ECONOMIC GROWTH CENTER

YALE UNIVERSITY

P.O. Box 208629
New Haven, CT 06520-8269
http://www.econ.yale.edu/~egcenter/

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Dams

Esther Duflo
Massachusetts Institute of Technology

and

Rohini Pande
Yale University

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Dams

Esther Duflo and Rohini Pande

Abstract

The construction of large dams is one of the most costly and controversial forms of public infrastructure investment in developing countries, but little is known about their impact. This paper studies the productivity and distributional effects of large dams in India. To account for endogenous placement of dams we use GIS data and the fact that river gradient affects a district's suitability for dams to provide instrumental variable estimates of their impact. We find that, in a district where a dam is built, agricultural production does not increase but poverty does. In contrast, districts located downstream from the dam benefit from increased irrigation and see agricultural production increase and poverty fall. Overall, our estimates suggest that large dam construction in India is a marginally cost-effective investment with significant distributional implications, and has, in aggregate, increased poverty.

Keywords: Dams, Development Planning, Program Evaluation, India

JEL Codes: O21, O12, H43, H23

1 Introduction

"If you are to suffer, you should suffer in the interest of the country."

Indian Prime Minister Nehru, speaking to those displaced by Hirakud Dam, 1948.

Dams epitomize a central fact about many public investments and policies, ranging from road construction to trade liberalization – economic gains often come at the cost of making some groups worse off. According to the World Commission on Dams (2000a) large dam construction has displaced between 40-80 million people worldwide and submerged, salinated or waterlogged vast tracts of land. In principle the aggregate gains from building dams could be used to compensate those who lose land or livelihood. However, it is unclear whether this occurs if, as is often the case, the winners, but not the losers, are politically and economically advantaged.

Economic evaluations of dams and similar public investments largely ignore their distributional effects. This is inappropriate if political support for a public investment can be realized with little commitment to a subsequent redistribution of the gains. Ignoring distributional implications is also problematic from an econometric viewpoint. For instance, if a public investment makes some regions worse off while others benefit, then a regional evaluation which does not account for the distribution of losers is likely to be biased.

Dams are a particularly good case for studying the potential disjunction between the distributional and productivity implications of a public policy. The likely winners and losers from dam construction are clearly identifiable: those who live downstream from a dam (in its "command" area) stand to benefit, while those in the vicinity of and upstream from a dam (in its "catchment area") stand to lose. From an econometric viewpoint, this implies that we can estimate the effect of dams separately for these two populations. From a policy perspective, this makes it relatively easy to identify, and compensate, losers. The absence or inadequacy of compensation in such a comparatively simple case would suggest that the distributional consequences of public policies are perhaps less easy to remedy than is typically assumed.

Worldwide, over 45,000 large dams have been built and nearly half the world's rivers are obstructed by a large dam. Proponents of large dam construction emphasize the role of large dams in enabling irrigation (both directly and by recharging the groundwater table), providing water and hydropower for domestic or industrial use, and as insurance against rainfall shocks. By the year 2000, dam reservoirs stored roughly 3,600 cubic kilometers of water, generated 19 percent of the world's electricity supply and provided irrigation for between 30-40 percent of the 271 million hectares irrigated worldwide (World Commission on Dams 2000a).

Opponents argue that most of the gains associated with dam construction occur downstream. The only gains enjoyed by the upstream population are from the construction activity itself and from economic activity around the reservoir. The losses they suffer, in contrast, are large; dam construction causes significant loss of agricultural and forest land, and increased salinity and waterlogging of the land around the reservoir(McCully (2001) and Singh (2002)). The upstream populations are also more exposed to diseases caused by the large-scale impounding of water, such as malaria.

The oscillating policy stance of the World Bank, the single biggest source of funds for large dam construction, illustrates the tension between aggregate productivity benefits and the social costs of large dams. Starting in the mid-1980s, the Bank responded to growing criticism by NGOs and civil society of the costs imposed on those living in the vicinity of dams by sharply reducing its funding for dam construction. However, it has recently changed its policy and restarted lending for dams (with a loan for a large dam in Laos), arguing that the rationale for the dam rests on proper use of revenues for poverty reduction and environmental management.

What is striking in the policy debates, both at the Bank and in civil society, is the absence of evidence on the impact of the average large dam, and on the success of governments in compensating any losers. The aim of this paper is to provide such evidence. Our empirical investigation focusses on India, which, with over 4,000 large dams, is the world's third most prolific dam builder (after China and the USA). Large dam construction remains the main form of public investment in irrigation in India, and dam irrigated areas account for 35% of the area irrigated throughout the country.[1]

Several factors, including geographic suitability, the political clout of local governments, and the economic implications of dam construction affect dam placement. Hence a simple comparison of outcomes in regions with and without dams is unlikely to provide a causal estimate of the impact of dams. Regions where relatively more dams are built are also likely to differ along other dimensions, such as potential agricultural productivity.

To address this problem we exploit the fact that a river flowing at a positive gradient favors dam construction. A higher water level upstream enables water storage and diversion into irrigation canals, and electricity generation. Too high a river gradient, however, makes it

[1]Between 1951-1997 public investment on major and medium irrigation projects in India was approximately 33 billion US dollars (Thakkar 2000)

difficult to build canals and to monitor the water flow into them. In contrast, a steep positive river gradient is good for hydro-electricity generation. This implies that the relationship between river gradient in an area and its suitability for dam construction is non-linear for irrigation dams and linear for hydro-electric dams.

Detailed GIS data on district geography allows us to exploit variation in dam construction induced by differences in river gradient across districts within Indian states to construct instrumental variable estimates.[2] Our regressions control for district fixed effects, state year interactions, and the interaction of most district geography variables with overall dam construction in the state. Only the interaction between the fraction of district rivers in different gradient categories and overall dam construction in the state is assumed to be exogenous. This makes our empirical strategy robust to a range of omitted variable and (potential) endogeneity concerns. First, we fully control for differential state-specific time trends. Second, if districts with greater river presence or relatively more gradient evolved differently from other districts in the same state in a way that is correlated with overall dam incidence in the state, then this is controlled for by the interaction term between the number of dams in the state and these variables. This estimation strategy is one of the contributions of this paper, and can be used to provide convincing estimates of the economic effects of large infrastructure projects, where project location is strongly influenced by geography.

Our outcome variables are district agricultural and poverty outcomes. Dams do not affect agricultural production in the district where they are located. In contrast, irrigated area and agricultural production increase in districts located downstream. A cost-benefit analysis suggests that the increase in agricultural productivity does not justify the average dam; even excluding the deadweight loss of taxation, environmental damages, and the increase in labor usage, the rate of return to the investment is only about 1% on average.

Further, it does not seem that productivity gains in downstream districts are used to compensate the losers. Poverty declines in the districts located downstream from a dam, but increases significantly in districts where dams are built. In downstream districts dams serve as insurance devices against rainfall shocks. However, they *increase* vulnerability to rainfall shocks in the districts where they are built.

These findings suggest that large dam construction in India is a cost-ineffective public policy that has increased poverty in some areas. The results also underscore the need to

[2]District is the administrative unit below the Indian state, and district size is typically determined on a population basis. The median Indian state has 23 districts, the maximum and minimum are 63 and 1 districts respectively.

account for distributional effects when evaluating any public policy. Dam construction in India created identifiable losers who were not adequately compensated. While identifying all the reasons for inadequate redistribution is beyond the scope of the paper, we do explore the role of district institutions. We build on Banerjee and Iyer (2005) who examine the present-day implications of the colonial land tenure system. They show that, relative to districts in which individuals remained responsible for tax collection, districts in which landlords were responsible for collecting taxes saw greater class conflict. They show that the economic effects of this institution have persisted – there is less collective action and public good provision in the latter districts today. In keeping with this, we find that the increase in poverty due to dams is twice as large in landlord districts, even though the impact of dams on production is similar in landlord and non-landlord districts. These findings are consistent with the view that adversarial relationships between the elite and the displaced populations limit the ability of the displaced to obtain compensation.

The remainder of the paper proceeds as follows: Section 2 reviews the case study literature on the productivity and welfare effects of large dam construction in India, and uses a simple production function framework to discuss the expected effects of dams. Section 3 describes the data, Section 4 the empirical strategy, Section 5 the empirical results, and Section 6 concludes.

2 Background

In this section we summarize the main insights about the economic impact of dams offered by the case-study literature on Indian dams, and provide a simple conceptual framework to understand the likely economic impact of dams.

2.1 Literature Review

The main purposes served by dams are irrigation, hydropower and flood control. Irrigation is the primary purpose of over 95% of large Indian dams, and dams built for this purpose form the focus of our discussion.[3]

Most irrigation dams in India are embankment dams. That is, an artificial wall is built across a river valley, and water is impounded behind this wall in a 'reservoir'. A system of

[3] The pre-requisites for construction and the economic consequences of hydro-electric and irrigation dams differ significantly.

spillways and gates conveys normal stream and flood flows over, around, or through this wall, and artificial canals channel water from the reservoir to downstream regions for irrigation. The area upstream from which water and silt flow into the reservoir, and the area submerged by the reservoir, form the *catchment* area. The area downstream from the reservoir that is covered by the dam's canal network makes up the *command* area.

Dam construction may increase economic activity in the catchment area. Reservoirs may provide a source of fishing, and are often developed as tourism sites. However, the main economic benefit of dams has been realized in agriculture, and this benefit accrues in the command area (here we draw upon the review in Thakkar (2000)). By 2000, dam irrigation accounted for 38% of India's irrigated area. Between 1951 and 2000 India's food grain production nearly quadrupled. Two-thirds of this increase was in irrigated areas. The most optimistic calculations suggest that roughly a quarter of India's increased food grain production over the last half century can be attributed to dam-irrigated areas. The main channels through which dam irrigation increases productivity are greater multi-cropping and the cultivation of more profitable water-intensive cash crops such as sugarcane (Singh 2002).

Clearly, the benefits linked to irrigation should not be entirely attributed to dams, since without them some areas would have been irrigated by other means. The fraction of increased food production in dam irrigated areas that is attributable to dam irrigation rather than, say, the concurrent uptake of mechanized agriculture also remains controversial, with estimates varying from 10% (World Commission on Dams 2000b) to over 50% (Gopalakrishnan 2000).

In defense of large dams, authors such as Biswas and Tortajada (2001) and Dhawan (1989) argue that other forms of water harvesting, such as ground water and small dykes, are relatively cost ineffective and incapable of meeting the demands of large and growing populations in countries with highly seasonal rainfall. Another major benefit of dams, not shared by other means of irrigation, is their ability to prevent floods and droughts by regulating the flow of water downstream. For very large dams, the flood control effect may extend thousands of miles downstream. There is, however, a trade-off between using dams for flood control (which requires emptying the reservoir) and their use for irrigation or electricity (which requires filling the reservoir). Another potential benefit of a large dam is seepage from its canals which recharges the aquifers that provide groundwater (Dhawan 1993). However, the extent of such groundwater recharge remains controversial.

In fact, critics of large dams argue that the more important consequence of such water seepage is waterlogging, and increased soil salinity; both of which make land less productive.[4]

[4] Land becomes toxic for plants when salt concentration is 0.5-1% (Goldsmith and Hildyard 1984)

The Indian Water Resources Ministry estimated that, in 1991, about 2.46 million hectares of the command area of dams suffered from waterlogging, and 3.30 million hectares from salinity/alkalinity (World Commission on Dams 2000b). This is roughly a tenth of the area irrigated by dams. The other main costs of dam irrigation are land submergence for construction of the reservoir and the displacement of people living on this land. The reservoir of a large dam can submerge up to 10% of an Indian district's total area. The World Commission on Dams (2000b) estimates that dam construction submerged 4.5 million hectares of Indian forest land between 1980 and 2000. Using data for 140 large dams, they estimate that the average dam displaces 31,340 persons and submerges 8,748 hectares. These figures, however, remain controversial. A World Bank review in the mid-1990s, for instance, estimated that each new large dam dispaced, on average, 13,000 people (Cernea 1996)). Total displacement figures vary from 16 million to over 40 million people. It is also widely agreed that the historically disadvantaged tribal populations who are more likely to live in uphill areas in river valleys have borne the brunt of displacement. Official figures for 34 large dams show that Scheduled Tribes, who make up 8% of India's population, constituted 47% of those displaced (World Commission on Dams 2000b).

The Land Acquisition Act of 1894, which empowers the government to acquire any land for public purpose and to pay cash compensation, has formed the the basis for rehabilitation of dam-displaced populations. Resettlement and compensation is, typically, the responsibility of the relevant project authorities, and is based on project-specific government resolutions. A number of studies suggest that actual compensation depends on the displaced population's political power and organizational abilities (Thukral 1992). Rights of the landless and those without formal land titles to compensation have typically not been recognized. Further, as the compensation is typically insufficient for the displaced to replace lost land by its equivalent in quality and extent elsewhere, the payment is often used as a temporary means of subsistence (J.Dreze, M.Samson, and S.Singh 1997). Finally, while an individual receives compensation after being displaced, development activities and land prices in the dam vicinity often decline as soon as a dam is planned, and the compensation rarely reflects takes this into account.

Another often-cited consequence of dam construction is adverse health consequences for those living near the reservoir. A reservoir provides a natural ground for vector breeding, and hence for diseases such as malaria, schistosomiasis, filariasis and river blindness (see Sharma (1991)).

The role of dams in increasing irrigation is largely undisputed. However, whether this increase in irrigation has, relative to a reasonable counterfactual, translated into substantial productivity gains remains controversial. As the discussion in this section should make clear, a distinctive feature of large dams is that the costs and benefits associated with dam construction vary by area. The benefits from irrigation accrue mainly to those living downstream to the dam site, but within its command area. In contrast, those living in the vicinity of the reservoir and immediately upstream (the catchment area) obtain no irrigation benefits.[5] Moreover, schemes that divert water upstream of the dam are often banned so as to ensure sufficient water flow to the dam (TehriReport 1997). This may further reduce irrigation potential in the catchment area. Finally, the displacement costs are largely borne by those in the catchment area of the dam. It has been suggested that compensation to those displaced has been inadequate.

Our objective is to provide a rigorous analysis of these claims. While investigating all the channels through which dams affect productivity and welfare is beyond the scope of this paper, we will evaluate the impact of dams on aggregate agricultural production, poverty, disease and a range of related outcomes.

2.2 Conceptual Framework

We provide a simple framework which summarizes the economic implications of dam construction. Assume that agricultural output is a function of labor inputs L, land surface K, land quality A, inputs such as fertilizer, seeds and electricity I, climate r (rainfall and temperature), farmer's ability u and a productivity shock ϵ. Denote the production function for land without access to an irrigation system (via pump or canal) as

$$y = F_1(L, K, A, I, r, u, \epsilon)$$

and the production function for land with access to an irrigation system as

$$y = F_2(L, K, A, I, r, u, \epsilon)$$

Farmers pay a one time fixed cost c for access to irrigation. This is the cost of a well or tube-well in a region with no dams, and the cost of accessing canal irrigation in a dam's command area.[6]

[5] Lift irrigation is rarely practiced in India.

[6] The annual recurrent cost for access to irrigation is very low and rarely enforced: it was Rs. 50 per hectare in most states in 1980 (the recurrent cost of dam maintenance is closer to Rs. 300.

Evenson and McKinsey (1999) estimate these production functions using Indian data, and find that irrigation mitigates the effect of rainfall shocks and temperature on farm net revenue for all crops. Further, irrigation and agricultural inputs, such as fertilizer, electricity and seeds for High Yielding Variety (HYV) crops are complements. HYV seeds are highly sensitive to water timing and require regular and controlled irrigation. Finally, multi-cropping and irrigation are also complements, which suggests that labor inputs are also likely to be complementary to irrigation.

We assume farmers can obtain the optimal set of inputs. Each farmer will compute her expected profit with and without irrigation. She will invest in irrigation if its cost is less than the long-run difference between the value function with irrigation and that without irrigation. The decision process follows a threshold rule: if the productivity shock exceeds some threshold in a given period, the farmer switches in that period.

As the costs and benefits of dam irrigation vary by region, we separately discuss the effects of dams on the catchment and the command areas.

In the command area, which is downstream to the dam, a dam lowers the fixed cost of irrigation. A farmer who has already paid the sunk cost of accessing ground water irrigation will not switch to canal irrigation. However, the set of farmers who would have chosen ground water irrigation in this period will now choose dam irrigation. Further, of the farmers who would have otherwise not irrigated their land, some will opt for dam irrigation. Demand for labor, fertilizer and seeds will increase and dependence on rainfall will decrease. Wages and profits will increase, and this will increase consumption and lower poverty.

Until now, we have not allowed for differences in farmer characteristics. However, the net impact of a dam on agricultural productivity is sensitive to differences in these. For instance, if farmers only differ in their cost of accessing ground water irrigation then, dams will have a large positive effect on productivity by making irrigation accessible to productive farmers. If instead, farmers face the same cost of irrigation but differ in their (idiosyncratic) productivity then the marginal farmer's productivity will be below that of the average farmer. In this case the effect of dams on agricultural productivity will be muted. The distribution of farmer characteristics will also affect the implications of dam construction for inequality.

The catchment area, which lies upstream from, and in the vicinity of, the dam, has three types of land. First, there is the land that is submerged by reservoir construction. Production on this land will stop, as will input and labor use. Second, there is land in the immediate vicinity of the reservoir. This will see more waterlogging and salination, and a worsening of land quality. Irrigation on such land is less profitable but fertilizer use may increase, since poorer soil requires more nutrients. Finally, some land in the catchment area will be physically unaffected. If restrictions on water use upstream from the dam are enforced then such land may see irrigation costs increase. On balance, in the catchment area, we expect a decline in cultivated land, and, potentially, a reduction in irrigated area and yield. This suggests a fall in wages and profits (and, therefore, higher poverty).

Data on the geographic extent of the catchment and command area is unavailable for most Indian dams. Our analysis uses data on the administrative unit within the Indian state – the district. We know the district in which a dam is located, and the districts downstream from it. A dam's catchment area usually falls in the district in which it is built, while its command area may include parts of the district in which it is located and parts of neighboring downstream districts (to identify the extent of the average dam's command area we will also examine its impact on non-neighboring downstream districts in the same river basin). The estimated effect in the district where the dam is built combines the effects in catchment, command and unaffected areas, and is *a priori* ambiguous. In contrast, part of the dam's command area may fall in the downstream district. Hence, the economic impact of a dam in the downstream district will reflect the effect of the dam on the command area.

3 Empirical Strategy

3.1 Dam Construction across States

India is a federation of states, and water resources are under the jurisdiction of state governments. However, the federal government plays an important role in approving and financing large dam projects. Before describing the growth in dam construction across states, we outline the project planning, approval and implementation process for large dams (our description draws upon World Commission on Dams (2000b)).

Every five years the Indian Planning Commission sets each state a water storage and irrigation target. To meet this target each state's Irrigation Department proposes dam projects. After approval by the state government, these projects are submitted to the 'National Advisory Committee on Irrigation and Multipurpose Projects'. This committee uses a cost-benefit ratio to decide whether a project is economically viable. Cost is defined as the direct project cost and benefit as the increase in agricultural production due to the irrigation provided by the project, and/or the value of power to be generated. Typically, a benefit cost ratio of 1.5:1 is desirable, but lower standards (1.1:1 or even less) are acceptable for projects in drought-prone areas (since dams are believed to provide valuable insurance against rainshocks in such areas).

The Planning Commission accepts or rejects economically viable projects on the basis of investment priorities and sectoral planning policies. Dam construction is funded out of the state budget. Dam projects also qualify for federal funding. Funding from international agencies, such as the World Bank, is usually allocated as part of federal funding. Actual dam construction, and subsequent cost recovery, is the responsibility of the state.

Table 1 provides descriptive statistics. Our sample spans 1970 to 1999 (the precise years covered vary by outcome variable).[7] In 1970, the mean number of dams in a district was 2.05, and the median district did not have a dam. Between 1970 and 1999 the number of large dams quadrupled (from 882 to 3,364). By 1999 the mean number of dams per district stood at 7.84, and the median district had one dam (46% of the districts had no dams).

Figures 1 and 2 show the distribution of dams across Indian districts in 1965 and 1995. The increase in dam construction has been concentrated in the Western region (notably, the states of Maharashtra, Gujarat and Madhya Pradesh).[8] There has been relatively little dam construction in North and North-Eastern India. Nine of the thirty two states or Union Territories in our sample saw no dam construction until 1999, seven of which also saw no dam construction in the bordering districts of neighboring states. As our identification strategy compares districts within a state, our analysis de facto excludes these seven states.[9]

Maharashtra and Gujarat, two of India's fastest growing states, are also the largest and third largest dam building states, respectively. An immediate implication is that regressing an agricultural, or welfare, outcome on the number of dams in a state is unlikely to provide a consistent estimate of the impact of dams. Clearly, richer states can build relatively more dams. It is also probably in the interest of states that anticipate a larger increase in agricultural productivity to make more of these investments. As fast growing states show both greater reductions in poverty and more dam construction, regressing changes in outcomes over the 1970-1990 period on changes in the number of dams built in the state during the same period is unlikely to solve the problem of endogenous dam placement.

Table 2 provides an empirical illustration of this argument. We regress y_{ist}, the outcome of interest for district i in year s in period t, on state and year fixed effects and the number

[7] The data appendix describes our various data sources.

[8] The median district in Maharashtra, Gujarat and Madhya Pradesh had 39, 18 and 15 dams, respectively.

[9] The nine states without dams are Arunachal Pradesh, Mizoram, Nagaland, Punjab, Sikkim, Dadra and Nagar Haveli, Daman and Diu, Delhi, Pondicherry. Punjab and Delhi have dams in neighboring upstream states.

of dams in state s in year t.[10]

$$y_{ist} = \lambda_1 + \lambda_2 D_{st} + \nu_s + \mu_t + \omega_{ist}, \tag{1}$$

As expected, the number of dams in a state is positively correlated with changes in irrigated area and production, and negatively correlated with poverty.

In columns (4)-(6) we regress the same outcomes on the total number of dams in the state inclusive of those built up to five years in the future. We continue to include state and year fixed effects.

$$y_{ist} = \lambda_3 + \lambda_4 D_{st+5} + \nu_s + \mu_t + \omega_{ist}, \tag{2}$$

The point estimates are remarkably similar across the two specifications, even though the latter specification includes dams built up to five years in the future. While dams may affect poverty before construction is complete, this is unlikely for irrigated area and production. A more plausible explanation is that states with high agricultural growth in the last five years build more dams. This is also consistent with our findings in columns (1)-(3) of Table 2, and suggests that a simple fixed effects strategy which compares changes in outcomes across states will provide a biased estimate of the economic effect of dams.

3.2 Dam construction within states

For the reasons outlined above, we do not directly exploit inter-state differences in dam construction to identify the economic impact of dams. Instead, we rely on differences in dam construction across districts within a state. We account for, and explore the geographic extent of, spill-overs from dams to neighboring districts. However, we cannot measure state-wide economic effects of dam construction that are independent of a district's proximity to the dam. These may include, for example, the effect on prices determined at the state level. We will discuss the possible direction of such state-wide effects as we interpret our results.

Consider the following regression

$$y_{ist} = \beta_1 + \beta_2 D_{ist} + \nu_i + \mu_{st} + \omega_{ist}, \tag{3}$$

[10]This regression parallels Merrouche (2004) who regresses state-level outcomes on number of dams in the state. We cluster standard errors by state*year to take into account the level of aggregation of the independent variable.

where ν_i is a district fixed effect, μ_{st} is a state-year interaction effect, and ω_{ist} a district-year specific error term.[11] This specification differs from equation (2) as we use the number of dams built in the district (rather than state), and include district and state-year fixed effects. District fixed effects control for time-invariant characteristics that affect the likelihood that a dam will be built in the district. State-year interactions account for annual shocks which are common to all districts in a state. Hence, we only exploit annual variation in dam construction across districts in a state for identification.

The fact that the district in which a dam is constructed includes some of the dam's catchment and command area makes predictions about the economic impact of a dam in its own district difficult. In contrast, the economic impact of a dam in the district downstream is predictable since the district is affected only by the dam's command area. Identifying how a dam affects economic activity in the downstream district, therefore, both tells us how a dam affects economic activity in its command area and helps us estimate the overall impact of the dam. We are, therefore, interested in estimating the equation:

$$y_{ist} = \beta_3 + \beta_4 D_{ist} + \beta_5 D_{ist}^U + \nu_i + \mu_{st} + \omega_{ist} \tag{4}$$

where D_{ist}^U denotes the number of dams that are located upstream from district i.

If these equations are estimated using OLS, then the identification assumption needs to be that the annual variation in dam construction across districts in the same state is uncorrelated with other district-specific shocks. However, even though dam allocation is at the state level, we may expect this assumption to be violated. For instance, we may expect relatively greater dam construction in or around agriculturally more productive districts which have a higher demand for irrigation. Therefore, in addition to OLS estimates, we also report instrumental variables estimates.

3.3 Dams and Geography

The viability and cost of dam construction at a location depends on its geographical features. The most obvious requirement for dam construction is the presence of a river. In addition, dam construction is cheaper and easier when the river flows at a moderate incline. By raising the water level upstream, a positive river gradient makes the diversion of water into canals (for irrigation) easier and enables electricity generation. It also makes the construction of the reservoir (where water is stored) easier. For irrigation dams a moderate river gradient

[11] We control for autocorrelation by clustering the equation at the district-level.

is optimal. If the river gradient is too steep, then controlling the flow of water into canals, and indeed building canals becomes difficult (in contrast, for electricity generating dams more gradient is better). This implies a non-linear relationship between the ease and cost of constructing irrigation dams and river gradient.

This non-linear relationship between river gradient and dam construction forms the basis of our identification strategy. Controlling for overall gradient and river length in a district, we use differences in river gradient to predict how, in a given year, dams constructed in a state are distributed across districts in that state. Figures 1-4 illustrate our identification strategy. Figures 1 and 2 depict the growth of dams across Indian districts between 1965 and 1995. North India, while home to one of the world's largest river basins, the Indo-Gangetic basin, has seen almost no dam construction. In contrast, most dam construction has been concentrated in Western India. This suggests that dam construction cannot be predicted solely by river presence. Figures 3 and 4 point to the importance of river gradient in determining dam placement. In Figure 3 we use GIS data to depict the average district gradient, and observe that while central North India is very flat most of Western India is at a moderate gradient. Figure 4 shows a similar pattern for the average gradient along the river in districts, even though overall district and river gradient differ for most districts.[12]

To predict the number of dams in a district we interact the number of dams in a state with the geographic variables (after controlling for a full set of state-year interactions). Our estimation strategy uses within state geographic variation to compare districts *within* states. That is, we do not assume that district geography determines overall dam incidence in an Indian state, but rather that it affects the allocation of dams within a state. We include a full set of state-year interactions to control for differential trends across states that may be correlated with dam construction.[13]

To illustrate how district geography variables predict the number of dams in a district

[12]Both were computed using GIS mapping software, which provides the gradient and elevation of multiple "polygons" per district. We averaged across all polygons in a district to obtain average district gradient and across polygons through which a river flows to obtain river gradient.

[13]If the demand for irrigation in a single district drives dam construction in the state, then the number of dams in the state is itself endogenous with respect to the outcome in that district. To address this concern we estimate all regressions using, instead of the number of dams in the state, the number of dams in the state predicted if all the dams built in India in that year had been allocated to states in keeping with their share of all dams in 1970. Our findings are unchanged (available from the authors).

we estimate the following regression (separately) for two years, $t = 1974$ and $t = 1994$.

$$D_{ist} = \alpha_1 + \sum_{k=2}^{5} \alpha_{2k}(RGr_{ki} * \overline{D_{st}}) + \sum_{k=2}^{4} \alpha_{3k}(El_{ki} * \overline{D_{st}}) + \sum_{k=2}^{5} \alpha_{4k}(Gr_{ki} * \overline{D_{st}}) + (X_i * \overline{D_{st}})\alpha_5 + \mu_s + \omega_{ist} \quad (5)$$

$\overline{D_{st}}$ is the cumulative number of dams in state s in year t. RGr_{ki} is the fraction of river area in gradient category k, and Gr_{ki} is the fraction district area in gradient category k. We consider five gradient categories – less than 1.5%, 1.5-3%, 3-6%, 6-10% and over 10%.[14] El_{ki} is the fraction of district area in elevation category k. We consider four categories (in meters) - 0-250; 250-500; 500-1000 and over 1000. Finally, X_i is a vector whose elements are district area and river length.

Columns (1) and (2) of Table 3 report results for 1974 and 1994 respectively. Districts with more kilometers of river have more dams. In addition, river gradient is a significant determinant of dam construction. We find that a river gradient of 1.5-3% is more conducive to dam construction than a gradient of less than 1.5%. For higher gradients we observe a non-monotonic relationship. River gradient in the 3-6% interval reduces dam construction. River gradient in the interval 6-10% does not significantly vary dam construction but having more river flowing at a gradient of over 10% increases dam construction. The positive relationship between very steep river gradient and dam construction reflects the suitability of such areas for hydro-electric and multi-purpose dams. Finally, we observe that the coefficients on overall district gradient and river gradient differ. A possible reason is that district gradient may directly affect agricultural outcomes in the district (which, in turn, affects the propensity to build dams). For instance, district gradient may affect the ease of growing certain crops (which may or may not be water-intensive).

Our estimation strategy exploits three sources of variations in dam construction: differences across years, differences across states, and differences across districts within a state. Table 4 shows the average change over our sample period in the number of dams constructed, the head count ratio (defined as the fraction rural population with consumption levels which place them below the poverty line), and log agricultural production for four state-district combinations. A district with less than 90% of river gradient below 1.5 percent is classified as a 'high' gradient district, and all other districts are classified as 'low' gradient. States are classified as high or low dam construction states: a state with more than a hundred dams by 1999 is a 'high' construction state, and 'low' otherwise.

[14] We have experimented with other categories, and get similar results.

Panel A compares dam construction between 1973 and 1999 in high and low gradient districts in both types of states. Relative to low dam construction states, the increase in dams is higher in *both* high and low gradient districts in high dam construction states. However, relative to low dam construction states, the difference between high and low gradient districts is greater in high dam construction states. Under the assumption that, absent state differences in overall dam construction, districts with the same gradient in different states would, on average, receive the same number of dams the difference in these differences can be interpreted as the causal effect of a district's river gradient on dam construction. Between 1973 and 1999 a high river gradient district, in a high dam construction state, received seven additional dams.

Panels B and C examine changes in rural head count ratio and log agricultural production. In a high river gradient district located in a high dam construction state the head count ratio increased by an additional 4.5 percent and log agricultural production fell by 0.32. The Wald estimate of the poverty impact of dam construction is the ratio of the difference in difference in Panels A and B, and stands at 0.64.

These tables illustrate our identification strategy, but our results are imprecise as we only use part of the available information. In addition, here, we do not control for other geographical variables which may be correlated with both river gradient and changes in, say, the head count ratio. We, therefore, turn to a more general framework.

3.4 Instrumental Variables Strategy

• **Effect of dams in own district**

We are interested in estimating equations (3) and (4), where we use information on district geography to predict the annual allocation of dams built in a state across districts.

To implement this strategy we first predict (as in Table 4) the district-wise number of *new* dams built in a year in a state by:

$$D_{ist} = \alpha_1 + \sum_{k=2}^{5} \alpha_{2k}(RGr_{ki} * \overline{D_{st}}) + \sum_{k=2}^{4} \alpha_{3k}(El_{ki} * \overline{D_{st}}) + \sum_{k=2}^{5} \alpha_{4k}(Gr_{ki} * \overline{D_{st}}) + (X_i * \overline{D_{st}})\alpha_5 + \nu_i + \mu_{st} + \omega_{ist} \quad (6)$$

The variables are defined as before. Column (3) of Table 3 provides the coefficient estimates. The pattern of coefficients is similar to the cross-sectional regressions in columns (1) and (2). The F-statistic for the joint significance of the river gradient variables is 10.05.

Columns (4) and (5) report the results from a regression of the same form, but with rural head count ratio and agricultural production as the dependent variables, respectively.

$$y_{ist} = \alpha_6 + \sum_{k=2}^{5} \alpha_{7k}(RGr_{ki} * \overline{D_{st}}) + \sum_{k=2}^{4} \alpha_{8k}(El_{ki} * \overline{D_{st}}) + \sum_{k=2}^{5} \alpha_{9k}(Gr_{ki} * \overline{D_{st}}) + (X_i * \overline{D_{st}})\alpha_{10} + \nu_i + \mu_{st} + \omega_{ist} \quad (7)$$

The α_{7k} coefficients in equation (7) parallel the α_{2k} coefficients in equation (6) and provide a reduced form estimate of the impact of dam construction on poverty. Annual dam incidence in a state is potentially endogenous and may be directly related to poverty and production outcomes in the state. However, we control for state-specific trends by including state-year interactions in the regression. Hence, we only compare districts within a state and use the interaction of the number of dams in the state with the district-specific river gradient variables for identification. For the α_{7k} coefficients to not reflect the effect of dams on poverty or production, we would require that, conditional on the interaction of overall dam incidence with district area, elevation, gradient, and kilometers of river, the evolution of poverty or production across districts in a state is correlated with the interaction between river gradient and overall dam incidence.[15]

Figures 5 and 6 plot the coefficients on river gradient from the head count ratio and production regression, respectively. In both figures, we also plot the coefficients for river gradient from the regression where dams built is the dependent variable (column (3), Table 3). The coefficients for the head count ratio regression track those for dam building. In contrast, there is no clear correspondence between the coefficients from the production and dam construction regressions. While the river variables are not jointly significant (columns (4) and (5), Table 3), the positive impact of moderate river gradient on head count ratio (t-statistic of 1.7) suggests that dam construction may have increased poverty in the dam's district. In contrast, the coefficients for the production regression are neither individually nor jointly significant.

Equations (6) and (7) form the first stage and the reduced form equations of our instrumental variables strategy for estimating a modified version of equation 3, which includes the geography variables (except for the river gradient variable) interacted with the number of dams built in the state as a control variable. Specifically, denote by Z_{ist} the vector of right

[15] One possible case is if only one district in a state are suitable for dam construction, so that the number of dams in the state endogenous to growth in this district. Footnote 13 describes how we check that our results are robust to this concern.

hand side variables in equation (6), except for the interactions $RGr_{ki} * \overline{D_{st}}$. We estimate:

$$y_{ist} = \delta_1 + \delta_2 D_{ist} + Z_{ist}\delta_3 + \nu_i + \mu_{st} + \omega_{ist} \tag{8}$$

using the four variables $RGr_{ki} * \overline{D_{st}}$ and Z_{ist} as instruments. For comparability, our OLS regressions estimate equation (8) and therefore include these control variables.[16]

• **Effect of dams in own and downstream districts**

To estimate the impact of dams located upstream from a district, we augment equation (4) to include control variables:

$$y_{ist} = \delta_4 + \delta_5 D_{ist} + \delta_6 D^U_{ist} + Z_{ist}\delta_7 + Z^U_{ist}\delta_8 + \nu_i + \mu_{st} + \omega_{ist} \tag{9}$$

Z^U_{ist} is a vector which includes the interaction of overall dams in the state with elevation, district gradient, kilometers of river for upstream districts (set at zero if the district has no upstream district), and a dummy for whether the district has any upstream districts.[17]

To generate instruments for D_{ist} and D^U_{ist}, we use parameters from equation (6) to predict the number of dams per district $\widehat{D_{ist}}$. For the number of dams in upstream districts $\widehat{D^U_{ist}}$ this is the sum of predicted values from equation (6) for all upstream districts (it equals zero if the district has no upstream district).[18] We estimate equation (3) with 2SLS, using $\widehat{D_{ist}}$ and Z_{ist} as instruments, and equation (9) using $\widehat{D_{ist}}$, $\widehat{D^U_{ist}}$ and Z^U_{ist} as instruments.

The first stage equations are:

$$\Delta_{ist} = \phi_1 + \phi_2 \widehat{D_{ist}} + \phi_3 \widehat{D^U_{ist}} + Z_{ist}\phi_4 + Z^U_{ist}\phi_5 + \nu_i + \mu_{st} + \omega_{ist} \tag{10}$$

where Δ_{ist} represent D_{ist} or D^U_{ist}.

This procedure would be identical to a 2SLS procedure using the interaction of river gradient variables with dam incidence in the state as instruments, if each district only had one upstream district. Since this is not the case, our procedure is an efficient way of using all information: it uses all districts to predict the relationship between district geographic features and the number of dams (rather than just those which are upstream), and avoids averaging these features when there are several upstream districts.

[16]The OLS results are unaffected by the inclusion of control variables.

[17]For multiple upstream districts, we sum river length and district area across all upstream districts, and average the other variables (which are proportions). We have run the regression controlling separately for these variables for each upstream district, and found very similar results.

[18]Below, we will also explore dams that are upstream from a district, but more than one district removed.

4 Results

4.1 Agricultural Outcomes

We examine the impact of dam construction on gross and net measures of irrigated and cultivated area. The net measures account for the relevant area at a single point in the year, while the gross variables account for each separate use of the same area during a year. Multi-cropping is measured as the ratio of gross to net cultivated area.

Panel A of Table 5 provides OLS estimates (equations (3) and (4)), and Panel B 2SLS estimates. Both sets of estimates suggest no significant impact of dams on gross or net irrigated area in the districts where they are built (columns (1)-(4)). The 2SLS estimate for own district irrigated area is positive but insignificant. The absence of a clear effect in the district where the dam is built suggests that the submergence and degradation of land around the reservoir has limited irrigation gains in the vicinity of the dam. The large standard errors potentially reflect variation in the extent of submergence associated with different sizes of dam.

Dams significantly increase gross and net irrigated area in districts located downstream.[19] The 2SLS estimates exceed the OLS estimates, but both are significant and statistically indistinguishable from each other. The point estimate suggests that an additional dam increases irrigated area (gross or net) in the downstream district by roughly 1.1%.

In columns (5)-(8) we examine gross and net cultivated area. The 2SLS estimates of the effect of a dam on both measures is negative and significant at the 10% level for downstream districts, and in columns (6) and (8) for own district. This suggests the causal effect of a dam is to reduce cultivable area, perhaps due to the submergence associated with construction of reservoir and canals. In addition, some land may be lost due to waterlogging and salination. Consistent with the idea that these effects are greater around the reservoir, we observe that the own district effect is five times as large as the effect downstream. One explanation for the insignificant OLS estimates is that more dams were allocated to districts where land availability was otherwise expanding (say, due to higher returns to agriculture).

Columns (9)-(10) examine the extent of multi-cropping and find a positive, but insignificant, increase in multi-cropping in the downstream districts. Finally in columns (9)-(10) we observe that, as expected, area under water-intensive High Yielding Varieties (HYV) crops increases downstream.

[19] That is, districts with more dams in neighboring *upstream* districts have more irrigated area: see columns (2) and (4), row 2 in both panels.

Table 6 uses annual data for 1971-1987 to examine agricultural production and yield for nineteen crops, and fertilizer use. Columns (1) and (2) consider total production. Both the OLS and 2SLS estimates suggest that dam construction led to an insignificant decline in overall production in the district where they were built, and a significant increase in production in the downstream districts. Similarly, agricultural yield showed an insignificant decline in the district where dams were constructed, but a significant rise downstream (see columns (3) and (4)). The own district results, again, suggest that the land around dams is degraded by dam construction. This degradation is, in part, compensated for by increased productivity elsewhere in the district. The downstream districts that do not bear any of the environmental costs associated with dam construction enjoy positive productivity gains. Finally, fertilizer use increases in downstream districts, (see column (6)).

Dam irrigation increases area devoted to water-intensive HYV crops. In Table 8 we examine crop-wise outcomes for six major crops, three of which are water-intensive.[20]

Columns (1)-(4) consider relatively less water-intensive crops, and columns (5)-(8) water-intensive crops. We observe no impact on area devoted to different crops in the dam's own district. In downstream districts we observe a weak positive increase in total area devoted to water-intensive and non water-intensive crops, and a very significant increase in the area devoted to wheat, sugar and rice. Wheat and rice saw a sharp increase in water-intensive HYVs over our sample period. Sugarcane is a water-intensive cash crop which is very important in Western India (where most dam construction is concentrated).

The impact of dams on crop yield is modest, even for highly water intensive crops (Panel B). The increase in area devoted to water intensive crops, combined with modest yield increases, leads to a significant increase in the production of water intensive crops in the downstream district. An additional dam increases production of water intensive crops downstream by 0.6%. This is mainly attributable to a large increase in sugar and rice production. However, millet and wheat production also increases significantly in the downstream district.

These results are significant given that a major claim of dam critics is that dams cause farmers to substitute towards water intensive crops which, while more profitable in the short run, accentuate water shortages in the long run. While we find evidence that the area and production of crops using more water, HYV crops and sugarcane, increase in downstream districts, we do not observe any significant substitution away from major non water-intensive

[20]Our log specification implies missing values for a crop in a district if it is not produced in the district. It is, therefore, not suited to examine whether dams affect the decision to produce a given crop. We estimated separate specifications to examine whether a certain crop is grown in a district, and did not find any significant effect of dams.

crops.

Moreover, the area and production of non-water intensive crops shows an insignificant decline in the district where the dam is placed whereas production of water-intensive crops increases. This pattern of coefficients is sensible given that irrigated area shows some increase while overall cultivated area in these districts declines. However, these results must be interpreted with caution, since none of the individual coefficients are significant.

Our results provide a consistent picture of the impact of dams on agricultural outcomes. In the districts where they are built dams do not significantly alter overall agricultural production. In downstream districts, they enhance overall agricultural production, and production of some water-intensive cash crops (sugar) and staples which have seen the advent of HYV (wheat and rice).

4.2 Other inputs

The change in crop mix and the increase in HYV seed and fertilizer use in downstream areas is consistent with the predictions of a simple agricultural production function.

The two other inputs that the agricultural production function suggests should be affected by increased dam irrigation are the use of alternative forms of water infrastructure (this should decline), and the use of electricity (this should increase because pumping water through the canals associated with dams requires electricity).[21]

Panel A of Table 8 examines the impact of dams on the incidence of different forms of village infrastructure (for brevity we only report 2SLS estimate). The results are as expected; in downstream districts electrification increases and non dam-related water infrastructure decreases (the number of canals shows an insignificant increase). There are no other significant implications of dam construction for public good provision in own district or downstream, suggesting no crowding in (or out) of other government inputs.

4.3 Cost Benefit Analysis of Dams

We use our above results to provide a cost-benefit analysis of dams. Our analysis is tentative since it requires several clearly contestable assumptions and is based on somewhat noisy point estimates. In order to obtain an upper bound on this cost benefit analysis we choose the assumptions which are the most favorable to dams.

[21] Labor use should also be affected but we lack good data on labor use.

We start with estimating the extent to which farmers substitute dam irrigation for other forms of irrigation. Our estimates suggest that a dam increased net irrigated area by 0.7% in its own district, and 1% downstream. Combined with the size of irrigated area in the average district, these point estimates imply a dam-induced net increase in irrigated area of 6,300 hectares in 1985 (row B5 in table 9). Using the Indian agricultural census the Planning Commission estimated that, in 1985, 23.6 millions hectares were irrigated by dams, or 8,758 hectares per dam (cited in Thakkar (2000)). These estimates suggest a modest crowding-out of other investment in irrigation (of the order of 30%: see row B6 in Table 9).

The cost of dam construction is generally expressed in terms of the cost of irrigating an additional hectare by dam. We therefore base the cost-benefit analysis on a comparison of the value of additional production per additional hectare irrigated (from our estimates) with the capital and recurrent cost of an additional hectare irrigated by a dam (Planning Commission estimates, cited in Thakkar (2000)). Using 1985 means and our estimates, we calculate the increase in production due to a dam in a district downstream to be Rs. 2.99 million annually, or Rs. 60 million in present discounted value (assuming a 5% discount rate, and an infinite life span for the dam). This is due to an increase in irrigated area of 3,864 hectares. The present discounted value of the net increase in production per irrigated hectare is Rs. 13,686. In addition, farmers face a lower irrigation cost (some farmers who would have used ground water irrigation now use dam irrigation). Since a farmer always had the option of not using irrigation, an upper bound on reduction in irrigation cost is the value of increased production on the land. As discussed earlier, our estimates suggest that dams substituted for other forms of irrigation in 30% of dam irrigated land. Therefore, we divide our benefit estimate by 70% to obtain the net benefit of the dam on agricultural profits (Rs. 19,011 in row C7).

The Planning Commission estimated the development cost per hectare of dam irrigation at Rs. 16,129 in 1985 (inclusive of capital cost, and an annual maintenance cost of Rs. 300 per hectare). Adding the fertilizer cost we obtain a total cost of Rs. 18,807 per hectare.

Without accounting for the deadweight loss of taxation, these estimates suggest a barely positive net present value of dam construction (1%). This turns negative if we assume a conventional 15% figure for the deadweight loss associated with raising funds through taxation. Our calculation overestimates the economic value of a dam in so far as it does not account for the production decline in the dam's own district (while imprecise and not significantly different from zero, the point estimate is large and negative), and additional labor and environmental costs. It underestimates the economic value of a dam in that it does not account for production gains in non-agricultural sectors due to electricity generation by multipurpose dams.

Our estimates for the production impact of each dam, combined with the annual increase in the number of dams over the period (about 0.4 per year), indicates that dam construction was responsible for about 9% of the growth in agricultural production between 1971 and 1987. The World Commission on Dams (2000b), using very different methods, attributed 10% of the growth in India's agricultural production since 1950 to dams, and concluded that the average dam's net present value was slightly negative. Although this estimate was made by a supposedly independent, non-partisan international body, dam proponents criticized these estimates as overly conservative. The International Commission on Large Dams (ICOLD), an international body for dam builders, claimed in its response that the contribution of large dams to the growth in agricultural production was closer to 80% (Gopalakrishnan 2000). Our estimates suggest that World Commission on Dams (2000b) estimates are closer to the truth.

4.4 Rural welfare

In this section we examine whether dams have created population groups who have not received adequate compensation for losses suffered, or whether the productivity effects of dam construction, combined with appropriate redistributive policies, prevented the creation of such groups.

We use a district panel data-set on rural consumption, poverty and wage outcomes. Clearly, our results would be biased if dam construction induces either the relatively rich or the relatively poor populations to migrate across district boundaries. Panel B of Table 8 estimates the impact of dam construction on district census rural population outcomes. Dam construction has a small insignificant positive effect on overall population and in-migrants in both the dam's own district and downstream district. This suggests that dam-induced population movements across the district boundaries are not a serious concern, and we can use the district panel to study the impact of dam building on rural welfare.[22] However, to assess the extent of any possible bias due to migration we compute bounds on the influence of migration on the estimated impact of dams on poverty. The results are in Table 10; Panel A provides OLS estimates and Panel B 2SLS estimates.

In columns (1) and (2) we consider mean per-capita expenditure. In column (1), we

[22] Anecdotal and case study evidence suggests that displaced populations prefer to remain near their original habitats. (Thukral 1992)

find that an additional dam causes a statsitically significant decrease of 0.3% in per-capita expenditure in the OLS specification, and an insignificant decline of 0.35% in the 2SLS specification. Column (2) includes dams built in upstream districts as an additional explanatory variable. The coefficient on the expenditure in a dam's own district remains negative, and is now significant at the 10% level in the 2SLS regression (and at the 5% level in the OLS regression). Dams have a modest positive impact on per-capita expenditure in downstream districts. However, both the OLS and 2SLS estimates are insignificant. The 2SLS estimate is almost twice as large as, but statistically indistinguishable from, the OLS estimate.

In columns (3) and (4) we observe that the decline in per-capita expenditure translates into an increase in poverty. Columns (3) and (4) consider the head-count ratio (this is the fraction of population with expenditure levels that place them below the poverty line). Dams significantly increase poverty in their own district, and lead to a decline in poverty in downstream districts. The downstream effect is significant at 5% in the 2SLS estimates. In column (3), the OLS estimate for the own district effect is positive and significant, but the 2SLS estimate, while positive, is insignificant: this parallels our reduced form estimate.

Columns (5) and (6) provide bounds that account for migration. We take the point estimate of the effect of dams on in-migrants and make alternative assumptions about their poverty status. We then recompute the head-count ratio (we follow the idea of "Manski bounds" (Manski 1990)). In column (5), we compute the head-count ratio assuming that all in-migrants are poor. This reduces the head-count ratio more in districts with more dams. The OLS estimate of the own district effect changes sign and is insignificant. However, the confidence intervals in columns (5) and (4) overlap. The 2SLS estimate is positive but insignificant. In column (6), we recompute the head-count ratio assuming that all in-migrants are rich. Not surprisingly, both the OLS and 2SLS estimates in column (6) exceed the original estimates. As usual, as the Manski bounds are not tight, and the results have to be interpreted with caution. However, they do not suggest severe bias with our 2SLS results.

The head-count ratio is a relatively crude measure of the extent of poverty. The poverty gap measures the depth of poverty – specifically, how much income would be needed to bring the poor to a consumption level equal to the poverty line. Columns (7) and (8) consider poverty gap as the dependent measure, and find similar effects: dams significantly increase the poverty gap in their own district, and significantly reduce it downstream. The point estimate for the poverty reduction associated with dam construction upstream varies from one-fourth (in the OLS) to one-eighth (in the 2SLS) of the poverty increase in the dams' own district. In our sample there are, on average, 1.75 districts downstream of each dam. This implies that the poverty reduction in districts downstream from the district where a dam is constructed is too small to compensate for the poverty increase in the dam's own district.

In columns (9) and (10) we find no significant effect of dam construction on inequality in either own or downstream districts. Columns (11) and (12) consider male agricultural wages. Annual data are available for 1971-1994, but for fewer states than in the poverty sample.[23] One might expect higher land productivity (especially from the production of cash crops) to translate into higher agricultural wages. Wages increase in districts located downstream from a dam. The 2SLS and OLS estimates are similar and suggest that 10 dams located upstream cause an increase in agricultural wages of roughly 0.02% (the 2SLS estimates are insignificant). The point estimate for own district is positive but imprecise.

Finally, columns (13) and (14) examine the claim that dams increase the incidence of malaria and other waterborne diseases in neighboring areas. We use data on annual malaria incidence from 1976 to 1995, but find no evidence of increased malaria incidence. This suggests that the poverty increase is more likely related to the loss of agricultural land and displacement than to negative health effects.

Dams and Rainfall Shocks

A different channel through which dams may affect rural welfare is by improving water security in the event of floods or droughts. If in years of bad rainfall dams provide insurance within their own district, then they may increase welfare even if, on average, they reduce consumption and increase poverty.

In Table 11 we use annual rainfall data for Indian districts to examine the role of dams in mediating the effect of rain shocks. Our rain shock measure is the fractional deviation of annual rainfall from the district's historical average.[24]

The odd columns in Table 11 document the effect of rain shocks on agricultural and welfare outcomes. Negative rain shocks decrease area irrigated, total production, and increase poverty. In the even columns of Table 11 we examine whether dams mitigate or accentuate the effect of rain shocks (for brevity, we only report 2SLS estimates, but the OLS estimates are very similar). Having a dam upstream reduces the adverse effect of a negative rain shock: the coefficients on dams-rain shock interaction variable and rainshock variable have the opposite sign. In contrast, dams *amplify* the effect of a bad rain shock in their own district; the coefficients on dams-rain shock interaction variable and the rainfall variable now have

[23] We get similar results when we restrict the year to years for which we have NSS data

[24] A higher value implies more rainfall, which, in general, is a good thing.

the same sign. The amplification effect is potentially due to restrictions on water use in the dam's catchment area.[25]

These findings have significant implications for the dynamics of poverty in these districts. Low level of migration and closed markets imply an amplification of negative shocks (Jayachandran 2004). The poor in India have limited access to insurance against risk in rural India (Morduch (1995)), and faced with limited insurance options the poor make inefficient investments (Rosenzweig and Binswanger (1993), Rosenzweig and Wolpin (1993), Morduch (1995)), which may further increase poverty.

Institutions and Poverty

The inability or unwillingness of those who benefit from dams to compensate groups of losers, or of the government to force them to do so, when both groups are clearly identifiable *ex-ante* suggests poor institutions of redistribution. To explore this possibility we build upon recent work by Banerjee and Iyer (2005).

Banerjee and Iyer (2005) demonstrate significant differences in the ability of the population to organize, and obtain public goods, across Indian districts. They argue that these differences stem, in part, from different historical legacies. During the colonial period, the British instituted different land revenue collection systems across districts. In some districts, an intermediary (landlord) was given property rights for land and tax collection responsibilities. In other districts, farmers were individually or collectively responsible for tax collection. "Landlord" districts saw the emergence of a class of landed gentry, who had conflictual relationships with the peasants. In these districts class relations remain tense, rendering collective action more difficult. Districts under the landlord system continue to have lower public good provision, lower agricultural productivity, and more infant mortality.[26]

If the politically and economically disadvantaged are more able to demand redistribution in non-landlord districts (and the elite feel more compelled to compensate losers), then the poverty impact of dams should be smaller in those districts. Using Banerjee and Iyer's data, we interact dams with either a dummy for being a non-landlord district, or the fraction of land under non-landlord rule in a district and include this interaction as an additional explanatory variable (our instrument set is as before, plus their interaction with the landlord variable). The results are presented in Table 12, and are striking. There is no systematic

[25]In order to ensure sufficient flow downstream, water use upstream from the dam is typically restricted, especially in periods of drought.

[26]Banerjee and Iyer (2005) document that whether a district was a landlord district was related to British politics, not district characteristics. Their results are robust to restricting the sample to neighboring districts or using the date of conquest as an instrument.

pattern in the production and irrigation regressions, suggesting that technology drives the differential impact of dams on production and irrigation. However, the impact of dams on poverty in own district is halved in non-landlord districts (the interaction coefficient has a t-statistic of 1.89 in the poverty gap regression), and we cannot reject the hypothesis that dams do not increase poverty in non-landlord districts. There is no significant pattern in the downstream districts where no losers are created.

We conjecture that in non-landlord districts the population is either more effective in organizing to demand compensation, or more equal in sharing among losers and winners within the district. It is also possible that the absence of the landed gentry gives the displaced more political power. More generally, these findings point to the relevance of the institutional framework within which public policies, such as dam construction, are executed and suggest 'weak institutions' or social conflict may help explain why dam construction has particularly strong distributional and poverty implications in developing countries.

4.5 Robustness Checks

We conclude this section with some alternative specifications and robustness checks

Leads and lags

Columns (1), (4), (6) and (8) in Table 13 examine whether dams affect economic outcomes prior to their construction. This specification check is particularly relevant for the poverty regression since one could potentially attribute the poverty findings to a return to normal poverty levels following a decline while the dam was being constructed. To examine this, we include dams built up to 5 years in the future as an additional variable. Our faith in our identification assumption is bolstered by the finding that in no case does future dam construction affect current outcomes.

Columns (2), (5), (7) and (9) examine whether the effect of dams persists 5 years after dam construction. We find some evidence that the effect of dam is gradual; dams built 5 years ago, for example, affect poverty more than those built today.

Column (3) investigates whether dams recharge the groundwater table. If they do, then, relative to the short run, irrigation potential in a district should increase by more in the long run. We estimate a level specification for 1994, where we regress gross irrigated area in 1994 on the number of dams built in 1974 and the number of dams in 1994 (see column (1), Table (3) for the corresponding first stage). We cannot reject the hypothesis that 1974 dams do not affect 1994 irrigated area and are, therefore, unable to find evidence of groundwater recharging.

Functional form

Table 14 examines whether the effect of dams varies with dam size. Our instruments are too weak for us to estimate multiple parameters. But since the 2SLS and OLS estimates are similar for most specifications, we feel confident about focusing on OLS estimates.

Our regressions include as separate regressors the number of small (below 16 meters), medium (16 to 30 meters) and large (above 30 meters) dams. The effect of dams on poverty is driven by large dams, while the impact of dams on productivity is driven by medium dams. This is in line with the case-study literature which suggests the negative impact of dams is the most pronounced for very large dams. It is also possible that, for small dams, the positive and negative effects on poverty occur within the same district (since both the catchment area and command area are smaller) and averaging these effects over the district implies no aggregate effect.

We also estimated, but do not report, a specification which includes as separate regressors a dummy for whether there is at least one dam in a district, and the number of dams. The dummy for "at least one dam" is insignificant, and the coefficient on the number of dams remained unchanged (in magnitude or size) suggesting that the effect of the number of dams on economic outcomes is linear in the number of dams.

Alternative neighborhood measures

Table 15 examines whether the impact of dam construction in a district extends beyond its neighboring downstream districts. For brevity, we only report 2SLS estimates.

In Panel A we examine all neighboring districts. The effect of dams constructed downstream to a district is negative but insignificant, and there is no effect in neighboring districts which are neither upstream or downstream. In Panel B we examine whether a district benefits from dam construction in districts which are upstream to its upstream neighbors and find no effect. Clearly, some large dams may help control floods several hundred kilometers downstream. But for the average dam, it is unlikely that any effect extends beyond the next two districts, and these results suggest that it does not extend beyond the next district.

This table suggests that our focus on the district in which the dam was built and the adjacent downstream district is appropriate for capturing the effects of most dams, even if some dams affect more than the immediate neighboring districts. It also suggests that our estimate of the economic impact of dams in own and upstream districts on district outcomes is a reasonable approximation of the overall effect of dams, save any general equilibrium effect which affects all district equally.

The most likely general equilibrium effect is a price effect, due to the increase in production. If the poor are net sellers of agricultural products (Deaton (1989)), a decrease in food prices is likely to accentuate poverty. In this sense, the failure to account for general equilibrium effects is likely to underestimate the impact of dams on poverty.

5 Conclusion

In 2000, public spending on infrastructure in developing countries averaged 9% of government spending, or 1.4 % of GDP (IMF Statistics). Despite the magnitude of such spending, and a widespread belief that infrastructure is integral to development, evidence on how investment in physical infrastructure affects productivity and individual well-being remains limited (Bank 1994). There is also very little evidence on the distributional consequences of such investment.

In this paper we have examined these questions in the context of large dam construction in India. We have argued that any credible evaluation of large dams must address the endogeneity of dam placement, which depends both on the wealth of different regions and the expected returns from dam construction. This problem of endogenous placement is central to the evaluation of any large infrastructure project. Placement will reflect both regional need and a complicated decision-making process (Gramlich (1994)). While a growing cross-country literature finds that productive government spending enhances growth, most studies are unable to convincingly control for unobserved heterogeneity (see, for instance, Canning, Fay, and Perotti (1994) and Esfahani and Ramirez (2003)). By taking account of geographic suitability for infrastructure we provide a potentially generalizable way of estimating returns to investment. Our estimation strategy also allows us to examine the relative importance of different factors in driving infrastructure decisions. For instance, we find that our 2SLS results are, with a few exceptions, very similar to OLS results when we restrict the comparison to districts within a state, with a few exceptions. This suggests that while the overall number of dams a state builds is endogenous, dam placement within a state has possibly been driven by cost considerations rather than political economy or rate of returns concerns.

We have also emphasized the importance of identifying who the beneficiaries of investment projects are, and who bears the costs. To return to the example of the World Bank, in Spring 2005 the Bank announced 270 million dollars in grants and guarantees for the Nam Theun 2 dam in Laos. The New York Times (June 5, 2005) quotes a bank official justifying the return to dam lending as driven by the need to support infrastructure development in a ‘practical’ way since “You’re never ever going to do one of these in which every single person is going to say, ’This is good for me”’ (Fountain 2005). Implicit in this statement is the belief that projects with an average positive return should be undertaken, as it will be possible to compensate the losers. We, however, find a strikingly unequal sharing of costs and benefits of large dam construction in India. The results on poverty suggest that the government failed to compensate people living near the dam for the inherent inequities in the gains and losses associated with dam construction. Given that dams are at best marginally cost-effective the absence of redistribution may well have been required to generate a political constituency for large dams. We provide suggestive evidence that one reason for the lack of compensation relates to the institutional framework within which policy decisions are made. In areas where the institutional structure favors the politically and economically advantaged dams cause a greater increase in poverty. We conclude that distributional implications of public policies should be central to any evaluation, and that more attention should focus on understanding the institutions, and power structures, that lead to the implementation of marginally cost effective projects with significant negative distributional implications.

6 Data Appendix

Dams
Data on dams is from the World Registry of Large Dams, maintained by the International Commission on Large Dams (ICOLD). The registry lists all large dams in India, completed or under construction, together with the nearest city to the dam and date of completion. We use city information to assign dams to districts in the year of completion.
Geography
Data on district area, river kilometers, district elevation and gradient and river gradient are collated from two GIS files: *GTOPO*30 (elevation data, available at http://edcdaac.usgs.gov/gtopo30/gtopo30.html), and 'dnnet' (river drainage network data, available at http://ortelius.maproom.psu.edu/dcw/). The files were processed by CIESIN, Earth Institute Columbia University using ARCGIS software. Polygon-wise GIS data exists for every district. District gradient and elevation was computed as % district land area in different elevation/gradient categories (summed across polygons in district). For river gradient we used the same process but restricted attention to polygons through which the river flowed. We identified neighboring districts, and within them upstream and downstream districts, from District Census Maps.
Agriculture data
These data are from the Evenson and McKinsey India Agriculture and Climate data-set (available at http://chd.ucla.edu/dev-data), with an update. The data-set covers 271 Indian districts within 13 Indian states, defined by 1961 boundaries. Kerala and Assam are the major excluded agricultural states. Also absent, but less important agriculturally, are the minor states and Union Territories in Northeastern India, and the Northern states of Himachal Pradesh and Jammu-Kashmir. Data on volume produced, fertilizer used and area cropped are from the original data-set (1971-1987). We use the average 1960-65 crop prices to obtain monetary production and yield values. Data on irrigated and total cultivated area and male agricultural wages span 1971-1994. All monetary variables are deflated by the state-specific Consumer Price Index for Agricultural laborers in Ozler and Ravallion. (1996), base year 1973-74.
Rural Welfare data
We use household expenditure survey data collected by Indian National Sample Survey (NSS). These are All India surveys with a sample size of about 75,000 rural and 45,000 urban households. Households are sampled randomly within districts.[27] Only NSS for 1973 regional averages were obtained from Jain, K.Sundaram, and S.D.Tendulkar (1988). For the 1983-84, 1987-88, 1993-94 and 1999-2000 ("thick") rounds, Topalova (2004) computed district-wise statistics using the poverty lines proposed by Deaton (rather than those of the Indian Planning Commission, which are based on defective price indices over time, across

[27]The NSS Organization does not report district averages, as it considers the district sample size inadequate for reliable district poverty estimates. This does not affect us, since we report regression results for a larger number of districts and do not make any inference about a particular district.

states and between the urban and rural sector) (Deaton (2003a), Deaton (2003b)).[28] The 1999-2000 round introduced a new 7-day recall period, along with the usual 30-day recall period, for household expenditures on most goods. This methodology is believed to have led to an overestimate of the expenditures based on the 30-day recall period, making the poverty and inequality estimates non-comparable to estimates for earlier years. To achieve comparability across surveys she follows Deaton and imputes, for 1999, the correct district per capita expenditure distribution from households expenditures on a subset of goods for which the new recall period questions were not introduced. The poverty, inequality, and mean per capita expenditure measures were derived from this distribution.

District identifiers are available 1987 onwards (in hard copy for 1993). For 1973 and 1983, we have NSS region estimates (a region is a group of neighboring districts for which the sample is sufficiently large for the NSS to deem the data "representative" of the region). We use the district matching across censuses, and region to district matching, provided in Murthi, P.V.Srinivasan, and S.V.Subramanian (2001) and in Indian censuses to match regions to districts and account for district boundary changes.

Population, Public Goods and Landlord data

Population and Public Goods data are from the Decennial Census of India for the years 1971,1981 and 1991. The public goods data are referred to as village directory data, and have been aggregated at the district level to generate the fraction of villages in the district that have a particular public good (obtained from Banerjee and Somanathan (2005)). The population data are in logs (obtained from the Maryland Indian District Database (http://www.bsos.umd.edu/socy/vanneman/districts/index.html)). District colonial land tenure system data is from Banerjee and Iyer (2005)

Rainfall

We use the rainfall data set, Terrestrial Air Temperature and Precipitation: Monthly and Annual Time Series (1950-99), Version 1.02, was constructed by Cord J. Willows and Kanji Maturate at the Center for Climatic Research, University of Delaware. The rainfall measure for a latitude-longitude node combines data from 20 nearby weather stations using an interpolation algorithm based on the spherical version of Shepards distance-weighting method. We define a rainfall shock as the fractional deviation of the district's rainfall from the district mean (computed over 1971-1999).

[28]Poverty lines were unavailable for the smaller states and union territories of Arunachal Pradesh, Goa, Daman and Diu, Jammu and Kashmir, Manipur, Meghalaya, Mizoram, Nagaland, Sikkim, Tripura, Andaman and Nicobar Islands, Chandigarh, Pondicherry, Lakshwadweep, Dadra Nagar and Haveli. Most are already excluded because they have no dams or we lack other data for them. For those included, we use the neighboring states' poverty line.

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Table 1: Descriptive Statistics

	Beginning Period	End Period	Source
A. Geography			
Fraction district with river gradient 0-1.5%	0.748		GIS
	(0.31)		
Fraction district with river gradient 1.5-3%	0.077		GIS
	(0.08)		
Fraction district with river gradient 3-6%	0.059		GIS
	(0.08)		
Fraction district with river gradient 6-10%	0.036		GIS
	(0.06)		
Fraction district with river gradient above 10%	0.077		GIS
	(0.19)		
B. Dams			
Number of dams in district	2.39	8.66	ICOLD Dam Register
	(4.55)	(16.58)	
Number of dams upstream to district	3.63	13.85	ICOLD Dam Register
	(7.77)	(30.57)	
C. Welfare			
Per capita expenditure (log Rupees)	3.80	5.79	National Sample Survey
	(0.196)	(0.271)	
Headcount ratio	0.46	0.22	National Sample Survey
	(0.156)	(0.139)	
Poverty gap	0.27	0.04	National Sample Survey
	(0.052)	(0.035)	
Gini coefficient	0.28	0.26	National Sample Survey
	(0.036)	(0.038)	
Agricultural wage (Rupees)	4.45	6.01	Evenson and McKinsey
	(1.79)	(2.19)	
D. Agriculture			
Gross cultivated area (in '000 hectares)	570	642	Evenson and McKinsey
	(278)	(324)	
Gross irrigated area (in '000 hectares)	138	253	Evenson and McKinsey
	(151)	(222)	
Total production (Rupees per '000 tons)	215841	297007	Evenson and McKinsey
	(143896)	(251412)	
Fertilizer use (Rupees per '000 tons)	11606	40275	Evenson and McKinsey
	(12177)	(36040)	
E. Demographics and Public Goods			
Rural Population	1295120	1887262	Census of India
	(867033)	(1254164)	
Rural In-migrants	365563	485667	Census of India
	(239150)	(308711)	
Fraction Villages with any water source	0.982	0.997	Census of India
	(0.026)	(0.006)	
Fraction Villages with power	0.244	0.806	Census of India
	(0.255)	(0.224)	
Fraction Non-landlord districts	0.611		Banerjee and Iyer
	(0.489)		

Notes

1. Beginning and end periods are: (i) Dams: 1971 and 1999; (ii)Welfare measures:1973 and 1999, and for wages: 1971 and 1987; (iii) Area variables:1971 and 1994; (iv)Production and fertilizer use: 1971 and 1987; (v) Demographic and Public goods:1971 and 1991.
2. Standard deviations in parentheses

Table 2: State Dams and Economic Outcomes

	Gross Irrigated Area	Agricultural Production	Headcount ratio	Gross Irrigated Area	Agricultural Production	Headcount ratio
	(1)	(2)	(3)	(4)	(5)	(6)
Dams in state	0.075	0.004	-0.0055			
	(0.012)	(0.017)	(0.0030)			
Dams in state, year [t+5]				0.076	0.005	-0.0045
				(0.012)	(0.017)	(0.0029)
N	6091	4571	1809	6091	4571	1805

Notes:

1. Regressions include state and year fixed effects.

2. Gross Irrigated Area and Agricultural Production are in logs.

3.Standard errors clustered by state*year in parentheses.

Table 3: Changes in Number of Dams, Poverty and Production by State Dam Incidence and District River Gradient

	District River Gradient		
	High	Low	Difference
	(1)	(2)	(3)
Panel A: Dams constructed b/w 1973-1999 (per 100 dams)			
High dam construction states	0.154	0.076	0.078
	(0.019)	(0.013)	(0.023)
Low dam construction states	0.01	0.003	0.007
	(0.200)	(0.110)	(0.003)
Difference	0.144	0.073	0.071
	(0.017)	(0.013)	(0.023)
Panel B: Change in head count ratio b/w 1973-1999			
High dam construction states	-0.2315	-0.235	0.0035
	(0.011)	(0.011)	(0.017)
Low dam construction states	-0.231	-0.189	-0.042
	(1.570)	(0.019)	(0.025)
Difference	-0.0005	-0.046	0.0455
	(0.019)	(0.022)	(0.030)
Panel C: Change in log production b/w 1970-1986			
High dam construction states	0.124	0.311	-0.187
	(0.046)	(0.034)	(0.010)
Low dam construction states	0.201	0.059	0.142
	(0.012)	(0.113)	(0.022)
Difference	-0.077	0.252	-0.329
	(0.014)	(0.017)	(0.024)

Notes:
1. A state with over 100 dams by 1999 is a high dam construction state, and a low dam construction state otherwise. A district with less than 90% of area along river with below 1.5% gradient is a high gradient district, and a low gradient district otherwise.

2. Each cell gives the average change in the variable for all districts with the specific district-state combination. Standard errors in parenthesis.

Table 4: Geography and Dam Construction

Dependent variable	Number of Dams			Head count ratio	Agricultural Production
	Cross-section		FE	FE	FE
years	1979	1994	1973-99	1973-1999	1971-1987
	(1)	(2)	(3)	(4)	(5)
Dams in state*(Fraction river gradient 1.5-3%)	0.082	0.114	0.152	0.077	-0.055
	(0.031)	(0.028)	(0.044)	(0.045)	(0.118)
Dams in state*(Fraction river gradient 3-5%)	-0.119	-0.188	-0.233	-0.077	-0.053
	(0.059)	(0.055)	(0.058)	(0.096)	(0.182)
Dams in state*(Fraction river gradient 6-10%)	0.094	0.118	0.044	-0.058	0.183
	(0.079)	(0.073)	(0.077)	(0.125)	(0.332)
Dams in state*(Fraction river gradient above 10%)	0.036	0.085	0.206	0.122	0.030
	(0.036)	(0.038)	(0.048)	(0.111)	(0.268)
F-test for river gradient	2.268	5.457	10.058	0.772	0.532
[p-value]	[0.061]	[0.000]	[0.000]	[0.543]	[0.712]
Dams in state*River length	0.004	0.005	0.006	0.003	0.007
	(0.002)	(0.001)	(0.001)	(0.003)	(0.005)
Dams in state*(Fraction district gradient 1.5-3%)	0.038	0.096	0.158	0.101	-0.158
	(0.037)	(0.034)	(0.049)	(0.076)	(0.183)
Dams in state*(Fraction district gradient 3-5%)	0.168	0.068	-0.009	-0.087	0.076
	(0.064)	(0.061)	(0.106)	(0.134)	(0.316)
Dams in state*(Fraction district gradient 6-10%)	-0.627	-0.307	-0.096	-0.197	-0.150
	(0.108)	(0.106)	(0.239)	(0.263)	(0.603)
Dams in state*(Fraction district gradient above 10%)	0.401	0.189	0.088	0.246	-0.014
	(0.098)	(0.095)	(0.174)	(0.208)	(0.511)
Dams in state*(Fraction district elevation 250-500 metres)	0.019	0.015	0.008	-0.003	0.006
	(0.005)	(0.005)	(0.007)	(0.010)	(0.022)
Dams in state*(Fraction district elevation 500-1000 metres)	0.033	0.030	0.022	0.003	0.023
	(0.004)	(0.004)	(0.006)	(0.010)	(0.023)
Dams in state*(Fraction district elevation over 1000 metres)	-0.351	-0.186	-0.082	-0.269	0.627
	(0.087)	(0.086)	(0.183)	(0.304)	(1.145)
Dams in state*District area (square kilometers)	0.001	0.000	0.0000	-0.0005	0.0005
	(0.000)	(0.000)	(0.0004)	(0.0002)	(0.0005)
District Fixed effects	No	No	Yes	Yes	Yes
R-squared	0.77	0.75	0.97	0.97	0.94
N	371	371	1855	1855	4537

Notes:

1.All regressions include a full set of state*year interactions. Columns (3)-(5) regression include district fixed effects.

2.Standard errors are in parentheses. They are clustered by NSS region*year in column (3) and (4), and district in column (5).

3.Years included in the 1973-1999 sample are: 1973, 1983, 1987, 1993 and 1999. The 1971-87 sample has annual data.

4. River length is per 1000 kms and District area per 10,000sq. kms. Coefficients in columns (1)-(3) are multipled by 100.

Table 5: Dams and Agricultural Area

	Irrigated area				Cultivated area						HYV area	
	Gross		Net		Gross		Net		Multicropping		Five crops	
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)
PANEL A. OLS												
Dams:												
Own district	-0.092	-0.190	-0.132	-0.233	0.013	-0.023	0.026	-0.028	-0.027	-0.007	0.104	0.249
	(0.413)	(0.370)	(0.387)	(0.331)	(0.066)	(0.061)	(0.049)	(0.054)	(0.060)	(0.047)	(0.371)	(0.387)
Upstream		0.655		0.616		0.001		-0.058		0.070		0.601
		(0.204)		(0.208)		(0.038)		(0.036)		(0.032)		(0.274)
PANEL B. 2SLS												
Dams:												
Own district	1.349	2.251	1.343	2.145	-0.385	-0.508	-0.149	-0.441	-0.333	-0.145	0.262	-0.602
	(1.104)	(1.371)	(1.046)	(1.352)	(0.225)	(0.278)	(0.205)	(0.249)	(0.212)	(0.208)	(1.216)	(1.018)
Upstream		1.135		1.142		-0.010		-0.077		0.071		0.739
		(0.288)		(0.291)		(0.056)		(0.054)		(0.053)		(0.379)
N	6067	6067	6067	6067	6055	6055	6055	6055	6055	6055	4493	4493

Notes

1. All regressions include district fixed effects, a full set of state*year interactions and interaction of the number of dams in the state with district gradient, kilometers of river, and district elevation (see table 4 for a full list of controls).

2. Regressions in even columns include as additional controls the interactions of the number of dams in the state with: the average of proportion district gradient and proportion district elevation, and the sum of river kilometers in the upstream districts (plus a indicator for whether the district has any upstream districts).

3. Standard errors clustered by district are reported in parentheses.

4. Dependent variables are in logs. All coefficients are multiplied by 100. Irrigated and cultivated area regressions are for 1971-1994, HYV regressions for 1971-1987. The crops in hyv area regression are wheat, rice, jowar, bajra and maize. Multicropping is the ratio of gross cropped area to net cropped area.

Table 6: Dams and Agriculture

	Production		Yield		Fertilizer Use	
	nineteen crops					
	(1)	(2)	(3)	(4)	(5)	(6)
PANEL A. OLS						
Dams:						
Own district	-0.204	-0.253	-0.203	-0.242	0.385	0.572
	(0.208)	(0.223)	(0.201)	(0.208)	(0.304)	(0.309)
Upstream		0.218		0.169		0.316
		(0.121)		(0.107)		(0.227)
PANEL B. 2SLS						
Dams:						
Own district	0.061	-0.436	-0.442	-0.744	-1.707	-1.758
	(0.749)	(0.643)	(0.597)	(0.594)	(1.440)	(1.537)
Upstream		0.357		0.350		0.592
		(0.165)		(0.162)		(0.272)
N	4537	4537	4537	4537	4521	4521

Notes

1. All regressions include district fixed effects, a full set of state*year interactions and the interaction of number of dams in the state with district gradient, kilometers of river, and district elevation (see table 4 for a full list of controls).

2. Regressions in even columns include as additional controls the interactions of number of dams in the state with: the average of proportion district gradient and proportion district elevation, and the sum of river kilometers in the upstream districts (plus a indicator for whether the district has any upstream districts).

3. Standard errors clustered by district are reported in parentheses.

4. Dependent variables in logs. All coefficients multiplied by 100. Regressions cover 1971-1987. The 19 crops are wheat, rice, jowar, sugarcane, groundnut, bajra, maize, gram, tur, other pulses, barley, tobacco, ragi, sesamum, cotton, potato, jute, soy, and sunflower.

Table 7: Dams and Crop Outcomes

	Non-water intensive crops				Water intensive crops			
	All	Millet	Pulse	Wheat	All	Sugar	Cotton	Rice
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
PANEL A. AREA CULTIVATED								
A1. OLS								
Dams								
Own district	-0.52	0.16	-0.16	-0.27	0.14	0.72	1.99	-0.39
	(0.36)	(0.38)	(0.44)	(0.36)	(0.23)	(0.53)	(0.86)	(0.35)
Upstream	0.29	0.38	0.11	0.26	0.05	0.64	-0.02	0.33
	(0.15)	(0.17)	(0.22)	(0.18)	(0.14)	(0.37)	(0.42)	(0.21)
A2. 2SLS								
Own district	-0.03	0.58	-0.42	-1.32	1.25	3.57	0.71	0.76
	(0.98)	(1.30)	(1.16)	(1.00)	(1.08)	(2.57)	(3.16)	(0.94)
Upstream	0.14	0.37	0.06	0.42	0.33	1.38	0.05	0.77
	(0.18)	(0.24)	(0.29)	(0.20)	(0.23)	(0.40)	(0.47)	(0.31)
N	4530	4480	4464	4104	4489	4264	2790	4373
PANEL B. YIELD								
B1. OLS								
Own district	-0.044	0.105	-0.136	0.229	-0.135	0.133	-0.399	-0.172
	(0.259)	(0.479)	(0.268)	(0.220)	(0.322)	(0.268)	(0.518)	(0.358)
Upstream	0.114	0.268	-0.085	0.140	0.246	0.066	-0.382	-0.196
	(0.134)	(0.182)	(0.086)	(0.103)	(0.207)	(0.105)	(0.254)	(0.138)
B2. 2SLS								
Own district	-0.816	-0.829	0.104	-0.327	-0.593	0.424	0.447	-1.024
	(0.655)	(0.955)	(0.586)	(0.921)	(0.950)	(0.895)	(1.351)	(0.868)
Upstream	0.266	0.531	-0.077	0.293	0.315	0.156	-0.373	-0.229
	(0.201)	(0.280)	(0.114)	(0.160)	(0.267)	(0.142)	(0.358)	(0.173)
N	4528	4476	4456	4073	4482	4252	2582	4359
PANEL C. PRODUCTION								
C1. OLS								
Own district	-0.600	0.271	-0.341	-0.024	-0.015	0.722	1.343	-0.624
	(0.427)	(0.554)	(0.416)	(0.424)	(0.400)	(0.634)	(1.112)	(0.419)
Upstream	0.322	0.645	0.003	0.442	0.274	0.552	-0.242	0.154
	(0.198)	(0.235)	(0.208)	(0.220)	(0.198)	(0.395)	(0.517)	(0.215)
C2. 2SLS								
Own district	-0.818	-0.240	-0.407	-1.534	0.624	4.268	0.492	-0.225
	(1.180)	(1.670)	(1.199)	(1.358)	(1.321)	(2.963)	(3.133)	(1.213)
Upstream	0.295	0.896	-0.014	0.753	0.619	1.386	-0.053	0.544
	(0.241)	(0.349)	(0.296)	(0.284)	(0.229)	(0.415)	(0.653)	(0.330)
N	4531	4483	4456	4085	4497	4362	2587	4361

Notes:

1. All regressions include district fixed effects, a full set of state*year interactions, and interaction of the number of dams in the state with district gradient, kilometers of river, and district elevation (see table 4 for a full list of controls).
2. They also include as controls the interactions of number of dams in the state with: the average of proportion district gradient and proportion district elevation, and the sum of river kilometers in the upstream districts (plus a indicator for whether the district has any upstream districts).
3. Standard errors clustered by district are reported in parentheses.
4. Area, yield and production variables are in logs. All coefficients are multiplied by 100.

Table 8: Dams and Public Good Provision and Demographics: 2SLS estimates

	Education facility	Medical facility	Water facility	Canals	Power	Tarmac road
	(1)	(2)	(3)	(4)	(5)	(6)
PANEL A: PUBLIC GOODS						
Dams						
Own district	0.109	0.421	0.029	0.035	0.358	0.063
	(0.210)	(0.337)	(0.059)	(0.168)	(0.413)	(0.254)
Upstream	0.015	0.041	-0.024	0.040	0.199	0.063
	(0.058)	(0.096)	(0.013)	(0.091)	(0.094)	(0.084)
N	847	847	847	562	848	848
PANEL B: POPULATION						
	Population	In-migrants	SC/ST population	Agricultural laborers	Cultivators	
Own district	0.481	0.481	-2.145	1.364	0.330	
	(1.070)	(1.555)	(8.489)	(1.961)	(1.920)	
Upstream	0.065	0.191	0.196	0.037	0.007	
	(0.104)	(0.145)	(0.937)	(0.182)	(0.161)	
N	947	947	853	944	945	

Notes:

1. Regressions include district fixed effects, a full set of state*year interactions, and interaction of the number of dams in the state with district gradient, kilometers of river, and district elevation (see table 4 for a full list of controls).
2. Other controls are the interactions of number of dams in the state with: the average of proportion district gradient and elevation, and the sum of river kilometers in upstream districts (plus a indicator for whether the district has any upstream districts).
3. Standard errors are reported in parentheses. These are clustered by district. All coefficients are multiplied by 100.
4. The regressions include 1971, 1981 and 1991. In panel A the dependent variable is the fraction villages in district with the public good facility. Water facility exclude dams. In panel B dependent variables are in logs and refer to the rural population.

Table 9: Cost Benefit Analysis for Dams

A. Parameters	
A1. Effect of dams on production downstream	0.00357
A2. Effect of dams on irrigation downstream	0.0113
A3. Effect of dams on area in own district	0.022
A4. Effect of dams on fertilizer downstream	0.0059
A5. Number of dams built per year (1970-1997) (ICOLD)	0.46
A6. Number of districts downstream from a dam	1.75
A7. Deadweight loss of taxation (assumption)	0.15
A8. Capital cost of dam construction, per hectare (Planning Commission)	12258
A9. Annual recurrent cost of dam upkeep (per hectare) (Planning Commission)	194
A10. Annual increase in production	0.0189
B. Calculating Substitution	
B1. Area irrigated by dams, 1985 (hectares) (Planning Commission)	23570000
B2. Number of dams in 1985 (ICOLD)	2691
B3. Area irrigated by per dam, 1985 (hectares) (B2/B1))	8759
B4. Area irrigated per district in 1996 (hectares) (Evenson and McKinsey)	150940
B5. Additional area of irrigation due to dams (hectares) (B4*A2*A6+A3*B4)	6306
B6. Fraction newly irrigated/total irrigated	**0.72**
C. Cost Benefit analysis, 1985	
C1. Total production in 1985(Rs per 1000 tons) (Evenson & Mc Kinsey)	83700000
C2. Total production increase per dam (downstream) C1*A1	298809
C3. Life time benefit (with 5% discount rate: C2*20)	5976180
C4. Area irrigated (in '000 hectares)	38641
C5. Increase in irrigation in downstream district per dam (C5*A2)	437
C6. Life time benefit per hectare irrigated (C3/C5)	13687
C7. Life time benefit, including cheaper irrigation (C6/B5)	19012
C8. Annual fertilizer cost , 1985 (Evenson and Mc Kinsey)	9912700
C9. Increase in fertlizer cost due to dams	58484.93
C10. Life time fertilizer cost per hectare	2679
C11. Life time capital cost+maintenance per hectare	16129
C12. Total life time cost	18808
C13. Total life time cost, with dead weight loss	21629
C14. Rate of returns, without deadweight loss	**1.011**
C15. Rate of returns, with deadweight loss	**0.879**
C16. Rate of returns, without deadweight loss, excluding fertlizer use	**1.179**
C17. Rate of returns, with deadweight loss, excluding fertlizer use	**1.025**
D. Contribution of dams to overall increase in production	
D1=Annual increase in production	1581930
D2=Annual increase in production due to dams	137452
D3=Contribution of dams to annual growth in production	**0.087**

Notes

1. All values are expressed in 1973 prices.

2. Unless otherwise specified the parameters are authors' calculations.

Table 10: Dams and Rural Welfare

	Percapita expenditure		Head count ratio				Poverty gap		Gini coefficient		Agricultural wages		Malaria incidence	
			Original		assume migrants are poor	assume migrants are rich								
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)
PANEL A. OLS														
Dams														
Own district	-0.266	-0.316	0.267	0.277	-0.158	0.616	0.083	0.081	0.006	-0.001	0.067	0.178	-4.79	-1.32
	(0.135)	(0.127)	(0.090)	(0.089)	(0.105)	(0.096)	(0.029)	(0.029)	(0.032)	(0.030)	(0.217)	(0.218)	(6.17)	(6.63)
Upstream		0.038		-0.051	-0.044	-0.059		-0.021		-0.005		0.207		-6.74
		(0.053)		(0.036)	(0.038)	(0.038)		(0.012)		(0.013)		(0.098)		(4.54)
PANEL B. 2SLS														
Dams														
Own district	-0.353	-0.756	0.493	0.772	0.387	1.188	0.144	0.228	-0.018	-0.014	-0.078	0.749	-15.20	-6.24
	(0.590)	(0.443)	(0.328)	(0.285)	(0.326)	(0.316)	(0.093)	(0.083)	(0.125)	(0.105)	(0.818)	(0.848)	(24.81)	(19.70)
Upstream		0.066		-0.098	-0.100	-0.107		-0.034		-0.008		0.222		-7.19
		(0.071)		(0.049)	(0.052)	(0.052)		(0.016)		(0.019)		(0.151)		(6.01)
N	1799	1799	1799	1799	1799	1799	1799	1799	1794	1794	6072	6072	7126	7126

Notes:

1. All regressions include district fixed effects, a full set of state*year interactions, and interaction of the number of dams in the state with district gradient, kilometers of river, and district elevation (see table 4 for a full list of controls).

2. The regressions in the even columns (and column 5) also control for the interactions of the number of dams in the state with: the average of the proportion of district gradient, the proportion of district elevation, and the sum of river kilometers in the upstream districts (plus a indicator for whether the district has any upstream districts)

3. Standard errors are reported in parentheses. These are clustered by 1973 NSS region*year in columns (1)-(10), and by district in columns (11) -(14).

4. The regressions in columns (1)-(10) include 1973, 1983, 1987, 1993 and 1999. Column (11)-(12) regression covers 1971-1994. Column 913)-1(14) cover 1975-1995.

5. Per capita expenditure and agricultural wages are in logarithms. Columns (3) and (4) use head count ratio figures as computed from NSS data. Column (5) and (6) adjust this using Table 7 migration estimates. Column (5) assumes all migrants are poor, and column (6) all migrants are rich. Malaria incidence is measured as annual Parasite Incidence (API) = (No. of blood smears found positive for malaria/ total population under surveillance)*1000. All coefficients are multiplied by 100.

Table 11 : Dams and Rainfall Shocks

	Gross irrigated area			Total production			Headcount ratio			Poverty Gap		
	OLS		2SLS	OLS		2SLS	OLS		2SLS	OLS		2SLS
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)
Rainshock	0.084	0.073	0.090	0.122	0.077	0.131	-0.060	-0.045	-0.051	-0.018	-0.009	-0.006
	(0.040)	(0.042)	(0.046)	(0.035)	(0.040)	(0.046)	(0.019)	(0.023)	(0.025)	(0.007)	(0.008)	(0.009)
Dams		-0.156	2.367		-0.138	-0.190		0.232	0.697		0.059	0.185
		(0.368)	(1.406)		(0.223)	(0.593)		(0.093)	(0.279)		(0.030)	(0.081)
Dams*Rainshock		0.752	0.591		1.211	0.472		-0.244	-0.238		-0.131	-0.196
		(0.260)	(0.267)		(0.343)	(0.288)		(0.113)	(0.175)		(0.045)	(0.086)
Upstream Dams		0.650	1.092		0.168	0.315		-0.043	-0.074		-0.020	-0.025
		(0.204)	(0.296)		(0.111)	(0.168)		(0.038)	(0.052)		(0.012)	(0.016)
Upstream Dams*		-0.180	-0.143		-0.333	-0.298		0.063	0.117		0.015	0.037
Rainshock		(0.077)	(0.073)		(0.103)	(0.103)		(0.039)	(0.062)		(0.013)	(0.023)
N	6067	6067	6067	4537	4537	4537	1799	1799	1799	1799	1799	1799

Notes:

1. All regressions include district fixed effects, a full set of state*year interactions, and the interaction of the number of dams in the state with district gradient, kilometers of river, and district elevation (see table 4 for a full list of controls).

2. All regressions with dams as a regressor also control for the interactions of number of dams in the state with: the average of the proportion of district gradient, the proportion of district elevation, and the sum of river kilometers in the upstream districts (plus a indicator for whether the district has any upstream district)

3. Standard errors reported in parentheses. These are clustered by district in columns (1)-(6), and by NSS region*year in columns (7)-(12).

4. Rainshock is the fractional deviation of district rainfall from district historic mean (over 1971-1999). Agricultural variables are in logarithms. All coefficients multipled by 100.

Table 12 : Dams and Historic Land Tenure System: 2SLS estimates

	Gross Irrigated Area		Total Production		Headcount ratio		Poverty Gap	
Non-landlord measure	Non-landlord dummy	Proportion non-landlord	Non-landlord dummy	Proportion non-landlord	Non-landlord dummy	Proportion non-landlord	Non-landlord dummy	Proportion non-landlord
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Dams	0.768	1.435	0.302	0.384	1.276	1.317	0.408	0.418
	(2.077)	(2.371)	(1.198)	(1.279)	(0.588)	(0.665)	(0.197)	(0.220)
Dams*Non-landlord	-0.059	-0.688	-0.522	-0.592	-0.527	-0.601	-0.208	-0.225
	(1.563)	(1.728)	(0.605)	(0.644)	(0.363)	(0.399)	(0.110)	(0.125)
Upstream Dams	0.859	1.052	-0.041	-0.172	-0.292	-0.439	-0.133	-0.167
	(0.851)	(0.912)	(0.667)	(0.684)	(0.334)	(0.348)	(0.099)	(0.108)
Upstream Dams*	-0.362	-0.593	0.445	0.576	0.077	0.214	0.056	0.086
Non-landlord	(0.805)	(0.809)	(0.654)	(0.665)	(0.308)	(0.313)	(0.089)	(0.096)
N	3427	3427	2550	2550	914	914	914	914

Notes:

1. All regressions include district fixed effects and a full set of state*year interactions, as well as interaction of the number of dams in the state with the district gradient, kilometers of river, and district elevation (see table 4 for a full list of controls)

2. All regressions also control for the interactions of the number of dams in the state with: the average of the proportion of district gradient, the proportion of district elevation, and the sum of river kilometers in the upstream districts (plus a indicator for whether the district has any upstream districts)

3. Standard errors reported in parentheses. These are clustered by district in columns (1)-(4), and by NSS region*year in columns (5)-(8).

4.The sample is restricted to districts under British direct rule. Our landlord measures are from Banerjee and Iyer (2005) . All coefficients multipled by 100.

Table 13: Lead and Lag Effects of Dams: 2SLS Estimates

	Gross Irrigated Area			Total Production		Head count ratio		Poverty Gap	
	FE	FE	Level in 1994	FE	FE	FE	FE	FE	FE
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
Dams									
Own district	17.001	10.277	-13.44	2.598	0.467	1.181	0.236	0.309	0.071
	(12.041)	(5.019)	(42.220)	(2.063)	(1.564)	(0.472)	(0.457)	(0.132)	(0.147)
Own district, t+5 years	-17.770			-2.707		-0.87		-0.203	
	(15.580)			(1.740)		(0.674)		(0.196)	
Own district, t-5 years		-8.918			-1.340		0.528		0.158
		(5.318)			(2.570)		(0.381)		(0.130)
Own district in 1974			49.45						
			(105.220)						
Upstream	0.068	2.279	-1.968	0.312	0.164	-0.084	-0.061	-0.015	-0.036
	(2.726)	(1.467)	(12.38)	(0.557)	(0.391)	(0.131)	(0.104)	(0.041)	(0.033)
Upstream, t+5 years	1.813			0.153		0.000		-0.039	
	(4.157)			(0.738)		(0.295)		(0.087)	
Upstream, t-5 years		-0.887			0.242		-0.034		0.002
		(1.213)			(0.454)		(0.088)		(0.028)
Upstream district in 1974			0.754						
			(34.220)						
F-test for own district and		2.57			0.230		4.89		4.95
own district t-5 years		(0.078)			(0.790)		(0.008)		(0.008)
F-test for upstream and		7.73			2.180		2.04		2.31
upstream t-5 years		(0.000)			(0.110)		(0.131)		(0.101)
District fixed effects	Yes	Yes	No	Yes	Yes	Yes	Yes	Yes	Yes
N	6067	6091	253	4554	4554	1799	1799	1799	1799

Notes:

1. For headcount ratio t-5 and t+5 refer to the previous and next year for which poverty data is available (on average 5 years).
2. All regressions include district fixed effects, a full set of state*year interactions and interaction of number of dams in the state with district gradient, kilometers of river, and district elevation (see table 4 for a full list of controls).
3. All regressions also control for the interactions of the number of dams in the state with: the average of the proportion of district gradient, the proportion of district elevation, and the sum of river kilometers in the upstream districts (plus a indicator for whether the district has any upstream districts).
4.All regressions except in column (3) include district fixed effect.
5. Standard errors are reported in parentheses. These are clustered by NSS region*year in columns (6)-(9) and by district in columns (1)-(2).
6. All agricultural outcomes are in logs. All coefficients multiplied by 100.

Table 14: Effect of Dam Size: OLS estimates

	Gross irrigated area		Production		Headcount ratio		Poverty Gap	
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Number of small dams	-0.931	-1.293	-0.292	-0.326	0.217	0.115	0.076	0.039
(less than 16 m)	(0.583)	(0.478)	(0.267)	(0.277)	(0.133)	(0.139)	(0.047)	(0.049)
Number of medium dams	1.305	1.500	-0.122	-0.057	0.192	0.371	0.036	0.074
(16-30 m)	(0.754)	(0.762)	(0.452)	(0.558)	(0.242)	(0.228)	(0.075)	(0.076)
Number of large dams	-0.863	0.067	0.174	0.353	1.575	1.584	0.600	0.589
(over 30m)	(2.586)	(2.689)	(1.130)	(1.304)	(0.811)	(0.824)	(0.285)	(0.286)
Number of small dams		0.885		-0.270		-0.055		0.014
upstream		(0.309)		(0.218)		(0.109)		(0.040)
Number of medium dams		0.663		0.796		-0.049		-0.045
upstream		(0.384)		(0.279)		(0.125)		(0.043)
Number of high dams		-3.359		0.069		0.136		-0.069
upstream		(2.150)		(1.342)		(0.606)		(0.212)
N	6067	6067	4537	4537	1799	1799	1799	1799

Notes:

1. All regressions include district fixed effects, a full set of state*year interactions and interaction of number of dams in the state with the district gradient, kilometers of river, and district elevation (see table 4 for a full list of controls).
2. All regressions in even columns also control for interactions of number of dams in the state with: the average of the proportion of district gradient, the proportion of district elevation, and the sum of river kilometers in the upstream districts (plus a indicator for whether the district has any upstream districts)
3. Standard errors are reported in parentheses. These are clustered by district in columns (1)-(4), and by NSS region*year in columns (5)-(8).
4. 16 m is the 50th percentile of dam height in our sample, and 30 m the 90th percentile.
5. Gross irrigated area and production are in logarithms.

Table 15: Dams and Neighborhood Effects: 2SLS estimates

	Gross irrigated area	Production	Head count ratio	Poverty Gap
	(1)	(2)	(3)	(4)
PANEL A. NEIGHBORING DISTRICTS				
Dams				
Own district	3.038	0.151	0.698	0.192
	(1.442)	(0.701)	(0.325)	(0.099)
Upstream	0.981	0.331	-0.102	-0.035
	(0.280)	(0.167)	(0.050)	(0.017)
Downstream	-0.408	-0.020	0.074	0.025
	(0.445)	(0.242)	(0.087)	(0.026)
Neighboring but not	-0.066	-0.054	-0.047	-0.019
upstream/downstream	(0.418)	(0.160)	(0.081)	(0.027)
PANEL B. NEIGHBORS OF NEIGHBORING DISTRICTS				
Dams				
Own district	3.923	-0.312	0.847	0.245
	(1.845)	(0.629)	(0.270)	(0.084)
Upstream	1.716	0.543	-0.060	-0.013
	(0.554)	(0.276)	(0.103)	(0.033)
Upstream to upstream	-0.219	-0.088	-0.016	-0.011
districts	(0.297)	(0.120)	(0.060)	(0.020)
N	6067	4537	1799	1799

Notes:

1. All regressions include district fixed effects, a full set of state*year interactions and interaction of the number of dams in the state with district gradient, kilometers of river, and district elevation (see table 4 for a full list of controls).

2. Panel A regressions control for interactions of the number of dams in the state with: the average of the proportion of district gradient, the proportion of district elevation, and the sum of river kilometers in the upstream, dowstream, and other neighboring districts (plus indicator variables for whether the district has any upstream, downstream or other neighboring districts).

3. Panel B regressions control for interactions of the number of dams in the state with: the average of the proportion of district gradient, the proportion of district elevation, and the sum of river kilometers in the upstream and upstream to upstream districts (plus indicator variables for whether the district has any upstream and upstream to upstream district).

3. Standard errors clustered at the district level (columns 1 and 2) or the region*year level (column 3 and 4)

4. All coefficients multiplied by 100.

Figure 1: Dams in 1965

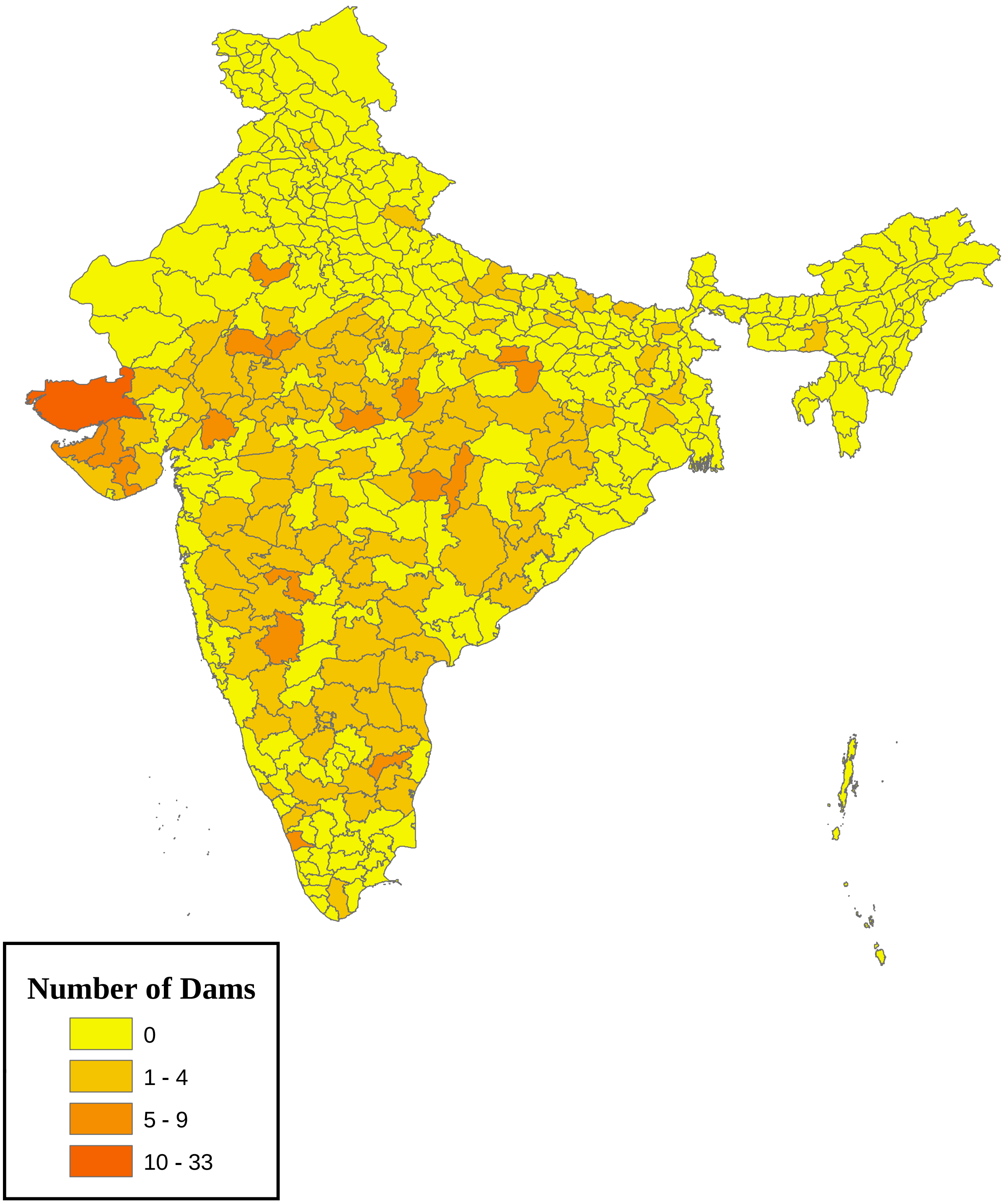

Figure 2: Dams in 1995

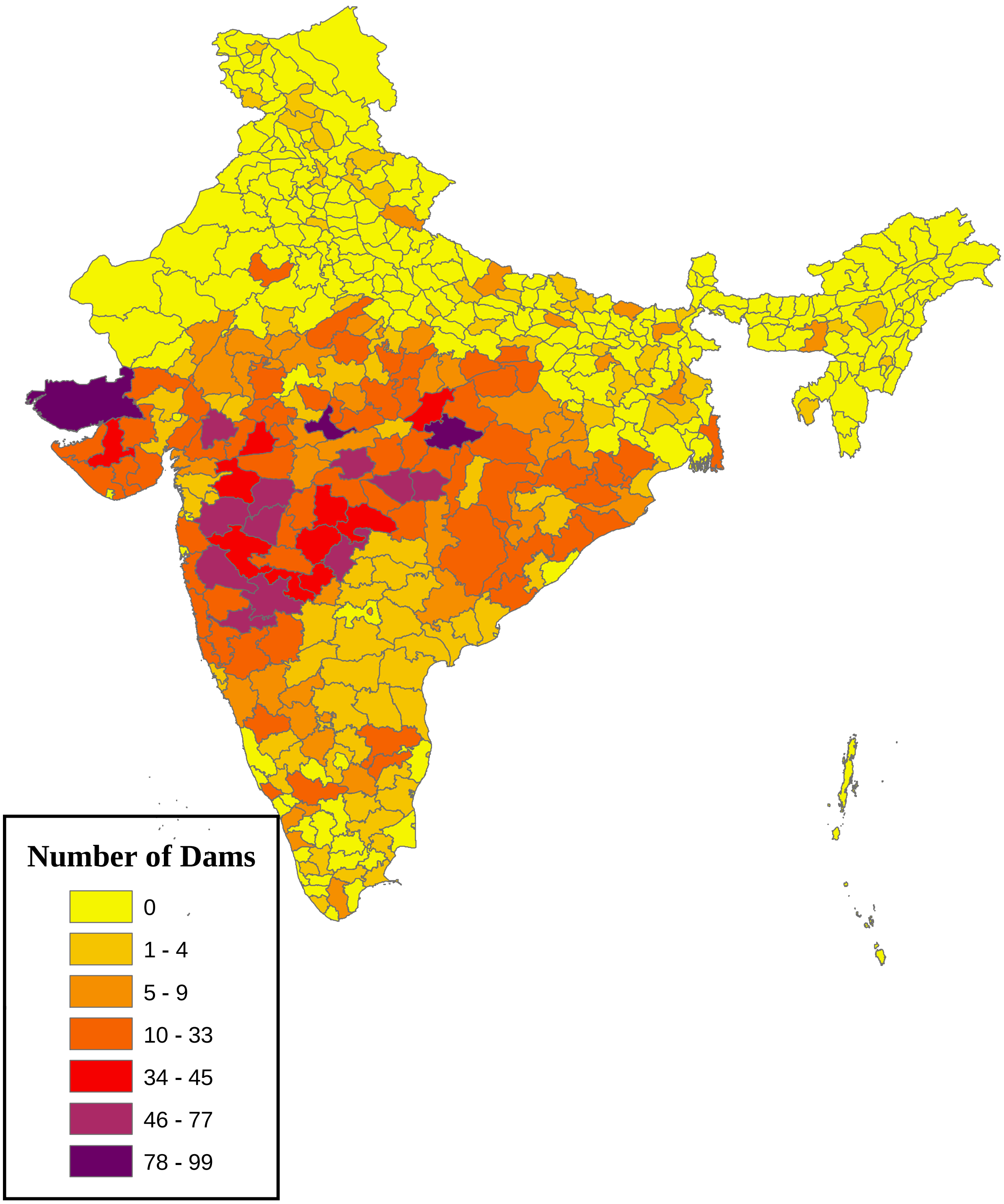

Figure 3:Average District Gradient

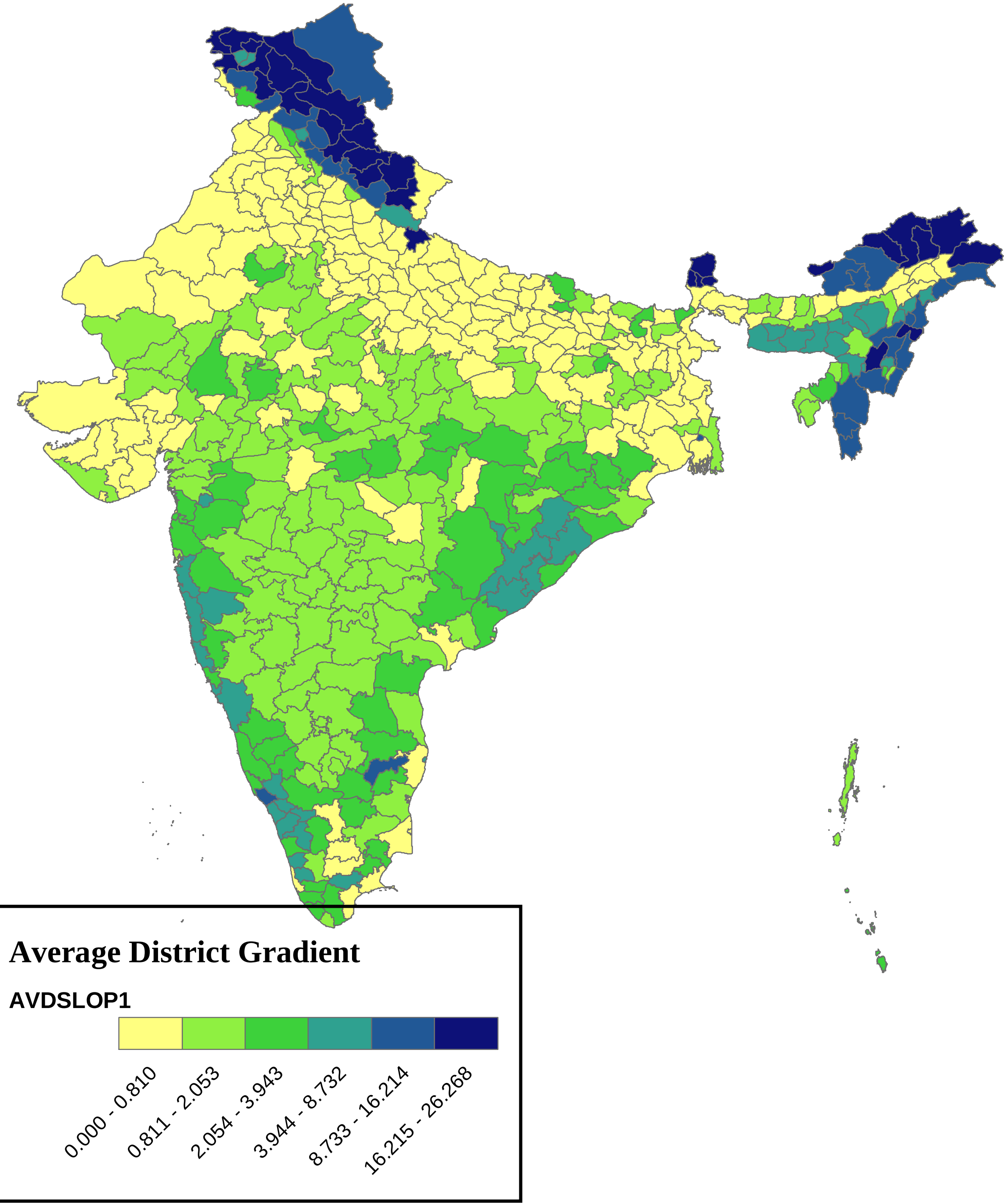

Figure 4: Average River Gradient

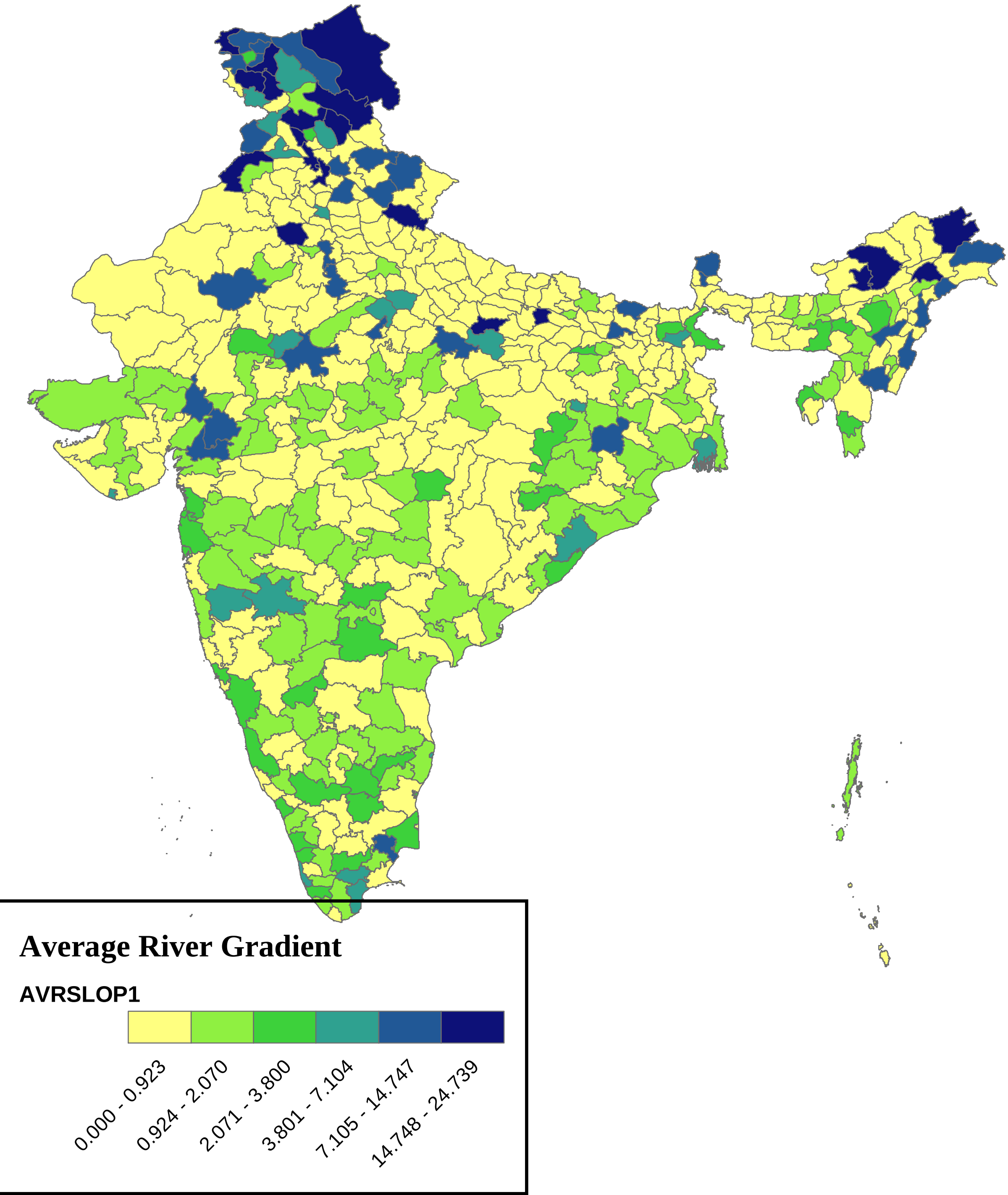

Figure 5: Coefficients of River Slope interactions in Poverty and Dam Regressions

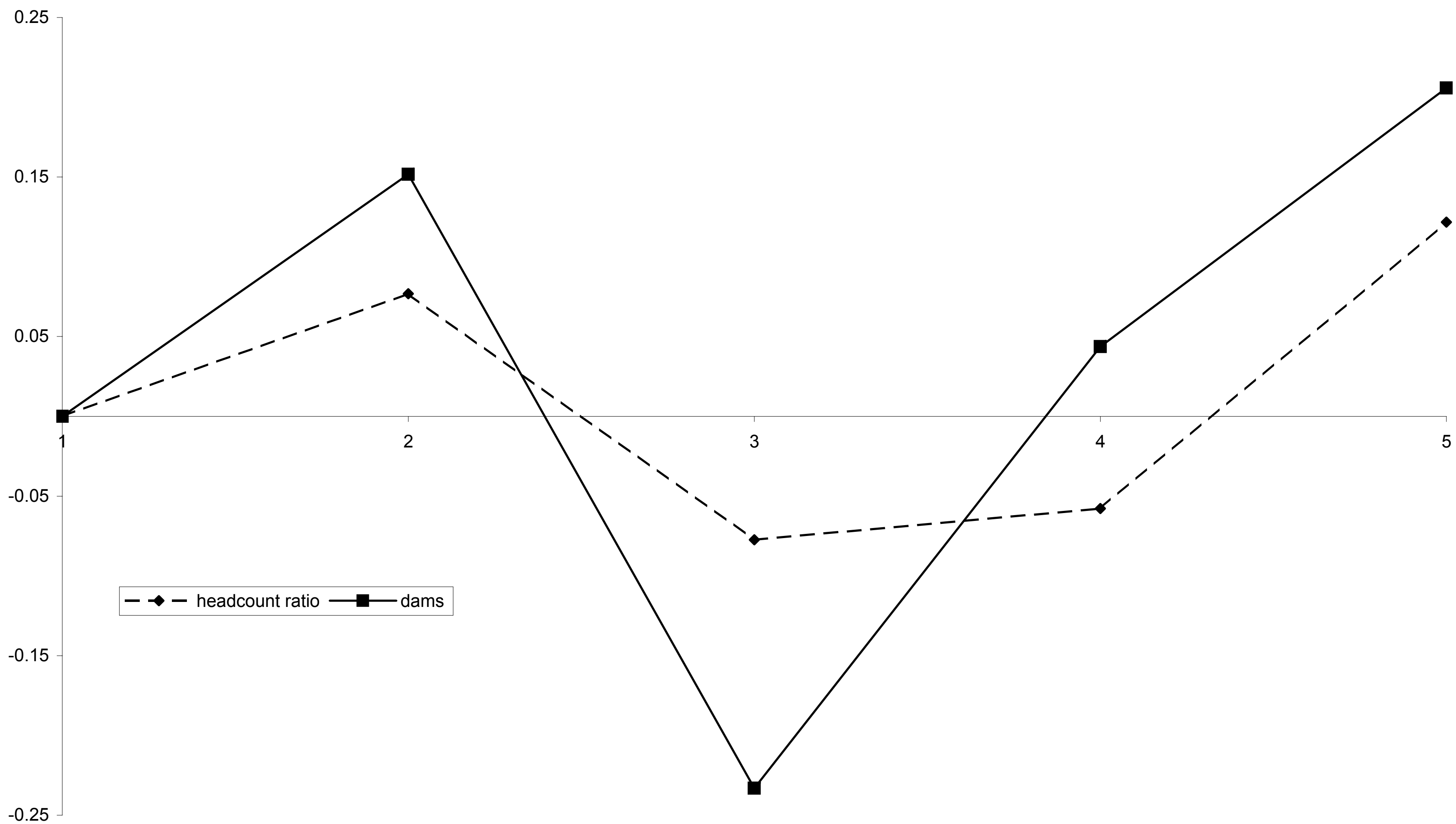

Figure 6: Coefficients of River Slope in Production and Dam regressions