.198**	-2.854***	0.005	0.113	-0.013
	(0.971)	(0.876)	(0.919)	(0.006)	(0.532)	(0.011)
Other State/District Controls Included	Yes	Yes	Yes	Yes	Yes	Yes
Observations, Villages	250,64	250, 64	245,63	245,63	245,63	245,63
w-R-squared	0.35	0.24	0.27	0.03	0.215	0.009

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

All regressions include village dummies

All other comments as in Table 9

Robust standard errors in parentheses clustered at village level.

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