WPS8352

Policy Research Working Paper 8352

Decentralization and Redistribution

Irrigation Reform in Pakistan's Indus Basin

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WORLD BANK GROUP
Development Research Group
Poverty and Inequality Team
February 2018

Policy Research Working Paper 8352

Abstract

Does decentralizing the allocation of public resources reduce rent-seeking and improve equity? This paper studies a governance reform in Pakistan's vast Indus Basin irrigation system. Using canal discharge measurements across all of Punjab province, the analysis finds that water theft increased on channels taken over by local farmer organizations compared with channels that remained bureaucratically managed, leading to substantial wealth redistribution. The increase in water theft was greater along channels with larger landowners situated upstream. These findings are consistent with a model in which decentralization accentuates the political power of local elites by shifting the arena in which water rights are contested.

This paper is a product of the Poverty and Inequality Team, Development Research Group. It is part of a larger effort by the World Bank to provide open access to its research and make a contribution to development policy discussions around the world. Policy Research Working Papers are also posted on the Web at http://econ.worldbank.org. The authors may be contacted at hjacoby@worldbank.org.

Decentralization and Redistribution: Irrigation Reform in Pakistan's Indus Basin*

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Keywords: Rent-seeking, bureaucracy, elite capture, landownership inequality

JEL codes: D73, P48, Q15, Q25

*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 providing access to FO data. 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.

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1 Introduction

Perceived corruption and lack of accountability associated with top-down public service delivery has led to calls for greater decentralization in developing countries. Participatory or grass-roots governance, in which resource control resides with local elected bodies rather than with centralized bureaucracies, has gained currency among international agencies and donors (see, e.g., World Bank 2004), even though communal authority is by no means immune from rent-seeking in its various forms. A key empirical question is, therefore, whether the promise of local governance can be realized in practice and, if so, under what conditions. Yet, empirical investigation is hampered by lack of large-scale controlled experiments in decentralization combined with a paucity of objective data on behavior associated with rent-seeking.[1] This paper takes advantage of a partial governance reform in the world's largest canal irrigation system, that of Pakistan's Indus Basin watershed. During the last decade, in an effort encouraged by the World Bank, the management of several large sub-systems in the Punjab was transferred from the provincial irrigation department to farmer organizations (FOs) organized at the channel level. We assess how this shift from bureaucratic to local control affected rent-seeking in the form of water theft along a channel.

Effective management of large irrigation systems has proven elusive in both historical and contemporary experience (Meinzen-Dick, 2007).[2] In the continuous gravity flow and rotation systems most common in Asia, volumetric pricing and widespread water trading–i.e., market-based allocation–faces daunting technical hurdles (Sampath 1992).[3] Instead,

[1]See Mansuri and Rao (2013) for a comprehensive and critical review of the evidence. A small literature looks at the impact of decentralization on corruption in cross-sections of countries (most recently, Fan et al. 2009). The challenges with cross-country analyses include heterogeneity in the nature of decentralization and, of course, reverse causation (See Bardhan and Mookherjee 2006b).

[2]The celebrated writings of Elinor Ostrom take a slightly more optimistic view, arguing that self-governing institutions sometimes arise organically to solve collective action problems, at least in smaller-scale irrigation systems (Ostrom and Garner 1993).

[3]Surface irrigation systems are distinct from other public utilities, such as piped water networks, in that property rights are vastly cheaper to enforce in the latter case; canal water thus has an important common property dimension (see Jacoby and Mansuri 2018).

irrigation bureaucracies have been established to operate and monitor 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. In such quota-based systems, users have a strong temptation to bribe local officials to "look the other way" as they use various means to illicitly enhance their water entitlement. Invariably, such water theft benefits farmers at the head of the channel, where water is first to arrive, at the expense of farmers at the tail (see Bromely et al. 1980, Wade 1982, and Chambers 1988). As even a cursory internet search reveals, canal water theft garners enormous media attention in Pakistan, where it is often portrayed as pitting large landlords at the head against multitudes of poor tail-enders.

While decentralization strips authority from unelected irrigation department bureaucrats, farmer organizations may also be subject to capture by these upstream elites and, hence, may sanction as much (if not more) water theft than the irrigation department functionaries they replace. In this sense, irrigation reform and decentralization, more broadly, could merely change the venue for rent-seeking without ameliorating its underlying causes.[4] To think about the implications of decentralizing irrigation management, we set out a simple model of water allocation, corruption, and rent-seeking along a canal system. Given the locational asymmetry, corruption and theft are concentrated at the head of a channel. However, theft induces rent-seeking by coalitions of gainers (farmers at the head) and losers (farmers at the tail), each with varying degrees of political influence. Under irrigation department control, lobbying effort is directed "over the head" of the local official involved in the corruption whereas, under decentralized control, it is directed toward the FO. The model has several

[4] Rijsberman (2008) elaborates on the view that water-users associations are not a panacea. Punjab's irrigation reform exemplifies what Meinzen-Dick (2007) terms "externally initiated programs...[with] top-down imposition of a rigid structure of user groups and uniform rules that would allow state agencies to recognize and interact with [them]." Such irrigation management transfers, according to her review of the evidence, have had mixed success. Vermillion (1997), considering much the same body of country case-studies, concludes that "the literature on irrigation management transfer does not yet allow analysts to draw strong conclusions about...impacts, either positive or negative." p29.

empirical implications for the impact of decentralization and how this impact interacts with asymmetry in political influence.

The centerpiece of our analysis of Pakistan's irrigation reform is an administrative database maintained by the Punjab Irrigation Department and consisting of readings taken from water discharge gauges installed at the head and tail of each channel of the entire system. These data arguably provide an objective measure of water theft along a channel. Moreover, water discharge data are available over the years 2006-2014, a period encompassing significant devolution of irrigation management to FOs. Importantly, we are also able to match villages along each irrigation channel back to unit record landownership data from recent Agricultural Censuses. This allows us to construct measures of *differences* in political power, proxied by landholdings, between head and tail villages and thus establish whether irrigation reform has had heterogeneous impacts along this dimension.

In a companion paper (Jacoby and Mansuri 2018), we study the allocation of canal water in the presence of rent-seeking farmers and corruptible irrigation officials with career concerns. Using data from several hundred distributaries in Punjab that were *not* subject to irrigation reform, we find that, under bureaucratic control, the extent of water theft is substantially affected by the distribution of political power along a channel: where political influence is relatively concentrated at the head of a channel, water allocations are more favorable toward the head as reflected in both the canal discharge and land value differential between head and tail. In this paper, by contrast, we focus on how inequality interacts with decentralization. Although the literature recognizes that local governance is more likely to serve the interests of elites where economic and political power is more asymmetric, empirical support for this proposition remains thin (see Mansuri and Rao, 2013).

We adopt two strategies for constructing a control group against which we compare the changes in canal water allocations following decentralization. Since FOs were phased-in starting in 2005, our first strategy is to look at variation in outcomes across distributaries with early and late FO formation while controlling for channel-level fixed effects. In this 'pipeline' approach, FOs that became operational later (or not at all) serve as controls for those that became operational early. Our second, and ultimately preferable, strategy uses geographically matched controls drawn from *adjacent* administrative zones that provincial authorities had not (yet) directed to establish FOs. That is, control channels are chosen on the basis of being within a geographical *buffer* of given distance around a particular FO channel. In this case, and in contrast to the pipeline strategy, we compare changes in discharges over the same time period between neighboring FO and non-FO channels.

To summarize our empirical results, we find strong evidence of an economically important *decrease* in the relative allocation of water to the tail of a channel once an FO becomes operational. Moreover, this decline is greater along FO channels where large landowners are more heavily concentrated at the head vis à vis the tail. This latter finding implies that, where power asymmetry is in the same direction as the inherent locational (head versus tail) asymmetry, decentralization leads to greater inequity in allocations. By contrast, where the power asymmetry and the inherent locational asymmetry work in opposition, the negative impact of decentralization is muted.

This study contributes to a growing micro-empirical literature on the impact of decentralization. Alatas et al. (2013) and Beath et al. (2017) look for direct evidence of elite capture based on field experiments (in Indonesia and Afghanistan, respectively) in which the authority or accountability of extant local governments is randomly varied (see also Basurto et al., 2015, for a nonexperimental study along similar lines). None of these studies, however, compares local-level to top-down control, the pre-reform scenario considered in this paper. Moreover, as noted by Mookherjee (2015), empirical work to date focuses almost exclusively on intracommunity allocations, although the "effects of decentralization on intercommunity allocations are no less important," precisely because much rent-seeking activity is undertaken by *groups* of actors in pursuit of their collective interests. Bardhan and Mookherjee

(2006c), using longitudinal data from West Bengal, find that district and/or state allocated development grants to villages are strongly negatively related to the percentage of low-caste poor households in the village. However, neither this study nor any other econometric analysis of which we are aware addresses whether devolution of resource control can exacerbate conflict and inequality *between* communities.

More broadly, this paper is related to, and the results consistent with, Acemoglu and Robinson (2008) who study the interaction between de jure and de facto political power: "A change in political institutions that modifies the distribution of de jure power," they argue, "need not lead to a change in equilibrium economic institutions if it is associated with an offsetting change in the distribution of de facto political power." Our question, in particular, is whether an institutional change (decentralization) reduces economic inequality or is instead thwarted by increased investments in political capture. We also follow Baland and Robinson (2008) and Anderson et al. (2015), among others, in associating land ownership in developing countries with political power or influence, although our mechanism (rent-seeking) is distinct from theirs (clientilism).

The next section of the paper presents the institutional backdrop and data for our analysis. Section 3 develops the model of corruption and rent-seeking along a canal system. Section 4 lays out the empirical methodologies and presents the main impacts of irrigation management reform in Punjab. Section 5 turns to the empirical analysis of power asymmetry along a channel and how it interacts with decentralization. Section 6 concludes the paper.

2 Context and Data

2.1 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 37,000

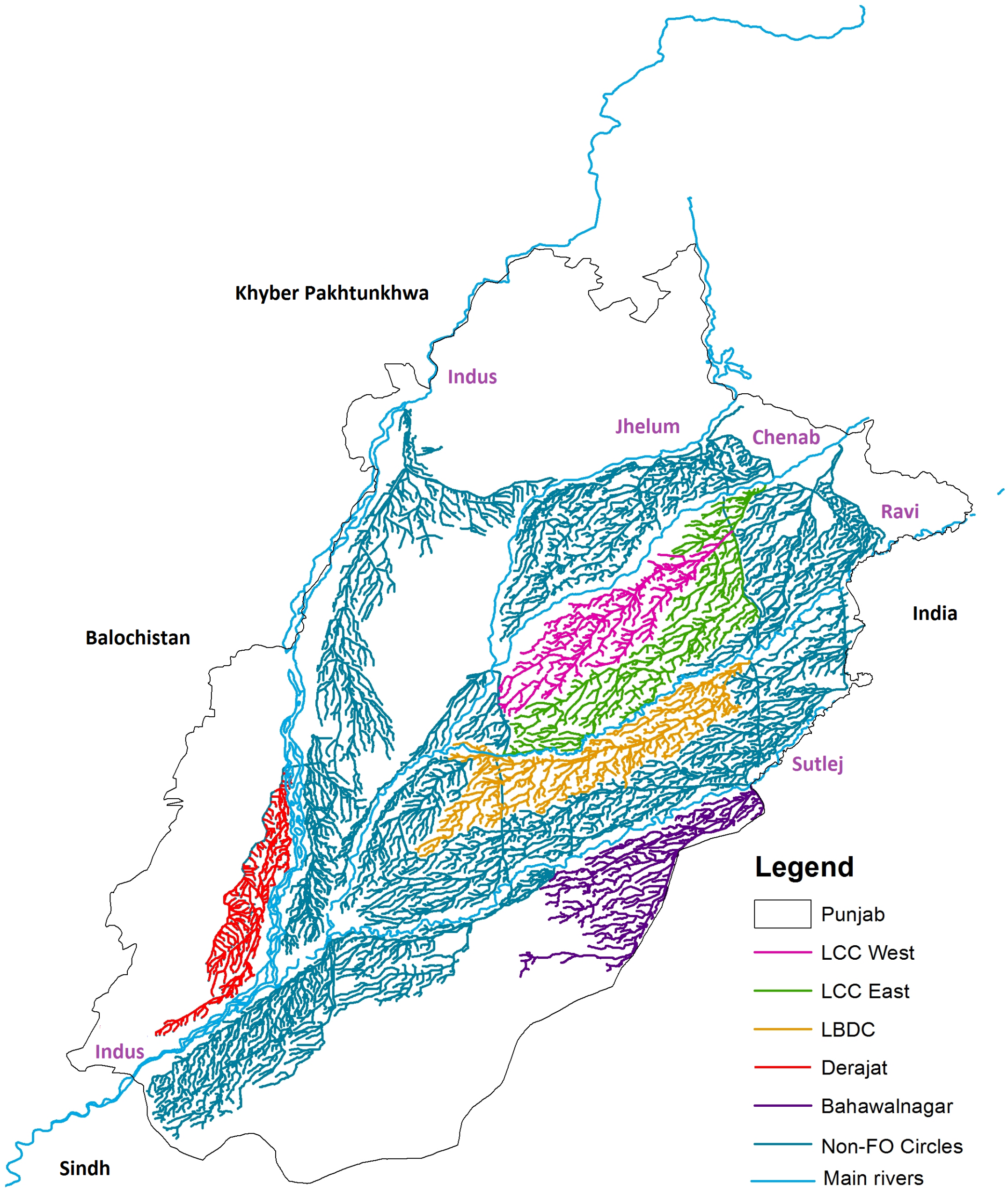

Figure 1: Indus Basin irrigation system in Punjab

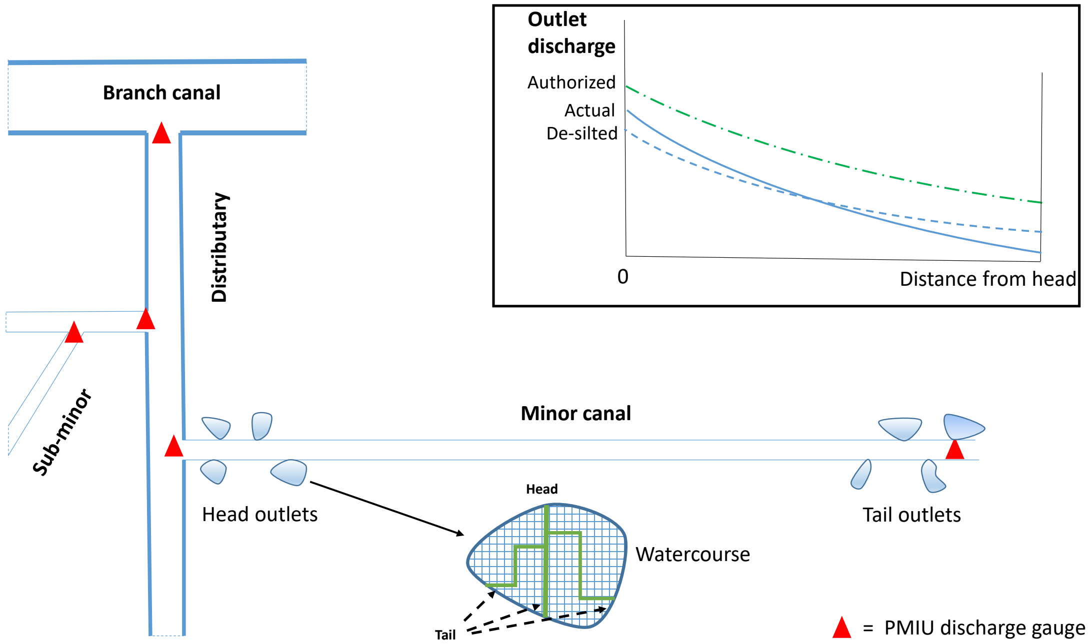

Figure 2: System schematic with discharge gauges

kilometers of canals and irrigates about 8.5 million hectacres (Figure 1). From the Indus, Jhelum, Chenab, Ravi, and Sutlej rivers issues a dense network of main canals, branch canals, distributaries, minors, and sub-minors, ultimately feeding 58,000 individual watercourses in Punjab alone (See Figure 2 for a schematic of the canal hierarchy.).

Each watercourse outlet or *mogha* supplies irrigation to typically several dozen farmers according to a rotational system known as *warabandi*. Tracing its origins to British colonial rule and to the early development of irrigation in the Indus basin, the institution of *warabandi* (literally "fixed turns") embodies a modified principle of equity: to each irrigator in proportion to his cultivated area. As discussed below, adherence to *warabandi* leads to an efficient allocation of canal water. 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 schedule. 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 (for a given canal discharge), 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 (see Figure 2), each farmer 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 2 inset), tail outlets should, in theory at least, receive their full water entitlement. In practice, however, discharge at the distributary head is often too low (Bandaragoda and Rehman 1995), or the canal is too silted up, for water to reach the tail outlets. Over-silting also results in higher water levels at the channel head and, consequently, greater discharge at head outlets (Van Waijjen et al. 1997). Lack of canal maintenance, therefore, tends to favor head outlets, which may give rise to lobbying of the irrigation department by farmers at the tail outlets to increase maintenance and by those at the head outlets to suppress it. Although such manipulation is difficult to confirm,[5] direct forms of water theft – i.e., tampering with outlets to increase width, siphoning off canal water with pipes, breaching of the canal banks, all supposedly undertaken with the connivance of irrigation officials – are pervasive in the Indus Basin (see, e.g., Rinaudo 2002; Rinaudo et al. 2000).

2.2 Irrigation management reform

Formally launched with the passage of the Punjab Irrigation and Drainage Authority Act of 1997 by the provincial assembly, irrigation management reform in the Indus Basin, and specifically the devolution to water user's associations, was strongly encouraged by the World

[5]Yet, one apparently widespread practice having the same effect is placing large boulders or other obstructions in the bed of a minor canal to increase flow at the head.

Bank.[6] Administratively, Punjab's irrigation system is divided into 17 circles. As part of the reform, Area Water Boards (AWBs) were established at the circle level with the responsibility of promoting the formation of FOs covering every water channel within the circle, with the FOs themselves tasked with the operations and management of distributaries and their off-taking channels. In particular, an FO is responsible for monitoring the rotational system to ensure equitable allocation along the distributary, for mediating and reporting water-related disputes among its irrigators, and for collecting water taxes to fund canal operations and maintenance. Five AWBs in what we will refer to as "FO circles" were initially directed to form FOs (see Figure 1). Subsequent roll-out to the remaining 12 circles has been indefinitely delayed due to concerns about FO performance.

The formation of an FO involves the following steps: First, an outlet level chairman is elected by all landowners in each watercourse. Second, a secret ballot election is held at the level of the distributary (including off-taking channels), through which a nine-member management committee (president, vice-president, secretary, treasurer, and five executive members) is selected from among the outlet level chairmen. The management committee exercises all powers of the FO. Once elected, an FO does not start operations until its members are trained and it is registered with the AWB.[7] Once operationalized, the FO membership remains in office for a tenure of three years, after which new elections are due. In practice, this electoral system has not functioned smoothly. Several incumbent FOs initiated legal action to remain in power and their tenures have been extended beyond the statutory 3-year term under court stays.

Starting from the universe of 2,902 irrigation channels in the Punjab, dropping cases that either had zero discharge at the head throughout the 2006-14 period or in which the

[6]See World Bank (1994). The Bank's support was premised on the government instituting a package of reforms, only some of which were ultimately carried out.

[7]In theory, FO members were to acquire formal training related to the daily operations and management of the system and be provided with ongoing institutional support. However, despite detailed rules and regulations to this effect, training and capacity building efforts stalled after the pilot phase in LCC East.

overseeing FO included a larger branch canal (3 FOs in all), leaves 2,860 channels. Of these, 1,007 are in FO circles, covered by 394 FOs, and 1,853 are in non-FO circles. The excess of channels over FOs in the former case reflects the fact that most distributaries have off-taking minors (and sub-minors) for which we also have discharge data. A distributary-level FO manages all of these minor canals as well. Appendix Table B.1 presents descriptive statistics for all channels by FO status of the circle. FO and non-FO circles look quite similar across design features, which include the number and location of outlets as well as position along parent channel (e.g., a minor canal's "parent" is a distributary canal).

Table 1 gives a timeline of FO operationalization in each of the circles where they have been formed. Between 2006 and 2014, FOs in LCC East and LCC West had completed one full tenure and started their second tenures, while FOs in Bahawalnagar, LBDC, and Derajat were in their first tenure. We do not have pre-reform data for LCC East because FOs there began their first tenure just prior to 2006. Also, because of delays in the election process, there was an interregnum between the two FO tenures in both LCC East and West. During this period, control of the channels reverted back to the irrigation department under a caretaker administration. Finally, note that legal action (court stays) extended the first tenure of 27 FOs (82 channels) in Bahawalnagar and extended the second tenure of 41 FOs (117 channels) in LCC East. An empirical concern addressed below is that these extensions may have occurred precisely in FOs where rent-seeking was intensifying.

2.3 Canal water discharge data

Punjab Irrigation Department's Program Monitoring and Implementation Unit (PMIU) has maintained daily records of authorized (designed) and *actual* discharge at the head and tail of each channel since 2006. Figure 2 illustrates the typical location of PMIU discharge gauges. 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.

Table 1: Timeline of FO Operationalization

Circle	No. channels (FOs)	Authority	% channels in circle-year 2006	2007	2008	2009	2010	2011	2012	2013	2014
LCC East	229 (84)	PID (pre)	4	4	4	4	4	4	0	0	0
		FO (1st)	96	96	96	0	0	0	4	4	0
		PID (post)	0	0	0	96	96	24	12	12	32
		FO (2nd)	0	0	0	0	0	73	84	85	68
LCC West	195 (73)	PID (pre)	100	100	3	3	2	2	2	2	0
		FO (1st)	0	0	97	97	98	1	1	0	2
		PID (post)	0	0	0	0	0	98	98	98	24
		FO (2nd)	0	0	0	0	0	0	0	0	74
Bahawalnagar	140 (67)	PID (pre)	100	100	100	100	100	0	0	0	0
		FO (1st)	0	0	0	0	0	100	100	100	59
		PID (post)	0	0	0	0	0	0	0	0	41
		FO (2nd)	0	0	0	0	0	0	0	0	0
LBDC	221 (52)	PID (pre)	100	100	100	100	100	100	2	2	0
		FO (1st)	0	0	0	0	0	0	98	98	100
		PID (post)	0	0	0	0	0	0	0	0	0
		FO (2nd)	0	0	0	0	0	0	0	0	0
Derajat	222 (120)	PID (pre)	100	100	100	100	100	100	100	0	0
		FO (1st)	0	0	0	0	0	0	0	100	100
		PID (post)	0	0	0	0	0	0	0	0	0
		FO (2nd)	0	0	0	0	0	0	0	0	0

Notes: Under the column heading "Authority" are PID (pre) = Punjab Irrigation Department pre-reform; FO (1st) = First tenure of Farmer Organization; PID (post) = Punjab Irrigation Department post-1st FO tenure; FO (2nd) = Second tenure of Farmer Organization. Thus, for example, in 2011, 167 (73% of 229) channels in LCC East were in their second FO tenure.

We construct a version of the "delivery performance ratio" or DPR (see, e.g., Waijjen et al. 1997) for the economically most important *kharif* (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

$$DPR_{it}^{j} = \frac{\sum_{d \in t} Q_{id}^{j}}{\sum_{d \in t} \bar{Q}_{id}^{j}} \tag{1}$$

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.

Figure 3 shows how head and tail DPRs vary across years for all channels in the 5 FO circles and 12 non-FO circles.[8] Two key facts emerge: First, the Indus Basin irrigation

[8]Even though a channel is in an FO circle, it may not actually come to be managed by an FO until as late as 2013 (see Table 1).

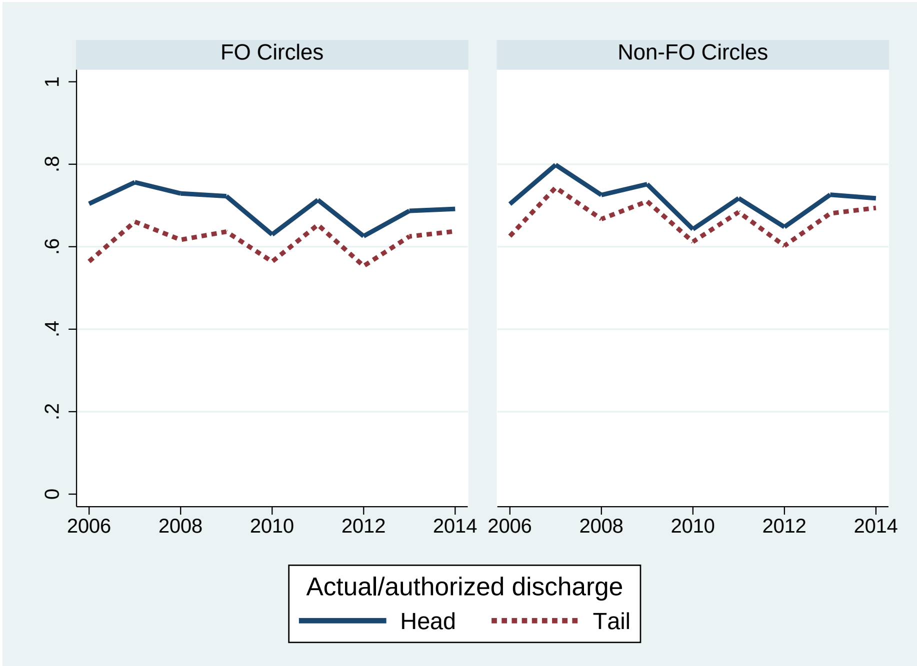

Figure 3: Head and Tail DPRs by year for FO and non-FO channels

system consistently under-provides surface water relative to its design parameters; i.e., the ratio of actual to authorized discharge is substantially less than one for the entire 9-year period. Second, the water shortfall is *greater* at the tail than at the head. To understand the greater water shortfall at the tail, recall that under the quota-based *warbandi* system each watercourse gets a share of flow into the channel determined by outlet width. Thus, if discharge measured at the head gauge of the channel is, say, 80% of authorized over the whole season, then each outlet along that channel, including the very last one where tail discharge is measured, would automatically receive 80% of its water entitlement or design flow. If, however, upstream outlets are enlarged or the canal is breached or silt is not removed in a timely manner – or, more benignly, the flow entering the channel is highly variable within the filling cycle – then relatively less water makes its way to the tail of the channel over the course of the season; for any given value of DPR^H, there is a lower value of DPR^T.

Defining tail shortage as

$$TS_{it} = DPR_{it}^{H} - DPR_{it}^{T}, \tag{2}$$

we see in Figure 3 that average tail shortage across all channels and years is twice as large in FO circles (0.096) as in non-FO circles (0.048), which suggests that water theft may be more prevalent in FO circles. However, inferring anything about the causal impact of FOs is premature. Indeed, the pattern could reflect selection; i.e., reforms may have been initiated in areas where inequities in water allocation were more pervasive to begin with.

3 Conceptual Framework

3.1 Centralized bureaucracy versus decentralization

Modeling public service delivery under alternative political institutions, such as centralized bureaucracy and local governance, using a common theoretical apparatus poses a distinct challenge. In perhaps the only other attempt to do so,[9] Bardhan and Mookherjee (2006a) consider a bureaucratic hierarchy engaged in rent extraction under asymmetric information and compare it against a local elected government captured by elites. Decentralization "shifts control rights away from bribe extractors to those who respond to the interests of local users, owing to electoral pressures. However, they respond with a bias in favour of local elites" (p. 110). Bribe-taking is, consequently, replaced by biased fiscal transfers.

In Bardhan and Mookherjee, the actions of bureaucrats are unconstrained by motivations associated with public service or career concerns (as discussed in, e.g., Dixit 2002). By contrast, Jacoby and Mansuri (2018) develop a model of bureaucratic canal water allocation in which corruption on the part of local irrigation department officials is constrained by a transfer threat coming from a higher level of the administration. The model is motivated by

[9]Hoffmann et al. (2017) examine political allocations under centralized and decentralized structures when home constituencies are favored. However, there is no bureaucratic hierarchy in the model.

Rinaudo et al.'s (2000) observations, informed by extensive field-work in Pakistan's Indus Basin, that "[i]nfluential farmers who are well connected to high-level administration officers or to local 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...[I]rrigation 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 this paper, we extend the model to cover the case of FO-managed channels. Under either form of management, water theft and corruption generates winners (farmers at the head of the channel) and losers (farmers at the downstream outlets) who receive less water than they are entitled to. Rent-seeking arises as these winners and losers lobby the powers-that-be to intercede on their behalf. To highlight the role of institutional structure, the only difference between centralized and decentralized systems lies in the incentive for corruption, which, in equilibrium, affects the incentive for rent-seeking.

3.2 Model 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 by

$$\int_0^N w(n)dn = Nw_0. \tag{3}$$

Agricultural output depends on water per acre cultivated, but with diminishing marginal product.[10] 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

$$s(w) = \int_0^w D(w)dw. \tag{4}$$

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

$$\int_0^N s(w(n))dn \tag{5}$$

subject to (3), 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.[11]

3.3 Theft 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

[10] Output, 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.

[11] Chakravorty 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 7 kilometers, 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.

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 3). 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 an authority, such as the irrigation department or an FO. While the authority could, at some cost, set $w < \hat{w}$ by fine-tuning the degree of outlet tampering and other such violations, we assume instead that the amount of water theft $\hat{w} - w_0$ is taken as a *fait accompli* (see Jacoby and Mansuri 2018 for an alternative justification of this assumption). However, once faced with an infraction, the official of the authority charges the farmers at the offending outlet a collective bribe of size b to overlook it (e.g., to not make a police report). How is the amount of this bribe set? 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 trade-off, we must first consider rent-seeking.

3.4 Rent-seeking

Water theft creates groups of winners (head outlets) and losers (tail outlets), each of which lobbies the "powers-that-be" for its desired outcome. Define the head outlet coalition $C_H = \{n | n \in [0, \hat{n}]\}$ and the tail outlet 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. C_H and C_T each try to sway the authority to, respectively, continue the water theft or to restore the de jure water allocation. As in Tullock (1980), we assume that the probability, P, of C_H winning this contest depends on the effort level, e_j, of both coalitions $j = H, T$ as follows:[12]

$$P = \frac{\iota_H e_H}{\iota_H e_H + \iota_T e_T}, \tag{6}$$

[12] The 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).

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; this is the sense in which intercommunity inequality matters for outcomes.[13]

Assuming a unitary marginal cost of effort,[14] expected net surplus for C_H is

$$\begin{aligned} \pi_H &= P\hat{n}(\hat{s} - b) + (1 - P)\hat{n}s_0 - e_H \\ &= \hat{n}s_0 + P\Delta_H - e_H, \end{aligned} \tag{7}$$

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

$$\begin{aligned} \pi_T &= (1 - P)(N - \hat{n})s_0 - e_T \\ &= (N - \hat{n})s_0 - P\Delta_T - e_T \end{aligned} \tag{8}$$

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). The nature of rent-seeking activities may also differ between head and tail, given head outlets' locational advantage. For instance, C_T may stage protests or, rather, exercise "voice" (see Reinikka and Svensson 2004 for a model along these lines), whereas C_H may engage in various more subtle forms of pressure and persuasion. We consider these different cases below.

Suppose, now, that each coalition chooses its rent-seeking effort taking that of the other coalition as given. Given an interior solution, $e_T = \Omega e_H$, where $\Omega = \Delta_T/\Delta_H$ is the ratio of

[13] Insofar as some of the rent-seeking effort translates into utility for the authority, there is an incentive for whoever is in charge to *hold* a lobbying contest with non-trivial win probabilites for each side.

[14] This 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.

win-loss differentials. Thus, in the Nash equilibrium, $P = \tilde{P}$, where

$$\tilde{P}(b) = \frac{\iota_H \Delta_H(b)}{\iota_H \Delta_H(b) + \iota_T \Delta_T}. \tag{9}$$

The equilibrium probability of maintaining corruption depends on each coalition's net gains from winning the lobbying contest weighted by their marginal influence. We may write equation (9) more compactly as

$$\tilde{P}(b) = \frac{\theta}{\theta + \Omega(b)}. \tag{10}$$

where $\theta = \iota_H/\iota_T$ is a parameter representing the *relative* influence of the head coalition vis-à-vis the tail coalition.

3.5 Optimal bribe

Bureaucracy: Bureaucracy is characterized by hierarchy; the official on the ground condoning the water theft in exchange for a bribe is an agent of a higher level office. We assume that the local official is, in effect, paid an efficiency wage and thus has career concerns (see Jacoby and Mansuri 2018 and the citations therein). As long as he stays in his current position he receives bribe income $\hat{n}b$; otherwise, he receives his outside option, which we normalize to zero. Whether the local official is retained depends on the pressure exerted on the irrigation department by the contending interests along the channel. If C_H wins the lobbying contest, as described formally in the previous subsection, the official will be retained, whereas if C_T wins, the official will be reassigned and replaced, at least temporarily, by direct irrigation department oversight.

The local official chooses his bribe b for the channel to maximize expected income

$$V_B(b) = \tilde{P}(b)\hat{n}b. \tag{11}$$

Thus, the official faces a trade-off between greater bribe income, on the one hand, and a higher *equilibrium* probability of retaining his position, on the other. In particular, the higher the bribe, the less net surplus is available to head outlets and, hence, the less effort their coalition exerts to retain the official.

Farmer Organizations: While FO officials are assumed to behave the same way as the local irrigation department officials, their objective function differs in a key respect. Under bureaucratic control, lobbying is directed upward, to the office with the authority to transfer a lower official. In a decentralized structure, farmers lobby the FO and at least part of this lobbying *directly* benefits FO officials. Decentralization thus breaks the separation between corruption and rent-seeking that prevails in the bureaucratic hierarchy.

Suppose that the FO receives some utility u from rent-seeking effort. We may think of u as the perks of power or the value of political support to remain in power or to be reelected, or all of the above. Let us distinguish the two cases alluded to earlier. In the first case, an equal fraction of the equilibrium rent seeking efforts $e_H(b)$ and $e_T(b)$ provide utility to the FO; thus, $u_1(b) = U(e_T(b) + e_H(b))$. In the second case, the nature of rent-seeking on the part of C_H is the same as above; C_T, however, only exercises its voice option. Since protests provide no direct utility to the FO, $u_2(b) = U(e_H(b))$.

Depending on case $c = 1, 2$, the FO chooses b to maximize

$$V_F(b) = \tilde{P}(b)\hat{n}b + u_c(b), \tag{12}$$

V_F can be seen to combine the local irrigation official's objective V_B with that of the higher-level department office, which we previously could ignore. Importantly, since $u_c' < 0$ — higher bribes, by curtailing valuable rent-seeking effort, make the FO worse off — the FO official has *lower* marginal corruption incentives than the irrigation official and, hence, charges a lower bribe. This result is formalized as lemma 1 in Appendix A.

3.6 Implications of decentralization

Our outcome variable, tail shortage, is the *expected* difference in water available at the first and last outlet of a channel. In terms of the model, $TS_r = \tilde{P}(b_r)(\hat{w} - 0) + \left[1 - \tilde{P}(b_r)\right](w_0 - w_0) = \tilde{P}(b_r)\hat{w}$, where $r = B, F$ denote bureaucracy and FO, respectively. The model yields three results (see Appendix A for proofs):

Proposition 1. $TS_F > TS_B$

This result says that water theft increases after decentralization, or $\Delta TS = TS_F - TS_B > 0$. Intuitively, the bribe amount falls under FO authority because, as noted, the marginal incentives for bribery are reduced. Water theft, however, is *decreasing* in the bribe amount, because higher bribes reduce head outlets' surplus and, hence, their support for the status quo (so $\tilde{P}$ must fall).

Next, we have that decentralization increases water theft by more on channels along which head outlets are relatively powerful; i.e., along those with high θ:

Proposition 2. $\frac{\partial \Delta TS}{\partial \theta} > 0.$

Essentially, theft responds more, at the margin, to political influence when bribes are low (i.e., under FOs).[15] Lastly, we have a symmetry result following directly from the definition $\theta = \iota_H/\iota_T$:

Proposition 3. $\frac{\partial \Delta T}{\partial \log \iota_H} = -\frac{\partial \Delta T}{\partial \log \iota_T}.$

A 1 percent increase in head influence has an equivalent effect on the change in tail shortage as a 1 percent decrease in tail influence.

In the remainder of the paper, we assess whether the experience of decentralization in the Indus Basin comports with these implications of our model.

[15] Jacoby and Mansuri (2018) prove that $\partial TS(b_B)/\partial\theta > 0$ so that, given Proposition 2, water theft is increasing in θ under both irrigation department and FO authority.

4 Main Impact of Irrigation Reform

4.1 Pipeline strategy

Our regression model for tail shortage, exploiting the pipeline variation, is

$$TS_{it} = \alpha_1 \tau_{it}^1 + \alpha_2 \tau_{it}^2 + \mu_i + \delta_t + \gamma_c t + \varepsilon_{it} \quad (13)$$

where the τ_{it}^k are indicators for whether channel i is in the midst of its first ($k = 1$) or second ($k = 2$) FO tenure during *kharif* season of year t. As noted, we control for channel fixed effects, μ_i, which sweep out permanent channel characteristics, such as those correlated with the likelihood of receiving an FO earlier rather than later. We also include year dummies δ_t and circle-specific time-trends, as represented by the penultimate term in equation (13). Difference-in-differences (or fixed effects) estimation of treatment effects is predicated on the parallel trends assumption, which is to say that, absent intervention, average outcomes would have evolved similarly for both treatment and control groups. Here, with the exception of LCC East, which has no pre-reform observations (see Table 1), we are able to estimate separate time trends, γ_c, for each circle.[16] Thus, we directly control for differential pre-intervention time trends across the unit of policy choice (recall that Area Water Boards for the formation of FOs were established at the circle level). Nevertheless, our pipeline identification strategy maintains the assumption that intertemporal shocks to relative water availability at channel tails, the ε_{it}, are uncorrelated with FO operationalization — i.e., do not *cause* FOs to begin or end their tenures sooner or later. It is the threat posed by the possible failure of this assumption that motivates our second strategy below.

[16] Our analysis of pre-trends in the three late-reforming FOs (Bahawalnagar, LBDC, and Derajat; see Table 1) is summarized in Appendix Figure B.1. While parallel trends between these FOs and all non-FO channels from 2006-2010 can be formally rejected, this is no longer the case when 2006 data are dropped. Below, therefore, we check our estimates for robustness to the removal of the 2006 observations.

Table 2: Baseline Treatment Effect Estimates – Pipeline Strategy

	(1)	(2)	(3)	(4)	(5)
1st FO tenure (α_1)	0.0485***	0.0474***	0.0483***	0.0427***	0.0478***
	(0.00716)	(0.00797)	(0.00724)	(0.00742)	(0.00719)
2nd FO tenure (α_2)	0.00423	0.00438	0.00381	-0.00288	—
	(0.0101)	(0.0101)	(0.0100)	(0.0111)	
$p-$values:					
$H_0 : \gamma_c = 0$	0.000	0.000	0.000	0.000	0.000
$H_0 : \alpha_1 = \alpha_2$	0.001	0.002	0.001	0.001	—
R^2 (within)	0.056	0.047	0.057	0.056	0.056
No. of observations	24983	23059	24791	22195	24146
No. of channels	2851	2626	2851	2848	2851
No. of FOs/distibutaries	1225	1101	1225	1223	1225

Notes: Robust standard errors in parentheses (*** p<0.01, ** p<0.05, * p<0.1), clustered on FO/distributary (distributary for non-FO channels). Dependent variable is tail shortage $DPR^H - DPR^T$. All specifications include channel fixed effects, year dummies, and circle-specific time trends (γ_c). Guide to specifications: (1) All channel-years; (2) Drops LCC East; (3) Drops cases of FO tenure extended by court-stay; (4) Drops observations from 2006; (5) Drops all channel-years in second FO tenure.

4.2 Pipeline results

Results for the pipeline approach using all channel-years (Table 2, column 1) indicate that the first FO tenure significantly *increased* tail shortage. The average treatment effect estimate of 0.0485 is 53% of average pre-reform tail shortage across all FO channels and years. Thus, the irrigation reform worsened discharge at the tail relative to the head by around half the original gap. The circle-specific time trends are strongly significant, net of overall year effects, as indicated in Table 2. However, we are not able to allow for a separate time trend for LCC East, as this FO circle has no pre-treatment observations. To ensure that LCC East is not driving our results as a consequence, we drop all observations from this FO from the estimation in column 2. Comparison to column 1 reveals that lack of pre-trends for LCC East is not a serious lacuna.

The pipeline results imply no discernible effect of the second FO tenure. Although the standard error on the second tenure coefficient is somewhat larger than that on the first tenure coefficient, lack of precision is clearly not the whole story since we can still strongly reject the equality restriction $\alpha_1 = \alpha_2$. As noted, however, FOs had their second tenures in only two of the five FO circles (see Table 1); 84% of these observations are from LCC East, which, recall, was intended to be a showcase for the irrigation reform. Additionally, as also noted, a large proportion of second tenures in LCC East were extended by court stays. To check robustness against the concern that FO tenures were endogenously extended by legal action, we drop all such channel-year observations (whether in the first or second FO tenures) in column 3. The results are virtually unchanged. We also drop the first year of data (see column 4) in light of the fact that pre-trends with 2006 included are not strictly parallel (fn. 16). This also makes little difference, nor should it since we are already controlling for circle-specific time trends. Finally, in the last column of Table 1, we present the estimate for the first FO tenure treatment effect when all second tenure observations are dropped.

4.3 Spatial matching strategy

Before setting out the regression model for use with spatially matched controls, we discuss our GIS buffer strategy. A buffer is a locus of GIS coordinates equidistant from each coordinate of an FO channel. Spatial matching consists in finding the set of channels from non-FO circles that lie entirely within a buffer of given radius. Figure 4 illustrates a 40 kilometer buffer for a channel in Bahawalnagar Circle along with one particular control channel, of which there are typically many.[17] Compared to the pipeline strategy, spatial matching uses the same underlying channels (both FO and non-FO) but weights them differently.

The choice of radius for the GIS buffer presents a trade-off. The smaller the radius, the more similar treatment and control channels are likely to be along unobserved dimensions (given spatial correlation in these unobservables). However, a smaller radius also implies a

[17]There are no GIS shape files for circle borders, so we cannot match on the basis of distance to these administrative boundaries.

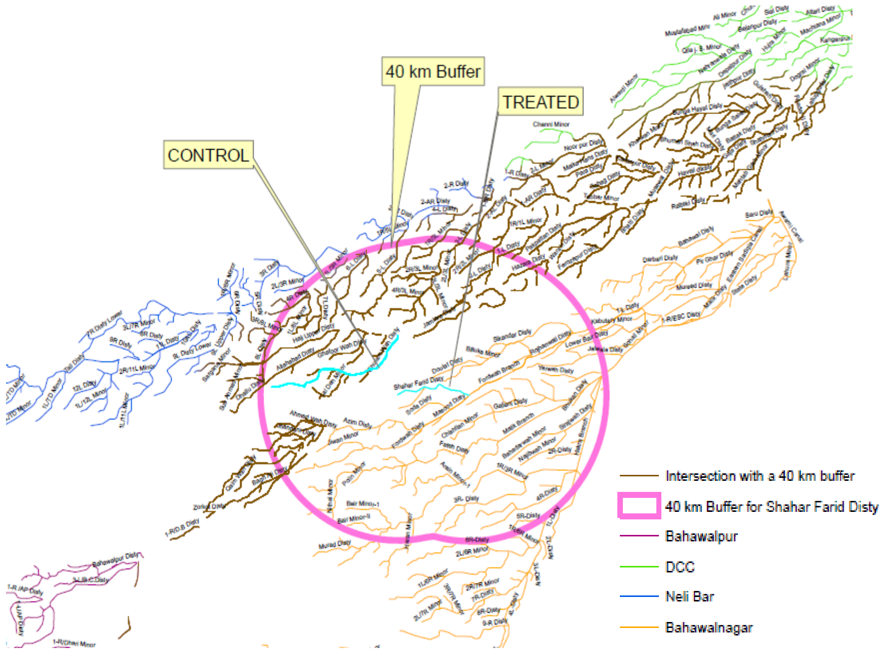

Figure 4: EXAMPLE OF 40 KM BUFFER FOR SPATIAL MATCHING

smaller likelihood of finding *any* channels lying both within the buffer and within an adjacent non-FO circle. A radius of 40 km, in particular, leads to a sample consisting of 302 FOs covering 747 channels, with 915 non-FO channels as controls (but each of these typically appearing in many buffers). Thus, the choice of 40 km radius implies a loss of 94 of our original 396 FOs in the sense that we do not have spatially matched controls for them. By contrast, moving to a 60 km buffer radius matches 348 FOs covering 883 channels (with 1,233 non-FO control channels). But shrinking the buffer radius down to 20 km nets only 130 FOs covering a mere 351 channels; since we believe that this is too few to constitute a useful sample, we do not pursue the 20 km buffer strategy.

Indexing buffers by subscript b, our regression model becomes

$$TS_{it} = \alpha_1 \tau_{it}^1 + \alpha_2 \tau_{it}^2 + \mu_i + \gamma_c t + \phi_{bt} + \xi_{it} \tag{14}$$

where ϕ_{bt} is a buffer-year fixed effect.[18] In terms of the pipeline specification, we may think of $\varepsilon_{it} = \phi_{bt} + \xi_{it}$ with ϕ_{bt} as the spatially intra-correlated component of the intertemporal shock to relative water supply at channel tails.

To understand the source of identifying variation in equation (14), we simplify the model to just two time periods, before and after reform. First-differencing over time for each channel in this case is equivalent to including channel fixed effects and yields

$$\Delta TS_{it} = \alpha_1 \Delta\tau_{it}^1 + \alpha_2 \Delta\tau_{it}^2 + \gamma_c + \tilde{\phi}_b + \Delta\xi_i, \tag{15}$$

where $\tilde{\phi}_b$ is a buffer fixed effect. Thus, the average treatment effect of an FO tenure is identified off of *within* buffer variation in channel-level discharge differences (pre/post) between FO and non-FO channels that lie in adjacent FO and non-FO circles, respectively. In contrast to the pipeline approach, the spatial matching estimator uses none of the variation in the timing of reform across FO circles since a given buffer can only contain channels from one FO circle.

While the general time-pattern of tail shortage is absorbed in the buffer-year fixed effects included in equation (14), circle-specific trends γ_c are estimable because channels from the same circle can appear in many different buffers. To allow for the possibility that tail shortages in FO circles and in adjacent non-FO circles were not on parallel trajectories prior to decentralization, we thus again control for circle-specific trends. Finally, let us emphasize that, insofar as the decomposition of the tail shortage shock ε_{it} into a spatially intra-correlated component ϕ_{bt} and a purely idiosyncratic component ξ_{it} is valid, the identifying assumptions are weaker in the spatial matching case than in the pipeline strategy; we only require that ξ_{it} be uncorrelated with changes in FO operationalization status.

[18] Due to the high dimensionality of both the channel and buffer-year fixed effects, we must estimate equation (14) using an iterative technique (Guimaraes and Portugal, 2010).

Table 3: Baseline Treatment Effect Estimates – Spatial Matching

	40 km buffer			60 km buffer		
	(1)	(2)	(3)	(4)	(5)	(6)
1st FO tenure (α_1)	0.0465***	0.0463***	0.0500***	0.0427***	0.0424***	0.0441***
	(0.0089)	(0.0089)	(0.0087)	(0.0087)	(0.0088)	(0.0086)
2nd FO tenure (α_2)	0.0430***	0.0429***	—	0.0280**	0.0278**	—
	(0.0162)	(0.0162)		(0.0139)	(0.0139)	
$p-$values:						
$H_0 : \gamma_c = 0$	0.000	0.000	0.000	0.000	0.000	0.000
$H_0 : \alpha_1 = \alpha_2$	0.845	0.851	—	0.367	0.371	—
R^2 (within)	0.598	0.598	0.599	0.567	0.567	0.567
Observations	223,109	222,970	222,508	674,296	674,121	673,517
Number of clusters	751	751	751	916	916	916
Number of FOs	302	302	302	348	348	348

Notes: Robust standard errors in parentheses (*** p<0.01, ** p<0.05, * p<0.1), clustered on FO/distributary (distributary for non-FO channels). Dependent variable is tail shortage $DPR^H - DPR^T$. All specifications include channel fixed effects, buffer-year fixed effects, and circle-specific time trends (coefficients on which are γ_c). Guide to specifications: (1,4) All channel-years; (2,5) Drops cases of FO tenure extended by court-stay; (3,6) Drops all channel-years in second FO tenure.

4.4 Spatial matching results

The spatial matching strategy yields similar estimates of the first FO tenure treatment effect regardless of whether we adopt a 40 km (Table 3, column 1) or a 60 km (column 4) buffer radius. Relative to the pre-reform scenario in FO circles, the first tenure effects imply a 51% (40 km buffer) and 46% (60 km buffer) increase in tail shortage. The second FO tenure effects here are statistically significant and of similar magnitude to the first tenure effects, so that we cannot reject the equality restriction $\alpha_1 = \alpha_2$. Moreover, none of these results depends on the inclusion of the potentially suspect observations involving court stays (cols. 2 and 6). Finally, Table 3 reports specifications that that drop channel-years in second FO tenures altogether (columns 3 and 6), which has little impact on the first tenure coefficient.[19]

[19] Equality of circle-specific time-trends can be rejected in all specifications. Note, as well, that dropping observations from 2006, thereby rendering parallel the pre-trends in FO and non-FO circles (see fn. 16), does not appreciably affect our results (the estimate of α_1 in specification (4) falls to 0.041 (0.009) and that of α_2 falls to 0.022 (0.014)).

4.5 Discussion

Two distinct panel data strategies have yielded broadly consistent findings: Irrigation reform in Punjab increased tail shortage initially (i.e., in the first FO tenure) by around 50% of the pre-reform baseline. Since, as we have argued, the efficient allocation of canal water involves *zero* tail shortage, decentralization had a social cost. In other words, the takeover by FOs could not both accentuate head-tail inequality in canal water *and* (through side-payments) lead to a Pareto improvement of welfare. While we cannot compute the social cost directly, outlet-level data on land values from Punjab (see Jacoby and Mansuri 2018) allow us to infer that the wealth redistribution was substantial; in particular, the reform increased the value of head-end land by about 9% *relative* to the value of tail-end land.[20]

Evidence on the second FO tenure, which is far less frequent in the data than the first tenure, is not as clear-cut. Using spatial matching, the estimated second tenure treatment effect is significantly different from zero and not significantly different from the first tenure effect, which is entirely plausible — there is no theoretical reason to suggest that these effects *should* differ. The pipeline strategy, by contrast, yields a more precise yet insignificant second tenure treatment effect. These divergent findings may indicate that the identifying assumption of the pipeline strategy is violated in the data; that water availability shocks *are* correlated with the timing of (second tenure) FO operationalization. Be that as it may, when we drop observations in second FO tenures, both the pipeline and spatial matching strategies yield virtually identical results. In the analysis to follow, therefore, we will rely on this restricted sample and, because it is more robust, the spatial matching strategy.

[20]The data come from 3,922 outlets along 448 non-FO channels in Punjab. Within the same channel, land at a head outlet is valued at a 11.2% premium over land at a tail outlet (Jacoby and Mansuri 2018, Table 1). Moreover, average head DPR on these same channels is 0.052 higher than average tail DPR. Assuming, plausibly, that the entire head-tail land value differential is attributable to variation in canal water availability, a treatment effect of 0.043 is tantamount to a $11.2 \times 0.043/0.052 = 9.3\%$ increase in relative land values.

5 Role of Political Influence

Under what conditions will decentralization produce more equitable allocations? Our theoretical model formalizes the political process at the canal level as a rent-seeking contest between rival coalitions of irrigators. Asymmetry of political influence (θ) thus affects the outcome of irrigation reform. The empirical challenge is to measure the *relative* influence of outlets at the head versus those at the tail. In Pakistan, the natural proxy for political power is land ownership. Indeed, large landowners not only have more political clout but also a proportionally greater stake in the contest over water rights, and hence a greater incentive to deploy their clout.[21] Despite active tenancy markets, land sales markets are relatively thin in Pakistan, with the bulk of ownership transferred through inheritance. As a consequence, the local distribution of land ownership can be seen as both stable and as largely independent of the distribution of farmer productivity or soil fertility (factors which are, at any rate, purged from our regression specifications using channel fixed effects).

5.1 Land ownership data and *mouza* matching

We use data from four Agricultural Censuses (1980, 1990, 2000, and 2010) to characterize the distribution of landownership along Punjab's irrigation channels. Since Pakistan carries out a "sample census," about 13% of villages (*mouzas*) are covered in any given round (and 9% of households), yielding roughly 3,500 villages per round with considerable overlap across rounds. Thus, between 1980 and 2010, nearly 7,700 unique villages appear in the Agricultural Census. Given the relative stability of the land ownership distribution over time, we treat the most recent observations on all of these villages equally for the purposes of constructing

[21] Jacoby and Mansuri (2018) create an index of lobbying power that combines information on both individual landownership and political/bureaucratic/hereditary office-holding, but the latter data are not available for the present sample of channels.

our aggregates.[22] Irrigated villages from the census are matched to their corresponding canal *outlets* using village-outlet lists supplied by the Punjab Irrigation Department. Following irrigation department designation, head villages are defined as those that match to outlets on the upper 40% by length of a given channel; tail villages as those that match to outlets on the lower 20%.

We compute land ownership statistics L_{ij} by position $j = H, T$ on channel i, such that

$$L_{ij} = G(\omega_{1ij} L_{1ij}, ..., \omega_{1ij} L_{N_{ij}ij}), \tag{16}$$

where N_{ij} is the number of census households matched to position j of channel i (we drop channel-positions with $N_{ij} < 20$), the L_{kij} are the unit record landownership data, the ω_{kij} are sample census population weights normalized to sum to one within a channel-position, and $G : \mathcal{R}^{N_{ij}} \rightarrow \mathcal{R}^1$ is a statistic. Since theory is silent on the form of G, we experiment with several, varying the weight given to large landowners. Thus, while we use the (weighted) arithmetic mean (G is simply the summation operator in this case), we also try a version of the generalized mean $G(x_1, ..., x_M) = (\sum x_m^q)^{1/q}$, which puts greater weight on large values of x_m insofar as $q > 1$, as well as the 75th and 90th percentile operators.[23]

Note that the Agricultural Census samples all types of households within each *mouza*, whether cultivating or not and whether they own land or not. Arguably, the population of cultivators and/or landowners is most relevant for the political-economy of irrigation. Since non-cultivating households without land should have little, if any, influence with the FO, or with the irrigation department for that matter, this population might reasonably be excluded

[22]To the extent that land ownership data from the 1980s and 1990s are dated, they introduce measurement error biasing against finding (differential) treatment effects.

[23]The Agricultural Census does not provide household landownership broken down by irrigated and rain-fed areas, even though it is the former type of land that is most germane to the lobbying effort along a channel. However, the Census does distinguish irrigated and rain-fed *cultivated* area at the household level. Therefore, we deflate household landownership by the ratio of cultivated area under irrigation (summed across household in a *mouza*) to total cultivated area in the *mouza*.

in calculating channel position-level land statistics. On the other hand, including these non-farm households could have an important scaling function. For example, a community of 100 households each owning 100 acres is likely to have more influence than a community consisting of just a single 100-acre farm surrounded by 99 non-farm households; yet, mean landholdings *across farm households* is identical in these two communities, whereas mean landholdings *across all households* is indeed higher in the presumptively more powerful one. If the second community, instead, consisted of 100 farms of 100 acres and 100 non-farm households, the mean across all households would imply that the second is less powerful than the first when it is, in fact, equally powerful. In this case, using the means across farm households would (correctly) imply communities with identical lobbying influence (see Appendix Table B.2 for a visual guide to these examples). In short, for our purposes, there is no unambiguously valid choice of population over which to compute land ownership statistics. Prudence, therefore, dictates using both approaches.

Because the four rounds of sample census data are not everywhere dense in villages, we are not able to match *both* head and tail *mouzas* for every channel. Our analysis of power asymmetry is, thus, based on fewer FOs than were present in the baseline samples. For the 60 km spatial matching sample, the number of FOs covered falls from 349 to 247, when land statistics are taken over only farm households, and to 252, when land statistics are taken over all census households.[24] There is also a modest (positive) correlation between land ownership statistics at head and tail of the same channel (see Appendix Figure B.2), which is why these variables must be included together in the regressions.

[24]Of the 247 FOs represented in the former case, 15% are in Bahawalnagar Circle, 29% are in Derajat, 17% are in LBDC, 21% are in LCC East, and 17% are in LCC West. The corresponding breakdown across all 396 FOs in Punjab is 17%, 30%, 13%, 21%, and 18%. In line with this similarity in composition, main treatment effects are very close to those in Table 3 when estimated on the smaller samples of channels with land data (results available upon request).

5.2 Heterogeneity results

With these considerations, we now specify a mapping from the land distribution at position j of channel i, summarized by the statistic L_{ij}, to political influence of the form $\iota_{ij} \propto \exp(L_{ij})$. If, for example, G is chosen to be the summation operator, then $L_{ij} = \bar{L}_{ij}$ (mean landownership), and we would have $\log \theta_i = \log \iota_{iH} - \log \iota_{iT} = \bar{L}_{iH} - \bar{L}_{iT}$, the mean difference in landownership between head and tail. The augmented spatial matching specification (dropping second FO tenure effects) is

$$TS_{it} = \alpha_1 \tau_{it}^1 + \delta_H \tau_{it}^1 L_{iH} + \delta_T \tau_{it}^1 L_{iT} + \tau_{it}^1 Z_i' \lambda \ + \mu_i + \gamma_c t + \phi_{bt} + \xi_{it}, \tag{17}$$

where Z_i is a vector of channel level characteristics—including its length, number of outlets, and position on parent channel—that might influence FO performance. Under the symmetry restriction $\delta_H = -\delta_T$ (see Proposition 3), this regression is equivalent to interacting the treatment dummy τ_{it}^1 with $\log \theta_i$. Symmetry, recall, implies that head outlets obtain just as much additional influence over allocations at the margin from (say) one acre higher mean landownership at the head as from one acre *lower* mean landownership at the tail.

Table 4 reports eight spatial matching specifications, crossing four versions of G with the two census populations. Even as the coefficients of interest in Table 4, the δ_j, vary in magnitude across specifications due to the different scaling of the L_{ij}, a consistent pattern emerges: In each case, $\hat{\delta}_H > 0$ and $\hat{\delta}_T < 0$ and we fail to reject the null of symmetry. That this test has power is supported by the fact that we *can* reject (in all but one case) the joint null hypothesis that $\delta_H = \delta_T = 0$. Finally, in the restricted models (i.e., with $\delta_H = -\delta_T$), we can strongly reject the null that relative political influence has no effect on water allocation along a channel.

Table 4: Influence Asymmetry and FO Performance — Spatial Matching Strategy

Land Statistic:	Mean		Generalized mean ($q = 1.5$)		75^{th} percentile		90^{th} percentile	
(a) census farm hhs:								
$\tau^1 \times L_H$ (δ_H)	0.00552**		0.00225**		0.00487**		0.00195*	
	(0.00225)		(0.00098)		(0.00217)		(0.00115)	
$\tau^1 \times L_T$ (δ_T)	-0.00512		-0.00174		-0.00489		-0.00175	
	(0.00330)		(0.00113)		(0.00310)		(0.00124)	
$\tau^1 \times (L_H - L_T)$		0.00534***		0.00204***		0.00488**		0.00185**
		(0.00204)		(0.000733)		(0.00199)		(0.00093)
$p-$values:								
$H_0 : \lambda = 0$	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
$H_0 : \delta_H = -\delta_T$	0.916	—	0.732	—	0.995	—	0.899	—
$H_0 : \delta_H = \delta_T = 0$	0.024	—	0.023	—	0.038	—	0.125	—
R^2	0.567	0.567	0.567	0.567	0.567	0.567	0.567	0.567
(b) all census hhs:								
$\tau^1 \times L_H$ (δ_H)	0.00975***		0.00375**		0.00690**		0.00404***	
	(0.00343)		(0.00158)		(0.00279)		(0.00140)	
$\tau^1 \times L_T$ (δ_T)	-0.0126***		-0.00426**		-0.00882***		-0.00568***	
	(0.00470)		(0.00167)		(0.00327)		(0.00206)	
$\tau^1 \times (L_H - L_T)$		0.0109***		0.00395***		0.00781***		0.00467***
		(0.00301)		(0.00120)		(0.00230)		(0.00121)
$p-$values:								
$H_0 : \lambda = 0$	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
$H_0 : \delta_H = -\delta_T$	0.593	—	0.822	—	0.617	—	0.484	—
$H_0 : \delta_H = \delta_T = 0$	0.001	—	0.003	—	0.004	—	0.001	—
R^2	0.566	0.566	0.566	0.566	0.566	0.566	0.566	0.566

Notes: Robust standard errors in parentheses (*** p<0.01, ** p<0.05, * p<0.1), clustered on FO/distributary. Number of observations (clusters) [FOs]: 586,417 (892) [247] in panel (a); 602,425 (909) [252] in panel (b). All specifications use spatial matching with 60 km buffer. Dependent variable is tail shortage $DPR^H - DPR^T$. Channel-years in 2nd FO tenure dropped (τ^1 is indicator for first FO tenure). All specifications include channel fixed effects, circle-specific time trends, and buffer-year fixed effects. L_j denotes land ownership statistic at position j of channel computed over census farm households (panel (a)) or all census households (panel (b)). τ^1 is interacted with Z variables: log channel length, log number of outlets, whether channel is on head or middle of parent channel (tail omitted category), and whether channel is minor or sub-minor (distributary omitted category), the coefficients on which are denoted by λ.

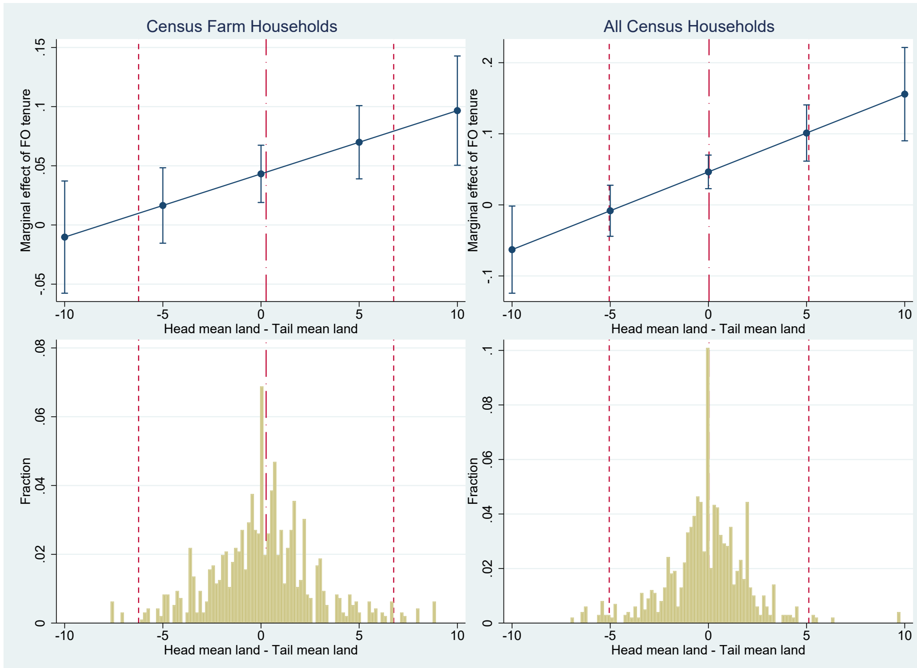

Figure 5: Marginal effect of 1st FO tenure by $\log\theta$

Notes: Left and right upper panels show marginal effects of first FO tenure at different values of relative influence ($\log\theta$) based on, respectively, census farm households (panel (a), col. 2, Table 4) and all census households (panel (b), col. 2, 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).

We summarize our key finding in Figure 5, which plots the marginal effect of FO tenure based on the restricted estimates (column 2 of Table 4). In channels with relatively greater average landownership at the head than at the tail, the post-reform allocation of canal water worsened (disfavored the tail) to a significantly *greater* extent. In other words, decentralization not only appears to have aggravated rent-seeking, but to have aggravated it by more in channels along which political power asymmetry reinforces locational asymmetry (Proposition 2). Tail-end irrigators on channels along which large landowners most predominate at the *head* (specifically, on which $\log\theta_i = \bar{L}_{iH} - \bar{L}_{iT}$ is two standard deviations above the mean) saw roughly a doubling of their relative shortage after reform, whereas tail-end

Table 5: Influence Asymmetry–Robustness to Channel-level Inequality

	Census Farm Households			All Census Households		
	Gini	Top 5% share	Landless prop.	Gini	Top 5% share	Landless prop.
$\tau^1 \times (\bar{L}_H - \bar{L}_T)$	0.00540***	0.00520***	0.00534***	0.0109***	0.0108***	0.0109***
	(0.00202)	(0.00201)	(0.00205)	(0.00299)	(0.00297)	(0.00295)
$\tau^1 \times inequality$	-0.0302	0.0471	-0.00525	0.142*	0.0557	0.123**
	(0.0893)	(0.0569)	(0.0659)	(0.0861)	(0.0524)	(0.0490)
R^2	0.567	0.567	0.567	0.566	0.566	0.566
No. of Obs.	586,417	586,417	586,417	602,425	602,425	602,425
No. of clusters	892	892	892	909	909	909
No. of FOs	247	247	247	252	252	252

Notes: See notes to Table 4. Columns 1-3 should be compared to Table 4, panel (a), column 2; Columns 4-6 should be compared to Table 4, panel (b), column 2.

irrigators on channels along which large landowners most predominate at the *tail* ($\log \theta_i$ two standard deviations below the mean) suffered essentially no erosion in water allocation following reform.

5.3 Robustness to channel-level inequality

A large literature on collective action in commons management highlights the importance of heterogeneity among users (e.g., Ostrom 1990; Baland and Platteau 1997), although the effect of inequality on outcomes is often theoretically ambiguous (Bardhan and Dayton-Johnson 2002). In the context of surface irrigation systems, Bardhan (2000) and Dayton-Johnson (2000) find that the landholdings Gini coefficient is negatively associated with co-operation in water allocation and channel maintenance. Our concern here is that, if FOs along channels with, say, greater wealth inequality produce less cooperative outcomes, and if overall *channel-level* land inequality is correlated with head-tail differences in landholdings, then our heterogeneity results in Table 5 may be spurious.

To deal with this concern, we construct channel-level measures of land inequality—Gini coefficient, share of land owned by top 5%, and proportion of landless—using the Agricultural

Census and both reference populations (see subsection 5.1).[25] These measures incorporate households from all census villages that match to outlets on the head, tail, *and* middle 40% of a given channel. In Table 5, we add these variables one-by-one to the specifications in column (2) of Table 4. In each case, the coefficient on $\tau^1 \times (\bar{L}_H - \bar{L}_T)$ is virtually unaffected.

6 Conclusion

How a shift in control from centralized bureaucracy to local government affects resource allocation has been empirical terra incognita up until now. It is worth reiterating why this is so: natural experiments in decentralization are extremely rare, rarer still in contexts where rent-seeking outcomes can be objectively measured. The devolution of irrigation management in Pakistan's Indus Basin provides just such a felicitous combination.

We have compared changes in water discharge along channels whose management was taken over by locally elected farmer organizations (FOs) to changes that occurred in channels that remained centrally managed. Water theft increased by more in the former case, leading to a large redistribution of wealth. That decentralization also increased water theft by more along channels with a greater preponderance of large landowners at the head suggests that investment in de facto political power (borrowing the terminology of Acemoglu and Robinson 2008) can sometimes *more* than offset changes in de jure political power brought about by institutional reform. Here, as our theoretical model indicates, decentralization shifts the lobbying arena from the upper-tier of the bureaucratic hierarchy to the communal governance structure, which leads to greater rent-seeking.

While our evidence is not favorable to the decentralization effort in the Indus Basin inasmuch as it did not deliver on its promise of a more equitable (and efficient) distribution of canal water, it would be premature to throw out the reform baby with the bathwater.

[25] For the calculation of the Gini coefficient, landholdings of landless households are set to 10^{-8} acres.

Successful decentralization would likely involve directly addressing power asymmetries along the irrigation system, such as by giving tail-enders *exclusive* control over FOs.[26] In terms of the model, this policy would make it more likely that the efficient allocation is implemented; tail-enders would have every incentive to enforce the *warabandi* system, while head-end influence within the FO would be minimized. Regardless of the precise governance structure, however, continual support of the central government, both in setting and enforcing the rules of the game, is critical to effective local administration (see Mansuri and Rao 2013).

[26]Merely establishing reservations whereby each FO must have a certain number of members or officers representing tail outlets may not be enough. In our data, a reasonable proportion of FO presidents (20%) and of the four-member FO management committee (18% on average) own land at the tail. In these cases, tail-enders' interests are nominally represented in the FO. However, analysis similar to that in Table 4 (available from the authors upon request) reveals no significant difference in decentralization outcomes between FOs with and without tail representation. To be sure, caution must be exercised in interpreting these results as we do not understand why some FOs have officers with tail-holdings and others do not. Nevertheless, taken on their own terms, these findings do not support a *partial* reservation for tail-enders.

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Appendix

A Proofs

Lemma 1. $b_F < b_B$.

Proof. The FOC for the bureaucratic official is $V_B'(b_B) = 0$ (the SOC $V_B'' < 0$ is always satisfied) and for the FO official is $V_B'(b_F) + u_c'(b_F) = 0$, for cases $c = 1, 2$. Since equilibrium efforts are $e_j = \tilde{P}(1 - \tilde{P})\Delta_j$, we have $e_H + e_T = \tilde{P}(1 - \tilde{P})(\Delta_H + \Delta_T) = \Delta_H \Delta_T / (\Delta_H + \Delta_T)$ at the point of equal marginal influence, $\theta = 1$. Thus,

$$u_1'(b_B) = \frac{U'(\cdot)\Delta_T^2 \Delta_H'}{(\Delta_H + \Delta_T)^2} < 0$$

since $\Delta_H'(b) = -\hat{n}$. Likewise, with $e_H = \Delta_H^2 \Delta_T / (\Delta_H + \Delta_T)^2$, we have

$$u_2'(b_B) = \frac{U'(\cdot)\Delta_T^2 \Delta_H \Delta_H'}{(\Delta_H + \Delta_T)^3} < 0.$$

It follows that, in both cases 1 and 2, $V_B'(b_F) > V_B'(b_B)$, which, by $V_B'' < 0, \Rightarrow b_F < b_B$. □

Proof of Proposition 1: We have $TS(b_r) = TS_r = \tilde{P}(b_r)\hat{w}$, and Taylor expansion

$$TS(b_F) \approx TS(b_B) + TS'(b_B)(b_F - b_B).$$

Since $\tilde{P}'(b_r) < 0 \Rightarrow TS'(b_B) < 0$, lemma 1 $\Rightarrow TS_F > TS_B$. ■

Proof of Proposition 2: We have Taylor expansion

$$TS_\theta(b_F) \approx TS_\theta(b_B) + TS_{\theta b}(b_B)(b_F - b_B).$$

where subscripts denote partial derivatives and $TS_{\theta b}(b_B) = \tilde{P}_{\theta b}(b_B)\hat{w}$. Next,

$$\tilde{P}_{\theta b} = \left[\frac{\tilde{P}}{b} + \tilde{P}_b\right] \frac{b_\theta}{b} - \frac{\tilde{P}_\theta}{\tilde{P}}.$$

Evaluated at b_B, the expression in square brackets is proportional to $V_B'(b_B)$ and thus vanishes. Since $\tilde{P}_\theta > 0, TS_{\theta b}(b_B) < 0$, which, with lemma 1, proves the result. ■

B Additional Figures and Tables

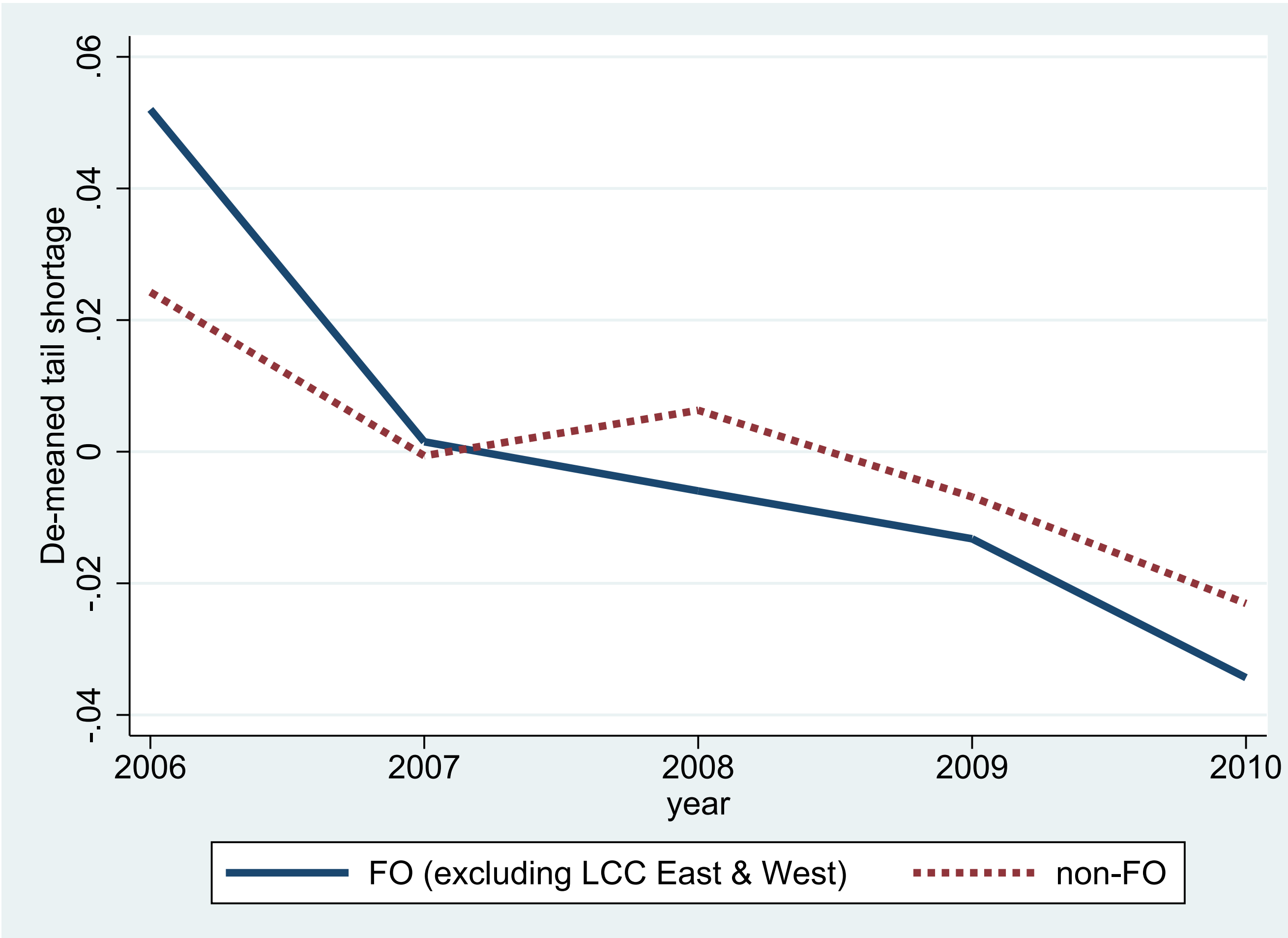

Figure B.1: Tail shortage pre-trends in FO and non-FO circles

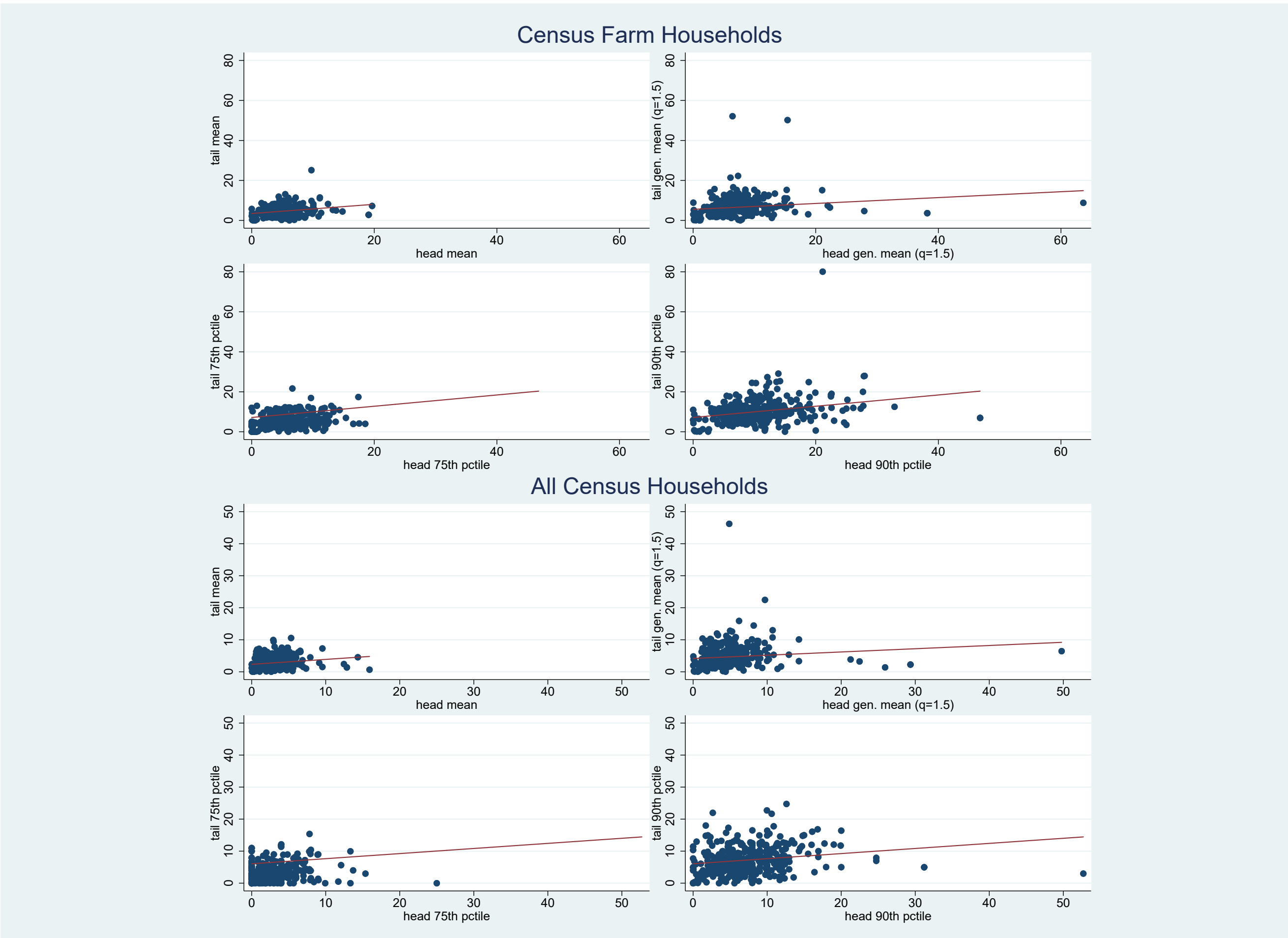

Figure B.2: Land ownership statistics at FO channel head and tail

Table B.1: Descriptive Statistics for Sample Channels

	FO circles							**Non-FO circles**						
	N	**Number of outlets**			**Position on parent**			N	**Number of outlets**			**Position on parent**		
Canal type	**(%)**	**Head**	**Middle**	**Tail**	**Head**	**Middle**	**Tail**	**(%)**	**Head**	**Middle**	**Tail**	**Head**	**Middle**	**Tail**
Distributary	453	9.9	7.0	9.8	0.31	0.40	0.29	788	10.5	8.0	10.5	0.28	0.38	0.34
	(45.0)	(11.1)	(8.3)	(9.8)	(0.46)	(0.49)	(0.45)	(42.5)	(10.7)	(8.2)	(9.5)	(0.45)	(0.49)	(0.47
Minor	488	3.0	2.8	4.7	0.44	0.37	0.19	921	4.3	3.7	5.6	0.41	0.42	0.17
	(48.5)	(4.3)	(3.5)	(3.5)	(0.50)	(0.48)	(0.39)	(49.7)	(5.1)	(3.7)	(4.3)	(0.49)	(0.49)	(0.37
Sub-minor	66	1.8	1.8	3.7	0.53	0.38	0.09	144	2.8	2.6	4.1	0.45	0.40	0.15
	(6.8)	(2.4)	(2.2)	(2.5)	(0.50)	(0.49)	(0.30)	(8.0)	(3.6)	(2.7)	(2.6)	(0.50)	(0.49)	(0.35
Total	1007	6.0	4.7	7.0	0.39	0.38	0.23	1853	6.8	5.4	7.6	0.36	0.40	0.24
	(100)	(8.9)	(6.6)	(7.7)	(0.49)	(0.49)	(0.42)	(100)	(8.5)	(6.4)	(7.4)	(0.48)	(0.49)	(0.43)

Notes: Figures are means or proportions (standard deviations in parentheses) unless otherwise noted. FO circles consist of the five Area Water Boards that formed FOs under the irrigation reform; non-FO circles consist of the 12 Area Water Boards that did not form FOs. Head, middle, and tail are defined as, respectively, the first 40%, second 40%, and last 20% of a channel by length. Parent refers to the canal from which a channel off-takes.

Table B.2: Choice of Reference Sample: A Simple Example

Comparison	Most powerful	Highest mean landholdings: Farm hhs	Highest mean landholdings: All hhs
1 vs. 2	1	=	1
1 vs. 3	=	=	1
2 vs. 3	3	=	3

Community 1: 100 x 100 acre farm hhs
Community 2: 1 x 100 acre farm hh + 99 x non-farm hhs
Community 3: 100 x 100 acre farm hhs + 100 x non-farm hhs

Notes: Most powerful community is based on the number of large landowners (equal sign denotes equally powerful). Mean landholdings refers to average across farm households (col. 3) or average across both farm and non-farm households (col. 4).