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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☆

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ABSTRACT

We estimate the role of private investments in irrigation in farm productivity growth in West Bengal, India between 1982 and 95. Using a state-wide farm panel, we find that falling groundwater costs generated significant growth in value added per acre for farms. These resulted from investments in minor irrigation which was 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.

## 1. Introduction

A key issue in agricultural development in LDCs concerns the respective roles of public and private sectors. Do 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? Do government development policies crowd out or stimulate private investment? This paper studies these questions in the context of the Indian state of West Bengal 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.[1]

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 three tier system of elected local governments, devolving to them responsibility for implementing programs for local infrastructure and delivery of subsidized farm inputs. Many authors have attributed most of the credit for the West Bengal green revolution to these institutional reforms (e.g., see Banerjee et al., 2002; Lieten, 1992; 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 investments in minor irrigation such as tubewells, thereby suggesting that 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

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[1] These numbers, as well as the analysis in this paper, are based on farm cost of cultivation surveys in an all-West-Bengal survey, used in Bardhan and Mookherjee (2011). See Section 3 below for further details of the sample and data. For corresponding statistics published by the West Bengal government concerning agricultural performance at the district level, see Banerjee et al. (2002) or Saha and Swaminathan (1994).

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farm productivity growth in West Bengal, nor any analysis of the determinants of such investments. Hence it is difficult to distinguish between the roles of the government reforms vis-a-vis private investments in irrigation.

The recent work of Bardhan and Mookherjee (2011, BM hereafter) has examined the role of various programs implemented by local governments to raise farm productivity, using three successive panels of farm-level cost of cultivation surveys spanning 1982–95. BM found a statistically significant effect of the tenancy registration program on farm value added per acre, and a much larger effect of public distribution of agricultural minikits (containing subsidized seeds and fertilizers) on farm productivity. One surprising finding was that the benign effects of the tenancy registration program were not confined to tenant farms alone: they exhibited substantial spillovers to non-tenant farms. This implies that the effects of tenancy reforms cannot be understood entirely in terms of Marshallian (partial equilibrium) effects on tenant effort and investment incentives. The exact nature of these spillovers however remained unclear from their analysis.

The purpose of this paper is to examine the role of private investments in minor irrigation in generating farm productivity growth, and subsequently whether these investments may have been stimulated by the tenancy reform. If so, does this account for the spillover effects of the tenancy reform to non-tenant farms?

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 involves large fixed costs (tubewells, dugwells and submersible pumps), subsequently 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.[2] A third possible channel is that implementation of the tenancy program by local governments was accompanied by investments in medium irrigation programs (such as river-lift schemes and ponds) intended to enhance access of registered tenants to groundwater. Either of these three channels would result in a fall in groundwater costs for all farms in the village, including non-tenant farms.

This hypothesis generates a number of empirically testable predictions. First, farm value added per acre should increase significantly when groundwater costs fall, controlling for other input costs. Second, stepped up implementation of the tenancy registration program should induce farm water costs in the village to subsequently fall. Using the same farm panel data set as BM, we test these predictions, and thereafter examine the extent to which this accounts for the spillover effect of the tenancy reform on non-tenant farms. We also examine evidence for each of the three channels described above.

The empirical analysis upholds the main predictions. Specifically, farm value added per acre exhibited a statistically significant elasticity of −0.24 with respect to water expenditures, controlling for farm expenditures on other inputs (fertilizers, seeds, hired labor, bullock), government provision of irrigation and roads, annual rainfall, year dummies and farm fixed effects. This estimate controls for potential endogeneity and measurement error in farm water expenditures, using as instruments (similar to the BM analysis) 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.

Next, we find that an increase in the proportion of village agricultural land covered by the tenancy registration program induced a significant reduction in farm groundwater costs. The estimated percentage cost reduction following an increase of 1% area covered by the tenancy registration program was 1.15 in the OLS estimate and 1.6 in the IV estimate. Moreover, consistent with our theory in which the direct (Marshallian) effect of the tenancy program increases demand for groundwater among tenant farms, we find that water expenditures in tenant farms fell by less than in non-tenant farms.

These two sets of estimates imply that farm value added per acre would rise roughly by 0.4 in non-tenant farms following a 1% increase in tenancy program coverage rate (1.6% reduction in groundwater costs, multiplied by 0.24). This is almost exactly equal to the observed magnitude of the reduced form impact of the tenancy program coverage rate on farm productivity in non-tenant farms. Hence the effect of the tenancy program on groundwater cost reduction seems to account for the entire spillover. To corroborate this, we construct a measure of farm value added net of irrigation costs (NOI), by subtracting groundwater expenditure weighted by the IV estimate of the elasticity of farm value added with respect to water costs. Regressing 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.

Finally, 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 household questions concerning the evolution of their landholdings including irrigation status and source over the period 1967–2004. In line with other findings in the literature, the main source of growth in irrigation in West Bengal during this period 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 was irrigated by tubewells, river-lift schemes and ponds, with the former exhibiting the dominant effect.

In summary, these results indicate that investments in minor and medium irrigation played a significant role in the growth of farm productivity in West Bengal between 1982 and 95. Private investments in minor irrigation accounted for the lions share of this expansion. But these investments in turn were endogenously stimulated by the tenancy registration reforms, mainly by expanding the market demand for groundwater. So the tenancy reforms exercised both a direct (Marshallian) effect on productivity in tenant farms, and a subsequent spillover effect on other farms by stimulating capacity investment by water-sellers which reduced groundwater prices. A secondary impact was a positive correlation between implementation of the tenancy reform and investments by local governments in medium irrigation programs. These general equilibrium impacts accounted for the observed productivity effects of the tenancy reform on owner cultivated farms.

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 empirical support for this view.

The state also played other important roles: the delivery of subsidized farm inputs (credit, seeds and fertilizers) and public employment schemes implemented by local governments. Indeed, the results in Bardhan and Mookherjee (2011) show that their

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[2] 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, 1996) and Paraguay (Carter and Olinto (1996)).

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 groundwater 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 water and other inputs as given. An owner–cultivator then decides on effort $e$ and input applications $x$,$z$ to maximize

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

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: together rising in $p$ and $\alpha$, falling in $q$ and $r$.

Tenancy registration results in an increase in $\alpha$ for tenant cultivators.[3] There is a direct effect on productivity of tenant farms alone, for a given set of 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 that 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 are 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 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 and 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), in which the basic mechanism we are focusing on would continue to apply. So we abstract from capacity limits for the sake of simplicity.

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 decides 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

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

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

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

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, inducing 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

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[3] 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.

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.

A third possible channel is direct investment by local governments in medium irrigation projects such as river-lift schemes and ponds. Local governments implementing the tenancy reform may be motivated to assist registered tenants by enhancing their access to groundwater, and thus increase their investment in medium irrigation projects.

## 3. Background, data and descriptive statistics

### 3.1. Land reforms and local government farm development programs

There were two land reform programs 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 (averaged across the entire set of 89 villages in our sample) at the end of 1978 and 1998 respectively. By 1998 about 6.1% of operational land had been 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 received titles to land amounting to 5.4% of operational land in the village.

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.

**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 full set of 89 sample villages, weighted by operational land areas.
Source: Bardhan and Mookherjee (2011), Table 1.

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 a 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 5 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 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 different forms of local infrastructure, such as roads, ponds and river-lift schemes, and other local buildings such as schools. They supervised construction and decided who would be employed on the projects. These employment opportunities were intended as a social safety net for poor households.

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. Bardhan and Mookherjee (2006) found inter-GP and inter-village allocation of these programs subject to anti-poor and anti-low-caste biases, while 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 Bardhan and Mookherjee (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 farm level data-set as Bardhan and Mookherjee (2011), consisting of over 500 farms spread across a total of 89 villages located in 15 major agricultural districts in West Bengal. It consists of three successive farm panels covering the periods 1982–85, 1986–90 and 1991–95 respectively. Each panel includes a subset of the 89 villages, with villages selected in pairs from within randomly selected blocks within each district. The first village was selected randomly and the other one selected from those with a different irrigation status within an 8 km 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. Within each village 8 farms were selected randomly, stratifying by farm size (across four classes, with thresholds of 2.5, 5 and 10 acres).

For any given farm in the sample, investigators were responsible for collecting data on all items of farm expenditures for each crop planted on a bi-weekly basis for five successive years. However, the data available to us is aggregated to the year level and entries are complete for between 3 to 5 years per farm. Apart from the main products and by-products harvested and sold, annual farm cultivation costs for each crop are broken down into (i) use of family and hired labor, and wages paid to the latter; (ii) seeds and plants; (iii) manures, fertilizer and pesticides; (iv) marketing costs; (v) groundwater costs; (vi) purchase, sale or repair of all articles used in farming; (vii) use of land and rents paid; (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 were 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 farm data is complemented by village survey data on local government composition, budgets, expenditure on major schemes administered by local governments. In addition we have access to: (a) data concerning land reforms implemented in the village between 1971 and 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.[4]

### 3.3. Descriptive statistics

Table 2 gives the trends for some of these programs, using the data for those villages contained in the farm panels for various years. 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 bottom two rows of this table provide averages of the cumulative land reforms implemented in the two programs for villages contained in the farm panel.[5]

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 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 and 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 and 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% of net sown area was irrigated by ground water which amounted to approximately 50% of net irrigated area in the state.[6] Surface lift schemes showed a comparatively modest increase of 49%.

Table 5 indicates the relative importance of different sources of irrigation in our sample villages, based on an independent household landownership survey carried out in 2004. This survey utilized a stratified random sample of approximately 25 households in the same villages involved in the cost-of-cultivation surveys. Each household was asked to list all plots they owned since 1967, including whether or not it was irrigated and the source of irrigation in any given year.[7] 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 the entire set of 89 villages for each year between 1981 and 1995. It indicates more than a four-fold expansion of land irrigated

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[4] Greater detail on the various datasets is provided in Bardhan and Mookherjee (2006, 2010, 2011).

[5] These averages differ from those in Table 1 because the latter pertain to the entire sample of 89 villages, whereas Table 2 reports averages for the subset of villages included in the farm panel corresponding to any given year.

[6] Census of Minor Irrigation 1993–94.

[7] Further details of the survey are provided in Bardhan et al. (2009).

**Table 2**
Trends in public supplies of agricultural inputs and land reform.

| | 1982 | 1985 | 1990 | 1995 |
|---|---|---|---|---|
| Minikits per household[a] | 0.11 | 0.11 | 0.08 | 0.06 |
| Minikits per hh cumulative | 0.67 | 1.03 | 1.46 | 1.68 |
| IRDP per household[a,b] | 36 | 29 | 25 | 18 |
| IRDP per hh cumulative[b] | 288 | 507 | 608 | 662 |
| GP irrigation expenditure[a,c] | 5233 | 4265 | 1485 | 2627 |
| GP road expenditure[a,c] | 6470[d] | 4501 | 2501 | 4572 |
| GP employment mandays per household[a] | 3.9 | 3.0 | 2.2 | 1.9 |
| Area irrigated by state canals (hectares) | 72,793 | 72,168 | 79,774 | 84,672 |
| State road length (km) | 1271 | 1282 | 1309 | 1320 |
| Cumulative proportion land area with tenancy registration | 0.05 | 0.15 | 0.14 | 0.12 |
| Cumulative proportion land area titles distributed | 0.03 | 0.06 | 0.07 | 0.07 |

Average across villages in farm panel for corresponding year, weighted by operational land areas.

[a] Average of yearly flows.

[b] IRDP credit subsidy, 1980 prices.

[c] Expenditure out of employment program funds, 1980 prices.

[d] Expenditure out of employment program funds for year 1983.

by shallow tubewells, from 7.6% to 31.4% of operational land between 1981 and 1995. 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. This assessment is consistent with that provided by Rawal (2001) in his overview of irrigation expansion in West Bengal during the 1980s and 90s.

Fig. 1 shows 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 was 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.

**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 all 89 sample villages, weighted by operational land area.
Source: Household survey.

### *3.4. Tenancy prevalence and effects of Operation Barga*

Table 6 provides the incidence of tenancy in farms in our sample at the beginning and end year of each panel. The middle panel appears to be characterized by an exceptionally low extent of tenancy, compared with the first and the third. Focusing on the latter, we see between 2 and 3% of farms leasing in land during 1982–85, a proportion which fell to between 1 and 2% during 1991–95. The proportion of cultivated land under tenancy was larger than the proportion of households, but also exhibited a downward trend: from 12.9% to 6.9% in the first panel, and from 6.5% to 4.3% in the third panel. These are roughly consistent with estimated proportions of 12% and 7% of operational land under sharecropping tenancy for the state as a whole in 1982 and 1992 respectively, from the land surveys of the National Sample Survey. And as seen in Table 1 the proportion of land covered by the tenancy registration program by 1998 was approximately 6%, representing a 4% increase over the 2% already registered by 1978.

Table 6 also shows the relationship between tenancy and farm size. It is *not* the case that tenancy is concentrated among small farms (where small farms are defined as those with less than 2.5 acres, medium farms with between 2.5 and 5 acres, and rest are considered large). The average size of tenant farms exceeded the

**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 | 10,915 | 11,223 | 19,070 | 20,553 | 27,349 |
| Hired labor wage rate | .57 | .54 | .83 | .76 | .81 | .99 |
| Hired labor annual h/acre | 180 | 188 | 242 | 279 | 319 | 265 |

Average across farms in each panel, weighted by cropped areas, except those data with "*".
All rupee figures deflated by cost of living index, 1974 = 100.
Source: Cost of Cultivation Surveys.

**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.

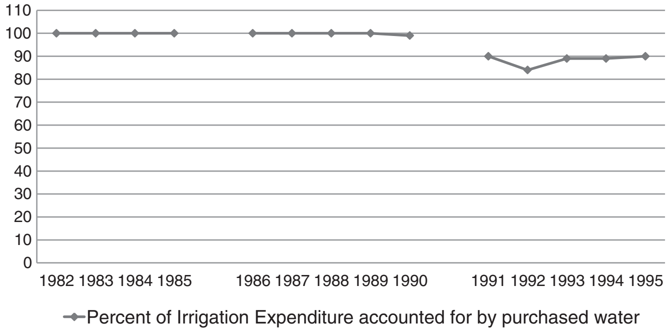

**Fig. 1.** Percentage of farms irrigated.

**Table 6**
Tenancy and farm size.

| | 1982 | 1985 | 1986 | 1990 | 1991 | 1996 |
|---|---|---|---|---|---|---|
| Percent farms leasing in land | 2.13 | 3.38 | 0.44 | 0.43 | 1.17 | 1.58 |
| Percent cultivable area of farms leasing in land | 12.98 | 6.94 | 1.2 | 2.07 | 6.54 | 4.27 |
| Average farm size (in acres) | 4.8 | 4.6 | 5.0 | 4.8 | 4.5 | 4.4 |
| Average farm size among leased farmers (in acres) | 6.6 | 3.2 | 4.1 | 5.7 | 5.1 | 4.1 |
| Average size of small farms (in acres) | 1.8 | 1.9 | 1.6 | 1.6 | 1.6 | 1.4 |
| Average size of medium farms (in acres) | 3.7 | 3.8 | 3.8 | 3.8 | 3.6 | 3.8 |
| Average size of large farms (in acres) | 9.7 | 8.8 | 8.7 | 8.6 | 7.9 | 7.9 |
| Fraction of farmers leasing among small farmers | 0.03 | 0.08 | 0.02 | 0.02 | 0.04 | 0.07 |
| Fraction of farmers leasing among medium farmers | 0.15 | 0.21 | 0.00 | 0.01 | 0.02 | 0.03 |
| Fraction of farmers leasing among large farmers | 0.12 | 0.00 | 0.02 | 0.02 | 0.10 | 0.04 |

Averages across farms in each panel for corresponding years.
Source: Cost of cultivation survey.

average size of all farms in 1982, 1990 and 1991. In the first panel, a larger proportion of medium and large farms leased in land were compared with small farms. In 1991 almost twice as many large farms leased in land were compared with small farms. These reflect the phenomenon of reverse tenancy, arising due to extensive fragmentation of landholdings, wherein large farmers often lease in land from small farmers in order to consolidate their agricultural operations.

Next, Table 7 presents an OLS regression of log of farm value added per acre on the major government initiatives during this time, essentially reproducing results from Column 3, Table 6 in Bardhan and Mookherjee (2011).[8] The regressors include the tenancy registration rate (representing percent operational land area covered by Operation Barga), delivery of agricultural minikits (cumulated number of kits per household), of subsidized credit (cumulative credit subsidy per household), employment mandays generated per household, land title program coverage (percent of operational land area distributed), a dummy for a farm that leases in land, and interaction of the lease dummy with the tenancy registration rate in the village. Controls include the price of rice, annual rainfall, farm and year dummies, district averages of state roads and canals, local government expenditures on roads and irrigation, and total cropped area of the farm and its square (capturing possible scale economies). Table A1 provides the definition of all variables used in the regressions, besides their means and standard deviations.

Table 7 shows that an increase of 1% land area covered by the tenancy reform program was associated with a 0.42% increase in value added per acre for the representative non-tenant farm in the village, with a supplementary 0.25% increase in tenant farms. The former is statistically significant at 1%, while the differential impact on tenant farms fails to be statistically significant. This possibly reflects the small proportion of tenant farms in the sample.[9]

These estimates imply that a 1% rise in area covered by Operation Barga resulted in a 0.7% increase in productivity in tenant farms, and 0.4% increase in non-tenant farms. The spillover effect of the program on non-tenant farms is sizeable and precisely estimated. One of the purposes of this paper is to understand the extent to which induced effects on irrigation investment accounted for this spillover.

## 4. Empirical results

### 4.1. Factor price effects on farm productivity

Consider first 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, Shephard's 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,

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

**Table 7**
Effects of land reforms and other development programs on log of total value added per acre.

| | OLS |
|---|---|
| Tenancy registration | 0.423*** |
| (% area) | (0.127) |
| Minikits/HH | 0.494*** |
| (cumulative) | (0.165) |
| IRDP credit/HH | 0.001* |
| (cumulative) | (0.000) |
| Mandays/HH | 0.048 |
| | (0.031) |
| Land titles | 0.187 |
| (% area) | (0.119) |
| Lease dummy | −.053 |
| | (0.056) |
| Lease dummy* | 0.254 |
| Tenancy registration | (0.155) |
| Observations | 2083 |
| $R^2$ | 0.135 |

Regression includes farm and year fixed effects. Other controls include rainfall, GP local irrigation expenditures, GP local road expenditures, log price of rice, state canals in district, state roads in district, total acreage cropped and its square.
Robust standard errors in parentheses clustered at village level. *, **, *** significant at 10%, 5%, 1%, respectively.

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[8] The only difference is that here we add a dummy for tenant farms, and its interaction with the area covered by the tenancy reform, to identify the differential effect of the reform on tenant farms.

[9] As shown in Bardhan and Mookherjee (2011), the effects of the tenancy reform did not vary significantly across small, medium and large farms. However the effects were less pronounced among marginal farms smaller than 1.25 acres. This is possibly due to the fact that the average size of farms leasing in land was in excess of 1.25 acres.

**Table 8**
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 water | −0.009 | −0.234$^{*}$ | −0.242$^{**}$ | −0.010 | −0.221$^{*}$ | −0.213$^{**}$ |
| per acre | (0.008) | (0.141) | (0.113) | (0.008) | (0.131) | (0.090) |
| Log expenditure on fertilizers | 0.017 | 0.037 | 0.063$^{**}$ | 0.032$^{*}$ | 0.117 | 0.075$^{**}$ |
| per acre | (0.018) | (0.160) | (0.032) | (0.018) | (0.170) | (0.030) |
| Log expenditure on seeds | 0.056$^{*}$ | −0.071 | 0.144$^{**}$ | 0.042 | −0.141 | 0.122$^{**}$ |
| per acre | (0.029) | (0.187) | (0.060) | (0.027) | (0.173) | (0.054) |
| Log expenditure on labor | 0.290$^{***}$ | 0.556$^{**}$ | 0.343$^{***}$ | 0.262$^{***}$ | 0.512$^{**}$ | 0.306$^{***}$ |
| per acre | (0.063) | (0.241) | (0.080) | (0.060) | (0.240) | (0.075) |
| Log expenditure on bullock | −0.007 | 0.016 | −0.054 | −0.005 | 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 | 0.373$^{***}$ | 0.356$^{***}$ | 0.427$^{***}$ | 0.392$^{***}$ | 0.409$^{***}$ | 0.456$^{***}$ |
| | (0.078) | (0.121) | (0.105) | (0.101) | (0.146) | (0.123) |
| Observations | 1856 | 1856 | 1856 | 1750 | 1750 | 1750 |
| $R^2$ | 0.169 | −0.543 | −0.437 | 0.155 | −0.556 | −0.334 |
| | | | | | | |
| *First stage F-stat*[a] | | | | | | |
| Log expenditure on water | | 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 water expenditure instrumented.
Set of excluded instruments: Congress seats in Parliament, average vote share difference, state average for kits, credit, and employment, lagged Left share and its square, and interactions among these Robust standard errors in parentheses clustered at village level.

[a] p-values on all first stage F-stats is 0.000.

$^{***}$ $p<0.01$.

$^{**}$ $p<0.05$.

$^{*}$ $p<0.1$.

where $\epsilon_{ii}$ denotes the own price-elasticity of demand for factor $i$. Inserting this into Eq. (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

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

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.[10]

In any case, viewing expenditure changes as induced by underlying factor price changes, we can estimate regressions corresponding to Eqs. (10) and (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:

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

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[10] 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 $\left[\left(1-\epsilon_{ii}\right)-\epsilon_{ji}\frac{\epsilon_{ij}}{1-\epsilon_{jj}}\right] > 0$, i.e., if and only if $\frac{d\log s_i}{d\log E_i} > 0$.

**Table 9**
Impact of policy interventions on log of per acre irrigation expenditure on all crops.

| | Log total water | | Log own water | | Log purchased water | |
|---|---|---|---|---|---|---|
| | Expenditure per acre | | Expenditure per acre | | Expenditure per acre | |
| | OLS | IV | OLS | IV | OLS | IV |
| Tenancy registration[a] | −0.965$^{***}$ | −1.614$^{***}$ | −0.133 | −0.303 | −0.801$^{**}$ | −1.294$^{**}$ |
| (% area) | (0.244) | (0.566) | (0.246) | (0.417) | (0.348) | (0.648) |
| Minikits/HH | 0.433 | −0.105 | −0.132 | −0.268 | 0.560$^{*}$ | 0.139 |
| (cumulative) | (0.285) | (0.539) | (0.223) | (0.438) | (0.321) | (0.567) |
| IRDP credit/HH | 0.002$^{*}$ | 0.002 | −0.001 | −0.001 | 0.004$^{*}$ | 0.003 |
| (cumulative) | (0.001) | (0.001) | (0.001) | (0.001) | (0.002) | (0.002) |
| Mandays/HH | 0.016 | 0.021 | 0.084$^{**}$ | 0.085$^{**}$ | −0.096 | −0.092 |
| | (0.062) | (0.059) | (0.042) | (0.043) | (0.083) | (0.081) |
| Land titles[b] | −1.203 | −0.880 | 0.484 | 0.565 | −1.795 | −1.542 |
| (% area) | (1.279) | (1.559) | (0.617) | (0.749) | (1.347) | (1.444) |
| Lease dummy | −0.169 | −0.193 | −0.141 | −0.147$^{*}$ | −0.045 | −0.064 |
| | (0.173) | (0.177) | (0.088) | (0.087) | (0.179) | (0.182) |
| Lease dummy* | 0.511 | 0.383 | 0.556 | 0.524 | 0.006 | −0.096 |
| Tenancy registration | (0.477) | (0.516) | (0.418) | (0.406) | (0.492) | (0.496) |
| Observations | 1780 | 1780 | 1780 | 1780 | 1780 | 1780 |
| $R^2$ | 0.038 | 0.035 | 0.030 | 0.029 | 0.042 | 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 and roads, total cropped area and its square, number of electrified deep and shallow tubewells at district level for each year.
Credit and kits are cumulative past provision.
Tenancy registration and minikits is instrumented in the IV regressions. Instruments included same as Table 8.
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.

[a] Lagged cumulative proportion of operational land registered under Operation Barga.
[b] Lagged cumulative proportion of operational land distributed as *pattas*.
[***] $p<0.01$.
[**] $p<0.05$.
[*] $p<0.1$.

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.

**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 | 0.047 | 0.217 | 0.121 | 0.477 | −0.516$^{***}$ | −0.386$^{**}$ | −0.035 | 0.014 |
| (% area) | (0.217) | (0.557) | (0.245) | (0.717) | (0.133) | (0.257) | (0.087) | (0.183) |
| Minikits/HH | 0.251 | 0.273 | 0.187 | 0.634 | −0.058 | 0.147 | 0.130 | 0.200 |
| (cumulative) | (0.204) | (0.513) | (0.314) | (0.925) | (0.136) | (0.260) | (0.136) | (0.237) |
| IRDP credit/HH | 0.000 | 0.000 | 0.003 | 0.003$^{*}$ | −0.001 | −0.001 | 0.000 | 0.000 |
| (cumulative) | (0.001) | (0.001) | (0.002) | (0.002) | (0.001) | (0.001) | (0.000) | (0.000) |
| Mandays/HH | −0.006 | −0.006 | −0.107$^{*}$ | −0.105$^{*}$ | −0.022 | −0.021 | −0.014 | −0.014 |
| | (0.045) | (0.046) | (0.059) | (0.059) | (0.030) | (0.030) | (0.026) | (0.026) |
| Land titles | −0.197 | −0.210 | −0.478 | −0.626 | −1.092$^{***}$ | −1.158$^{***}$ | −0.293 | −0.316 |
| (% area) | (0.917) | (0.941) | (2.667) | (2.892) | (0.422) | (0.427) | (0.418) | (0.444) |
| Observations | 1926 | 1926 | 1926 | 1926 | 1926 | 1926 | 1926 | 1926 |
| $R^2$ | 0.014 | 0.013 | 0.045 | 0.039 | 0.018 | 0.015 | 0.033 | 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 9.
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 log of total value added per acre.

| | Total | | Net of water expenditure[a] | |
|---|---|---|---|---|
| | OLS | IV | OLS | IV |
| Tenancy registration | 0.200*** | 0.404** | 0.072 | −0.067 |
| (% area) | (0.079) | (0.178) | (0.094) | (0.188) |
| Minikits/HH | 0.175 | 0.404* | 0.283*** | 0.353 |
| (cumulative) | (0.123) | (0.212) | (0.127) | (0.227) |
| IRDP credit/HH | 0.000 | 0.001 | 0.001** | 0.001** |
| (cumulative) | (0.000) | (0.000) | (0.000) | (0.000) |
| Mandays/HH | 0.059*** | 0.060*** | 0.063*** | 0.064*** |
| | (0.020) | (0.021) | (0.022) | (0.023) |
| Land titles | −0.742 | −0.822* | −1.094 | −1.116 |
| (% area) | (0.594) | (0.453) | (0.784) | (0.728) |
| Lease dummy | −0.041 | −0.033 | −0.134 | −0.131 |
| | (0.057) | (0.056) | (0.087) | (0.087) |
| Lease dummy* | 0.115 | 0.183 | 0.276 | 0.302 |
| Tenancy registration | (0.141) | (0.147) | (0.201) | (0.206) |
| Observations | 1919 | 1919 | 1919 | 1919 |
| $R^2$ | 0.113 | 0.106 | 0.081 | 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%) |

i.e. $\log(va_{pa}) - \hat{\beta} \log Exp_{water}$, where $\hat{\beta}$ is estimated from Table 8.
All other comments as in Table 9.
Robust standard errors in parentheses clustered at village level.
*, **, *** significant at 10%, 5%, 1%, respectively.
[a] The dependent variable is log of total value added per acre net of the effect of water expenditure.

A problem in estimating Eq. (13) is that expenditure on inputs is 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 Bardhan and Mookherjee (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. Bardhan and Mookherjee (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.[11] 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 are 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. Bardhan and Mookherjee (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 8 use as instruments the 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 8, for log of total value added 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 water (shown in columns 3 and 6). The relevant first-stage results are presented in the bottom panel of Table 8. 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 that the OLS and IV estimates of the elasticity with respect to water 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 water 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

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[11] 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.

**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 |
| (% area) | (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 |
| (cumulative) | (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 |
| (cumulative) | (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 |
| (% area) | (26.826) | (30.831) | (32.134) | (0.039) | (12.031) | (0.126) |
| GP irrigation expenditure | −0.325** | −0.226 | −0.240* | 0.000 | −0.100 | −0.001 |
| | (0.165) | (0.145) | (0.144) | (0.001) | (0.074) | (0.001) |
| Area irrigated by state canals | 0.107 | 0.005 | −0.051 | 0.000 | 0.098 | −0.001 |
| | (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 9.
Robust standard errors in parentheses clustered at village level. *, **, *** significant at 10%, 5%, 1%, respectively.

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 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. Plowing 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 it is plausible that their demands will be price elastic.

The first three columns in Table 8 are based on all farms in the sample, including tenant farms. A possible objection to these results is the underlying implicit assumption that the same production relationship prevails for tenant and non-tenant farms. A related problem is possible endogeneity bias owing to exclusion of controls for tenancy: 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, resulting in 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 8 pertain mainly to non-tenant farms. To check this, columns 3–6 in Table 8 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.

**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 | 11.176*** | 8.555** | 8.344** | 0.007 | 2.596** | 0.018 |
| (% area) | (3.339) | (3.397) | (3.329) | (0.008) | (1.201) | (0.017) |
| Land titles | 3.234 | 20.661 | 21.574 | −0.021 | −17.324 | 0.076 |
| (% area) | (25.490) | (29.324) | (31.151) | (0.041) | (12.119) | (0.124) |
| Minikits/HH | 1.733 | 2.921 | 2.633 | 0.011 | −1.220 | 0.011 |
| (cumulative) | (3.081) | (3.327) | (3.226) | (0.012) | (1.460) | (0.013) |
| IRDP credit/HH | 0.008 | 0.007 | 0.009 | 0.000 | 0.000 | 0.000 |
| (cumulative) | (0.011) | (0.010) | (0.010) | (0.000) | (0.005) | (0.000) |
| Mandays/HH | −1.334** | −1.329** | −1.624** | 0.003 | −0.038 | −0.016 |
| | (0.626) | (0.604) | (0.637) | (0.003) | (0.298) | (0.012) |
| GP irrigation expenditure | −0.310* | −0.215 | −0.233 | 0.000 | −0.098 | −0.001 |
| | (0.160) | (0.141) | (0.149) | (0.001) | (0.071) | (0.001) |
| Area irrigated by state canals | −0.017 | −0.101 | −0.130 | −0.000 | 0.080 | −0.001 |
| | (0.193) | (0.157) | (0.153) | (0.000) | (0.108) | (0.001) |
| Observations | 232 | 232 | 227 | 227 | 227 | 245 |
| Number of mouza | 60 | 60 | 59 | 59 | 59 | 63 |
| $R^2$ | 0.108 | 0.097 | 0.113 | 0.013 | 0.066 | 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 9.
Robust standard errors in parentheses clustered at village level.
*, **, *** significant at 10%, 5%, 1%, respectively.

**Table A1**
Summary statistics of outcome and control variables (regression sample).

| Variable | Definition | Mean | S.D. |
|---|---|---|---|
| *Input expenditure variables* | | | |
| Log expenditure on water per acre | Log total per acre expenditure on water, real | 2.19 | 2.06 |
| Log own water expenditure per acre | Log total per acre expenditure on own water, real | 0.16 | 0.80 |
| Log purchased water expenditure per acre | Log total per acre expenditure on purchased water, real | 2.05 | 2.05 |
| Log expenditure on fertilizer per acre | Log total per acre expenditure on fertilizer, real | 3.63 | 1.54 |
| Log expenditure on seeds per acre | Log total per acre expenditure on seeds, real | 3.91 | 0.73 |
| Log expenditure on labor per acre | Log total per acre expenditure on labor, real | 6.01 | 0.52 |
| Log expenditure on bullock per acre | Log total per acre expenditure on bullock, real | 4.36 | 1.06 |
| *Farm input programs and reform variables* | | | |
| Minikits/HH | Cumulative minikits per household | 1.31 | 1.73 |
| IRDP credit/HH | Cumulative IRDP credit per household in INR | 544.37 | 836.22 |
| Mandays/HH | Mandays per household | 2.07 | 2.81 |
| Tenancy registration (% area) | Lagged cumulative percentage of land that is registered | 0.19 | 1.00 |
| Land titles (% area) | Lagged cumulative percentage of land that is titled | 0.06 | 0.20 |
| *State and local government variables* | | | |
| GP irrigation expenditure | Log of local government irrigation expenditure | 5.41 | 7.26 |
| Area irrigated by state canals | Log of area irrigated by state canals (hectares) | 5.97 | 7.24 |
| GP road expenditure | Log of local government road expenditure | 7.22 | 6.20 |
| State roads | Log of state road length (km) | 7.11 | 0.43 |
| No. of electrified deep tubewells in district | Total number of electrified deep tubewells in district | 298.27 | 266.12 |
| No. of electrified shallow tubewells in district | Total number of electrified shallow tubewells in district | 5831.73 | 5286.17 |
| *Farm variables* | | | |
| Log total value added per acre | Log total value added per acre, in real terms | 6.93 | 0.54 |
| Total cropped area | Total area cropped, acres | 4.12 | 3.16 |
| Total cropped area squared | Total area cropped squared | 26.98 | 45.60 |
| Lease dummy | Indicator for whether farm is leased | 0.06 | 0.23 |
| Log price of rice | Log price of rice | 0.01 | 0.19 |
| Annual rainfall | Log annual rainfall (mm) | 7.54 | 0.43 |

All expenditure variables and value added are expressed in Indian rupees in 1974 prices. Averages reported here correspond to the sample of villages used in the regressions, averaged across all years used.
Source: Cost of cultivation survey, household survey, Block Agricultural Development Offices, lead banks, local government budgets, West Bengal Economic Review.

### 4.2. Effects of land reforms and other government programs on factor prices

We now turn to the key prediction of our model: the tenancy reforms lowered the price of groundwater. Ideally, we would estimate a regression corresponding to Eq. (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 water expenditures exhibited a negative coefficient, so we can interpret movements in water expenditures as reflecting price movements in the same direction.

The first prediction we shall test is that water expenditures per acre of farms fell as a consequence of increased coverage of the tenancy registration program. The second prediction is that the effect of the latter should vary between tenant and non-tenant farms, owing to the direct effect of the tenancy reform on water demand in tenant farms. Hence the effect of expansion of the program on water expenditures should be lower in tenant farms, reflecting the increased use of water in those farms compared with non-tenant farms.

The regression specification is the following:

$$\log\left(E_{jkvt}\right) = \alpha_k + \delta_t + \beta_1 TR_{vt} + \beta_2 L_{kvt} + \beta_3 TR_{vt} * L_{kvt} + \beta_4 LT_{vt} + \beta_5 Kits_{vt} + \beta_6 Cred_{vt} + \beta_7 Emp_{vt} + \epsilon_{jkvt} \tag{14}$$

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 $t$. $L_{kvt}$ is a dummy taking the value 1 if farm $k$ in village $v$ leases in land in year $t$. We run this regression for different inputs separately. Our theory predicts that in the case of water expenditures, the coefficient $\beta_1$ is negative while $\beta_3$ is positive.

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 local tenancy reforms may be biased owing to its correlation with subsidized provision of electrically powered tubewells by the State Electricity Board of the West Bengal government.

Table 9 shows the OLS and IV regression results for the effect of various programs on farm irrigation expenditures.[12] 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' in terms of aspiring to raise productivity, 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 water.

The other prediction is also borne out: the tenancy reform had a positive differential impact on water expenditures of tenant farms. The OLS estimate is larger than the IV estimate but they are both imprecisely estimated. This is not surprising, considering the small proportion of farms that leased in land. A 1% increase in the area covered by the tenancy reform induced a rise of water expenditures in tenant farms ranging from 0.51% the OLS estimate, to 0.38% the IV estimate. This increase in water demand among tenant farms is the source of the increases in investment in tubewells by water sellers.

We do not observe significant effects of the land titles, the minikits, the IRDP credit or the employment program on irrigation expenditures.

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[12] Tenancy registration and the kits program are instrumented here, just as in Bardhan and Mookherjee (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.

Columns 3–6 examine corresponding effects on self-supplied and purchased irrigation services. Almost all the effects of tenancy registration operated through water 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 we do not see any evidence for the second channel by which the tenancy program may have expanded investment in irrigation, by increasing access to credit of registered tenants and thereby increasing investment in their own irrigation capacity.

Table 10 shows analogous results for the effect of government programs on farm expenditure on other inputs. The IV coefficients of tenancy reform are 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 8 showed that 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 shown evidence suggesting that groundwater prices represented an important source of spillover from the tenancy registration program to productivity in non-tenant farms. Farm productivity was decreasing significantly in water cost for both non-tenant and tenant farms. And water costs fell in response to the tenancy registration program. Moreover, the product of the two effects (0.24 times 1.6, using the IV estimates) generates a total effect (0.4) of the tenancy program on farm productivity, which is almost the same as the measured reduced form impact of the former on the latter (in Table 7). This suggests that the effect on water costs accounted for the entire spillover of the tenancy reform on non-tenant farms.

To verify this directly, we construct a measure of productivity which nets out the irrigation effect, by subtracting from value added the term involving water expenditures, weighted by the IV-estimate of its elasticity (from Table 9). We then regress this on implementation rates of the various programs:

$$\begin{aligned}\log y_{kvt} - \hat{\beta}_i \log E_{ikvt} = {} & \mu \log p + \gamma_1 TR_{vt} + \gamma_2 L_{kvt} + \gamma_3 TR_{vt} * L_{kvt} \\ & + \gamma_4 LT_{vt} + \gamma_5 Kits_{vt} + \gamma_6 Credit_{vt} + \gamma_7 Mandays_{vt} + \epsilon_{ikvt}\end{aligned} \tag{15}$$

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 water cost (from Table 8). As in Table 9, 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 among 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 provide the same reduced form regressions for productivity without netting out the irrigation impact.[13] Without accounting for the irrigation impact, tenancy registration has a large positive and statistically significant impact on productivity on *all* farms, not just tenant farms. Columns 3 and 4 of Table 11 show that this effect vanishes when the irrigation impact is netted out. However, the direct impact of the tenancy reform on productivity in tenant farms continues to survive: both OLS and IV estimates are now larger compared with the first two columns where the irrigation effect has not been netted out (though it is still imprecisely estimated). Hence the effect on water costs captures the entire spillover effect on non-tenant farms; netting them out removes the effect on productivity in non-tenant farms while preserving and enlarging the measured effect on tenant farms. These results also imply 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 9 that the minikit program had no significant impact on farm groundwater costs. Consistent with this, the effect of the minikit program is not much affected by netting out water 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 Bardhan and Mookherjee (2006), these programs increased the wage rate for hired labor. This would be expected to induce farmers to substitute away from hired labor and increase application of family labor, thereby raising 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. 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, we seek to corroborate the preceding results by providing direct evidence concerning the effect of Operation Barga on irrigation investments. Table 12 reports 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 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. The former effect is twice as large as the latter in the IV estimates, and two and a half times as large in the OLS estimates. Hence the tenancy program was associated predominantly with increased private investment in minor irrigation, and supplemented by increased investments in medium irrigation by local governments themselves.[14]

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[13] The IV estimate of tenancy registration is significant here, while it was not significant in Bardhan and Mookherjee (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. Note also that the OLS coefficients of tenancy registration and minikits in the first column differ considerably from those reported in Table 7, because the regression reported here is run for fewer observations which coincide with those for which the IV regression in the second column can be run. However, the IV estimates in the second column are similar to the OLS coefficients in Table 7.

[14] 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.

## 5. Concluding comments

We have found evidence of pecuniary externalities operating through effects of the tenancy reforms on the cost of groundwater. These help explain the spillover effects of the tenancy reforms on farm productivity in non-tenant farms found in earlier work on West Bengal agriculture by Bardhan and Mookherjee (2011). Most of this is accounted for by induced effects of the tenancy reform on investment in minor irrigation by water sellers, with a secondary effect operating through a complementarity of the reform with investment by local governments in medium irrigation. We found no role for enhanced credit access for registered tenants and consequent investments by these farmers in self-supplied irrigation.

Our results complement the detailed studies carried out by Moitra and Das (2005) documenting presence of 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 are consistent with the central hypothesis of this paper.

The general picture suggested by our study is that institutional reforms implemented by local governments stimulated private 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 thus contributed to the West Bengal green revolution of the 1980s and 1990s. This supplemented the direct effects of the tenancy reforms.

Nevertheless, it is appropriate to keep in mind that the overall contribution of the tenancy reform to farm productivity growth was small owing to the limited scale of the tenancy program (with approximately 4% area covered between 1982 and 1995, and 7% since 1971). As shown earlier in Bardhan and Mookherjee (2011), the contribution of the tenancy reform to growth in farm productivity was at most of the order of 3–4%, in contrast to a 44% increase arising from subsidized provision of minikits. Hence the lions share was still accounted for by delivery of subsidized farm inputs by local governments.

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