

Misgoverning the Commons: Corruption and Rent-seeking in Pakistan's Indus Basin

Hanan G. Jacoby* Ghazala Mansuri†

December 30, 2017

Abstract

Surface irrigation is a common pool resource characterized by asymmetric appropriation opportunities across upstream and downstream water-users. Large canal systems are also predominantly state-managed. We study water allocation under an irrigation bureaucracy subject to corruption and rent-seeking. Data on the landholdings and political influence of nearly a quarter-million irrigators in Pakistan's vast Indus basin watershed allow us to construct a novel index of lobbying power. Consistent with our model of misgovernance, the decline in water availability and land values from channel head to tail is accentuated along canals having greater lobbying power at the head than at the tail.

*World Bank (hjacob@worldbank.org), 1818 H St NW, Washington DC 20433. Funding for this project was provided by the World Bank's Knowledge for Change Program, its Strategic Research Program, and its Research Support Budget. The project would not have been possible without the support of the Punjab Irrigation Department. The authors are particularly grateful to Mr. Habibullah Bodla at the PMIU for providing access to the discharge data and to Mr. Afzal Toor at PIDA for facilitating the irrigation outlet survey. The team also thanks Mr. Saif Anjum (ex-Secretary Irrigation) for his consistent support. The views expressed herein are those of the authors, and do not necessarily reflect the opinions of the World Bank, its executive directors, or the countries they represent.

†World Bank (gmansuri@worldbank.org).

1 Introduction

Human efforts to control the flow of water for agriculture gave rise to the world’s first great civilizations,¹ and today surface irrigation delivers lifeblood to tens of millions of farmers across the globe. Gravity-flow surface irrigation is also significant as a common pool resource. Because it is prohibitively costly to fully enforce off-take from a river or canal, irrigation water is subject to appropriation by upstream users (“headenders”) at the expense of those downstream (“tailenders”), a version of the tragedy of the commons.² In *Governing the Commons*, Ostrom (1990) argued that non-state institutions often arise organically to avert such tragedies through collective action. Yet, private (free market) allocation of canal water in large-scale irrigation systems faces daunting economic and technical hurdles (Sam-path 1992). Instead, extensive irrigation bureaucracies have been established to operate centralized systems for the allocation of water as it makes its way down from the rivers and main canals to the network of distributaries, minor and sub-minor canals, and, finally, to the watercourse outlets, where it is delivered to individual farms. While the dysfunction of state-managed irrigation has been well documented (e.g., Wade 1982 and Chambers 1988),³ we lack a falsifiable theory of commons regulation that accounts for the differing incentives within the bureaucratic hierarchy as well as between the regulator and the regulated.

In this paper we consider the interplay between bureaucratic management and common property users, or rather groups of users, in the context of the world’s largest canal irrigation system, that of the Indus basin watershed of Pakistan. On this vast system, de jure water allocations are based on a proportionality principle inherited from the British colonial

¹Wittfogel (1957) famously claimed that the need to mobilize labor for large irrigation works and to manage water allocation brought into being the authoritarian state.

²Bromley et al. (1980), Ostrom and Gardner (1993) and Ray and Williams (2002), among many others, highlight this locational asymmetry inherent in canal irrigation systems.

³Disappointment with the performance of state-run systems has sown the seeds for irrigation management reform underway worldwide (Garces-Restrepo et al. 2007). In a companion paper (Jacoby et al. 2017), we study just such a reform carried out in Pakistan’s Punjab province.

administration: to each according to his cultivable area. De facto allocations, however, are determined by interactions between groups of farmers, organized by channel outlet, and the provincial irrigation department. As we will argue, this interaction is characterized by both corruption *and* rent-seeking. Corruption is of the “with theft” variety (Shleifer and Vishny, 1993), in that the farmers who pay the bribe and the local irrigation official who demands it both benefit; the losers are the farmers at the downstream outlets who receive less water than they are entitled to. Rent-seeking arises as coalitions of headenders and tailenders lobby the higher irrigation department office to intercede on their behalf, e.g., by replacing (or not replacing) the local official. In choosing how hard to lobby, we assume that the head coalition takes into account the bribes its members must pay, while the rational local official internalizes the rent-seeking induced by his own corruption.

Our theoretical model allows a role for political influence in the rent-seeking contest. Of critical importance for the contest outcome is the distribution of lobbying power (or efficacy) along a channel. We establish that, insofar as such influence is relatively greater at the head reaches than at the tail, “theft” will be greater, which is to say that more water will be diverted toward the head and away from the tail. Our model also has implications for the value of farmland, which is assumed to reflect not only the productive value of the canal water delivered but also the bribes that farmers may have to pay to ensure these deliveries. Even though the bribe amount is increasing in the relative influence of headend landowners, thus depressing their land values, we show that the productive value of the greater off-take at the head more than makes up for this; thus, on balance, the head-tail land value differential increases with relative head influence. Finally, the assumption of competitive rent-seeking delivers a distinctive symmetry result: a one unit increase in lobbying influence of the head coalition has an equivalent impact on the head-tail differential in both water availability and land values as a one unit decrease in political influence of the tail coalition.

To test these implications, we have collected a truly unique data set on both landowner-

ship and influential positions held by *every* water-user in each of 3923 watercourses (outlets) along 448 channels throughout Punjab province; in all, we have information on about 220,000 individual farmers. Knowledge of these two dimensions of influence, land and official position-holding, allows us to extend recent work equating political power with landownership (e.g., Anderson et al. 2015 and Baland and Robinson 2008). We construct a novel and intuitively appealing index of lobbying power that takes into account the interaction between irrigated landholdings, a measure of an individual's economic stake, and personal influence aggregated across *all* members of each contending coalition. Landowners contribute to the index more than in proportion to their economic stake insofar as they hold an influential position (such as a local political office). Our empirical strategy exploits variation in canal discharge and land values across head and tail outlets along the same channel, thus purging channel-level unobservables that may be correlated with both lobbying influence and water availability.

The main contribution of this paper is to develop and empirically test a political-economy model of common pool resource management in the spirit of Krueger (1974). Past literature, by contrast, is largely prescriptive, focusing on the welfare costs of overexploitation and the optimal regulation of the resource by a benevolent social planner (e.g., Huang and Smith 2014 for the case of a fishery; Gisser 1983 and Timmins 2002 for the case of a groundwater aquifer).⁴ We also contribute to a growing empirical literature concerned with bureaucratic incentives and corruption (Reinikka and Svensson 2004; Olken 2007; Olken and Barron 2009; Burgess et al. 2012; Neihaus and Sukhtanakar 2013). What differentiates our work is the focus on competitive rent-seeking amongst the agents affected by the bureaucrat's actions; in other words, we recognize the political context in which a bureaucracy operates.⁵

⁴An important exception is Johnson and Libecap (1982), who consider the conflicting interests of heterogeneous fishermen in the formation of fishery regulation along the Texas coast. In their context, however, corruption within the regulatory enforcement agency does not appear to be an issue.

⁵Reinikka and Svensson (2004) touch upon this issue by considering how communities interact with their local officials' school-fund disbursement decision. Importantly, however, there is no inter-community competition for resources in their context and, hence, officials are not balancing opposing interests. Also related, Banerjee et al. (2001) explore the implications of rent-seeking within private sugar cooperatives in

The remainder of the paper is organized as follows. In the next section, we provide institutional background on the canal irrigation system in Pakistan, the basis upon which we build our theoretical arguments in section 3. Section 4 describes the data collection effort on the two aspects of political influence and on land values, as well as the measurement of canal discharge in the Indus basin. In Section 5, we present empirical tests of the theory, consider alternative explanations for the results, and analyze their implications for wealth inequality. We conclude in Section 6.

2 Indus Basin irrigation system

The Indus Basin irrigation system, which accounts for 80% of Pakistan’s agricultural production, lies mostly in its most populous province, Punjab, wherein it encompasses 37 thousand kilometers of canals and irrigates about 8.5 million hectares. From the Indus, Jhelum, Chenab, Ravi, and Sutlej rivers, a dense network of main canals, branch canals, distributaries, minors, and sub-minors ramify out, ultimately feeding 58 thousand individual watercourses in Punjab alone (See Figure 1 for a schematic of the canal hierarchy).⁶

Each watercourse outlet or *mogha* supplies irrigation to typically several dozen farmers according to a rotational system known as *warabandi*. The institution of *warabandi* (literally “fixed turns”), which traces its origins to British colonial rule and to the early development of irrigation in the Indus basin, embodies a modified principle of equity: to each irrigator in proportion to his cultivated area. At each level of the canal hierarchy in this continuous gravity-flow irrigation system, “authorized discharge” is allocated in proportion to cultivable command area (CCA). At the main canal level, irrigation department staff operate a series of gates regulating flow into the off-taking distributaries according to a rotational sched-

India, focusing on the conflict of interest between large and small growers.

⁶On about a third of Punjab’s irrigation system, canal management was devolved, in fits and starts, to locally elected farmers organizations beginning in the early 2000s (see Jacoby et al. 2017). This paper focuses on the remaining two-thirds of the system.

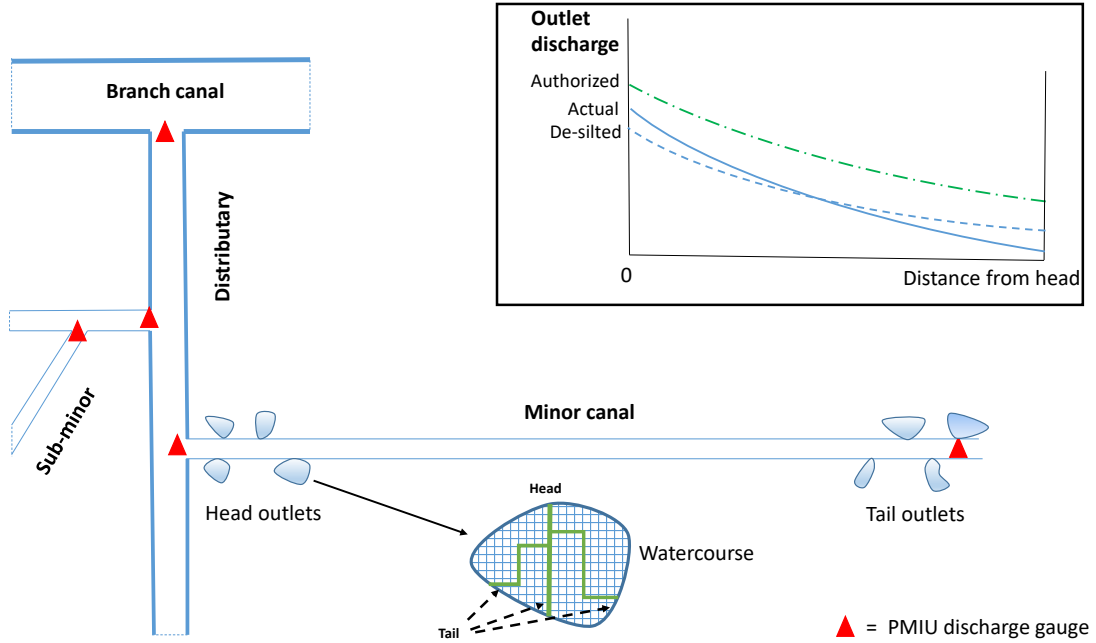


Figure 1: CHANNEL SCHEMATIC WITH DISCHARGE GAUGES

ule. However, since *moghas* are ungated, discharge into tertiary units, the watercourses, is determined by the width of the outlet; the greater the watercourse CCA, the greater the authorized outlet width and thus the greater the water in-take each week. Over the course of a week, proceeding from the head to the tail of the watercourse, each farmers takes his pre-assigned turn at using the entire flow to irrigate his field, with the length of turn proportional to the size of the field.

Although design discharge at any point along a channel accounts for seepage and conveyance losses and is therefore a declining function of distance to the head (see Figure 1 inset), tail outlets should, by virtue of their greater width, receive their full water entitlement.⁷ In practice, however, this elaborately constructed allocation system does not guarantee equity. If discharge at the distributary head is intermittent during the filling cycle (as is often the case; see Bandaragoda and Rehman 1995), or if the canal becomes over-silted, water may fail

⁷Since there is no adjustment for seepage within a watercourse, farmers at the tail-end of a *watercourse* are at a disadvantage relative to those at the head even on paper (more on this below).

to reach the tail outlets. Canal maintenance, which consists largely of de-silting operations conducted during the January canal closures, is the responsibility of the irrigation department, giving it discretion over whether and how a canal gets dredged.⁸ When a channel becomes silted up, water level rises at the head, increasing discharge there, while falling at the tail (Van Waijjen et al. 1997). Lack of canal maintenance, therefore, would typically favor farmers at the head outlets (Figure 1 inset), which may give rise to lobbying by farmers at tail outlets to increase maintenance and by those at head outlets to suppress it. Maintenance suppression can thus be seen as one form of water theft.

More blatant forms of theft are well documented in the Indus basin:

Groups of farmers located in the upper reaches of the distribution canals may partly break their outlet or enlarge it in order to increase the discharge delivered to their fields...Farmers offer bribes to irrigation officials to avoid that the outlet be repaired and brought back to its official dimension, but also to avoid that the offense be taken to court. The outlet changes are typically made for a period of 6 months, after which it is repaired unless the farmers pay a new bribe. (Rinaudo 2002, p. 407-8).

Indeed, based on field measurements of 423 watercourse outlets in the Chishtian subdivision of southern Punjab, Rinaudo (2002) reports that 23% show physical evidence of illegal enlargement (see Lashari et al. 1997 for even higher rates of outlet tampering). Other modes of theft along a distributary, also with official connivance, include “the use of flexible siphoning pipes...[and] cuts in the banks,” (Rinaudo et al. 2000). Particularly egregious cases, especially if accompanied by downstream farmer protests, frequently make their way into national newspapers in Pakistan.

Rinaudo et al. (2000) emphasize a higher level contest for water rights, the locus of which is typically the sub-divisional office of the irrigation department:

Influential farmers who are well connected to high-level administration officers or to local

⁸Farmers are responsible for maintaining tertiary canals; i.e., their own watercourses.

politicians...are able to put pressure on the local staff of the irrigation bureaucracy in charge of water distribution...[C]o-operative local staff...benefit from promotions and favourable postings.

Uncooperative local staff may be transferred to another position.⁹ But, such rent-seeking presents a tradeoff:

The change in outlet dimensions are made by the line agency staff on a temporary basis, and they are periodically re-negotiated...[This] seems to indicate that the irrigation agency staff regulates the competition between rent-seekers, and maintains the potential costs of tail-enders' opposition under a threshold guaranteeing the stability of their position.

In the next section, we develop a model that incorporates precisely this tradeoff: too much corruption and the irrigation official risks losing his plum position.

3 A model of bureaucratic canal management

3.1 Preliminaries

Assume a continuum of outlets along a channel indexed by $n \in [0, N]$, with $n = 0$ representing the first outlet at the head of the channel and $n = N$ the last outlet at the tail of the channel. Suppose that each outlet has the same command area, normalized to one, and hence the same *de jure* endowment of water w_0 . The *de facto* inflow of water to each outlet is given by the function $w(n)$, which for the channel as a whole is constrained by¹⁰

$$\int_0^N w(n)dn = Nw_0. \tag{1}$$

⁹“Many [irrigation department] functionaries say they feel quite vulnerable to pressure from politicians who, although they could not get them fired, could still arbitrarily get them transferred from their positions.” (Mustafa 2002, p. 49)

¹⁰In practice, the aggregate endowment Nw_0 may not always be fully delivered to the head of the channel, but this does not affect our present argument.

Agricultural output depends on water per acre cultivated, but with diminishing marginal product.¹¹ The demand schedule for water $D(w)$ is, therefore, downward sloping ($D' < 0$ for $\forall w$). Suppose further that $D(w_0) > 0$ and that surplus from off-take w is

$$s(w) = \int_0^w D(w)dw. \quad (2)$$

So, the de jure allocation has a positive marginal value and confers a collective surplus or total value of $s_0 = s(w_0)$ to farmers on the outlet.

The efficient allocation of canal water along a channel maximizes

$$\int_0^N s(w(n))dn \quad (3)$$

subject to (1), which requires that $D(w(n))$ be equal across outlets. The de jure allocation, with $w(n) = w_0 \forall n$, is thus efficient and deviations from equal per acre allocations, such as those discussed below, create deadweight losses.¹²

3.2 Appropriation and corruption

Assume that canal water at each outlet is appropriated until its marginal value is zero subject to availability. Since water arrives first at the head of the channel, outlets at the head have first-mover advantage; some outlets at the tail must, therefore, get no water. Define outlet

¹¹Output, of course, also depends on purchased inputs such as seed and fertilizer, but to the extent that these are optimally chosen and that their prices do not vary along a channel, the presence of such complementary (to water) investments will not affect our analysis.

¹²Chakravorty and Roumasset (1993) point out that equal per-acre allocation along a canal is not necessarily efficient once conveyance losses—i.e., water seepage into the channel itself—are taken into account. They show that, in this case, optimal inflow at each outlet should *decline* with distance to the head. Chakravorty and Roumasset’s simulations, however, indicate that these conveyance loss effects only become quantitatively relevant for outlets at a considerable distance from the head. With a median length of 9 kilometers (see Appendix Table C.1), the channels that we consider are, in general, too short for conveyance losses to be consequential. Moreover, these simulations overstate the effect of canal seepage in our context by not accounting for the resulting aquifer recharge, which is recovered and used productively by farmers through groundwater pumping (as discussed in Section 4).

off-take \hat{w} such that $D(\hat{w}) = 0$ and the ‘critical’ outlet \hat{n} by $\hat{n}\hat{w} = Nw_0$ (using equation 1). Thus, all outlets $n \in [0, \hat{n}]$ off-take $\hat{w} - w_0$ in excess of their legal entitlement and receive surplus $\hat{s} = s(\hat{w})$, whereas all outlets $n \in (\hat{n}, N]$ receive no water and get zero surplus.

Now consider the role of the local irrigation department official with the authority to enforce the de jure water allocation. While the official could, at some effort cost, set $w < \hat{w}$ by restricting outlet tampering and other such violations, we assume that the amount of water theft $\hat{w} - w_0$ is taken as given (the enforcement cost is prohibitive). Alternatively, we may suppose that the official engages in Nash bargaining with each outlet over w , which yields the same result, i.e., $w = \hat{w}$.¹³ In any case, the official accepts a bribe from each offending outlet to overlook the infraction.¹⁴ If the official cannot commit to charging a particular bribe amount b to every outlet, then b would also be determined outlet-by-outlet in a Nash bargain and would thus only depend upon excess surplus $\hat{s} - s_0$.¹⁵ However, in the more general case developed in the next two subsections, the official commits to a bribe amount and in so doing takes into account the *channel-level* impact of the corruption. What bribe will the official charge? A larger bribe, up to the maximum willingness to pay $\hat{s} - s_0$, yields higher income to the official, but there is a potential downside. Before turning to the local official’s tradeoff, we must first consider rent-seeking.

3.3 Rent-seeking

Water theft creates groups of winners, namely farmers at head outlets, and losers, namely farmers at tail outlets. Define the head outlet coalition $C_H = \{n | n \in [0, \hat{n}]\}$ and the tail outlet

¹³In particular, w would be chosen to max $[s(w) - s_0 - b]^\eta b^{1-\eta}$, where b is the bribe and η is an exogenous bargaining weight. The necessary condition for an optimum implies that $s'(w) = D(w) = 0$.

¹⁴“The distinction between a bribe, offered by farmers to get the [irrigation official] to do something he might not otherwise do, and extortion money, demanded by the officer in return for not inflicting a penalty, is often difficult to draw in practice.” (Wade 1982, p. 297).

¹⁵In the model of Mookherjee and Png (1995), which resembles ours inasmuch as it involves a triad of regulator, inspector, and polluter, bribes paid by the polluter to the inspector *are* determined in a Nash bargain. A crucial difference between their set-up and ours, however, is that they have only one polluter and thus no competition for rents between those subject to regulation.

coalition $C_T = \{n | n \in (\hat{n}, N]\}$, where \hat{n} is the last outlet that would receive water under the appropriation scenario described in the last subsection. Each coalition can exert political pressure on the higher-level irrigation department bureaucracy to obtain their preferred outcome. C_H lobbies to maintain the water theft, which we take as the status quo, and C_T lobbies to restore the de jure water allocation. To effectuate the latter outcome, we may think of the local official as being transferred to another posting and replaced, at least temporarily, by direct irrigation department oversight and enforcement.¹⁶

Following Tullock (1980), then, we assume that the probability P of C_H winning the rent-seeking contest depends on the effort level, e_j , of both coalitions $j = H, T$ as follows:¹⁷

$$P = \frac{\iota_H e_H}{\iota_H e_H + \iota_T e_T}, \quad (4)$$

where the ι_j represent the *marginal influence* of coalition j . When $\iota_H \neq \iota_T$, there is a power asymmetry along the channel.

Assuming a unitary marginal cost of effort,¹⁸ expected net surplus for C_H is

$$\begin{aligned} \pi_H &= P\hat{n}(\hat{s} - b) + (1 - P)\hat{n}s_0 - e_H \\ &= \hat{n}s_0 + P\Delta_H - e_H, \end{aligned} \quad (5)$$

where $\Delta_H = \hat{n}(\hat{s} - s_0 - b)$, and for C_T is

$$\begin{aligned} \pi_T &= (1 - P)(N - \hat{n})s_0 - e_T \\ &= (N - \hat{n})s_0 - P\Delta_T - e_T \end{aligned} \quad (6)$$

¹⁶Motives of the higher level office to provide for such a “clean” regime may include the need to respond to demands for political accountability.

¹⁷The linearity of each player’s effort in the probability function is a standard simplification in the literature on games of rent-seeking (see Nitzan 1994).

¹⁸This assumption, applied to lobbying effort by both head and tail coalitions, is innocuous. High (low) marginal influence ι_j is equivalent to low (high) marginal cost of effort.

where $\Delta_T = (N - \hat{n})s_0$. Although we abstract here from free-riding on rent-seeking effort within each coalition, political influence ι_j can be seen, in part, as a measure of the efficacy of collective action (as in Acemoglu and Robinson’s 2008 political contest model). Moreover, rent-seeking effort may consist of an array of activities that could differ between head and tail, especially given the nature of the status quo. For instance, C_T may engage in protests (as in Reinniki and Svenson 2004) whereas C_H may adopt actions ranging from “mutual backscratching” with bureaucratic officials to hiring private goon squads to block any effort at restoring the de jure allocation.

Each coalition chooses its rent-seeking effort taking that of the other coalition as given. Assuming an interior solution, $e_T = \Omega e_H$, where $\Omega = \Delta_T/\Delta_H$ is the ratio of win-loss differentials. Thus, the Nash equilibrium win probability is

$$\tilde{P} = \frac{\iota_H \Delta_H}{\iota_H \Delta_H + \iota_T \Delta_T}. \quad (7)$$

This equilibrium probability of maintaining corruption depends on each coalition’s net gains from winning the lobbying contest weighted by their marginal influence, and may be written more compactly as

$$\tilde{P}(b; \theta) = \frac{\theta}{\theta + \Omega(b)}, \quad (8)$$

where $\theta = \iota_H/\iota_T$ is a parameter representing the *relative* influence of the head coalition vis-à-vis the tail coalition. If $\theta = 1$, then the two coalitions’ influence is perfectly symmetric.

3.4 The local official’s problem

Because the local official’s position hinges on the outcome of the lobbying contest, he is effectively paid an efficiency wage. As long as he is retained he receives bribe income $\hat{n}b$; otherwise, he receives his outside option, which we normalize to zero. Bureaucratic career

concerns thus generate a tradeoff with regard to b , the amount of the bribe.¹⁹ In particular, the expected income maximization problem is

$$\max_b \tilde{P}(b; \theta) \hat{n} b. \quad (9)$$

We can, therefore, view the local irrigation official as trading-off lower bribe income against greater net surplus to head outlets and, consequently, a higher *equilibrium* probability of retaining his position.

Given equation (8), it is straightforward to derive an explicit expression for the optimal bribe amount from the first-order conditions to problem (9):

$$b^* = r + \Delta s - \sqrt{r(r + \Delta s)}, \quad (10)$$

where $r = (N - \hat{n})s_0/\hat{n}\theta$ and $\Delta s = \hat{s} - s_0$.²⁰ Directly, we obtain (see Appendix for all proofs)

Lemma 1 $b_\theta^* > 0$,

which says that the greater the relative influence of the head coalition, the greater the bribe that head outlets have to pay. Intuitively, a more influential head coalition can be left with less net surplus (through a higher bribe) and still exert the same amount of effective lobbying power in favor of the status quo.

Although we do not observe bribes, lemma 1 helps deliver testable implications concerning water theft. Expected water availability at the head and tail are, respectively, $w_H(\theta) \equiv \tilde{P}\hat{w} + (1 - \tilde{P})w_0$ and $w_T(\theta) \equiv (1 - \tilde{P})w_0$. We have for the theft percentage $\tau(\theta) \equiv \log w_H/w_T$,

Proposition 1 $\tau'(\theta) > 0$.

¹⁹See Iyer and Mani (2012) for evidence on the role of career concerns in India's civil service. Banerjee (1997) provides a more general theory of corruption in which there is an exogenous probability that the bureaucrat is punished for malfeasance.

²⁰This is the smaller root of a quadratic equation. The larger root $r + \Delta s + \sqrt{r(r + \Delta s)}$ is precluded by the requirement that $b \leq \Delta s$; i.e., the bribe cannot exceed the net gain from theft.

Water theft is thus increasing in the relative influence of the head, a result not as obvious as it seems at first blush. While an increase in θ raises the probability \tilde{P} of C_H success, it also increases the bribe that headenders must pay (lemma 1), which *lowers* \tilde{P} . Nevertheless, \tilde{P} (and hence τ) rises on balance.

3.5 Land values

The market value of farmland reflects both the productive value of irrigation water and the cost of obtaining it. Put simply, bribes are capitalized into land values. Theoretical expressions for land values V_j (ignoring discounting) at, respectively, tail ($j = T$) and head ($j = H$) are thus

$$V_T = (1 - \tilde{P})s_0 \tag{11}$$

$$V_H = \tilde{P}(\hat{s} - b^*) + V_T. \tag{12}$$

In other words, abstracting from other sources of irrigation, tail-end land has value only insofar as it receives canal water (which occurs with probability $1 - \tilde{P}$), whereas the value of land at the head is negatively related to the size of the bribe.

Our focus is on the percentage land value *differential* between head and tail, or $\delta = \log(V_H/V_T)$, regarding which the model delivers

Proposition 2 $\delta'(\theta) > 0$.

So, as headend irrigators gain in political influence relative to tailend irrigators, the value of land at the head rises relative to the value of land at the tail. As with Proposition 1, this result is also not obvious because the higher probability of C_H 's lobbying success and the higher bribe amount (see Lemma 1) have countervailing effects on δ .²¹

²¹The proof (see appendix) requires the assumption of a linear demand for water or at least that \hat{w} is sufficiently close to w_0 that demand is effectively linear over $[w_0, \hat{w}]$.

Finally, since only *relative* political influence matters for lobbying success in our model, we have

Proposition 3 $\frac{\partial \tau}{\partial \log \iota_H} = -\frac{\partial \tau}{\partial \log \iota_T}$ and $\frac{\partial \delta}{\partial \log \iota_H} = -\frac{\partial \delta}{\partial \log \iota_T}$.

A one percent increase in head influence has an equivalent effect on water theft and land values as a one percent decrease in tail influence.

Before taking these propositions to the data, note that we have described a possible scenario in which an equitable allocation of water between head and tail is Pareto optimal and yet property rights are de facto assigned exclusively to the head. In a Coasean world with zero transactions costs, water would be transferred from head to tail in exchange for payment. While there are many reasons to believe that such water contracts between head and tail outlets of a channel are infeasible, it is worth considering their empirical implications. Of course, no actual theft (misallocation) would be observed in this situation and, in particular, $\tau'(\theta) = 0$. Moreover, the value of land at the tail would be $s_0 - t$, where t is the payment to the head, and the value of land at the head would be $s_0 + t$. So, the price of land at the head would still carry a premium relative to the price of land at the tail, but $\delta'(\theta) = 0$.

4 Data

4.1 Survey of Irrigation Outlets in Punjab

In 2016, the World Bank commissioned a survey of 4294 outlets on 470 irrigation channels distributed across 24 of 49 administrative Divisions of the Punjab Irrigation Department (see Figure 2). Only channels in the 32 Divisions not covered by the post-2005 irrigation management reform were selected; see Appendix B for the precise selection criteria. Although, for convenience, we sometimes refer to the selected channels collectively as a “sample,” they actually comprise the full population of channels meeting our selection criteria (this point

becomes important below). The objective was to obtain landholdings and other information on all irrigators at the head and tail of each channel, where head outlets, by Irrigation Department designation, are those on the upper 40% of a channel by length and tail channels are those on the lower 20%. While all tail outlets were included in the survey, we restricted attention to the first four head outlets of each channel to keep the effort manageable.

The survey was carried out in close cooperation with the Punjab Irrigation Department, and, in particular, with its canal *patwaris* (record-keepers). These junior-most officials are responsible for maintaining lists of farmers and their cultivated area on one or more watercourses for the purpose of calculating the canal water tax (*abiana*) payment. *Patwaris* were mobilized in each of the 24 Divisional offices to provide two levels of information:

- Irrigator characteristics: Name and father's name, land owned on outlet, tubewells owned on outlet and their characteristics, and positions (political, irrigation department, other government office, or hereditary) held by each irrigator or members of their immediate family. Lists of names and landownership had already been compiled in hard copy through the course of the *patwaris*' normal duties. The other information was familiar to the *patwaris* through their continuous interactions with farmers on watercourses under their purview.
- Outlet characteristics: Average land values (at the head and tail of each watercourse), current and past groundwater levels and quality. Canal *patwaris* used their detailed local knowledge to provide this information. The land value assessments, in particular, were formed in close consultation with local revenue department (tax administration) *patwaris*, the latter responsible for maintaining the cadastre and recording land sales. In addition, the survey firm visited one outlet at the head and tail of each selected channel to verify that the assessments were accurate.

Survey teams were able to cover all but one of the intended 470 channels (all but 13 of

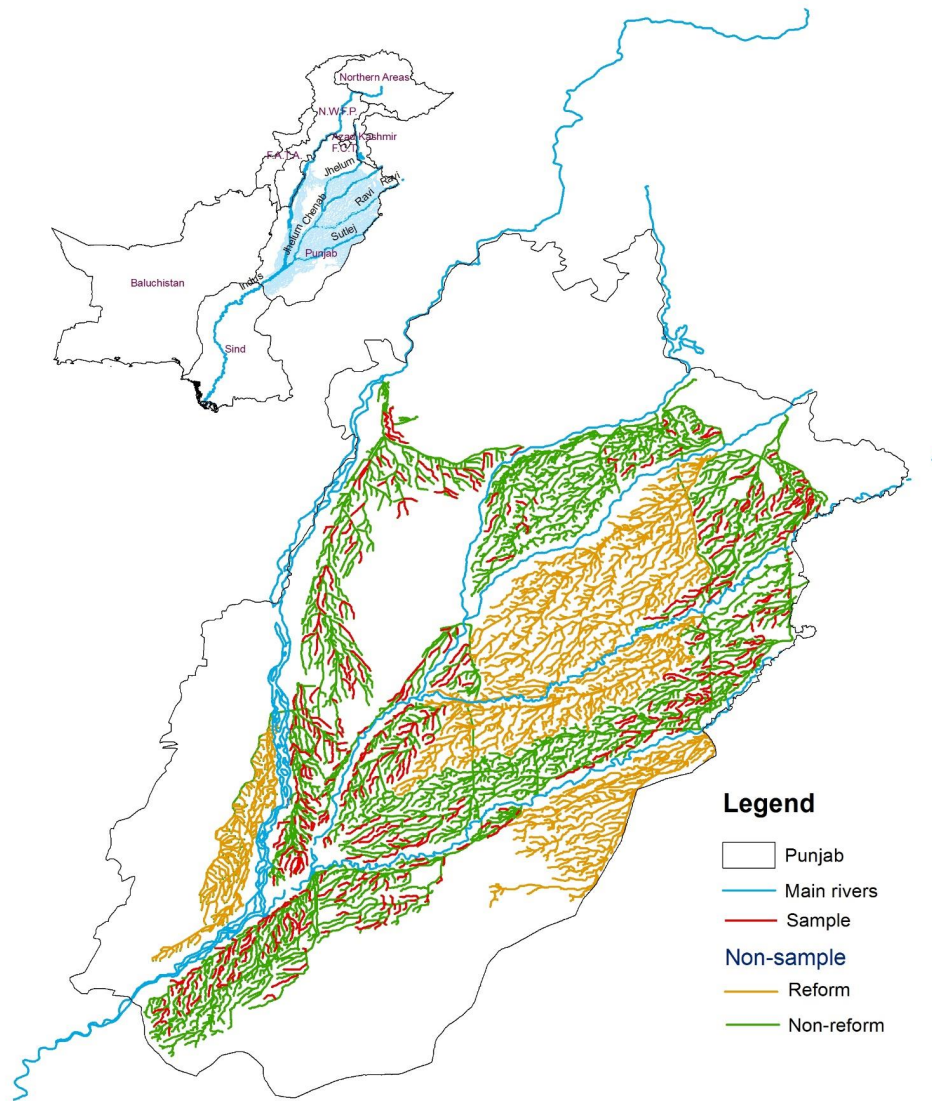


Figure 2: CHANNELS IN PUNJAB PROVINCE SELECTED FOR SURVEY

4294 outlets). However, 286 of the remaining 4281 outlets were found to be permanently closed by 2016 for reasons including destruction in floods, population shifts, or perennial lack of water in the channel.²² Of the closed outlets, 29 occurred on 4 channels on which every other outlet was also closed, leaving us with 465 open channels. There are 103 open channels on which at least one selected outlet was closed, which is not a problem for us empirically, but in 15 cases the channel had no head outlets and in 2 cases no tail outlets. This leaves us 448 channels with *both* head and tail outlet data, which our empirical strategy requires (see Appendix Table C.1 for channel characteristics by Division). That we lose only two channels to tail closure suggests that selection bias — i.e., less water theft on average in observed channels — is unlikely to be a serious issue.

4.1.1 Lobbying influence variables

Data are available on nearly a quarter-million irrigators on our final sample of 448 channels. Rather than consider the distribution of individual landholdings, however, we aggregate across brothers to obtain total “family” landownership. In particular, we sum (canal irrigated) land owned on each outlet across individuals sharing the same father’s name, yielding almost 150,000 family level observations. Given inheritance norms in Pakistan, patrimonial land is typically controlled by the sons. Using individual landholdings would imply that influence (as measured by economic stake) along a channel is diluted by a factor of N once landownership passes from a father to his N sons, which strikes us as extreme since, at a minimum, brothers are likely to cooperate on land-related matters and in many cases even designate one of their own as operator of their joint holdings. Figure 3 illustrates the distribution of family landholdings on all head outlets and all tail outlets pooled together. Average family landownership on head outlets is 8.4 acres, compared to 8.9 acres on tail outlets; the 98th percentiles are 45.8 and 47.5 acres, respectively. Thus, families with large

²²In some cases, outlets had actually been closed years ago but the outlet lists provided to us by the irrigation department and used for sampling had not been updated.

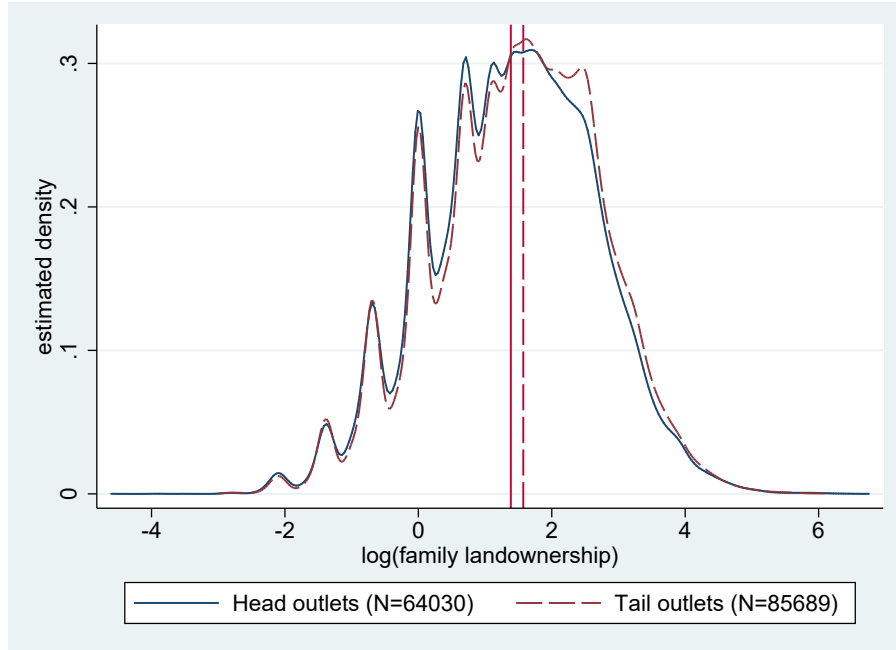


Figure 3: FAMILY LANDOWNERSHIP BY CHANNEL POSITION

Notes: Distribution of total family landholdings across 448 channels by position of outlet on channel. Vertical lines denote medians.

landholdings are not especially concentrated at either head or tail of the typical channel, nor is the correlation between mean landholdings at head and tail particularly high (Figure 4).

As noted, *patwaris* were asked whether each irrigator under their purview ever held a political office, an official position in the irrigation department, a position in another government agency, or a local hereditary or village position. If so, the nature of the position was recorded. Based on these responses, we construct two indicators for influential office holding at the level of the individual. The first indicator assumes a value of one if the individual held political, hereditary, or irrigation department positions as well as high level civil positions, thus excluding such government posts as teachers, clerks, health workers, as well as members of the police and army. The second indicator subsumes the first, but also takes on a value of one if the individual was in the police or military, in case such a position also confers influence or the ability to mobilize collective action (the army is a particularly

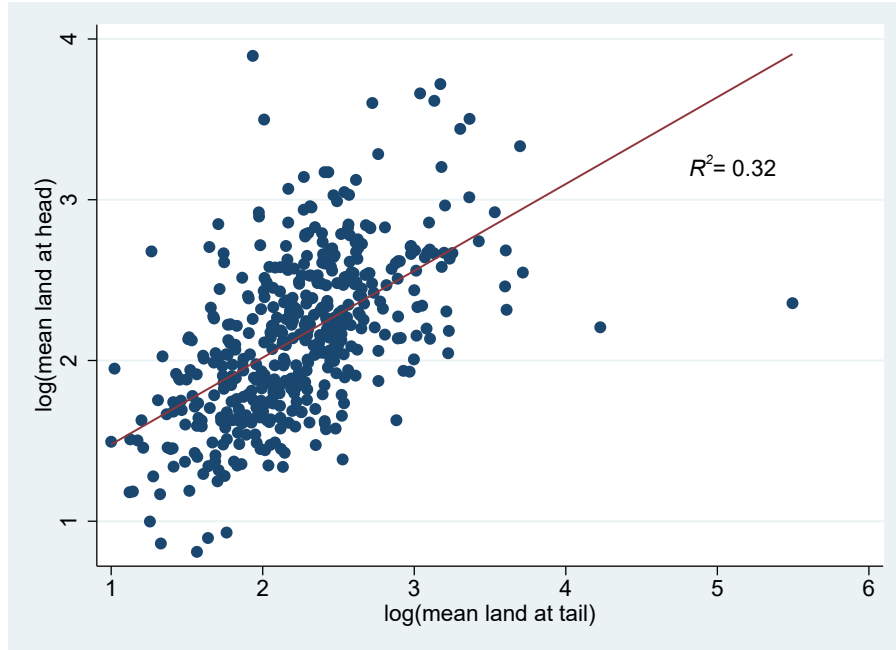


Figure 4: HEAD-TAIL CORRELATION OF MEAN FAMILY LAND OWNERSHIP.

Notes: Regression of mean family landholdings at head of channel (based on sampled head channels) on mean family landholdings at tail of same channel for 448 channels.

strong and deeply networked institution in Pakistan). Next, we aggregate to the family level, as we did with landownership, so that our indicators take on a value of one if *any brother* ever held such a position. The percentage of influential families at the head and tail of each channel is typically extremely small (see Appendix Figure C.1 for more detail). Across all 448 channels, 0.61% of families hold influential positions using the more restrictive indicator and 0.78% when police and military are included.²³ Nearly 60% of channels have either no influentials whatsoever at head or none at tail, and 40% have none at *both* head and tail. Given that influential office-holding is so sparsely distributed along channels, its effects may prove difficult to detect in practice.

²³Of the families categorized as influential based on the restrictive definition, 54% hold political office (such as member of the provincial assembly and various more local posts), 36% hold hereditary positions, 12% are or were irrigation department officials, and 9% had posts in the civil administration.

4.1.2 Land values and groundwater

Data on land values and groundwater conditions were collected at the head and the tail of each watercourse (tertiary canal), thus providing 2 observations per outlet on 3922 outlets (1 outlet had missing land value data), for a total of 7844 observations. Since watercourses are typically unlined and, in contrast to secondary channels (i.e., distributaries and minors), no allowance is made in their rotational schedules for the considerable seepage losses (Bandaragoda and Rehman 1995), land values should be lower at the tail of a watercourse than at the head. And, this is indeed what we find. Estimates in the first column of Table 1 show that land at the watercourse head is 15% more valuable per acre than land at the tail. More reflective of canal water misappropriation, however, is that land at a head outlet of a secondary canal carries an 11% premium over land at a tail outlet of that same channel – typically such land is separated by little more than 10 km of canal (see Appendix Table C.1). Specification (2) in Table 1 replaces the dummy variable for whether the outlet is at the head of the channel with the actual distance from the head, which of course attracts a coefficient of opposite sign. Since this refinement barely improves fit, we retain what will prove to be the simpler specification (1) in the sequel.

These inequities in the distribution of canal water are also reflected in groundwater conditions, which, in turn, affect land values. Depth to water table (DWT) is inversely related to the extent of aquifer recharge from nearby sources of surface water, especially irrigation canals. Results reported in the third column (first row) of Table 1 indicate that groundwater depth increases by a little more than 1% from head to tail of the average watercourse, attributable to both the inefficiency of conveying surface water through these tertiary channels as well as to the greater distance to good recharge (adjacent to the distributary or minor canal). On secondary canals, we estimate (second row) that water tables fall by about 3% from head to tail of the average channel. Once again, the mechanism is recharge, or lack thereof, due to the pervasive tail-end water deprivation that we document in the next sub-

Table 1: Land Values and Groundwater Conditions

	Log(land value/acre)		Log(DTW)	GW quality
	(1)	(2)		
Land at head of watercourse (tertiary canal)	0.152*** (0.0089)	0.152*** (0.0089)	-0.0119*** (0.0035)	0.0479*** (0.0077)
Outlet at head of channel (secondary canal)	0.112*** (0.0194)	—	-0.0265** (0.0108)	0.0607*** (0.0118)
Km to head of channel	—	-0.0137*** (0.0028)	—	—
R^2	0.770	0.772	0.954	0.879

Notes: Robust standard errors in parentheses clustered on channel-head/tail (***) $p < 0.01$, ** $p < 0.05$, * $p < 0.1$). All specifications include 448 channel fixed effects and use 7,844 observations (in 896 clusters). Mean depth to water table (DTW) = 23.5 meters (median = 15.5 meters). Groundwater (GW) quality is coded as 3 = sweet; 2 = brackish but usable; 1 = unusable. Sample percentages in each category are, respectively, 74, 16, and 10.

section. In the final column, we see that groundwater quality, measured on a three-point qualitative scale of decreasing salinity (see notes to Table 1), follows the same pattern, higher at the head reaches of both tertiary (watercourses) and secondary channels. Crop-damaging salinity is another consequence of poor freshwater recharge, which leaves only deeper, more highly mineralized, groundwater available for pumping (Qureshi et al. 2010).

4.2 Canal water discharge

Punjab Irrigation Department’s Program Monitoring and Implementation Unit (PMIU) has maintained daily records of authorized (designed) and *actual* canal discharge since 2006. Figure 1 illustrates the location of PMIU discharge gauges at the head and tail of each channel – no gauges are set up at intervening outlets. Since tail discharge is measured at the last watercourse outlet of the channel, design discharge at the tail is never zero; all sanctioned outlets are entitled to off-take canal water. We construct a version of the “delivery performance ratio” or DPR (see, e.g., Waijjen et al. 1997) for the economically

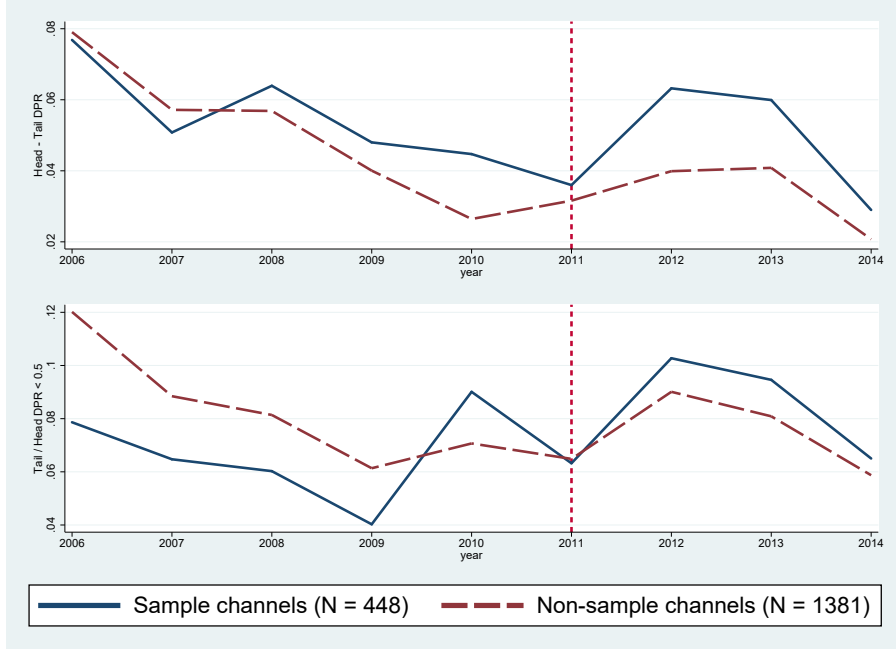


Figure 5: TAIL SHORTAGE BY YEAR IN PUNJAB: 2006-14

Notes: Top panel shows average tail shortage, $DPR_{it}^H - DPR_{it}^T$ and bottom panel average extreme tail shortage, indicated by whether $DPR_{it}^T / DPR_{it}^H < 0.5$., for *khariif* 2006-2014. Only data from 2011 (dashed vertical line) onward are used in the empirical analysis.

most important *khariif* (summer) season, which runs from mid-April to mid-October. During *rabi* season, from November to March, 42% of channels in Punjab are dry. Letting d index days and t index year, define

$$DPR_{it}^j = \frac{\sum_{d \in t} Q_{id}^j}{\sum_{d \in t} \bar{Q}_{id}^j} \quad (13)$$

for $j = H(ead), T(ail)$, where Q_{id}^j is daily discharge at position j of channel i and \bar{Q}_{id}^j is the corresponding authorized daily discharge.

Tail shortage, $DPR_{it}^H - DPR_{it}^T$, is a measure of water theft, albeit a noisy one. As noted earlier, the extent to which tail outlets are deprived of water relative to their endowment (given discharge at the head) may also depend on exogenous factors such as flow *variability* into the channel. At any rate, tail shortage averages 0.053 (or 8.2% of mean tail DPR) across the 448 sample channels and across all years of discharge data (2006-14); the corresponding

figure for all other irrigation channels in Punjab is 0.044 (6.3% of mean tail DPR).²⁴ Breaking this down by year, Figure 5 shows that, despite their selection on specific criteria, our sample channels track non-sample channels quite closely; in both sets of channels, tail shortage appears to be trending downward over time. An indicator for whether $DPR^T/DPR^H < 0.5$, a measure of extreme tail shortage in the channel, averages 0.073 in the sample across years, which is to say that, on about 7% of channels, tail outlets receive less than half the volume of irrigation relative to their allotment than head outlets.²⁵

So as to more closely match the timing of the outlet-level land data, collected in 2016, our empirical analysis of DPR is limited to the last 4 years of currently available data (2011-2014). Over this period, tail shortage averages 0.047, or 7.3% of mean tail DPR.

5 Estimation

5.1 Empirical strategy

5.1.1 Econometric specification

For sake of exposition, suppose that we have data on an outcome Y_{pc} at position $p = H, T$ of channel c . Letting $H_{pc} = \mathbf{1}(p = H)$, our basic estimating equation is

$$Y_{pc} = H_{pc} [\beta_0 + \beta_H \log \iota_{Hc} + \beta_T \log \iota_{Tc} + \lambda' Z_c] + \mu_c + \varepsilon_{pc}, \quad (14)$$

where Z_c is a vector of channel level controls, μ_c is a channel-level fixed effect (absorbing the constant term) and ε_{pc} is an idiosyncratic error. Notice that for $\beta_H = \beta_T = \lambda = 0$, the fixed effects estimator $\hat{\beta}_0 = \frac{1}{N_C} \sum (Y_{Hc} - Y_{Tc})$ is the average head-tail outcome differential

²⁴For the sake of comparability, we exclude all 1053 channels that were covered by the irrigation management reform that began in the mid-2000s (see Jacoby et al. 2017).

²⁵Although the corresponding average for non-sample channels is similar (0.080), Figure 5 indicates a substantial discrepancy for years prior to 2010. To reiterate, this is not an issue of sample representativeness.

across all N_C channels (see previous section). Equation (14) not only controls for all unobserved fixed channel-level characteristics (as in Table 1), but also for observed channel-level characteristics (Z_c) that may be correlated with head-tail outcome *differences*.

5.1.2 Clustering and inference

Continuing with our two observations per channel (Head/Tail) set-up, let us now ask whether the standard errors from the channel fixed effects estimation should be clustered on channel. Abadie et al. (2017) show that the answer to this question, rather than depending on whether clustering the standard errors “makes a difference,” depends on whether there is clustering in *sampling* or in *assignment*. If either form of clustering is present and if there is treatment effect heterogeneity, only then should one cluster standard errors.

Clustering in sampling concerns how many clusters in the population are present in the sample. In our case, as noted, the term “sampling” of channels is really a misnomer. All channels in Punjab that met the selection criteria set out in Appendix B were chosen for analysis. Since there was no random selection within this universe, the cluster sampling probability is one. Clustering in assignment concerns the regressor of interest. Returning to the restricted version of equation (14)

$$Y_{pc} = \beta_0 H_{pc} + \mu_c + \varepsilon_{pc}, \tag{15}$$

think of H_{pc} as the treatment and consider the assignment process that determines its value within clusters (channels). In our case, trivially, $\Pr(H_{pc} = 1) = 0.5$ and hence the assignment process is the same across all clusters. Since the cluster sampling probability is one and there is no clustering in assignment of treatment, the fixed effects standard errors for regression equation (15) should not be adjusted for clustering on channel.²⁶

²⁶Another way to see this is by analogy to a two-period panel with H_{pc} playing the role of time, in which case Stock and Watson (2008) show that clustering fixed effects standard errors is unnecessary.

Thus far, we have assumed one observation per position on channel, but our actual data are stacked at each channel-position. For example, in the case of DPR, there are multiple years of data at both head and tail of each channel. To account for this, we cluster our standard errors at the *channel-position* level.

5.1.3 Estimating the lobbying influence function

Letting N_{pc} be the number of irrigators (or, rather, families) at position p of channel c , we posit an aggregate lobbying influence function for coalition C_p of the form

$$\iota_{pc}(\gamma) = G\left(L_{1pc}^{1+\gamma I_{1pc}}, \dots, L_{N_{pc}pc}^{1+\gamma I_{N_{pc}pc}}\right) \quad (16)$$

where L_{ipc} is landholdings of irrigator $i = 1, \dots, N_{pc}$ at position p of channel c and I_{ipc} is an indicator for whether that same irrigator holds an influential office. The parameter γ reflects the importance of influential office-holding and the aggregator function G can be the mean operator $G(x_1, \dots, x_k) = \bar{x}$ or a percentile operator. In the former case, we have $\iota_{pc}(0) = \bar{L}_{pc}$, which is mean landownership at position p of channel c (see Figure 4). Here, of course, each irrigator contributes to ι_{pc} in proportion to their landholdings. For $\gamma > 0$, irrigators with large landholdings, to the extent that they hold influential positions, contribute to ι_{pc} more than in proportion to their landholdings. Conversely, an office-holder contributes little to aggregate influence of his coalition unless he also has a significant economic stake in the outcome of the lobbying contest in the form of large landholdings.

Since γ is an estimated parameter, equation (14) falls under the class of regression models analyzed by Hansen (1996) in which the nuisance parameter, in this case γ , is not identified under the null $H_0 : \beta_H = \beta_T = 0$. Following Hansen (1999), estimation is straightforward: For any given value of γ , estimate $[\beta_0(\gamma), \beta_H(\gamma), \beta_T(\gamma), \lambda'(\gamma), \mu_c(\gamma)]$ using a conventional fixed effects regression and form the sum of squared residuals $S(\gamma) = \sum_{c=1}^{N_C} \hat{\varepsilon}_{pc}^2$. Next, do a line

search over some range $\{\gamma_{min}, \dots, \gamma_{max}\}$ to find the $\hat{\gamma}$ that minimizes $S(\gamma)$. If we indeed find a nonzero $\hat{\gamma}$, hypothesis testing proceeds as follows: First we test the symmetry hypothesis $H_0 : \beta_H = -\beta_T$, using a conventional Wald test as though γ were known with certainty. As discussed by Hansen (1999), the sampling variance of γ is not of first-order asymptotic importance. If we cannot reject symmetry, we then impose it so that $\beta_H = -\beta_T \equiv \beta_1$.²⁷ Finally, we test $H_0 : \beta_1 = 0$. In this case the test statistic is non-standard because of the non-identification of γ under H_0 , requiring a special bootstrap procedure.

5.2 Baseline results ($\gamma = 0$)

Before turning to estimation of the office-holding influence parameter γ , we consider the role of economic stake – irrigated landholdings on the channel – in isolation, focusing on the form of aggregator function G . In Table 2, we present results for equation (14) using the delivery performance ratio, $Y_{pc} = \log DPR_{pc}$, and land values per acre, $Y_{pc} = \log V_{pc}$, along with various G functions (mean, 80th, 90th, and 98th percentile) and γ set to zero. As mentioned, in the case of DPR (columns 1-4), we stack the 4 years (2011-2014) of *kharif* season data and cluster our standard errors on channel-position.²⁸ Thus, the estimates of β_H and β_T reflect the average impact of (log) influence at channel positions head and tail, respectively, on the *percentage difference* in DPR between head and tail of that channel. Land value estimates in columns 5-8 have the analogous interpretation. However, in this case, we stack outlets and, within outlets, the two watercourse-level observations (see subsection 4.1.2), with standard errors again clustered on channel-position.

As indicated in equation (14), all regressions include a set of channel-level controls (Z_c)

²⁷Under the null, we may first-difference equation (14) to obtain

$$Y_{Hc} - Y_{Tc} = \beta_0 + \beta_1(\log \iota_{Hc} - \log \iota_{Tc}) + \lambda'Z_c + \varepsilon_{Hc} - \varepsilon_{Tc}.$$

²⁸We drop 74 channel-position-year observations with missing or unusable discharge data.

Table 2: Baseline Estimates with Alternative Aggregators

	Log(DPR)				Log(land value per acre)			
	mean	80th pctile	90th pctile	98th pctile	mean	80th pctile	90th pctile	98th pctile
$\beta_H : H \times \log \iota_H(0)$	0.137* (0.0737)	0.129** (0.0570)	0.127** (0.0599)	0.141** (0.0639)	0.133** (0.0588)	0.0985* (0.0538)	0.0640 (0.0473)	0.108* (0.0598)
$\beta_T : H \times \log \iota_T(0)$	-0.267*** (0.0614)	-0.204*** (0.0569)	-0.179*** (0.0489)	-0.233*** (0.0522)	-0.128** (0.0604)	-0.130** (0.0551)	-0.100** (0.0503)	-0.114** (0.0481)
<i>p</i> -values:								
$H_0 : \beta_H = -\beta_T$	0.116	0.310	0.468	0.224	0.914	0.527	0.493	0.884
$H_0 : \beta_H = \beta_T = 0$	0.000	0.000	0.000	0.000	0.058	0.054	0.116	0.059
$H_0 : \lambda = 0$	0.000	0.000	0.000	0.000	0.0159	0.0142	0.0124	0.0136
R^2	0.642	0.641	0.641	0.643	0.779	0.779	0.779	0.780
Observations	3,510	3,510	3,510	3,510	7,844	7,844	7,844	7,844

Notes: Robust standard errors in parentheses (*** p<0.01, ** p<0.05, * p<0.1), clustered on channel-position (head/tail). DPR data are from 2011-2014. All specifications control for channel fixed effects and include the following channel characteristics interacted with the head dummy (H): a constant term, the total number of outlets on channel, whether channel is on tail of its parent channel (versus at middle or head), whether channel is a distributary (versus minor or sub-minor), and a full set of 23 division dummies. In addition, specifications in col. 1-4 include year dummies and specifications in col. 5-8 include a position on watercourse dummy. Column headings refer to the form of the G function used to construct $\log \iota_j(\gamma)$ (see equation 16) with γ set to zero.

Table 3: Restricted DPR Specifications

	mean	80th pctile	90th pctile	98th pctile
$\beta_1 : H \times \log \theta$	0.213*** (0.0516)	0.176*** (0.0436)	0.157*** (0.0402)	0.185*** (0.0453)
R^2	0.642	0.641	0.641	0.643

Notes: See notes to Table 2. Columns 1-4 correspond to, respectively, columns 1-4 of Table 2 with the restriction $\beta_H = -\beta_T$ imposed.

interacted with the head of channel dummy (H_{pc}). These controls – the total number of outlets on the channel, whether the channel is on the tail of its parent channel (versus at middle or head), whether the channel is a distributary (versus a minor or sub-minor), and a full set of 23 division dummies (see Appendix Table C.1) – are exogenous determinants of head-tail differences in DPR or land values. For example, these variables might capture differences in the extent of flow variability into the channel, as discussed earlier.

The main takeaways from Table 2 are as follows. First, all four forms of G do about equally well in fitting both the canal discharge and the land values data, with a slight preference for the 98th percentile. Second, in all cases, the estimates of β_H and β_T have the predicted sign. For instance, when the top 2% of family landownership at the head (tail) is larger (smaller), head-tail inequity in canal water availability and in land values worsens, in the sense that head outlets become even more favored. Moreover, the hypothesis of symmetry ($\beta_H = -\beta_T$), established in Proposition 3, cannot be rejected in any specification. Finally, in the case of DPR, this symmetry test has considerable power, which is to say that non-rejection is noteworthy. In particular, we are able to strongly reject the joint null that $\beta_H = \beta_T = 0$. By this same metric, however, power is substantially lower in the case of land values, an issue revisited in the next subsection.

5.3 Main results

Next, we free up the γ parameter as described in subsection 5.1 under two alternative G functions, mean and 98th percentile, and the two definitions of influential positions (exclusive and inclusive of members of the army/police). In the case of DPR, results of the line search over a large range of γ values are not encouraging. For all four specifications, the γ that minimizes the sum of squared residuals is near zero and the estimated confidence intervals (see discussion below) are extremely wide and contain zero. Hence, there is no evidence that holding an influential position interacts with one's economic stake in determining canal water allocations; at least, we cannot detect such an effect in the discharge data. Given this finding and our inability to reject symmetry in Table 2, we re-run the $\log(\text{DPR})$ regressions with the restriction $\beta_H = -\beta_T \equiv \beta_1$ imposed. As shown in Table 3, in each restricted specification we strongly reject the null that $\log \theta = \log(\nu_H/\nu_T)$ has no effect on water allocation; more importantly, $\frac{d \log(\text{DPR}_H/\text{DPR}_T)}{d \log \theta} = \beta_1 > 0$, confirming Proposition 1 ($\tau'(\theta) > 0$).

We turn next to land values, and here the results on influential positions are far more encouraging. Figure 6 displays Hansen's (1999) likelihood ratio statistic as a function of γ ,

$$LR(\gamma) = S(\gamma)/S(\hat{\gamma}) - 1, \tag{17}$$

where $\hat{\gamma}$ is the estimate that minimizes the sum of squared residuals as defined in subsection 5.1. Of course, $LR(\hat{\gamma}) = 0$, the minimum of the function, and the lower and upper 95% asymptotic confidence bounds are where $LR(\gamma)$ intersects the horizontal line at the critical value of 7.35 from, respectively, above and below. A γ of zero lies far to the left of the lower confidence bound under all four specifications. Taking the mean as the aggregator function G , yields $\hat{\gamma} = 0.815$ regardless of our definition of influential position. With G as the 98th percentile function, however, $\hat{\gamma} = 0.440$ based on the more restrictive definition of influential position and $\hat{\gamma} = 0.545$ based on the less restrictive definition. Nevertheless, given

the confidence intervals, adding members of the police/army to the list of influentials does not make an appreciable difference even in this case. In sum, these are sizable estimates of γ inasmuch as they substantially change ι_{pc} on those channels with influential families (see Appendix Figure C.2 for a regression of $\iota_{pc}(0.545)$ on $\iota_{pc}(0)$ using the 98th percentile specification inclusive of army/police).

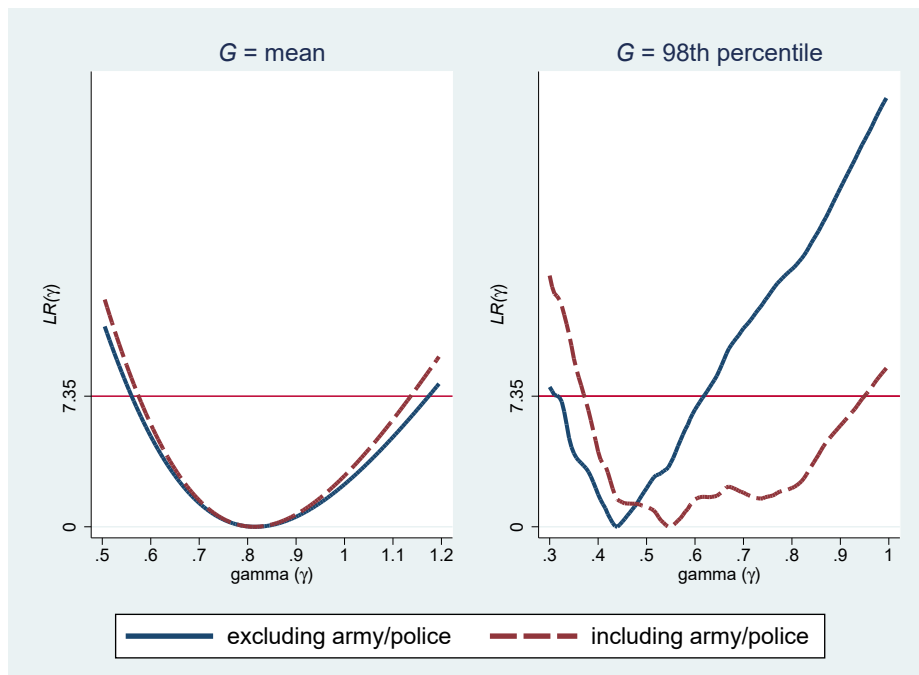


Figure 6: $LR(\hat{\gamma})$ UNDER ALTERNATIVE SPECIFICATIONS

Notes: Refer to equation (17) for the definition of $LR(\hat{\gamma})$. Panel headings refer to the form of the G function used to construct $\log \iota_j(\hat{\gamma})$ (see equation 16). Solid curves use definition of influential that excludes members of army/police, whereas dashed curves use definition including them. Horizontal line represents Hansen's (1999) 5% critical value for the $LR(\hat{\gamma})$ statistic.

Full estimates of these four specifications are reported in Table 4 with and without the imposition of the symmetry condition $\beta_H = -\beta_T$. Despite the differences in $\hat{\gamma}$, the estimates of β_H and β_T are quite similar across specifications and quite similar as well to those with $\gamma = 0$ in Table 2. A major difference, however, is that the estimates in Table 4 are far more precise, a consequence of the better fit of the augmented lobbying influence function

Table 4: Land Values and Influence

	$G = \text{mean}$				$G = 98\text{th percentile}$			
	no army ($\hat{\gamma} = 0.815$)		army ($\hat{\gamma} = 0.815$)		no army ($\hat{\gamma} = 0.440$)		army ($\hat{\gamma} = 0.545$)	
$\beta_H : H \times \log \nu_H(\hat{\gamma})$	0.0726**		0.0775**		0.0876**		0.0836**	
	(0.0321)		(0.0325)		(0.0427)		(0.0384)	
$\beta_T : H \times \log \nu_T(\hat{\gamma})$	-0.121***		-0.123***		-0.109***		-0.104***	
	(0.0338)		(0.0327)		(0.0346)		(0.0298)	
$\beta_1 : H \times \log \frac{\nu_H(\hat{\gamma})}{\nu_T(\hat{\gamma})}$		0.0975***		0.101***		0.0984***		0.0942***
		(0.0286)		(0.0286)		(0.0339)		(0.0297)
<i>p</i> -values:								
$H_0 : \beta_H = -\beta_T$	0.164	—	0.174	—	0.580	—	0.557	—
$H_0 : \beta_H = \beta_T = 0$	0.001	—	0.001	—	0.007	—	0.002	—
$H_0 : \beta_1 = 0^a$	—	0.000	—	0.000	—	0.000	—	0.000
R^2	0.781	0.780	0.781	0.781	0.780	0.780	0.781	0.781

Notes: Robust standard errors in parentheses (***) $p < 0.01$, ** $p < 0.05$, * $p < 0.1$), clustered on channel-head/tail. Sample size is 7,844. All specifications control for channel fixed effects and include the following channel characteristics interacted with the head dummy (H): a constant term, the total number of outlets on channel, whether channel is on tail of its parent channel (versus at middle or head), whether channel is a distributary (versus minor or sub-minor), and a full set of 23 division dummies. Position on watercourse dummy is also included in all specifications. Column headings refer to the form of the G function used to construct $\log \nu_j(\hat{\gamma})$ (see equation 16), where $\hat{\gamma}$ is the estimate that minimizes the residual sum of squares.

^aBlock-bootstrapped p -value of Hansen's (1999) F -statistic based on 1000 replications.

to the land value data. Even though this higher precision substantially improves the power of our symmetry test, we still fail to reject the null across all specifications. So, proposition 3 is again confirmed. Imposing symmetry, we may now formally address Proposition 2 ($\delta'(\theta) > 0$) by testing $H_0 : \beta_1 = 0$. As noted, the standard Wald tests are invalid since γ is not identified under H_0 . We thus report block-bootstrapped p-values for these hypothesis tests as suggested by Hansen (1999), which yield similar strong rejections of the null.²⁹

²⁹Indeed, the bootstrapped p-values are smaller than those of the conventional Wald test based on the cluster-robust variance-covariance matrix. Hansen's statistic essentially uses the likelihood ratio principle and hence cannot be adjusted for clustering. One additional caveat, albeit probably a minor one, is that Hansen assumes a balanced panel, whereas our data are unbalanced due to varying numbers of outlets per channel. It is unknown if Hansen's results extend to our case.

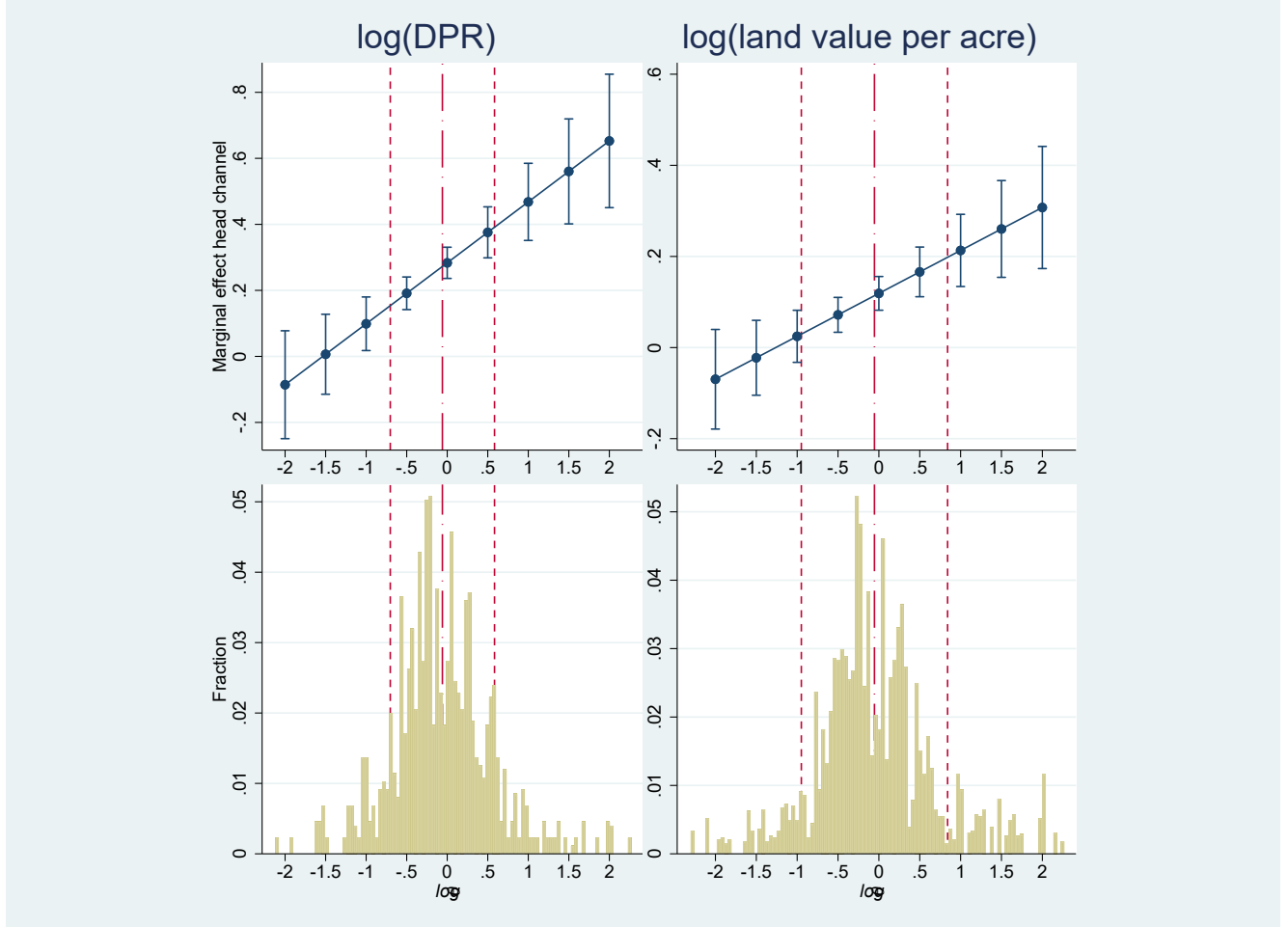


Figure 7: MARGINAL EFFECTS OF HEAD OUTLET BY $\log \theta$

Notes: Left and right upper panels show marginal effects of head outlet at different values of relative lobbying power ($\log \theta$) on, respectively, $\log(\text{DPR})$ and $\log(\text{land value})$. The former marginal effects are based on column 4 of Table 3 and the latter on column 8 of Table 4. Lower panels show histograms of $\log \theta$ for the corresponding specifications. Bars in upper panels denote 95% confidence intervals. Short-dashed vertical lines denote one standard deviation above and below the mean of $\log \theta$ (long-dashed vertical line).

The restricted DPR estimates in Table 3 and the corresponding estimates for land values in Table 4 allow us to quantitatively assess the impact of a relative shift in lobbying influence parameterized by $\theta = \iota_H/\iota_T$. Looking across channels, there is near equality of influence between head and tail outlets, with a very slight advantage for the tail (see the $\log \theta$ histograms in the lower panels of Figure 7, with G as the 98th percentile). Now consider the predicted

effect of a shift in $\log \theta$ by one standard deviation about its mean, as illustrated in the top panels of Figure 7. Our estimates imply that such a shift in favor of the *head* coalition increases the head-tail differential in DPR from a base of 27.2 (2.3) log points to 39.1 (4.3) log points, whereas the equivalent shift in favor of the *tail* would bring this differential down to 15.4 (3.1) log points.³⁰ At the same time, a one standard deviation shift in influence in favor of the head would increase the head-tail land value premium from a base of 11.4 (1.8) log points to 19.8 (3.6), whereas the equivalent shift in favor of the tail would virtually eliminate the premium, bringing it down to 2.9 (2.8).^{31,32} Given the primacy of agricultural land in the asset portfolio of most of rural Pakistan’s households, these hypothetical reallocations of political power entail substantial redistributions of wealth along a channel.

5.4 Alternative explanations

One explanation of our findings is that the head-tail differential in lobbying influence as measured by $\log \theta$ is picking up something besides relative influence. In our regressions, we control for several channel-level variables (Z_c), including administrative division dummies, that turn out to be highly correlated with head-tail differences in DPR and, to a lesser extent, with head-tail differences in land values. Nonetheless, we may be omitting some confounding variables. For instance, a large literature on collective action in commons management highlights the importance of heterogeneity among users (e.g., Ostrom 1990; Baland and Platteau 1997), though the effect of this inequality on cooperative outcomes is often theoretically ambiguous (Bardhan and Dayton-Johnson 2002). In the context of surface

³⁰Standard errors in parentheses. Notice that, as a consequence of Jensen’s inequality, the mean percentage head-tail differential in DPR is larger than the absolute differential as a percentage of mean tail DPR reported in subsection 4.2

³¹Recall that we are using a different γ for land values than for DPR (i.e., $\gamma = 0.545$ in the former case versus $\gamma = 0$ in the latter case), which is why the scales of $\log \theta$ are different.

³²That the base head-tail land value differential of 11.4 log points is smaller than the corresponding DPR differential of 27.2 log points is consistent with the diminishing marginal product of water (concavity of $s(w)$). In particular, $\log(V_H/V_T) \approx \tilde{P}(\hat{s} - b)/(1 - \tilde{P})s_0$ and $\log(w_H/w_T) \approx \tilde{P}\hat{w}/(1 - \tilde{P})w_0$. Now, $s''(w) = D'(w) < 0 \Rightarrow \hat{w}/w_0 > s(\hat{w})/s(w_0) \Rightarrow \log(w_H/w_T) > \log(V_H/V_T)$.

Table 5: Channel-level Inequality

	Log(DPR)		Log(land value per acre)	
	mean	98 th percentile	mean	98 th percentile
$\beta_1 : H \times \log \theta$	0.213*** (0.0520)	0.185*** (0.0455)	0.0997*** (0.0291)	0.0928*** (0.0314)
$H \times$ Gini	0.0229 (0.327)	0.0439 (0.309)	-0.165 (0.311)	-0.138 (0.330)
R^2	0.642	0.643	0.781	0.781
Observations	3,510	3,510	7,844	7,844

Notes: See notes to Table 2. Compare columns 1 and 2 to, respectively, columns 1 and 4 of Table 3, column 3 to column 4 of Table 4, and column 4 to column 8 of Table 4. Gini coefficient of family landholdings is computed at the channel level (i.e., across head and tail outlets).

irrigation systems, Bardhan (2000) and Dayton-Johnson (2000) provide evidence that the landholdings Gini coefficient is negatively associated with cooperation in water allocation and channel maintenance. The question here is whether $\log \theta$ merely reflects land inequality along a channel, vitiating our rent-seeking contest interpretation.

An immediate problem with the inequality story, however, is that, if there is a relationship between $\log \theta$ and the channel-level Gini coefficient, it is likely to be a U-shaped one. High channel-level inequality should (mechanically) be associated *either* with high or with low relative influence of the head outlets; low channel-level inequality should be associated with more equal influence between head and tail outlets. Which is exactly the pattern that we observe in the data (Appendix Figure C.3). Hence, it comes as no surprise that controlling for the channel-level Gini coefficient leaves our estimates of β_1 virtually unchanged, as seen in Table 5. Moreover, differences in the degree of land inequality on the channel as a whole cannot explain variation in collective action or, rather, in its converse – water theft. This finding is consistent with our presumption that cooperation between head and tail outlets of a channel is practically nonexistent.

Another threat to our lobbying power interpretation revolves around the role of ground-

Table 6: Robustness Checks — Land Values

	mean		98 th percentile	
$\beta_1 : H \times \log \theta$	0.114*** (0.0294)	0.0907*** (0.0347)	0.112*** (0.0321)	0.0816*** (0.0309)
$H \times \Delta \text{TW}/\text{acre}$	1.732*** (0.593)	—	1.905*** (0.636)	—
$H \times \Delta \log \text{NC}/\text{acre}$	—	-0.0301 (0.0531)	—	-0.0331 (0.0432)
R^2	0.782	0.781	0.782	0.780
Observations	7,844	7,798	7,844	7,798

Notes: See notes to Table 2. Dependent variable is $\log(\text{land value per acre})$. Compare columns 1 and 2 to column 2 of Table 4, and columns 3 and 4 to column 8 of Table 4. $\Delta \text{TW}/\text{acre}$ is the difference in no. of tubewells per acre cultivable command area (CCA) between head and tail outlets and $\Delta \log \text{NC}/\text{acre}$ is the difference in \log no. of cultivators per acre CCA between head and tail outlets (available for 446 of 448 channels, which accounts for 46 fewer observations in the corresponding regressions).

water. As suggested above, the market premium on land at the head of a channel is partly attributable to better groundwater recharge at the head (due to more plentiful canal water supplies). Recovering this groundwater, however, requires costly private investments in tubewells. Only about a third of farmers in our data-set actually own a tubewell (or tubewells) and ownership is heavily skewed toward the larger landowners; around half of all tubewells are owned by the top 25% of farmers ranked by landholdings. Thus, one reason why the head-of-channel premium is higher along channels with larger average landholdings at the head might be that along these channels farmers at head outlets are better able to exploit existing groundwater potential than those at tail outlets. In other words, our relative influence variable $\log \theta$ may be picking up differential groundwater *access*. To address this concern, which is obviously not relevant for DPR, we include the head-tail difference in tubewell density (total number of tubewells per acre CCA), $\Delta \text{TW}/\text{acre}$, in the land value regressions (see Table 6). While this control attracts a significantly positive coefficient, so that relatively greater access to groundwater does seem to enhance the head-of-channel land

value premium,³³ the lobbying power effect is undiminished.

A final issue is that head-tail differences in the size distribution of family landholdings may be correlated with head-tail differences in average land productivity, another example of the potential incompleteness of Z_c . There are three necessary elements to the argument, each of which may be questioned: (1) substantial variation in average land quality between head and tail outlets of the same channel; (2) larger returns to consolidating landholdings in areas with higher average land productivity; (3) consolidation that mostly occurs through land purchases. Under these conditions, we could observe larger landholdings on higher productivity sections of the channel, thus reversing the arrow of causation relative to our interpretation of the land value regressions (but, of course, not of the DPR regressions).

On element (1), we reiterate that median channel length (the maximum distance between head and tail outlets) is only 9 kilometers, which limits the extent of spatial variation in land quality. On (2), there is no theoretical or evidentiary basis for the returns to scale varying with land quality, although it is certainly a possibility. On (3), consolidation could be achieved in part by one brother jointly managing his other brothers' land, keeping *family* landholdings (and, hence, $\log \theta$) constant or, similarly, through tenancy markets (leasing or sharecropping), which are quite active in Pakistan. Note, as well, that according to the 2010 Agricultural Census, farmland purchases in Punjab over the previous 10 years amounted to just 1.4% of total landownership.

These doubts aside, the differential returns to scale argument implies that the number of cultivators *per acre* must be lower where land is more productive. Our survey records how many cultivators (inclusive of pure tenant households) are at each outlet, from which we can compute, except for two channels with missing values, the head-tail *difference* in the (log) number of cultivators per acre CCA, $\Delta \log NC/\text{acre}$. There is a strong negative

³³It is also possible that this effect is not causal and that tubewell density is merely correlated with, e.g., unobserved land productivity. The interpretation, however, is irrelevant for the robustness test.

association between $\log \theta$ and $\Delta \log \text{NC}/\text{acre}$ (see Appendix Figure C.4) — not surprisingly, where average landholdings are larger there tend to be fewer cultivators per acre. However, when we include $\Delta \log \text{NC}/\text{acre}$ in our land value regressions (Table 6), its coefficient is insignificant, which suggests that returns to scale are *not* correlated with unobserved land productivity differentials. Moreover, the estimates of β_1 barely change. In sum, we find support for our contention that the arrow of causation runs from differential influence to land values, not the other way around.

5.5 Implications for inequality

Does variation in lobbying power exacerbate wealth inequality? We have already seen that such variation can either reinforce or dampen wealth differences along a *channel* depending on whether head or tail outlets have greater influence. Moreover, as indicated in Figure 7, head and tail outlets have nearly equal lobbying power on the average channel (i.e., mean $\log \theta$ is quite close to zero). Here we consider the implications of rent-seeking for the overall concentration of wealth.

We calculate land wealth by multiplying owned area by average land value on the outlet for each of the roughly 220,000 individual farmers on the nearly 4,000 outlets. Figure 8 shows the Lorenz curve for land wealth at current land prices, indicating that the top 10% of landed households own about half of land wealth.³⁴ Next, we compute wealth at land prices that net out the effect of $\log \theta$. In other words, in this counterfactual experiment, land at head outlets with relatively high lobbying influence is assumed to be no more valuable than land at head outlets with relatively low lobbying influence, and likewise for land at tail outlets. As illustrated in Figure 8, the Lorenz curves for land wealth computed at current and at these counterfactual land prices virtually coincide.

³⁴While our sample is not necessarily representative of landowning households in Punjab province, let alone agricultural households overall, this is not critical for the illustrative calculations in Figure 8.

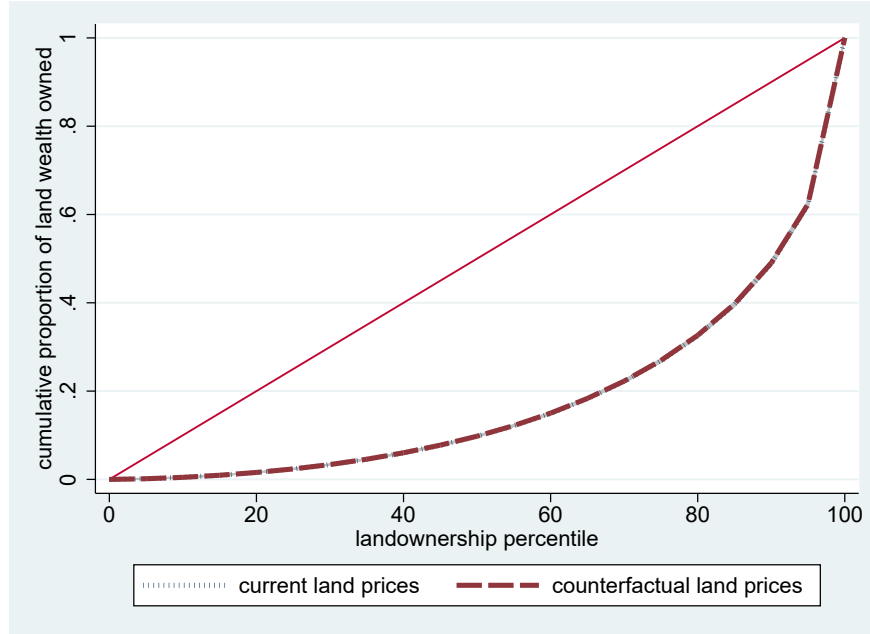


Figure 8: RENT-SEEKING AND LAND WEALTH CONCENTRATION

Notes: Counterfactual land prices zero out the effect of variation in $\log \theta$. Each point on the Lorenz curve indicates the cumulative proportion of land wealth owned by the households at or below a landownership percentile. The solid curve is the 45° line of zero land wealth concentration.

Since eliminating the return to rent-seeking, therefore, has a negligible impact on the concentration of land wealth, we can conclude that variation in lobbying power does *not* exacerbate overall inequality (even as it may do so along particular channels). While the above-noted similarity of wealth distributions by location along a channel contributes to this result, a more fundamental explanation is that the returns to lobbying for a common pool resource are, in general, non-excludable. In our particular context, these rents accrue, not only to the rich and powerful on an outlet, but also to their poor and powerless neighbors.

6 Conclusions

While optimal exploitation of common pool resources has received considerable attention in economics, actual regulation of competing users on a commons has not. This paper

begins to fill this lacuna by studying bureaucratic canal management in the Indus basin watershed. Our theory of misgovernance views the irrigation administration as having to mediate between contending coalitions of water-users along each channel. Supporting this theory, we find that greater *relative* lobbying power – as measured by a novel index combining economic stake and influential position-holding – enhances a coalition’s water allocation and thereby redistributes wealth in its favor.

Looking beyond the Indus basin, we suspect that similar mechanisms are at play in other large state-managed irrigation systems and might explain why irrigation management transfer, the devolution of authority to water-users groups, has not always been successful (e.g., Meinzen-Dick 2007), a point elaborated on in Jacoby et al. (2017) in the context of Pakistan’s own reform effort.

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Appendix

A Proofs

Proof of lemma 1. Using equation (10) it is easy to show that $b^* > \Delta s/2$. Next, differentiation of equation (10) yields

$$b_\theta^* = -\frac{r}{\theta} \left[1 - \frac{r + \Delta s/2}{\sqrt{r(r + \Delta s)}} \right]. \quad (\text{A.1})$$

So, $b_\theta^* > 0 \Leftrightarrow \sqrt{r(r + \Delta s)} < r + \Delta s/2 \Leftrightarrow r + \Delta s/2 - \sqrt{r(r + \Delta s)} = b^* - \Delta s/2 > 0$. ■

Proof of Proposition 1. We have that $\tau'(\theta) > 0 \Leftrightarrow \frac{\Delta w'}{\Delta w} - \frac{w'_T}{w_T} > 0$, where $\Delta w = w_H - w_T = \tilde{P}\hat{w}$, and also that $\frac{\Delta w'}{\Delta w} - \frac{w'_T}{w_T} > 0 \Leftrightarrow \tilde{P}'(\theta) > 0$, where

$$\tilde{P}'(\theta) \equiv \tilde{P}_\theta + \tilde{P}_b b_\theta^*. \quad (\text{A.2})$$

FOC to problem (9) $\Rightarrow \tilde{P}_b/P = -1/b^*$, and $\tilde{P}_b/P = -(1 - \tilde{P})\Omega_b/\Omega = -(1 - \tilde{P})/(\Delta s - b^*)$, where the latter equality follows from the differentiation of $\Omega = \Delta_T/\Delta_H$. Finally, $\tilde{P}_\theta = \tilde{P}(1 - \tilde{P})/\theta$. Inserting these results in (A.2) and rearranging yields

$$\tilde{P}'(\theta) = \frac{\tilde{P}(1 - \tilde{P})}{\theta} \left(1 - \frac{\theta b_\theta^*}{\Delta s - b^*} \right). \quad (\text{A.3})$$

Hence, $\tilde{P}'(\theta) > 0 \Leftrightarrow \Delta s - b^* > \theta b_\theta^*$. Using equation (A.1), we thus have that

$$\begin{aligned} \tau'(\theta) > 0 &\Leftrightarrow \\ \sqrt{r(r + \Delta s)} - r &> -r \left[1 - \frac{r + \Delta s/2}{\sqrt{r(r + \Delta s)}} \right] \Leftrightarrow \\ r(r + \Delta s) &> r(r + \Delta s/2) \Leftrightarrow \\ \Delta s &> 0, \end{aligned}$$

which is the condition for any theft to occur. ■

Proof of Proposition 2. We have that $\delta'(\theta) > 0 \Leftrightarrow \frac{\Delta V'}{\Delta V} - \frac{V'_T}{V_T} > 0$, where $\Delta V = V_H - V_T = \tilde{P}(\hat{s} - b^*)$. Now,

$$\begin{aligned} \frac{\Delta V'}{\Delta V} - \frac{V'_T}{V_T} &= \frac{\tilde{P}'(\theta)}{\tilde{P}(1 - \tilde{P})} - \frac{b_\theta^*}{\hat{s} - b^*} \\ &= 1 - b_\theta^* \left[\frac{1}{\Delta s - b^*} + \frac{1}{b^*(\hat{s} - b^*)} \right] > 0 \Leftrightarrow \\ b_\theta^* &< \frac{(\Delta s - b^*)(\hat{s} - b^*)}{\Delta s - b^* + \hat{s} - b^*} \end{aligned} \tag{A.4}$$

where the second line uses (A.3) and sets $\theta = 1$. Since $b^* > \Delta s/2$,

$$\frac{(\Delta s - b^*)(\hat{s} - b^*)}{\hat{s}} < \frac{(\Delta s - b^*)(\hat{s} - b^*)}{\Delta s - b^* + \hat{s} - b^*}.$$

Hence, it is sufficient to prove that $b_\theta^* < (\hat{s} - b^*)(\Delta s - b^*)/\hat{s}$. Using equation (A.1), this condition can be shown, after some algebra, to be equivalent to

$$b^* < \sqrt{\frac{\hat{s}\Delta s}{2}}. \tag{A.5}$$

Next, we require that $D(w)$ be linear, at least locally (i.e., on $[w_0, \hat{w}]$). Thus, letting $D(w) = d_0 - d_1 w$, where $d_0, d_1 > 0$ are parameters, we have $\hat{w} = d_0/d_1$. Further, let $\rho = \hat{n}/N = w_0/\hat{w}$. We may now write $\hat{s} = d_0^2/2d_1$, $s_0 = \hat{s}\rho(2 - \rho)$, and $\Delta s = \hat{s}(1 - \rho)^2$. Again with $\theta = 1$, we also have

$$r = \frac{1 - \rho}{\rho} s_0 = \hat{s}(1 - \rho)(2 - \rho).$$

Substituting these results into equation (10), we get

$$b^* = \hat{s} \left[3 - 2\rho - \sqrt{(2 - \rho)(3 - 2\rho)} \right].$$

Since $\sqrt{\hat{s}\Delta s} = \hat{s}(1 - \rho)$, (A.5) amounts to $3 - 2\rho - \sqrt{(2 - \rho)(3 - 2\rho)} < \sqrt{1/2}$ or, after more algebra,

$$h(\rho) = 2\rho^2 + \left[7 - 4(3 - \sqrt{1/2}) \right] \rho - (3 - \sqrt{1/2})^2 \rho^2 < 0.$$

It is straightforward to verify that, indeed, $h(\rho) < 0$ for $\rho \in [0, 1]$. ■

B Channel-Outlet Selection

B.1 Channels

From the universe of 2978 channels with outlets:

1. Keep the 2184 channels without off-taking minors or sub-minors.
2. Of these, keep 1375 channels in areas that were not part of the irrigation reform.
3. Of these, keep 731 channels for which the total number of outlets is between the median (9) and the 99th percentile (52), inclusive.
4. Of these, keep 518 channels having at least 4 outlets at head (top 40% by length) and 2 outlets at tail (bottom 20% by length).
5. Count the total number of channels per administrative division. Drop 8 divisions in the lower quartile of the channel-count distribution to economize on visits to divisional offices.

This leaves 470 channels across 24 divisions.

B.2 Outlets

The total number of outlets on these 470 channels is 9614, of which 3404 are at the head, 3796 are at the middle, and 2414 are at the tail.

1. Keep the first four outlets on the head of each channel (1880 in total).
2. Keep all outlets on the tail (2414).

This gives a total of 4294 outlets.

C Additional Figures and Tables

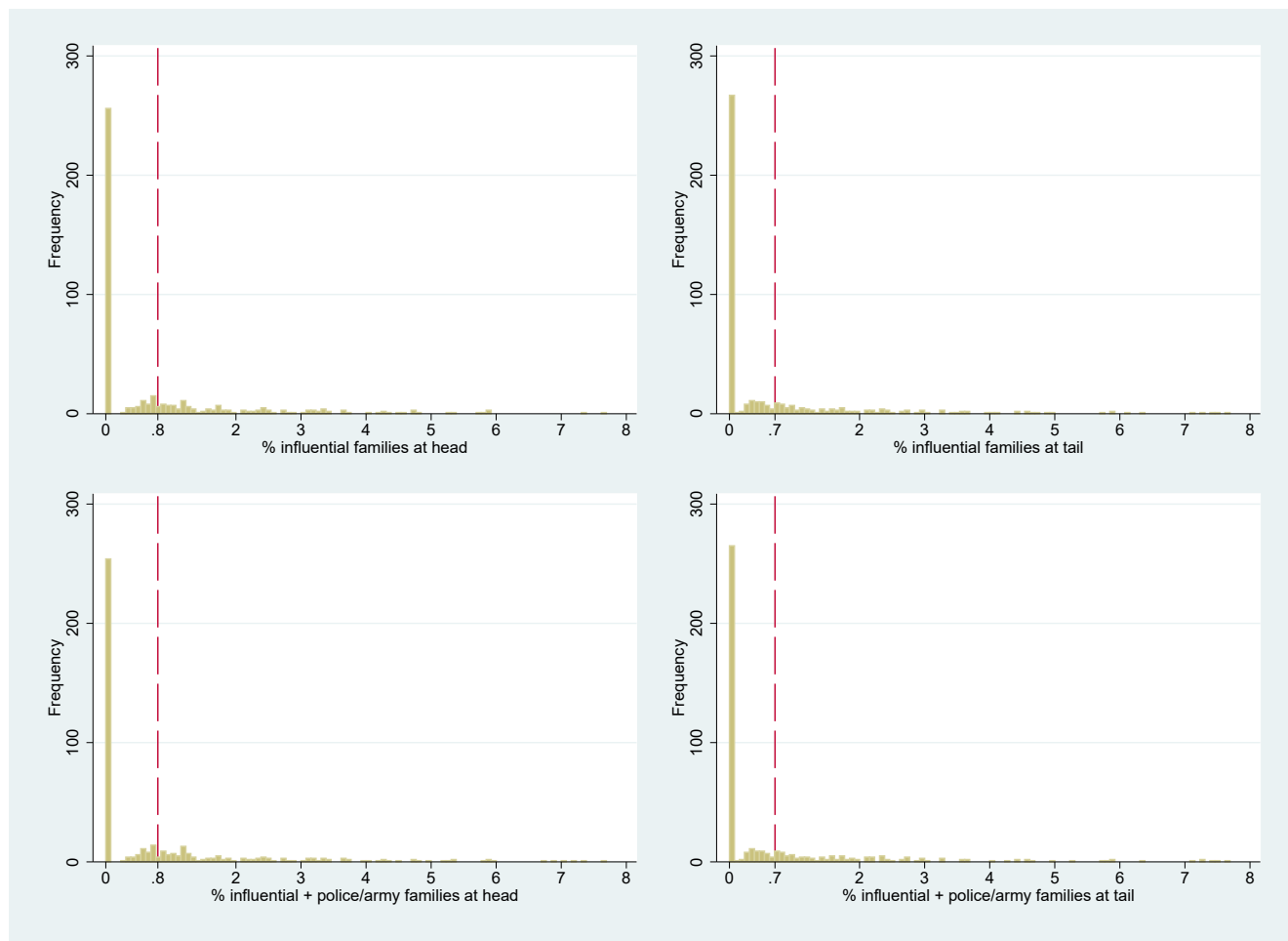


Figure C.1: PERCENTAGE OF INFLUENTIAL FAMILIES BY CHANNEL POSITION

Notes: Top panel shows histograms of percentage of influential families (indicated by political, hereditary, irrigation department, or high civil positions) at the head (left) and tail (right) of 448 sample channels. Bottom panel changes definition of influential family to include members of the police and army. Vertical lines indicates mean percentage across all channels (by position).

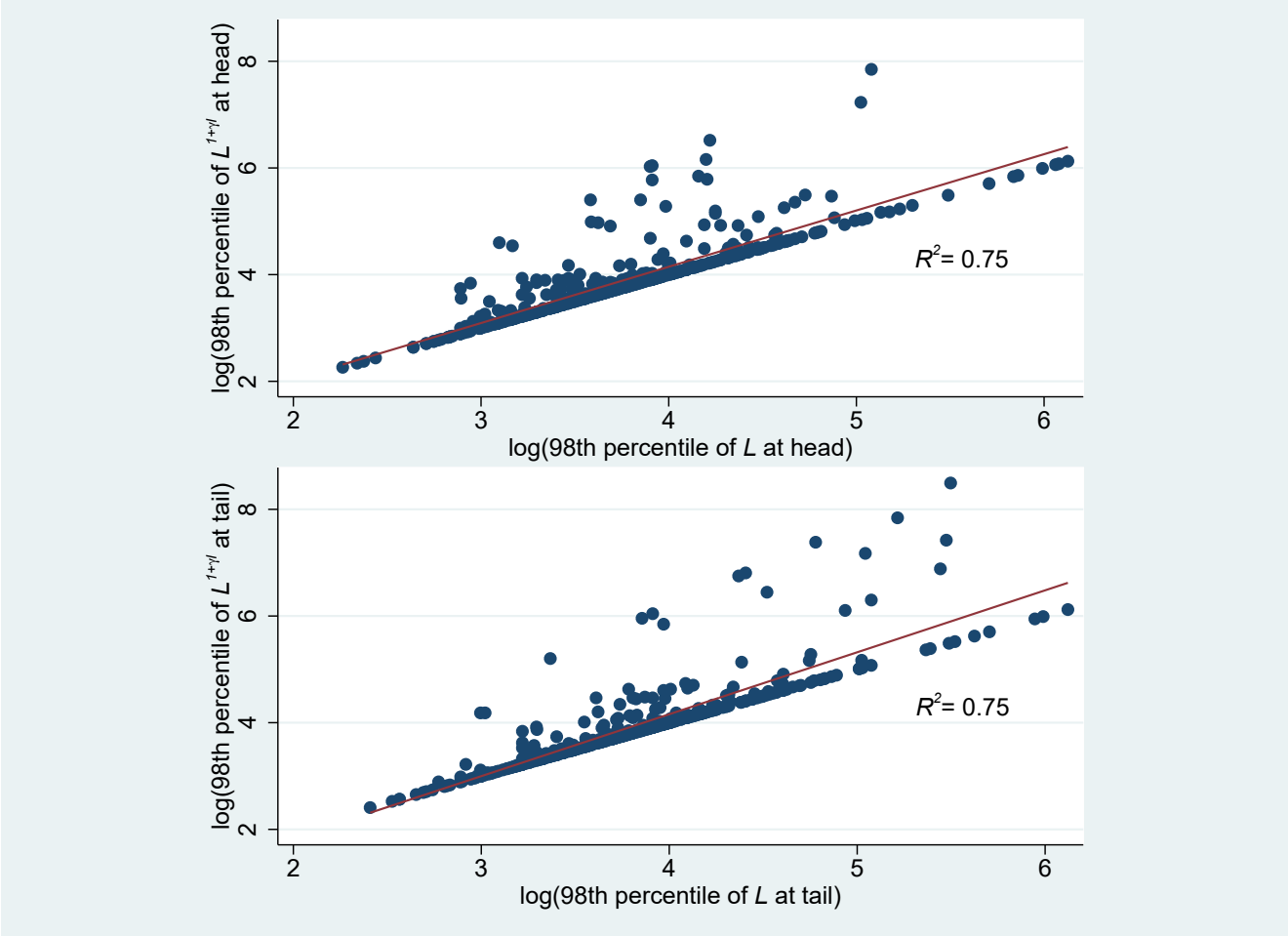


Figure C.2: UNRESTRICTED VERSUS RESTRICTED ($\gamma = 0$) INFLUENCE.

Notes: Regression of $\iota_{pc}(0.545)$ on $\iota_{pc}(0)$ (upper panel for $p = H$, lower panel for $p = T$) using the 98th percentile specification inclusive of army/police ($N = 448$).

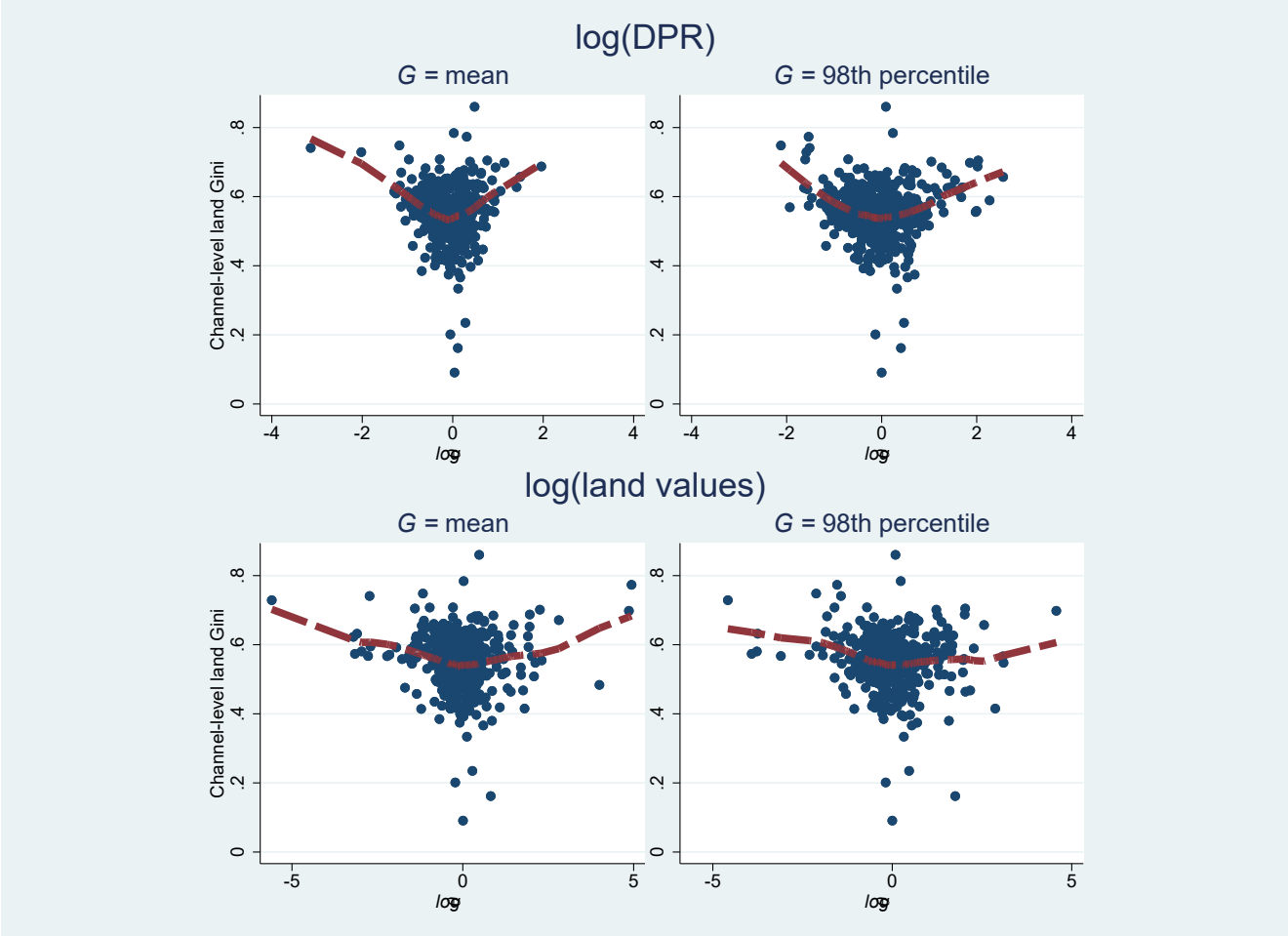


Figure C.3: CHANNEL-LEVEL GINI COEFFICIENTS AND $\log \theta$

Notes: Nonparametric regression of the channel-level land Gini coefficient on $\log \theta$ across 448 channels. Top panels, from left to right, use the $\log \theta$ in the DPR specifications with $G = \text{mean}$ and 98th percentile, and with $\gamma = 0$ in both cases. Bottom panels, from left to right, use the $\log \theta$ in the land value specifications with $G = \text{mean}$ ($\gamma = 0.815$) and 98th percentile ($\gamma = 0.545$), and army/police included.

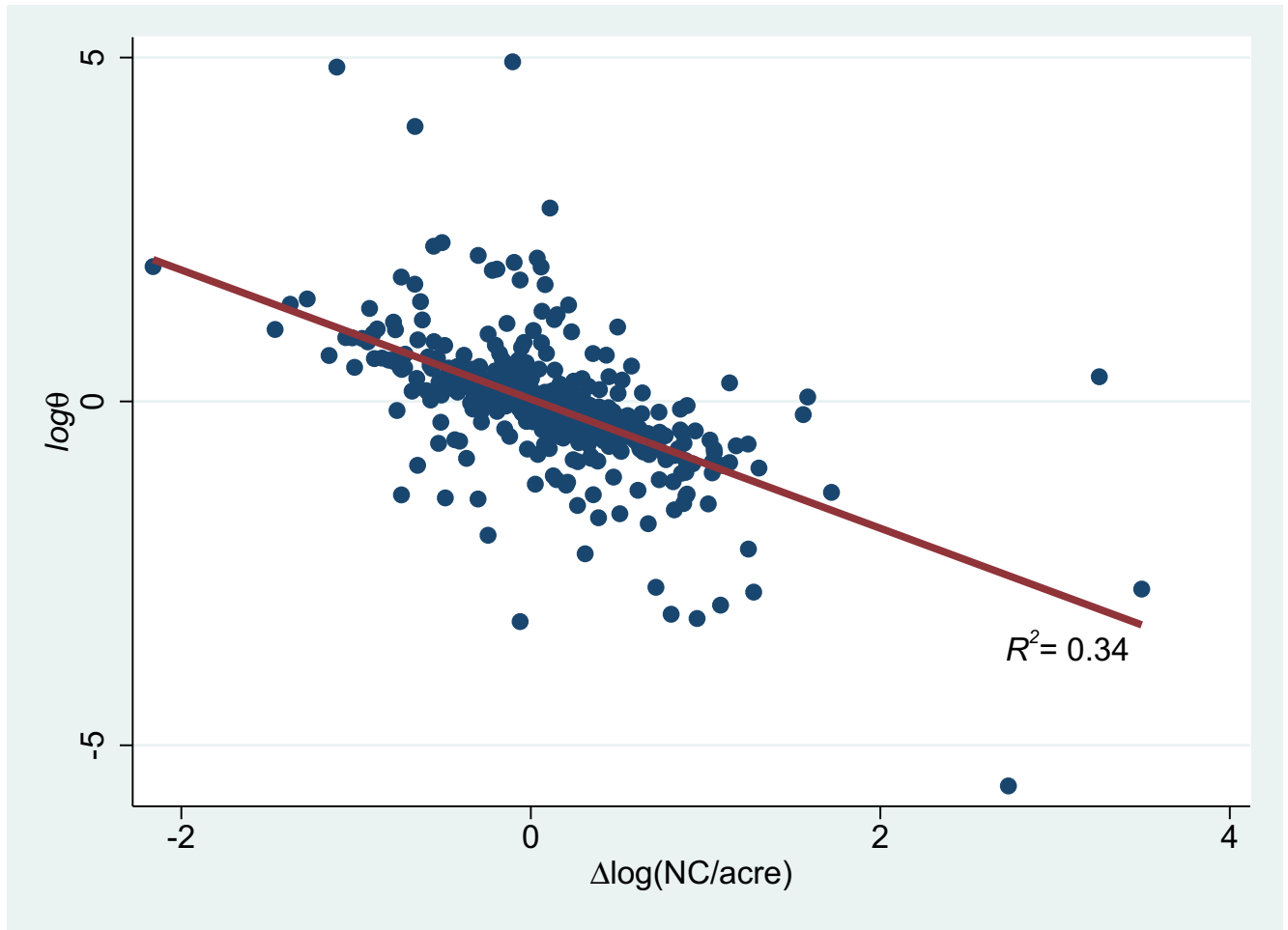


Figure C.4: RELATIVE INFLUENCE AND NUMBER OF CULTIVATORS PER ACRE

Notes: Regression of $\log \theta$ from specification in column 2 of Table 4 on $\Delta \log(\text{NC}/\text{acre})$, the head/tail difference in log number of cultivators per acre CCA ($N = 446$).

Table C.1: Selected Channel Characteristics by Administrative Division

Division	No. of selected channels	Median channel length (km)	No. of selected outlets	Mean no. of selected outlets		Median no. of irrigators per outlet
				Head	Tail	
Ahmedpur	16	8.9	144	3.9	5.1	73
Bahawalpur	24	7.7	201	3.9	4.5	35
Bhakkar	12	13.3	94	3.8	4.1	45
Dallas	23	8.2	198	3.9	4.7	57
Gujranwala	19	10.1	166	3.9	4.8	46
Gujrat	12	9.6	90	4.0	3.5	65
Kasur	13	10.8	104	3.9	4.1	69
Khanpur	26	7.7	225	3.9	4.8	56
Khanwah	27	8.5	238	3.9	4.9	36
Khushab	13	14.1	111	4.0	4.5	36
Kotadu	22	7.7	189	3.4	5.2	31
Lahore	18	7.3	148	3.8	4.4	54
Layyah	18	14.3	149	4.0	4.3	53
Lodhran	21	11.9	199	3.9	5.6	68
Mianwali	10	10.4	87	4.0	4.7	49
Multan	23	10.9	213	3.9	5.3	48
Muzaffargarh	36	9.2	344	3.9	5.7	49
Pasrur Link	11	7.4	98	4.0	4.9	33
Rahimyar Khan	30	8.4	261	3.9	4.8	50
Sarghoda	11	8.8	80	3.6	3.6	45
Sheikhupura	22	12.3	206	3.9	5.5	46
Shujabad	15	7.3	126	4.0	4.4	42
Suleimanki	11	8.5	87	3.6	4.3	61
Trimmu Barrage	15	12.5	165	3.9	7.1	48
All sample	448	9.2	3923	3.9	4.9	47

Notes: Of the 470 intended channels, 1 could not be surveyed, 4 were permanently closed, 15 had no open head outlets, and 2 had no open tail outlets, leaving 448 channels (3923 outlets) for the empirical analysis.