Governance and Contract Choice: Theory and Evidence from Groundwater Irrigation Markets*

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Abstract

This paper examines the role governance institutions play in the adoption of contracts. We develop a simple model of the contracting relationship in a setting where unverifiable outcomes exist and use it to interpret data on groundwater irrigation contracts in Bangladesh. A distinguishing feature of this market is the variety of village-level institutions which impose different degrees of punishment for contract violation. Consistent with the model, we find households adopt contracts that rely on unverifiable outcomes, which are not formally contractible, when punishment for contract violation is weak. Conversely, households adopt contracts that rely on formally contractible and verifiable outcomes when punishment is severe. This evidence is consistent with contract terms being chosen optimally given what is or is not formally contractible.

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1 Introduction

When governance institutions exist to observe, verify, and enforce contracts, individuals can rely on formal agreements to manage economic conduct. However, when governance institutions are absent (Dixit, 2004) or when third-party verifiable performance measures are of low-quality (Baker et al., 1994), contracting parties can choose to exploit observable but unverifiable information. Even in situations where formal contracting is possible, parties may still prefer to design contracts that rely on unverifiable information if third-party verifiable measures are weak signals of agent action. Alternative contracting terms may be associated with distinct contracting environments, such as the severity of third-party punishment for contract breach or the quality of verifiable outputs.

This paper focuses on how governance institutions affect contract design given what is or is not formally contractible. Two factors have limited the study of the role institutions play in the contract design problem. First, there are few settings, outside of international trade, where institutional enforcement of contracts varies within the market for a good (Antras and Foley, 2015). Second, almost by definition, relational agreements are difficult to collect data on, since there is no need to formalize the terms of trade (Gil and Zanarone, 2017). We address these two limitations by using a novel data set from Bangladesh that records detailed information on a variety of contracting agreements, both relational and formal, for the purchase of groundwater for irrigation. A distinguishing feature of this market is the existence of a variety of village-level governance institutions that differ in the severity with which they punish contract violation.

The data consist of farm production and contract information for 960 households randomly selected from 96 villages that provide representative coverage of irrigated rice cultivation in Bangladesh. Supplementing the household survey is a village-level survey of village governance institutions and their mechanisms for enforcing contracts. Contracts in this setting are one of three types. A fixed price contract in which water buyers (principals) pay water sellers (agents) at the start of the season for the delivery of water inputs throughout the season. A two-part tariff contract in which the principal pays an upfront fee and then makes smaller payments throughout the growing season as the water input is delivered. We consider both of these types of input-based incentive contracts as "water contracts" and interpret them as relational agreements with respect to water delivery, because water delivery is not third-party verifiable. The final contract type is an output share contract in which, at the end of the season, the agent receives a share of the rice harvest as payment for water delivered throughout the season. These output-based incentive "crop contracts" are formal agreements under strong institutions, because, unlike water input, crop output is verifiable, but the agreements are relational under weak institutions.

These observed contracts motivate a simple model of the contracting relationship in a setting where enforcement varies and unverifiable information exists. The model highlights two key features that help explain the variety of groundwater contracts. First, the severity of punishment can limit the ability to choose formal contract terms. When governance institutions punish contract violation severely, contracting parties can implement high powered, output-based incentives on verifiable performance measures without having to worry about breach. Conversely, if punishment is weak, institutions may be unable to credibly enforce those terms, with the result that parties must rely on self-enforcement. Second, the level of noise in verifiable performance measures can limit their usefulness in designing output-based incentive contracts, even if strong institutions are available to enforce contracts. If the performance measure is a highly accurate signal of agent action, then output-based incentive contracts tied to the performance measure can be more effective than alternative contract types.

We use these key features of the model to guide our econometric analysis. Our first set of results explores how the severity of punishment affects contract choice. We find that water contracts (fixed price and two-part tariff) are less likely than crop contracts (output share) when institutions provide strong punishment for the violation of formal contract terms. This finding is robust to a variety of specifications, various alternative categorizations of punishment type, and the inclusion of village-level effects to control for unobserved heterogeneity. Our second set of results focuses on the quality of the verifiable performance measure in revealing unverifiable information on agent action. We find that crop contracts, which rely on a verifiable output, are more likely than water contracts when the verifiable output provides a strong signal of agent action in the delivery of the input. This finding is robust to various model specifications and alternative categorizations of quality, but not to the inclusion of village-level effects.

The theoretical and empirical analysis provides three insights regarding the contract design problem in a setting where institutional enforcement varies. First, there is strong evidence of a negative relationship between the severity of punishment and the adoption of water contracts. Intuitively, weak enforcement institutions turn output share contracts, which condition incentives on verifiable crop output, from formal to relational. Once the enforceability advantage of crop contracts is removed, these contracts are less attractive than water contracts, which condition incentives on observable but non-verifiable inputs (water provision). As such, the paper contributes to the literature on the optimal choice of contract terms, given what is or is not formally contractible. Previous literature has focused on the inflection point where formal elements of the contract stop supporting relational elements and start to make relational contracting infeasible.[1] We expand the understanding of this issue by studying a setting in which there is variation in the severity of external enforcement. Thus, this paper is similar to Hermalin et al. (2013) and Antras and Foley (2015) in that it explicitly accounts for how the institutional environment shapes contract choice.

Second, there is modest evidence that an increase in the quality of the verifiable performance measure decreases the use of water contracts in favor of crop contracts. Intuitively, institutions that strengthen contract enforceability reduce the appeal of input-based incentives, which are not verifiable, and favor output-based incentives, which are third-party verifiable. However, even when strong enforcement exists, the output-based incentives of crop contracts will be less attractive than the input-based incentives of water contracts when the quality of the verifiable output in revealing agent input is low. We contribute to the literature on the choice between input-based and output-based incentives, a topic that has received little attention in the empirical literature.[2] We also add to the rapidly growing literature on the determinants of contract choice in developing countries.[3]

Finally, we provide a theoretical model that elucidates the interaction of principal, agent, and institutions in the market for groundwater irrigation. The majority of the groundwater contracting

[1] Representative papers in this literature include Baker et al. (1994, 2002), Schmidt and Schnitzer (1995), Johnson et al. (2002), Dixit (2004), Gillan et al. (2009), Desrieux et al. (2013), and Gil (2013).

[2] Papers that investigate this issue include McMillan and Woodruff (1999), Lazear (2000), Prendergast (2002), Raith (2008) and Chennamaneni and Desiraju (2011).

[3] These include Banerjee and Duflo (2000), Aggarwal (2007) Bellemare (2012), Macchiavello and Morjaria (2015, 2016), Arouna et al. (2019), Bubb et al. (2018), and Macchiavello and Miquel-Florensa (2018).

literature examines market structure and tests for the existence of market power.[4] However, some studies investigate the transactional relationships within the market. These studies often uses the language of contract theory to motivate descriptive analysis of groundwater markets.[5] Although these studies use principal-agent terminology, few have used theoretical models to ground their empirical investigation. The recent work by Giné and Jacoby (2020) proves an exception to this trend by developing a contract-theoretic model of groundwater transactions to examine the trade-off between relational and formal contract terms within a given institutional environment. We go beyond their work by examining contract choice across a number of different governance institutions.[6]

2 Market Setting and Contract Details

2.1 The Bangladeshi Groundwater Irrigation Market

The market for groundwater in Bangladesh is one of imperfect competition (Mukherji, 2004). Irrigation channels in Bangladesh are usually unlined and uncovered, increasing the transportation cost of water and limiting a seller's potential pool of buyers to nearest neighbors. Further limiting competition is the fragmented nature of landholding in Bangladesh. Because of cultural conventions concerning inheritance, it is rare for a household's landholding to be contiguous. Non-contiguous landholding, combined with high water transportation costs, create a market in which most water sellers are also water buyers on at least one of their parcels. The dual role of well owners as both water sellers and water buyers circumscribes market power in an economic environment of limited competition. We find that the price of water does not vary greatly within a village but, despite this, contracts for water do vary within a village.

Three key features distinguish the market for groundwater irrigation in Bangladesh from irrigation markets in more developed countries. The first is a lack of credible institutional legal

[4]Examples include Shah et al. (1993), Jacoby et al. (2004), Palmer-Jones (2010), and Ansink and Houba (2012).

[5]Papers the use the language of contract theory include Kajisa and Sakurai (2005), Aggarwal (2007), and Rahman et al. (2011).

[6]Another study that attempts to model the behavior of buyers and sellers in the market for groundwater is by Banerji et al. (2012). Yet this work is narrowly focused on a rare contract type. Their model seeks to explain behavior in a single Indian village where the price of water is set by a council of village elders. This situation is uncommon in South Asia and unobserved in Bangladesh.

authority beyond the village. The second is the difficulty for a third-party to verify the delivery of sufficient water input to crop production. The third is variation across villages in the mechanism for enforcing contracts. These institutional features mean that contract theory is well suited to provide clarity regarding the real world environment in Bangladesh.

The court system that serves the rural areas of Bangladesh is not well developed, making the enforcement of contracts inconsistent and prohibitively expensive. As a result, written, legally-binding contracts are unobserved in the market for groundwater irrigation. Even if courts operated effectively, the verifiability problem in the delivery of groundwater would still exist. Water buyers determine the amount of water input they will needed for the entire growing season after which water is delivered multiple times throughout the season (usually spanning 120 days). In theory, a third-party could observe each delivery of the input to verify that the contracted amount of water was delivered. Yet, this is costly, and in practice third-party observation of water delivery is rare. In the data, only two percent of contracting parties report that a third-party observes the adequacy (volume) or the reliability (timing) of water delivery. In contrast, 95 percent of water buyers report that they observe the adequacy of water delivery while 94 percent of buyers report that they observe the reliability of water delivery. Similarly, 86 percent of water sellers report that they observe the adequacy of water delivery and 85 percent of sellers report that they observe the reliability of water delivery. This evidence suggests that there are real costs to third-party verification of water delivery and that contracting parties can use contracts that are relational with respect to water delivery, in that the agreements neither specify nor incentivize quality.

Within villages, extralegal institutions exist, such as councils of village elders, village headmen, and religious leaders that may be called upon to adjudicate disputes. Extralegal institutions play an important role in governing water markets both historically (Smith, 2018) and in modern South Asia (Wade, 2007), as do the social norms they are based upon (Tsusaka et al., 2015). While enforcement of contracts by village institutions is prevalent, not all villages provide such enforcement. In fact, about 45 percent of villages in the study provide no enforcement mechanism at all. This creates a contracting environment where some households can use contracts that rely on strong institutional enforcement of verifiable output while other households lack this opportunity.[7]

2.2 Contracting Practices

Contracts for groundwater irrigation are for a single season, though contracting relationships span many seasons. The decision making process in securing irrigation for a parcel is sequential and begins with the principal (water buyer) choosing whether or not to grow rice during the dry *Boro* season.[8] Next, the water buyer chooses a water seller (agent) with which to contract. Once a buyer has chosen a seller, the buyer and seller negotiate over the type and terms of the contract. Contracts are agreements between a water buyer and a water seller concerning the quantity of and price for water delivery to a farmed parcel in that season. The water buyer may own a well but, due to transportation costs, chooses to purchase water for that parcel.

Three different forms of groundwater contracts are used in Bangladesh: 1) fixed price, 2) two-part tariff, and 3) output share. These three are a subset of the irrigation contracts discussed by Shah (1993) in his systematic study of groundwater markets in developing countries. The observed contracts are distinguishable from each other by variation in several different contract characteristics. Table 1 provides a summary of the various characteristics across the three forms of contracts.

In a fixed price contract the water buyer makes a one-time cash payment to the water seller at the beginning of the growing season. Prior to payment being made, both parties agree on the volume and timing of irrigation. Water is then delivered multiple times during the growing season, making it exceedingly rare for a third-party to verify that the *ex ante* agreed upon input was received. This verification problem means that fixed price contracts must rely on self-enforcement with respect to water delivery.

In a two-part tariff contract the water buyer makes a one-time cash payment to the water seller at the beginning of the growing season for access to the seller's pump throughout the season. Once the growing season has commenced, the buyer provides payment to the seller at the time of

[7]Additional data describing the environment can be found in the Appendix.

[8]Since 99 percent of land cultivated in the *Boro* season is allocated to rice (VDSA, 2016) the choice to plant a crop in this season implies that the crop chosen will be rice.

water delivery. Since water is delivered throughout the growing season, it is rare for third parties to verify that the *ex ante* agreed upon input was received. This means that, liked fixed price contracts, parties must rely on self-enforcement with respect to water delivery.

In an output share contract the water buyer agrees to pay the water seller a share of crop output at the end of the season for water delivered throughout the season. In the previous two contracts, incentives are input-based, with payment contingent water delivery that, due to its recurring delivery throughout the growing season, is costly to verify. In the output share contract, incentives are output-based, with payment contingent on crop production, which is realized once, at the end of the season. Furthermore, the rice harvest is typically milled and bagged in a communal area, allowing third parties to easily observe output and verify that the agreed upon share of production was delivered. This makes crop production a noisy but verifiable measure of agent performance in the delivery of water. If village institutions are willing to verify payment and sufficiently punish contract breach, then output share contracts can rely on third-party enforcement. However, there are a limited number of output share contracts used in villages without governance institutions. In these, output share contracts must be relational.

3 A Simple Model of Groundwater Contracting

This section presents a simple model of the contracting relationship between the water seller and water buyer. Specifically, the model distinguishes water contracts from output share arrangements and highlights institutional conditions where output share contracts might be preferred over water contracts and vice versa.

Consider a (possibly repeated) contracting game between a single principal (the water buyer) and a single agent (the water seller). In each trading period, the contracting game begins after the matching of principal and agent. In this way, the contract choice decision is sequential and separate from the matching decision. This assumption is also made by Baker et al. (1994). We assume that (1) the seller is cash constrained so that negative payments (i.e. from seller to buyer) or excessively harsh financial penalties are ruled out; (2) both parties are risk neutral.[9]

[9] We will ignore optimal risk sharing/incentive strength tradeoffs. While risk sharing is a potential consideration,

In a period, the agent undertakes actions related to the delivery of a specific volume of water (adequacy) at a specific time (reliability). We denote the volume of water, $y \in [\underline{y}, \overline{y}] \subset \mathbb{R}_+$, which is observable to both the principal and agent, but is difficult for a third-party to verify. The difficulty of verifying y is due to the necessity of delivering the input at multiple specific times during the growing season and the need to have third-party verifiers present at the relevant times. Thus, it is prohibitively costly for third-party enforcement of agreements that condition on y. Our assumption is empirically supported by the data.

When water is not verifiable, the principal-agent literature suggests that a credible signal of whether water was delivered can still be useful for structuring a contract. A potential candidate is crop output, q which is correlated with water input. Because q is realized only once, at the end of the growing season, as opposed to reoccurring throughout the season, it is much less costly for a third-party to verify. The cost of verification is further reduced by the fact that the output, rice, is usually processed in a communal area.

Given the lower cost of verifying crop output versus water input, we assume that a third-party enforceable contract can be structured around q if contracting institutions are strong in a village. To model a stochastic relationship between q and y in a simple framework, we assume that q is binary valued so that $q \in \{0, q_g\}$. Moreover, let $f(y) = Prob\{q = q_g|y\}$ and $1 - f(y) = Prob\{q = 0|y\}$. To further simplify things, we let $f(y) = ky \in (0, 1)$, where k is a parameter. For example, k can represent soil quality where high quality soil (larger k) makes output more responsive to water input. These basic preliminaries allow us to now model both water contracts and output share contracts, starting with water contracts.

3.1 Water Contracts

The principal and agent can agree on a contract which promises an upfront fixed payment S, for access to the seller's pump and possibly a fee, B, paid at the time of water delivery. Within the Bangladesh ground water irrigation context, when there is a fee, the buyer pays the seller the

it largely affects the strength of optimal incentives rather than the qualitative predictions about incentives and performance. Since we are not calibrating a structural model, but instead focusing on qualitative predictions about contractual form, we avoided the complexity of specifying risk preferences in our model.

marginal cost of the water, which in most cases is the cost of the diesel for the pump.

Given the non-verifiability of y, the water contract must be a relational contract. Under a generic payment structure of the form $W = S + By$, and a seller cost function, $c(y) = \frac{1}{2}y^2$, the principal's and agent's payoffs are, respectively, $E(V) = kyq_g - S - By$ and $U = S + By - \frac{1}{2}y^2$. The reservation payoffs for the principal and agent are $\overline{v}$ and $\overline{u}$, respectively.

To consider the optimal relational contract, consider the stage-game timeline, which follows the typical principal-agent sequence:

1. Principal (buyer) offers a contract, (S, B, y).
2. The agent (seller) accepts or rejects. If rejected, the parties receive their reservation payoffs.
3. If accepted, the agent chooses water volume, y.
4. The principal observes y and makes the payment B. The fixed payment, S, is also made.[10]

In a relational contract, the above stage game is repeated indefinitely between the principal and the agent. Moreover, the relational contract is self-enforcing if it describes a subgame perfect equilibrium of the infinitely repeated game. Levin (2003) shows that there exist stationary contracts that are optimal in that the same (optimal) contract is offered in every period, t. If δ is the common discount factor, then the principal's contract design problem is:

$$\max_{(y,S,B)} \quad kyq_g - S - By + \frac{\delta}{1-\delta}V(C), \tag{1}$$

$$\text{s.t.} \quad kyq_g - S - By + \frac{\delta}{1-\delta}V(C) \geq \frac{\overline{v}}{1-\delta}, \tag{2}$$

$$S + By - \frac{1}{2}y^2 + \frac{\delta}{1-\delta}U(C) \geq \frac{\overline{u}}{1-\delta}, \tag{3}$$

$$q_g - S - By + \frac{\delta}{1-\delta}V(C) \geq q_g - S + \frac{\delta}{1-\delta}\overline{v}, \tag{4}$$

$$y \in \arg\max \left\{ S + By - \frac{1}{2}y^2 + \frac{\delta}{1-\delta}U(C) \right\}. \tag{5}$$

[10] S is easy to make third-party enforceable because it is not conditional on any non-verifiable variable.

Equations (2) and (3) are the individual rationality (IR) constraints and equation (4) is the payment self-enforcement (SE) constraint for the buyer. Equation (5) is the incentive compatibility (IC) constraint for the seller to deliver the water quantity specified in the contract. $V(C)$ and $U(C)$ are the continuation payoffs under cooperation; i.e. when both parties have honored their obligations under the agreement.

MacLeod and Malcomson (1989) find that the form of the optimal relational contract can range from fixed price contracts to discretionary bonus contracts. Our water contract model is very general and can nest a range of contractual forms observed in Bangladesh irrigation markets. However, our focus is not on contractual form because distinguishing between different relational contractual forms is not empirically relevant. Instead, we focus on testable implications with respect to water contracts versus output share contracts.

Under the assumption of stationarity, the same contract is offered every period, t, so the above contract design problem becomes essentially a static optimization problem. Because the agent's objective function is clearly concave, constraint (5) can be replaced with the first order condition:

$$\frac{dU}{dy} = B - y = 0. \tag{6}$$

The optimization problem is linear in both S and B but because these are payments, the optimal solution requires a rational buyer to minimize both these payment terms while ensuring the constraints are not violated. Constraint (6) implies a solution of $B^* = y$. This can be substituted back into constraint (3) to obtain $S^* = \overline{u} - \frac{1}{2}y^2$. The principal's (buyer's) optimized payment, or "incentive cost function" is given by $W^* = S^* + B^*y = \overline{u} + \frac{1}{2}y^2$.[11] Note that W^* just ensures that the agent receives his reservation utility. The important point for our purpose is that *under the optimal water contract incentive structure, the principal need not leave rents to the agent.*

The principal's payoff under the optimal contract is:

$$V^* = kyq_g - \overline{u} - \frac{1}{2}y^2. \tag{7}$$

[11]Note that the principal does not produce water; she purchases water from the agent so her cost is the cost of structuring an optimal incentive payment scheme with the agent.

The first order condition with respect to y is:

$$kq - y \leq 0. \tag{8}$$

So for an interior solution, this suggests that $y^* = kq$ is the first-best optimal water volume under the incentive cost function.

Whether first-best y^* is implementable depends on the tightness of the self-enforcement constraint (4). In order for the relational contract to be non-trivial, we assume that the discount factor is sufficiently low so that the self-enforcement constraint limits the implementable y to those that are $y < y^*$. This constraint can be rearranged to get $\frac{\delta}{1-\delta}[V(C) - \overline{v}] \geq By$. Given the assumption of stationarity, so that the same optimal contract is offered every period, and letting $B^* = y$, the self-enforcement constraint becomes:

$$\frac{\delta}{1-\delta}\left[kyq_g - \frac{}{2}y^2 - \overline{u} - \overline{v}\right] \geq y^2, \tag{9}$$

which says that discounted future surplus must exceed the immediate payment promised to the seller. Under the assumption that the self-enforcement constraint is violated at y^*, the highest y that can be implemented is the level at which the constraint is just satisfied with equality.[12]

3.2 Output Share Crop Contracts

Given the difficulty of enforcing y, the parties can resort to an output share contract that is structured around q. In the Bangladesh groundwater irrigation market, output share contracts are of the general form $S = 0$ and $\xi \in [0, 1]$ where ξ denotes a share of crop output q. Thus, the form of the output share contract is $W_{os} = \xi q$. Given our parametric assumptions of $f(y) = ky$ and $c(y) = \frac{1}{2}y^2$, the agent's stage-game expected payoff is $\mathrm{E}(U) = ky\xi q - \frac{1}{2}y^2$ and the principal's stage-game expected payoff is $\mathrm{E}(V) = kyq - ky\xi q$.

[12]To understand why lowering, rather than raising y can satisfy the constraint, note that the left-hand-side of the constraint is concave in y whereas the right-hand-side is convex. Thus, if y^* does not satisfy the constraint, then neither will any $y \geq y^*$.

3.2.1 Output Share Contract with Third-Party Enforcement

One of the appealing features of these output-based incentive contracts is that, when institutions for third-party enforcement exist and punishment for contract breach is sufficient, then the parties can structure a third-party enforced contract around q. Thus, parties do not have to rely on self-enforcement or repeat trading to ensure contract compliance. As such, third-party enforced contracts are not constrained by low discount factors.

We begin by setting up the optimal output share contract design problem when contracting institutions are strong, allowing third-parties to enforce the contract. The optimal contract is one where, for a given y, the principal minimizes the cost of implementing that y.[13]

$$\min_{\xi} \quad ky\xi q, \tag{10}$$

$$\text{s.t.} \quad ky\xi q - \frac{1}{2}y^2 \geq \overline{u}, \tag{11}$$

$$k\xi q - y \geq 0, \tag{12}$$

where equation (11) is the agent's IR constraint and equation (12) is the agent's IC constraint. Note that the problem is linear in ξ which suggests that the solution can be obtained by choosing the minimum ξ that obeys the constraints. By constraint (12), we have:

$$\xi \geq \frac{y}{kq}. \tag{13}$$

Moreover, by constraint (11) we require:

$$\xi \geq \frac{\overline{u}}{kyq} + \frac{y}{2kq}. \tag{14}$$

Hence, the optimal share rate is:

[13] One can also set up an optimization problem that maximizes profit. However, in the third-party enforceable case, the minimization problem yields the optimal contract in a simpler framework.

$$\xi^* = \max\left\{\frac{y}{kq}, \frac{\overline{u}}{kyq} + \frac{y}{2kq}\right\}. \tag{15}$$

Finally, the above can be substituted into the principal's objective function to obtain the optimized incentive cost function:

$$W_{os}(y) = kyq \max\left\{\frac{y}{kq}, \frac{\overline{u}}{kyq} + \frac{y}{2kq}\right\} = \max\left\{y^2, \overline{u} + \frac{1}{2}y^2\right\}. \tag{16}$$

An important aspect of the output sharing rule is that it provides incentives to the seller largely through rewards and not harsh penalties (e.g. negative payments), even in the worst state of nature. As a consequence, an incentive compatible share rate may have to be so large that it leaves the agent with rents. The optimal share rate, equation (15), captures this by indicating that the optimal share rate is the higher of two expressions, the first derived from the incentive compatibility constraint and the second from the individual rationality constraint. If the first term is higher, then the share rate has to be so large that the agent is left with rents. The important point is that *under the optimal output share contract, the principal may have to leave the agent with rents to maintain incentive compatibility.*

Leaving rents could decrease efficiency. To see this, note that the principal's payoff under the optimal share contract is:

$$v = kyq_g - \max\left\{y^2, \overline{u} + \frac{1}{2}y^2\right\}. \tag{17}$$

This is identical to equation (7) if the agent's individual rationality constraint binds, which implies no rent. However, if a rent must be paid, then

$$v = kyq_g - y^2, \tag{18}$$

which results in the first order condition with respect to y:

$$kq_g - 2y \leq 0. \tag{19}$$

This yields an interior solution of $y^{**} = \frac{kq_g}{2}$ which is clearly lower than first-best.

With regard to the relationship between q and y, we primarily focus on the marginal impact of water on the probability of successful crop yield. This can be encapsulated by the parameter k. Note that if the relationship between q and y was completely random, then $k = 0$. While we do not have an exact measure of k, we do have data on soil quality. If soil quality is poor, crop output is likely to be poor even with adequate water. However, when soil quality is high, then crop output is more sensitive to water and serves as a more informative performance measure of agent action in the delivery of the water input. We will exploit this insight when discussing the empirical implications of the model in a subsequent section.

3.2.2 Output Share Contract Without Third-Party Enforcement

When institutions are weak so that no credible third-party can enforce even an output share contract, then an output share contract must be self-enforcing. The contracting problem becomes:

$$\max_{y,\xi} \quad kyq_g - ky\xi q + \frac{\delta}{1-\delta}V(o), \tag{20}$$

$$\text{s.t.} \quad kyq_g - ky\xi q + \frac{\delta}{1-\delta}V(o) \geq \frac{\overline{v}}{1-\delta}, \tag{21}$$

$$ky\xi q - \frac{1}{2}y^2 + \frac{\delta}{1-\delta}U(o) \geq \frac{\overline{u}}{1-\delta}, \tag{22}$$

$$q_g - \xi q + \frac{\delta}{1-\delta}V(o) \geq q_g + \frac{\delta}{1-\delta}\overline{v}, \tag{23}$$

$$y \in \arg\max \left\{ ky\xi q - \frac{1}{2}y^2 + \frac{\delta}{1-\delta}U(o) \right\}. \tag{24}$$

Equations (21) and (22) are the IR constraints and equation (23) is the payment SE constraint for the buyer. Equation (24) is the IC constraint for the seller to deliver the water quantity specified in the contract. $V(o)$ and $U(o)$ are the continuation payoffs under cooperation. With the assumption of stationarity, the optimal share rate and incentive cost function are the same as the third-party enforced output share contract (see equations (15) and (16)).

The key difference between the self-enforcing and third-party enforced output share contract is the need to include equation (23) for the self-enforcing contract. This constraint can be rearranged to get $\frac{\delta}{1-\delta}[V(o) - \overline{v}] \geq \xi q$. Given the assumption of stationarity, and substituting in the optimal share rate, the self-enforcement constraint becomes:

$$\frac{\delta}{1-\delta}\left[kyq_g - \max\left\{y^2, \overline{u} + \frac{y^2}{2}\right\} - \overline{v}\right] \geq \max\left\{\frac{y}{k}, \frac{\overline{u}}{ky} + \frac{y}{2k}\right\} \tag{25}$$

Like the water contract, the self-enforcement constraint potentially limits the level of y that can be implemented, depending on the size of the discount factor, which can result in efficiency loss. Moreover, if rents must be paid to the seller to satisfy incentive compatibility, then the output share contract faces two potentially limiting constraints to efficiency and profitability.

3.3 Empirical Implications

Our simple models of water and output share contracts provide us with empirical implications for our study. We focus on two hypotheses that can be tested with our data from the Bangladeshi groundwater irrigation market. First, the institutional environment matters in shaping the contract type (water versus output share) that is likely to be adopted. Second, better soil quality increases the likelihood that output share contracts are used. The following proposition provides theoretical basis for our first testable implication.

Proposition 1. *In the absence of strong institutions that provide punishments for contract breach, water contracts are optimal relative to output share contracts.*

Proof. In the absence of third-party punishments for contract breach, both water contracts and output share contracts must be self-enforcing. We need to show that the self-enforcement constraint under output sharing, constraint (25), is tighter than the self-enforcement constraint under the water contract, constraint (9), and that this leads to lower profitability of the crop output contract.

Under our assumption that the discount factor is low enough to act as a constraint to first-best y^* being implemented, it follows that the largest implementable y under the water contract just satisfies the self-enforcement constraint, (9). The largest implementable y under the output share contract just satisfies the self-enforcement constraint, (25). It is obvious that the left-hand-side of (9) is weakly higher than the left-hand-side of (25). Next, we must show that the right-hand-side of (9) is weakly smaller than the right-hand-side of (25). This is true if and only if $y^2 \leq \max\{\frac{y}{k}, \frac{\overline{u}}{ky} + \frac{y}{2k}\}$. Note that $y^2 \leq \frac{y}{k}$ always holds because this is equivalent to $ky \leq 1$, which must be true because ky is a probability. If $\frac{\overline{u}}{ky} + \frac{y}{2k} \geq \frac{y}{k}$, then by transitivity, $\frac{\overline{u}}{ky} + \frac{y}{2k} \geq y^2$. Hence, it follows that $y^2 \leq \max\{\frac{y}{k}, \frac{\overline{u}}{ky} + \frac{y}{2k}\}$.

Given that the left-hand-side of (9) is weakly higher than the left-hand-side of (25), and the right-hand-side of (9) is weakly smaller than the right-hand-side of (25), it follows that the self-enforcement constraint under the water contract is more relaxed than the output share contract. Consequently, a weakly higher y can be implemented under the water contract.

Finally, given that the output share contract cannot implement a higher y, a simple comparison of the profit functions under the water contract, equation (7), and the output share contract, equation (17), shows that the water contract yields higher profit. □

The above proposition leads to our first empirical implication.

Empirical Implication 1. *Holding other factors constant, the use of water contracts should increase in villages that do not provide third-party punishment for contract breach.*

This implication follows from Proposition 1 because, in the absence of third-party enforcement, we show that water contracts are optimal. Thus, we expect to observe more water contracts relative to output share contracts in villages that provide little to no punishment for contract breach.

While we have a clear prediction for when water contracts should dominate, it is not necessarily the case that output share contracts would dominate in villages with harsh punishments. Our model shows that buyers may have to pay rents when using the output-based incentives of crop contracts even with third-party enforcement. It is not clear that the inefficiencies driven by rents would be smaller than the inefficiencies due to the self-enforcement constraint under the input-based incentives of water contracts. Ultimately, this is an empirical question, though it seems plausible that output share contracts are more attractive in villages that provide third-party enforcement because third-party enforcement removes the self-enforcement constraint.

Our model also provides insights into how the noisiness of output as a signal of input might impact contract choice. As mentioned earlier, soil quality can serves as a proxy for the response parameter k in the probability function $f(y) = ky$. Qualitatively, better quality soil can be associated with a higher k. An increase in k makes the crop contract more profitable to the buyer because, by (15), the optimal share rate is decreasing in k. Thus, if water input has a larger marginal impact on the probability of successful crop output, then the principal optimally allocates a smaller share to the agent to induce adequate and reliable water delivery. Note that the response parameter does not have the same impact on water contracts because the relationship between q and y is not noisy. Thus, a higher k should primarily benefit output share contracts.

Empirical Implication 2. *Holding other factors constant, the number of crop contracts (output share) relative to water contracts (fixed price or two-part tariffs for water) should increase with soil quality.*

Our econometric framework is designed to test these two empirical implications from our model.

4 Data and Descriptive Evidence

To document patterns of how different contracts are used to purchase groundwater for irrigation and to test the implications of the model, we employ data on 960 households from 96 villages. These households were surveyed immediately after the 2013 *Boro* season to collect information on contracts used in that season. A village-level survey collected information on village-level governance institutions and sanctions for contract violations. Households and villages were randomly selected while *upazilas* (counties) were selected using a weighted random sampling method to ensure a representative sample of irrigated agriculture in Bangladesh. The subsequent analysis relies on the 707 households in the survey that purchased irrigation for their largest parcel in the 2013 *Boro*, or dry, season.

4.1 Village-Level Punishment

Villages can be broadly categorized as those that provide enforcement of formal contracts and those that do not. Among villages that provide enforcement, there are several varieties of governance institutions. Some villages rely on a single individual, often a relative, trusted friend, or religious leader, to enforce contracts. The disputants appeal to this individual who then arbitrates the dispute and determines punishment. Other villages rely on a group of village elders or community leaders to enforce contracts. The elders together discuss and rule on the dispute. A small set of villages rely on the official court system to enforce contracts.

In addition to variation in the type of governance institution, villages also differ in what types of punishments are used by each institution. Using data collected at the village-level, we categorize these into three types of punishment, ranked from least severe to most severe.[14] The least severe punishment is when the governance institution devolves responsibility for determining punishment to the disputants. These punishments are determined through bi-partisan negotiation, and are most often not enforceable, making them relatively mild. This private form of punishment is uncommon, occurring in only seven villages. More severe than privately determined punishment is economic punishment, most often in the form of a monetary or in-kind fine. This type of punishment is most commonly used when a trusted individual or a court is arbitrating the dispute. The most severe form of punishment observed in rural Bangladesh is social ostracism. This punishment is generally imposed by village elders and can take the form of reduced access to community subsidized mechanical devices (i.e., hullers, etc), trade embargoes, or exclusion from social and religious activities. Given the small and stable nature of rural communities in Bangladesh, this type of punishment is more severe to a household than monetary fines, even if these fines are levied by a court. Panel A in Table 2 presents the frequency with which each of these methods of punishment are utilized by each governance institution.

A clear empirical pattern emerges from a descriptive analysis of the village-level data and how it relates to household-level contract choice. Households that live in villages which use more severe punishment in the resolution of contract disputes tend to use output share crop contracts (see Panel B in Table 2). While only 22 percent of output share contracts are used in villages with no

[14] The data contain both household and village-level information on contract enforcement and punishment. Given that not all households have experienced contract violation, we use the village-level data on enforcement and punishment. In each village a focus group discussion was conducted with seven to ten village members to determine what institutions exist to enforce contracts and what types of punishments are used by those institutions when contracts are violated.

third-party enforcement over half (56 percent) of output share contracts are used in villages that employ social ostracism to enforce contracts. Conversely, half of water contracts (fixed price and two-part tariff) are used in villages that provide no contract enforcement, while these contracts are used only around 16 percent of the time in villages that utilize social ostracism. Figure 1 displays the number of water contracts and output share crop contracts used within villages utilizing each of the three different types of punishment. The frequency of water contracts is much higher in villages that provide weak (private resolution) punishment while crop contracts are much more common in villages that provide severe (social ostracism) punishment. This stylized fact - that water contracts are more likely in villages that have weak punishment for contract violation - is a key implication in the theoretical model.

4.2 Soil Quality

The second implication of the model is that the frequency of output share contracts based on crop production will be increasing in the output response parameter, k. One potential credible proxy for this response parameter that is easily observable to both parties is soil quality. The data contain information on the soil quality of irrigated parcels in the form of color, consistency, and texture. We aggregate this information into a simple ranking of soil as either poor, good, or excellent. Examining the data, a clear pattern exists in the distribution of soil quality in regards to the types of contracts used to secure groundwater irrigation (see Panel A in Table 3). For parcels farmed by households using either of the water contracts, the distributions of soil quality is relatively uniform. In contrast, the distribution of soil quality for parcels farmed by households using the output-based incentives of crop contracts is skewed towards excellent quality soil.

An obvious reason for this relationship is that since groundwater irrigation is an input into crop production, and output share contracts are contingent on crop production, the quality of the soil will partially determine the value of the contract to the water seller. A more subtle intuition behind this relationship is that soil quality makes crop output a more informative signal regarding the agent action in delivering water input. When soil quality is extremely poor, crop output is likely to be a poor performance measure of whether or not the agreed upon amount of water was delivered. The appropriate amount of water may be delivered but, because of sandy or alkaline soil, crop output is low. As soil quality increases, however, the accuracy of crop output as a performance measure of agent action improves. Better soil quality increases the reliability of using output-based incentive contracts, regardless of their enforceability by governance institutions.

If soil quality increases the reliability of crop output, then one should find evidence that better quality soil reduces the variance in crop production. To verify this, we conduct regressions of crop output on inputs using a parsimonious yield function, with indicator variables for soil type.[15] Regression results confirm that better quality soil increases output. To determine is if better quality soil reduces the variance or noise in crop output, we square the residuals from those regressions and compare the mean of the residuals across soil types (see Panel B of Table 3). Not only does better soil increase yield but better soil reduces the variance of yield.[16] Figure 2 graphs the squared residuals, which when they come from parcels with excellent soil are closer to zero than squared residuals from parcels with poor soil. Squared residuals from parcels with good soil tend to fall between these two extremes. This evidence provides conditional support for the empirical implication that the frequency of output share contracts should increase when output is a more accurate measure of agent input.

4.3 Additional Data Considerations

Because the choice of contract may also be influenced by the type of the well that irrigates the parcel and the ability of the seller, we control for well/project characteristics (see Table 4). We include an indicator variable for the type of well. The majority of wells in the sample (85 percent) are shallow tubewells while the remaining 15 percent are deep tubewells. Shallow tubewells tend to be owned by individuals while deep tubewells tend to be owned by groups of individuals. Negotiating over contracts with a group instead of an individual may influence contract choice (Gil and Zanarone, 2017). Deep tubewells have larger command areas and provide water to more buyers than shallow

[15] Regression results are presented in Table A4 and A5 in the Appendix along with an extended discussion of soil quality in the data and its role as an informative signal.

[16] We conduct a Mann-Whitney test for equality of means across each pair. The test rejects the null of equality between squared residuals for poor soil quality and excellent soil quality at the 90 percent level. Results are stronger when we use a t-test.

tubewells. This could increase competition for water, making contract violation more likely and therefore making third-party enforceable contracts more common with deep tubewells. In addition to the type of well used, we include the horsepower of the pump, the depth of the water table, and the time in minutes it takes to irrigate a decimal of land (40.46 m^2). All three of these well characteristics affect the cost of delivering water and therefore may be related to contract choice. Pumps with lower horsepower, that draw from deeper water tables, or take longer to irrigate a given area may make agent action more costly, reducing the value of the self-enforcing contracts, and making defection more likely.

We also include a number of variables that control for the project and contracting relationship. This includes measures of the buyer's discount rate along with proxies for the principal's and agent's outside option. Discount rates were elicited through a stated preference choice experiment.[17] To proxy for the value of each party's outside options, we use a binary measure of whether or not the water seller/buyer has alternative buyers/sellers in the case that the current contracting relationship broke down. The variable takes a value of one if alternatives exist. We also include linear distance between the well and the irrigated plot, since proximity between these two points is a key determinant in a buyer's choice of seller. Finally, the seller's reputation for completing a job and the buyer's previous relationship with the seller may influence the choice of seller. To control for this, we include a binary indicator equal to one if the water seller has a reputation as being trustworthy and a variable equal to one if parties are related to each other or of the same social caste.

5 Econometric Framework

Our simple model of groundwater contracting yields two testable empirical implications. Implication 1 predicts that water contracts (fixed charge and two-part tariff) will be more frequent in villages that do not provide third party punishment or provide only weak punishment. Implication

[17] In the experiment we followed Coller and Williams (1999) in presenting the choices in both nominal Bangladesh Taka amounts and interest rates. We worked to reduce time-inconsistent responses by asking households to choose smaller sooner or larger later outcomes for various time frames per Read et al. (2005). Finally, we adhered to the more parsimonious experimental approach of interval elicitation, instead of point valuations, following Harrison (1992).

2 predictions that crop contracts (output share) will be more frequent when crop production is a strong predictor of agent action. We first define our econometric specification and then discuss details of our identification strategy.

5.1 Empirical Specifications

The basic econometric framework for testing our hypotheses is:

$$C_{ij} = \beta_0 + \beta_1 P_j + \beta_2 K_{ij} + \mathbf{W}_{ij}\gamma + \nu_{ij}, \tag{26}$$

where the dependent variable is a binary indicator that equals one if household i in village j uses a water contract (either fixed price or two-part tariff) and zero if it uses a crop contract (output share). P_j measures the severity of punishment used in village j, K_{ij} measures the quality of the soil. Also included are a set of well/project characteristics ($\mathbf{W}$). We allow for a composite error term, $\nu_{ij} = \epsilon_{ij} + v_j$ made up of an idiosyncratic household term (ϵ_{ij}) and an unobserved village-level heterogeneity term (v_j) that may be correlated with household characteristics.

A simple test of Empirical Implication 1, which predicts more water contracts when no punishment exist is $\beta_1 < 0$. Empirical Implication 2 states that crop contracts will be more frequent with better soil quality. A test of this implication is simply a test for $\beta_2 < 0$.

5.2 Identification Strategy

Before discussing the identification strategy, it is useful to reflect upon the characteristics of an ideal data set for causal identification. Ideal data would be either derived experimentally or be cross-sectional with multiple observations over time. While experimental data provides the cleanest possible identification, the social and institutional environment in rural Bangladesh makes it difficult (if not impossible) to randomly assign village governance institutions. Alternatively, panel data would allow for the inclusion of household or relationship fixed effects but there is no guarantee that there would be variation in the contracts chosen by households and it is highly unlikely that there would be any variation in institutions or soil quality, both of which change extremely slowly over time. Thus, it is not clear that experimental or panel data would prove adequate to the empirical task at hand.

Although clean identification is difficult with cross-sectional data there are unique aspects to Bangladesh's groundwater irrigation market that reduce the potential for endogeneity. One aspect is that the matching of buyer and seller is not endogenous to the contract choice equation. As Ackerberg and Botticini (2002) point out, non-random matching between contracting parties may lead to endogeneity in the contract choice equation, though as Corts and Singh (2004) argue, this is not a given. While non-random matching surely exists between contracting parties in the data, there is no evidence that the choice of contract is a determinant of the contracting partner. Rather, matching of buyer and seller appears to be solely a function of proximity and reputation, both of which we are able to directly control for. In the data, 53 percent of water buyers responded that the most important factor in choosing a water seller was the proximity of the seller's well to the buyer's parcel. The remaining 47 percent responded that a seller's reputation or the buyer's previous relationship with the seller was the most important factor in choosing a water seller. No buyer responded that the ability to select a particular type of contract was an important factor in their choice of seller.[18]

A second unique aspect is that many of the contract interlinkages discussed in the development literature are not present in the Bangladeshi groundwater irrigation market. The most common contracts in agrarian contexts are landlord-tenant relationships and the giving and receiving of loans (Basu, 1990; Wood and Palmer-Jones, 1991; Shah, 1993; Hayami and Otsuka, 1993). In the data, only four percent of water-buying households purchase water from their landlord. Similarly, only four percent of water-buying households receive loans from the water seller, while two percent provide loans to the water seller. Thus, the typical contract interlinkages are not common in the data set and we exclude them from the regression. We do however, follow Bellemare (2012, 2013) by directly controlling for a set of variables that account for the matching of water buyer and water seller, such as reputation, caste or kinship, distance between buyer and seller, and the specific

[18]In the survey, the respondent was asked to rank, in order of importance, the determinants in their choice of water seller. Options included 1) good existing relationship with water seller, 2) water seller has a good reputation, 3) water seller will allow me to choose the terms of the contract (not including price) that I prefer, 4) water seller offers the best price (due to proximity of well/parcel), 5) water seller offers the best price (by guaranteeing discounts if seller is unable to provide irrigation), 6) the number of alternative water sellers is limited.

characteristics of the well.

These unique aspects of the groundwater irrigation market do not completely eliminate the potential for bias, especially bias resulting from unobserved heterogeneity at the village-level, confounding identification of the causal effect of enforcement on contract choice. A straightforward solution is to include village-level fixed effects. However, since we want to identify the impact of village-level punishment, village-level fixed effects would create perfect collinearity with our variable of interest, which is measured at the village-level. As an alternative, we adopt a Mundlak (1978)-Chamberlain (1984) device as discussed in Papke and Wooldridge (2008). The intuition is that, similar to Aggarwal (2007), the data can be viewed as a quasi-panel with multiple observations per village over households, instead of the traditional panel structure of multiple observations per household over time. This implies that household-level observations are, within villages, not *i.i.d.* Thus standard errors are clustered at the village-level to account for correlated errors within the village. Consistent with Mundlak (1978) and Chamberlain (1984), we assume that the unobserved effect can be replaced with its projection onto the village averages of all well/project variables. Including these averages in the regression as additional covariates controls for the unobserved village-level heterogeneity and allows us to generate consistent and unbiased point estimates. Conditional on these controls for the contracting environment, we can identify the impacts of village-level punishment and soil quality on contract choice.

6 Econometric Evidence

6.1 Village-Level Punishment

The key feature of the theoretical model is the extent to which the severity of punishment influences contract choice. Empirical Implication 1 predicts that water contracts are more likely in environments where punishment for violation of contracts is weak or absent. Table 2 and Figure 1 present descriptive evidence of this relationship.

Table 5 presents results from basic tests of the prediction regarding the effect of third-party punishment on contract choice. We report coefficient estimates from linear probability models regarding the effect of punishment for contract breach on the likelihood that a household adopts either of the two water contracts relative to an output share crop contract. Panel A treats a rank ordering of punishment as a continuous variable that has a linear effect on the probability of adopting water contracts. The punishment rank variable equals zero for no third-party punishment, one for privately determined punishment, two for economic fine, and three for social ostracism. Panel B allows for non-linearity in the punishment term, thereby relaxing the assumption that a marginal increase in punishment has a linear effect on the outcome of interest. Coefficients in column (1) come from a model that excludes village-level controls. Coefficients in column (2) come from a model that includes the Mundlak-Chamberlain device to control for unobserved village-level effects.

Result 1. *There is strong and consistent support for Empirical Implication 1, that harsher punishment for contract breach decreases the probability of adopting a water contract and increases the probability of adopting a third-party enforceable output share contract.*

The negative and significant coefficient on the linear punishment term across both regressions in Panel A implies that as the severity of punishment increases, the probability of adopting a water contract, which is not third-party enforceable decreases. This result is robust to the inclusion of village-level controls. In Panel B, which allows for non-linear effects in the punishment term, the coefficients on social punishment are negative and significant. Again, these results are robust to the use of village-level controls.

As expected, social ostracism exerts a larger negative effect than other forms of punishment. The marginal effects of a change in village-level governance are large. Focusing on the results from column (2) of Panel B, households living in villages that use economic fines to punish contract violation are eight percent less likely to use water contracts compared to households living in villages that provide no contract enforcement, though this is not statistically different from zero. Households living in villages that use social ostracism are 26 percent less likely to use a water contract. Villages with extremely weak enforcement, such as those that allow disputants to determine their own punishment (private punishment), are actually more likely to give rise to water contracts than self-enforcing output share contracts. We conclude that, for surveyed households, the existence of severe third-party punishment decreases the likelihood of water contracts and has a strong positive effect on the probability of adopting third-party enforceable output share contracts.

In interpreting these results, one may be concerned that the punishment variables are acting as proxies for other factors that may be driving the relationship. Such a bias could exist if villages with better soil were richer and therefore had more developed village institutions. In this case, since soil quality is correlated with village wealth, village characteristics not captured in this term would result in correlation between the punishment variables and the error term. While this is a plausible story, there is no evidence in the data to support it. As a statistical test of this evidence, we calculate the variance inflation factor (VIF), which measures the degree of collinearity between variables, for each of the models in both panels. The VIFs for the punishment variables and for the soil quality indicators are less than two in every case. The mean VIF for the regressions without village controls are also less than two while the mean VIF for the regressions with village controls are slightly larger than two (2.58 for Panel A, 2.53 for Panel B). All of these values are not considerably different than one and far from the threshold value of 10, where collinearity becomes a concern (O'Brien, 2007). We conclude that there is no empirical evidence that the punishment variables are acting as proxies for village-level unobservables, such as wealth.

6.2 Soil Quality

One of the attractive features of output share crop contracts is that they are third-party enforceable. However, since crop output is a noisy measure of the water seller's performance, contracting parties will be more likely to use output-based incentives when crop production is a reliable signal of agent input. The estimates presented in Table 3 and graphed in Figure 2 provide evidence that soil quality provides information on the strength of the correlation between crop output and water delivery.

Table 5 presents more rigorous evidence in support of the second empirical implication. As with punishment, Panel A treats a rank ordering of soil quality as a continuous variable that has a linear effect on the probability of adopting water contracts. The quality rank variable equals zero for poor quality soil, one for good quality soil, and two for excellent quality soil. Panel B allows for non-linearity in soil quality by replacing it with indicator variables for each level of quality. This relaxes the assumption that a marginal increase in soil quality has a linear effect on the outcome of interest. Again, results in column (1) come from a model that excludes village-level controls while in column (2) models include the Mundlak-Chamberlain device to control for unobserved village-level effects.

Result 2. *There is modest support for Empirical Implication 2, that an increase in the quality of soil decreases the probability of adopting a water contract and increases the probability of adopting a crop contract.*

As expected, the rank ordering of soil quality has a negative effect on the probability of adopting water contracts. Allowing for non-linearity in the variable's effect on contract choice, the coefficient on good and excellent soil quality is negative, but only significant when soil quality is excellent. Focusing on the results in column (1) of Panel B, a household with excellent quality soil is nine percent less likely to use water contracts compared to a household with poor quality soil.

These results, however, are not robust to the inclusion of village-level controls. While the coefficients on the soil rank term continues to be negative, it no longer has a statistically significant impact on the contract choice decision. One potential explanation for this is a lack of variation in soil quality within a village. Having controlled for village-level effects, the soil term lacks explanatory power. That both the coefficient size and significance of good and excellent soil quality are less in the models with village controls compared to the models without village controls indicates that a lack of variation in soil quality at the village-level may be responsible for this lack of robustness in the results.

6.3 Robustness Checks

The descriptive and econometric evidence thus far tells a consistent story in regards to the groundwater contract decisions made in rural Bangladesh. The evidence regarding the role of governance institutions, particularly the severity of punishment, is strong and consistent across a variety of specifications. Strong institutions that can enforce severe punishment for contract breach allow for parties to use output share contracts while weak or absent institutions require parties to rely on self-enforcing water contracts. By comparison, the evidence regarding the role of soil quality in decreasing the frequency of water contracts is modest, with coefficients losing significance when we control for village-level effects.

Given that our empirical analysis relies on observable proxies or potentially subjective measures of the model's key parameters, it makes sense to wonder how robust our results are to alternative variable definitions. In this section, we briefly discuss the results from a host of robustness checks in which we replace our preferred variable with alternative categorizations.

First, we examine alternative definitions of what qualifies as severe punishment. We compare any punishment (private, economic, or social) to no punishment, economic or social punishment to weak punishment (none or private), and finally we compare social punishment to all other forms (none, private, and economic). Table 6 displays the results. Regardless of how we group the various measures of punishment severity, more severe punishment always has a negative and statistically significant effect on the probability of water contracts, meaning more severe punishment increases the probability of adopting third-party enforceable output share contracts. Additionally, these alternative categorizations do not effect the results for soil quality, the coefficients of which continue to be negative and significant without village-level controls and insignificant when we control for village-level unobservables.

Second, we conduct a similar exercise by making alternative categorizations of what qualifies as quality soil. In Table 7 we group the soil quality proxy in order to compare good/excellent soil to poor soil and excellent soil to good/poor soil. Our main results are robust to these alternative categorizations of the variable. In regressions without village-level controls a higher quality soil decreases the probability of water contracts being used and increases reliance on output share contracts. As in our main results, controlling for village-level unobservables removes any significance.

The foregoing analysis regarding contract choice always compares the two water contracts (fixed price and two-part tariff) to output share contracts. Given that payment in fixed price and two-part tariff contracts is contingent on water delivery, and that only two percent of the sample report a third-party present to verify water delivery, we believe the categorization is justified in this setting. However, one might be concerned that since two-part tariffs operate like spot contracts during the season, they require a different level of self-enforcement compared to fixed price contracts. To investigate the sensitivity of the results to the definition of two-part tariffs as self-enforcing water contracts, we compare output share contracts to only fixed price contracts and then output share to only two-part tariff contracts.

Table A7 present results from this pairwise comparison. Coefficient estimates on the linear effect of punishment are negative and significant in all specifications. Similar results are present for the estimates of the non-linear effects of punishment in Panel B of the table. Social punishment is negative and significant in all four comparisons of either of the two water contracts to output share contracts. These results suggest that the categorization of two-part tariffs as self-enforcing contracts is reasonable, at least in terms of how the contracts respond to changes in enforcement. We also verify that our results are not driven by the presence of output share contracts that appear in villages without third-party enforcement (see Table A8). Removing these contracts substantially increases the predictive power of our model, meaning that the main results presented in the paper are conservative estimates.

7 Conclusion

There is little existing evidence on how different modes of governance influence the decision to adopt different contracts. To address this research gap, this paper uses data on contracts for groundwater irrigation in Bangladesh. We develop a simple model of contract choice in a setting where unverifiable information exist and enforcement varies. We use the model to help explain the empirical regularities in the data, which are robust to more rigorous econometric testing.

Before proceeding, it is important to address the generalizability of the results, given that the empirical application relies on cross-sectional data from a unique contracting environment where institutions vary from village to village. Cross-sectional data does limit the scope of the current investigation. However, since the focus is on institutions, it is not clear that panel or experimental data would generate any additional variation in the primary variable of interest. Considering the difficulty in collecting information on contracts, especially in developing countries, related empirical research frequently relies on cross-sectional survey data.[19] Regarding the uniqueness of the setting,

[19] Research includes McMillan and Woodruff (1999), Banerjee and Duflo (2000), Banerji et al. (2012), and Macchi-

key results are not driven by idiosyncrasies in the Bangladeshi irrigation market. Rather, when viewed through the lens of the theoretical model, the empirical evidence is stable and consistent, with contract terms being chosen optimally in what Dixit (2004) calls “the shadow of the law.” While it is true that few local markets exhibit the degree of variability in enforcement that exists in Bangladesh, one can easily imagine similar results from an analysis of global markets in which institutional enforcement varies from country to country.

Two main conclusions emerge from the analysis. First, the types of contracts used to purchase groundwater for irrigation are, to a large extent, determined by the governance institutions that exist to enforce contracts. The theoretical model demonstrates that the severity of punishment levied for contract violation directly impacts contract choice. Descriptive and econometric analysis are indicative of this result. Across a variety of specifications there is strong and consistent evidence that an increase in the severity of punishment imposed by local institutions decreases the probability of parties using water contracts that rely on unverifiable agent action.

Second, an increase in the accuracy of the verifiable performance measure reduces the use of water contracts in favor of crop contracts. Output share crop contracts are formal under strong institutions, since output is verifiable, but relational under weak institutions. The theoretical models shows that even if strong institutions exist to enforce output-based incentive contracts, a noisy verifiable performance measure makes these contracts less attractive than unenforceable input-based incentive contracts. Descriptive and econometric analysis provides modest support for the use of soil quality in overcoming the verifiability problem in the groundwater irrigation market in Bangladesh.

To date, there has been little evidence of how enforcement institutions affect contract design. An important implication of this research is the degree to which differences in governance institutions, especially local, deeply embedded institutions like those in this study, influence economic decision making. In much of the developing world, rural households lack access to credible institutional authority beyond their village. This study pushes forward research on the importance of these governance institutions while at the same time pointing to the need for future research that considers

avello and Morjaria (2016).

the existence, or lack thereof, of these extralegal institutions in framing the contract design problem.

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Table 1: Contract Characteristics

	Contingency of Payment	Timing of Deliverable	Frequency of Delivery	Ease of Verification	Timing of Payment
Fixed Price	Water delivery	Throughout season	Recurring	Difficult	Before delivery
Two-Part Tariff	Water delivery	Throughout season	Recurring	Difficult	At delivery
Output Share	Crop production	End of season	One-time	Easy	After delivery

Note: Table provides a summary of the various characteristics of the three forms of contracts used to purchase groundwater for irrigation in Bangladesh. Contingency of payment refers to what deliverable payment will be based upon. Timing of deliverable refers to when, in the life of a contract, the good is delivered. Frequency of delivery refers to how often, during the life of a contract, the good is delivered. Ease of verification refers to the opportunity cost incurred by a third-party in verifying delivery of the good. Timing of payment refers to when, in the life of a contract, payment changes hands.

Table 2: Village Governance Institutions and Punishment Methods

Panel A: Punishment Method By Governance Institution

	None	Private	Economic	Social	Obs.
None	100%	0%	0%	0%	43
Individual	0%	11%	67%	22%	9
Elders	0%	16%	24%	60%	37
Court	0%	0%	100%	0%	7
Obs.	43	7	22	24	96

Panel B: Punishment Method by Contract Type

	None	Private	Economic	Social	Obs.
Water Contract	51%	9%	24%	16%	558
Crop Contract	22%	1%	21%	56%	149
Obs.	315	52	165	175	707

Note: Panel A presents the rate at which each village-level governance institution uses a specific punishment method. Rows sum to 100. The far right column presents the frequency of each type of governance institution while the bottom row presents the frequency of punishment method. Panel B presents the rate at which a contract is used within a village employing a given method of punishment. Rows sum to 100. The far right column presents the total number of each type of contract observed in the data set while the bottom row presents the total number of observations of each type of punishment.

Table 3: Descriptive Statistics of Soil Quality and its Relation to Crop Yield

Panel A: Frequency of Soil Quality by Contract

	Poor	Good	Excellent	Obs.
Water Contract	35%	31%	34%	558
Crop Contract	24%	24%	52%	149
Obs.	232	207	268	707

Panel B: Yields and Yield Variance by Soil Quality

	ln(yield)	Residuals^2
Poor Soil Quality ($n = 232$)	0.472	0.007
	(0.101)	(0.019)
Good Soil Quality ($n = 207$)	0.496	0.005
	(0.082)	(0.009)
Excellent Soil Quality ($n = 268$)	0.497	0.004
	(0.087)	(0.008)

Note: Panel A presents the rate at which a contract is used on a parcel of a given soil type. Rows sum to 100. The far right column presents the total number of each type of contract observed in the data set while the bottom row presents the total number of observations for each soil type. Panel B presents mean log of yields by soil quality and the mean of the squared residuals from the production function regression in Column (3) of Table A4 in the Appendix. A Mann-Whitney-test rejects equality between the residuals for poor soil quality and excellent soil quality is rejected at the 90% level.

Table 4: Descriptive Statistics of Well/Project Characteristics

	Water	Crop
Shallow Tubewell (%)	0.849	0.846
	(0.358)	(0.362)
Horsepower	10.08	9.839
	(9.879)	(7.463)
Depth of Water Table (m)	10.99	11.51
	(5.898)	(5.872)
Time to Irrigate (min/dec)	3.032	2.640
	(2.062)	(1.735)
Distance from Plot to Well (m)	234.0	172.6
	(332.4)	(276.8)
Discount Rate (%)	0.301	0.297
	(0.065)	(0.070)
Buyer Outside Option (%)	0.360	0.336
	(0.480)	(0.474)
Seller Outside Option (%)	0.380	0.302
	(0.486)	(0.461)
Relative or Same Caste (%)	0.384	0.248
	(0.487)	(0.433)
Seller has Good Reputation (%)	0.342	0.389
	(0.475)	(0.489)
Obs.	558	149

Note: Table presents descriptive statistics for the well owned by the water seller but utilized by the water buyer to irrigate the parcel under contract. The sample is divided by the form of contract used to purchase water from the well.

Table 5: Contract Choice, Punishment, and Soil Quality

	(1)	(2)
Panel A: Linear Effects		
Punishment Rank	-0.121^{***}	-0.095^{***}
	(0.027)	(0.028)
Soil Rank	-0.054^{**}	-0.015
	(0.023)	(0.025)
Village Controls	No	MC
Observations	707	707
Log Likelihood	-297.2	-212.5
R^2	0.184	0.358
Panel B: Non-linear Effects		
Private Punishment	0.043	0.198^{*}
	(0.042)	(0.103)
Economic Punishment	-0.112	-0.080
	(0.080)	(0.080)
Social Punishment	-0.385^{***}	-0.261^{***}
	(0.091)	(0.090)
Good Signal Quality	-0.007	0.030
	(0.042)	(0.036)
Excellent Signal Quality	-0.092^{**}	-0.017
	(0.043)	(0.045)
Village Controls	No	MC
Observations	707	707
Log Likelihood	-285.2	-195.6
R^2	0.211	0.388

Note: Dependent variable is contract choice, where water contracts (fixed charge and two-part tariff) = 1 and output share crop contracts = 0. Panel A explores the linear effects of the variables of interest. Panel B allows for non-linearities by accounting for multiple categorical indicators. Each regression includes a set of well/project characteristics (if well is a shallow tubewell, pump horsepower, log of water table depth, log of time to irrigate, log of distance from well to plot, buyer discount rate, buyer and seller outside options, if buyer and seller are related, and if the seller has a good reputation). Cluster corrected robust standard errors are reported in parentheses (* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$).

Table 6: Contract Choice and Alternative Categorization of Punishment

	(1)	(2)	(3)	(4)	(5)	(6)
Panel A: Linear Effects						
Private/Economic/Social Punishment	-0.219^{***}	-0.140^{**}				
	(0.061)	(0.070)				
Economic/Social Punishment			-0.264^{***}	-0.225^{***}		
			(0.065)	(0.069)		
Social Punishment					-0.351^{***}	-0.270^{***}
					(0.093)	(0.084)
Soil Rank	-0.063^{**}	-0.023	-0.059^{**}	-0.017	-0.047^{**}	-0.011
	(0.025)	(0.026)	(0.024)	(0.026)	(0.021)	(0.022)
Village Controls	No	MC	No	MC	No	MC
Observations	707	707	707	707	707	707
Log Likelihood	-322.2	-233.3	-308.4	-214.2	-292.3	-208.7
R^2	0.124	0.319	0.158	0.355	0.195	0.365
Panel B: Non-linear Effects						
Private/Economic/Social Punishment	-0.215^{***}	-0.135^{*}				
	(0.062)	(0.069)				
Economic/Social Punishment			-0.261^{***}	-0.221^{***}		
			(0.066)	(0.069)		
Social Punishment					-0.350^{***}	-0.266^{***}
					(0.093)	(0.084)
Good Soil Quality	-0.022	0.025	-0.027	0.022	0.003	0.032
	(0.045)	(0.039)	(0.043)	(0.037)	(0.041)	(0.037)
Excellent Soil Quality	-0.124^{**}	-0.046	-0.116^{**}	-0.034	-0.091^{**}	-0.021
	(0.050)	(0.051)	(0.049)	(0.051)	(0.042)	(0.045)
Village Controls	No	MC	No	MC	No	MC
Observations	707	707	707	707	707	707
Log Likelihood	-321.4	-231.9	-307.9	-213.2	-291.0	-207.5
R^2	0.126	0.322	0.159	0.357	0.198	0.367

Note: Dependent variable is contract choice, where water contracts (fixed charge and two-part tariff) = 1 and output share crop contracts = 0. Panel A explores the linear effects of the variables of interest. Panel B allows for non-linearities by accounting for multiple categorical indicators. Each regression includes a set of well/project characteristics (if well is a shallow tubewell, pump horsepower, log of water table depth, log of time to irrigate, log of distance from well to plot, buyer discount rate, buyer and seller outside options, if buyer and seller are related, and if the seller has a good reputation). Cluster corrected robust standard errors are reported in parentheses (* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$).

Table 7: Contract Choice and Alternative Categorization of Soil Quality

	(1)	(2)	(3)	(4)
		Panel A: Linear Effects		
Punishment Rank	-0.123^{***}	-0.096^{***}	-0.120^{***}	-0.094^{***}
	(0.027)	(0.028)	(0.028)	(0.028)
Good/Excellent Soil Quality	-0.066^{*}	-0.004		
	(0.038)	(0.037)		
Excellent Soil Quality			-0.097^{**}	-0.041
			(0.040)	(0.043)
Village Controls	No	MC	No	MC
Observations	707	707	707	707
Log Likelihood	-299.7	-212.9	-296.8	-211.8
R^2	0.178	0.357	0.185	0.359
		Panel B: Non-linear Effects		
Private Punishment	0.045	0.197^{*}	0.043	0.196^{*}
	(0.040)	(0.102)	(0.042)	(0.104)
Economic Punishment	-0.119	-0.083	-0.111	-0.082
	(0.079)	(0.080)	(0.079)	(0.080)
Social Punishment	-0.394^{***}	-0.267^{***}	-0.385^{***}	-0.262^{***}
	(0.091)	(0.090)	(0.091)	(0.090)
Good/Excellent Soil Quality	-0.053	0.006		
	(0.036)	(0.035)		
Excellent Soil Quality			-0.089^{**}	-0.032
			(0.037)	(0.040)
Village Controls	No	MC	No	MC
Observations	707	707	707	707
Log Likelihood	-288.3	-196.7	-285.3	-196.0
R^2	0.204	0.386	0.211	0.387

Note: Dependent variable is contract choice, where water contracts (fixed charge and two-part tariff) = 1 and output share crop contracts = 0. Panel A explores the linear effects of the variables of interest. Panel B allows for non-linearities by accounting for multiple categorical indicators. Each regression includes a set of well/project characteristics (if well is a shallow tubewell, pump horsepower, log of water table depth, log of time to irrigate, log of distance from well to plot, buyer discount rate, buyer and seller outside options, if buyer and seller are related, and if the seller has a good reputation). Cluster corrected robust standard errors are reported in parentheses (* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$).

Figure 1: Water and Output Share Contracts by Method of Punishment

Note: The graph presents the frequency of contract use, similar to that in Panel B of Table 2, but with contracts categorized as water contracts or output share contracts. The northwest panel presents the frequency of contracts used in villages that provide enforcement but rely on contracting parties to privately resolve their disputes. The northeast panel presents the frequency of contracts used in villages that impose economic fines. The southwest panel presents the frequency of contracts used in villages that impose social sanctions.

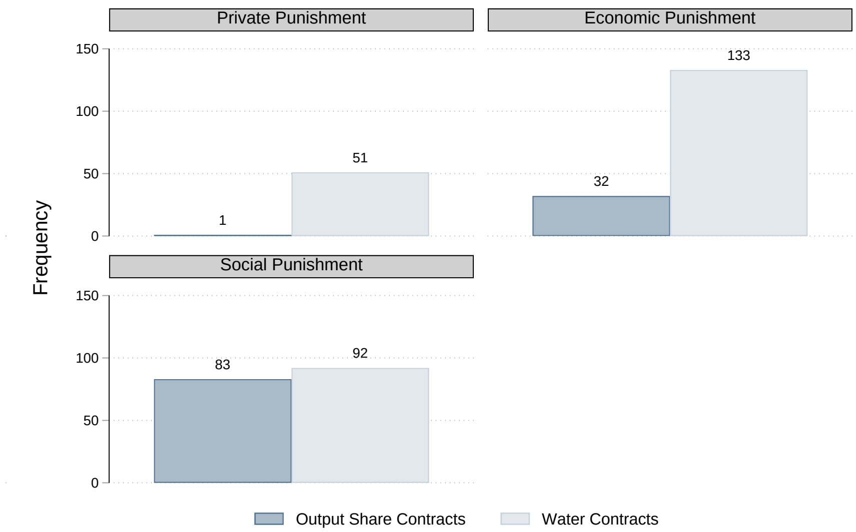
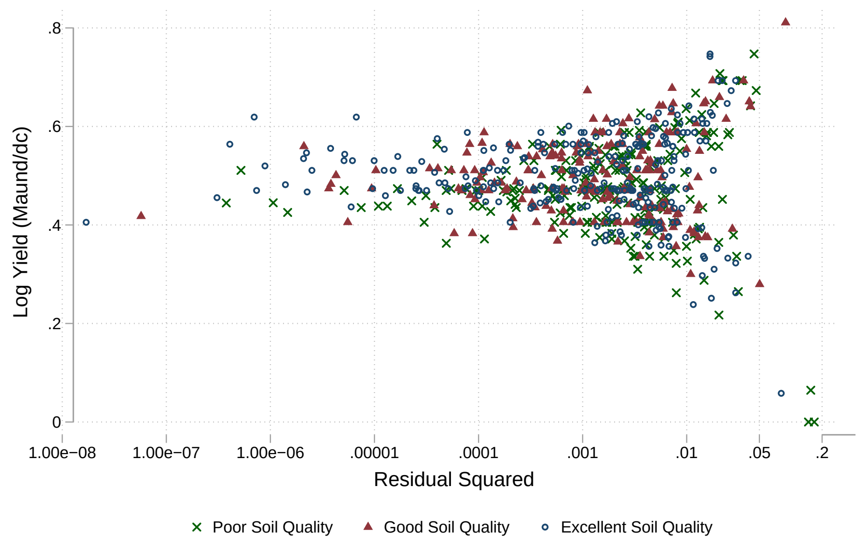


Figure 2: Yield Variance and Soil Quality

Note: The scatter plot is of the squared residuals from the regression presented in column (3) of Table A4 in the Appendix. Since squared residuals are clustered near zero, we use the logarithmic scale on the x-axis to provide visual separation in the graph. Residuals from plots with poor soil quality are denoted with an ×, residuals from plots with excellent soil quality are denoted with ○, and residuals from plots with good soil quality are denoted with ▲.



Online-Only Appendix to "Governance and Contract Choice: Theory and Evidence from Groundwater Irrigation Markets"

This appendix contains additional details and discussion of the market four groundwater irrigation contracts in Bangladesh. It also provides a brief discussion of the experiment used to measure the discount rate and the tests to measure the correlation between soil quality and yield, which is used to justify soil quality as an informative signal in contracting. Finally, it contains the results of the robustness checks discussed in section 6.3.

A The Contracting Environment and Household Characteristics

While we use relationship characteristics as control variables in our econometric analysis, readers may be interested in details regarding the households themselves. Additionally, if there are significant and consistent differences between households in villages with and without enforcement, these differences may represent an omitted variable that impacts both the formation of village-level governance and contract choice.

In Table A1 we report the average prices for each of the contracts in the data. The typical price for irrigation under a fixed price contract is 1,535 Bangladesh Taka, while the typical price for a two-part tariff contract is 1,449. The average output share paid for irrigation was five percent of crop output. Table A2 presents summary statistics for a number of relevant household characteristics by village enforcement. The final column of the table reports the results of a Mann-Whitney test for differences in means between the two populations. Of the ten household characteristics, only one (income per capita) is significantly different across the two populations. For the remaining nine characteristics, there is no significant difference between households living in villages with enforcement and households living in villages without enforcement. The typical household in our study has between four and five members, just under half of which are female. The typical household has about two members of prime labor age (20-49 years old). The typical household head has only five years of formal education. About 20 percent of households have a member who has migrated out of the village for work. Average household earning is between 22,000 and 27,000 Taka per member per year, or around \$350 in 2013 U.S. dollars. Wealth per capita (which sums assets, working capital, and income) is around 80,000 Taka or about $\$1,000$. Land per capita is around 20 decimals or about a fifth of an acre per household member. The vast majority of households (80 percent) own their largest plots, though households may rent in smaller plots. The value of output in Taka per decimal is around 360 Taka, or \$4.5 per fifth of a hectare.

In rural regions, such as our study locations in Bangladesh, it is not uncommon for households to form numerous economic interactions with other households. The development literature has long noted these interlinkages, particularly in terms of tenancy and credit. Landlords frequently lend credit to their tenants, tying the tenant to the land through the use of loans. (Basu, 1990). In Bangladesh, with the prevalence of non-contiguous landholding, it is also possible for household a to sell water to household b for use on one plot while also having household b sell water to household a to irrigate a different plot (Wood and Palmer-Jones, 1991).

While these sorts of economic interlinkages are clearly possible, we find little evidence for their role in our setting. In the survey, households were asked a number of questions regarding their business relationship with their contracting partner. Table A3 provides summary statistics from buyer responses to each of these questions. As is clear from the data, very few water buyers have additional economic ties to the water seller and vice versa.

Finally, as mentioned in the body of the paper, instead of coming from the household data, our punishment variable comes from a village-level survey. Not all households will have experience with contract violations and therefore may have imperfect knowledge of how the village's governance institutions operate. Because of this, we conducted surveys of village governance institutions (when they existed) and use data from these village surveys for the village-level punishment variable. In the village-level survey, the question regarding punishment was as follows:

> "When disputes arise between contracting parties what types of punishments are used to resolve the dispute? These punishments need not actually be used, they could simply be threatened as punishment to help ensure that disputes do not arise. Specifically, when [dispute resolution party] is called upon to resolve a dispute what types of punishment do they threaten to use OR actually use to help resolve the dispute?"

B Soil Quality as a Response Parameter

Empirical measures of the response of observable crop output (q) to water delivery (y) are difficult to come by. Such a measure should relate to the marginal impact of water on the probability of a successful crop yield, and thus should be related to $f'(y)$. While we do not have an exact measure of $f'(y)$, we do have data on soil quality. The logic is that if soil quality is poor, crop output is likely to be poor regardless of water. However, when soil quality is high, then crop output is more sensitive to water and serves as a more informative signal of whether the seller delivered water. Thus, soil quality can serve as a proxy for the degree to which crop yield is responsive to water.

To test this logic, we want to verify two empirical relationships. First, does better soil result in higher crop output, meaning does better soil increase the probability of successful crop output? Second, does better soil reduce the variance in crop output, meaning does better soil reduce the noise in the relationship between water delivery and crop output? If there is empirical evidence that soil quality is effective in both of these roles, we can consider soil quality as providing information on accuracy of crop output as a signal of the agent's performance. Recall that the informativeness principle states that any additional information, however imperfect, can be used to improve outcomes in formal contracts (Holmstrom, 1979). When soil quality is extremely poor, crop yield provides no information regarding the delivering of water. As soil quality increases, the noise in the contracting relationship is reduced. Better soil reveals (on the margin) information about agent action in delivering water.

The data set contains information on the soil quality of irrigated parcels in the form of the color/consistency of the soil. Quality ranges from high quality (black or clayey) to poor quality (sandy or alkaline). We aggregate soil quality information into a simple ranking of soil as either poor, good, or excellent (see Panel A in Table A6).

To verify that the soil quality rankings are accurate, we first run a regression of crop output on inputs using a parsimonious yield function, with indicator variables for soil type. We estimate the model with no geographic indicators, with division-level fixed effects, and with village-level fixed effects to account for potential unobserved regional differences in weather and production technologies. Results from all three regressions are presented in Table A4. An important result of the yield regressions is that contract type is not related to yield. The coefficients on excellent quality soil are positive and significantly improve output compared to poor quality soil in all three regressions.

An additional indication that soil quality acts as an informative signal would be if yields are more responsive to water when soil quality is good. To test this we interact the soil quality indicators with the amount of irrigated water applied to the plot. Results from three regressions are presented in Table A5. These results are consistent with the previous results. We find that the interaction between quantity of water and excellent soil is positive and significant. This indicates that yields are more responsive to water when soil quality is excellent than when soil quality is poor.

While the regression results generally confirm that better quality soil increases yield, what we are really interested in is if better quality soil reduces the variance or noise in yield. To accomplish this, we square the residuals from the yield regression with village-level fixed effects and compare the mean of the squared residuals across soil type (see Panel B in Table A6). Not only does better soil quality increase yield but better soil quality is associated with a reduction in the variance of yield. We conduct a Mann-Whitney test for equality of means across the three groups, allowing for heterogeneity in the group covariance matrices. We reject the null of equality of means at the 90 percent confidence level.

Table A1: Price of Irrigation

	Price
Fixed Price	1,535
	(2,614)
Output Share	0.053
	(0.107)
First Two-Part Tariff Payment	437.0
	(843.9)
Second Two-Part Tariff Payment	1,012
	(1,857)
Total Two-Part Tariff Price	1,449
	(2,562)

Note: Table presents mean of buyer reported prices paid for each type of contract (standard deviations in parenthesis). Prices in Taka.

Table A2: Household Characteristics by Village Enforcement

	Without Enforcement	With Enforcement	MW-test
Num. of Household Members	4.687	4.757	
	(1.498)	(1.449)	
Share of Female Members	0.458	0.467	
	(0.158)	(0.158)	
Num. of Prime Age Laborers (20-49)	2.268	2.169	
	(1.081)	(0.896)	
Education of Household Head (years)	4.578	4.909	
	(4.044)	(4.307)	
Household has Migrant (=1)	0.225	0.220	
	(0.575)	(0.565)	
Income per Capita (Taka)	22,067	27,019	**
	(20,840)	(35,251)	
Wealth per Capita (Taka)	79,567	82,078	
	(91,688)	(80,819)	
Land per Capita (dc)	20.37	20.27	
	(13.92)	(14.79)	
Owns Largest Parcel (=1)	0.834	0.794	
	(0.372)	(0.404)	
Area of Largest Parcel (dc)	47.66	49.40	
	(26.06)	(28.54)	
Value of Output (Taka/dc)	362.4	360.5	
	(93.40)	(98.65)	
Observations	315	392	

Note: Table present means of household characteristics for water buyers analyzed in the paper (standard deviations in parenthesis). Summary statistics are presented for households in villages without and with third-party contract enforcement. The final column presents the results of the Mann-Whitney test for differences in mean between the two populations, with significance levels (* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$).

Table A3: Interlinked Contracts

	% Yes	% No
Are Wayer Buyer and Water Seller Partners in Another Business?	4.67	95.33
Does Water Buyer Provide Irrigation to Any Plot Owned by Water Seller?	1.42	98.58
Does Water Buyer Rent Any Plots from Water Seller?	3.83	96.17
Does Water Seller Rent Any Plots from Water Buyer?	1.84	98.16
Has the Water Seller Made a Loan to the Water Buyer?	3.97	96.03
Has the Water Buyer Made a Loan to the Water Seller?	3.83	96.17

Note: Table present frequency with which a household responded “yes” or “no” to the stated survey questions.

Table A4: Estimation Results of Production Function

ln*(yield)*	(1)	(2)	(3)
Good Signal Quality	0.025***	0.023***	0.026***
	(0.007)	(0.007)	(0.009)
Excellent Signal Quality	0.027***	0.025***	0.021**
	(0.007)	(0.007)	(0.008)
Contract Type	0.014	0.015	−0.008
	(0.009)	(0.012)	(0.018)
ln(Labor)	−0.009**	−0.006	−0.004
	(0.004)	(0.004)	(0.003)
ln(Fertilizer)	0.003	0.004	0.005
	(0.004)	(0.004)	(0.004)
ln(Pesticide)	−0.001	−0.001	−0.002
	(0.002)	(0.002)	(0.002)
ln(Irrigation)	0.032***	0.034***	0.028*
	(0.012)	(0.012)	(0.016)
ln(Other Material)	0.009*	0.012**	0.013**
	(0.005)	(0.005)	(0.006)
Tenure	−0.007	−0.008	−0.007
	(0.008)	(0.009)	(0.009)
ln(Wealth Per Capita)	0.012**	0.013**	0.012**
	(0.006)	(0.006)	(0.006)
ln(Land Per Capita)	0.007	0.006	0.003
	(0.005)	(0.004)	(0.006)
Shallow Tubewell	−0.028**	−0.023*	−0.017
	(0.013)	(0.013)	(0.016)
ln(Horsepower)	0.003	0.003	0.000
	(0.007)	(0.007)	(0.007)
ln(Water Table Depth)	−0.008	−0.005	0.002
	(0.010)	(0.009)	(0.011)
Fixed Effects	None	Division	Village
Observations	707	707	707
R^2	0.095	0.119	0.337

Note: The table presents correlation between production inputs and log of rice yield. Fixed effect indicator for divisions are included in column (2) while column (3) reports results using village fixed effects. Cluster corrected robust standard errors are reported in parentheses (* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$).

Table A5: Estimation Results of Production Function with Interactions

ln(*yield*)	(1)	(2)	(3)
Good Soil Quality	−0.052	−0.053	−0.056
	(0.081)	(0.078)	(0.080)
Excellent Soil Quality	−0.156*	−0.150*	−0.206**
	(0.086)	(0.086)	(0.088)
ln(Irrigation)	0.013	0.015	0.006
	(0.018)	(0.018)	(0.022)
Good Soil × ln(Irrigation)	0.018	0.018	0.019
	(0.019)	(0.019)	(0.019)
Excellent Soil × ln(Irrigation)	0.042**	0.041**	0.053**
	(0.020)	(0.020)	(0.021)
Contract Type	0.015*	0.016	−0.006
	(0.009)	(0.012)	(0.018)
ln(Labor)	−0.009**	−0.006	−0.004
	(0.004)	(0.004)	(0.003)
ln(Fertilizer)	0.003	0.004	0.005
	(0.004)	(0.004)	(0.004)
ln(Pesticide)	−0.001	−0.001	−0.002
	(0.002)	(0.002)	(0.002)
ln(Other Material)	0.009*	0.011**	0.013**
	(0.005)	(0.005)	(0.006)
Tenure	−0.007	−0.008	−0.006
	(0.008)	(0.009)	(0.009)
ln(Wealth Per Capita)	0.012**	0.013**	0.011*
	(0.006)	(0.005)	(0.006)
ln(Land Per Capita)	0.006	0.005	0.004
	(0.005)	(0.005)	(0.006)
Shallow Tubewell	−0.028**	−0.023*	−0.019
	(0.013)	(0.013)	(0.015)
ln(Horsepower)	0.003	0.003	0.001
	(0.007)	(0.007)	(0.007)
ln(Water Table Depth)	−0.008	−0.005	0.003
	(0.010)	(0.010)	(0.011)
Fixed Effects	None	Division	Village
Observations	707	707	707
R^2	0.106	0.129	0.351

Note: The table presents correlation between production inputs and log of rice yield, with soil quality × irrigation interactions. Fixed effect indicator for divisions are included in column (2) while column (3) reports results using village fixed effects. Cluster corrected robust standard errors are reported in parentheses (* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$).

Table A6: Descriptive Statistics of Soil Quality and its Relation to Crop Yield

Panel A: Frequency of Soil Quality by Contract

	Poor	Good	Excellent	Obs.
Water Contract	35%	31%	34%	558
Crop Contract	24%	24%	52%	149
Obs.	232	207	268	707

Panel B: Yields and Yield Variance by Soil Quality

	ln(yield)	Residuals^2
Poor Soil Quality ($n = 232$)	0.472	0.007
	(0.101)	(0.019)
Good Soil Quality ($n = 207$)	0.496	0.005
	(0.082)	(0.009)
Excellent Soil Quality ($n = 268$)	0.497	0.004
	(0.087)	(0.008)

Note: Panel A presents the rate at which a contract is used on a parcel of a given soil type. Rows sum to 100. The far right column presents the total number of each type of contract observed in the data set while the bottom row presents the total number of observations for each soil type. Panel B presents mean log of yields by soil quality and the mean of the squared residuals from the production function regression in Column (3) of Table A4 in the Appendix. A Mann-Whitney-test rejects equality between the residuals for poor soil quality and excellent soil quality is rejected at the 90% level.

Table A7: Pairwise Comparison Between Contracts

	Fixed Price to Output Share		*Two-Part Tariff to Output Share*	
	(1)	(2)	(3)	(4)
		Panel A: Linear Effects		
Punishment Rank	-0.150^{***}	-0.104^{**}	-0.158^{***}	-0.121^{***}
	(0.040)	(0.046)	(0.033)	(0.032)
Soil Rank	-0.054	0.001	-0.066^{**}	-0.029
	(0.033)	(0.035)	(0.031)	(0.026)
Village Controls	No	MC	No	MC
Observations	458	458	398	398
Log Likelihood	-248.2	-173.9	-179.8	-111.9
R^2	0.211	0.430	0.383	0.561
		Panel B: Non-linear Effects		
Private Punishment	0.162	0.437^{**}	0.065	0.112
	(0.113)	(0.182)	(0.066)	(0.114)
Economic Punishment	-0.090	0.024	-0.178	-0.114
	(0.126)	(0.115)	(0.124)	(0.110)
Social Punishment	-0.382^{***}	-0.154	-0.492^{***}	-0.362^{***}
	(0.126)	(0.134)	(0.107)	(0.102)
Good Soil Quality	0.024	0.059	-0.041	0.011
	(0.061)	(0.051)	(0.061)	(0.050)
Excellent Soil Quality	-0.082	0.016	-0.119^{**}	-0.046
	(0.062)	(0.061)	(0.056)	(0.046)
Village Controls	No	MC	No	MC
Observations	458	458	398	398
Log Likelihood	-238.5	-155.1	-172.4	-103.9
R^2	0.244	0.475	0.405	0.579

Note: Dependent variable is contract choice, where one or the other of the water contracts = 1 and output share crop contracts = 0. Panel A explores the linear effects of the variables of interest. Panel B allows for non-linearities by accounting for multiple categorical indicators. Each regression includes a set of well/project characteristics (if well is a shallow tubewell, pump horsepower, log of water table depth, log of time to irrigate, log of distance from well to plot, buyer discount rate, buyer and seller outside options, if buyer and seller are related, and if the seller has a good reputation). Cluster corrected robust standard errors are reported in parentheses (* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$).

Table A8: Punishment and Soil Quality without Self-Enforcing Output Share Contracts

	(1)	(2)
Panel A: Linear Effects		
Punishment Rank	−0.147***	−0.118***
	(0.026)	(0.025)
Soil Rank	−0.035	0.002
	(0.021)	(0.021)
Village Controls	No	MC
Observations	674	674
Log Likelihood	-182.8	-93.37
R^2	0.293	0.458
Panel B: Non-linear Effects		
Private Punishment	−0.012	0.137
	(0.032)	(0.094)
Economic Punishment	−0.196***	−0.152**
	(0.074)	(0.072)
Social Punishment	−0.458***	−0.332***
	(0.089)	(0.082)
Good Soil Quality	−0.041	0.002
	(0.039)	(0.032)
Excellent Soil Quality	−0.060	0.015
	(0.040)	(0.039)
Village Controls	No	MC
Observations	674	674
Log Likelihood	-173.5	-77.52
R^2	0.312	0.483

Note: Dependent variable is contract choice, where water contracts (fixed charge and two-part tariff) = 1 and output share crop contracts = 0. Panel A explores the linear effects of the variables of interest. Panel B allows for non-linearities by accounting for multiple categorical indicators. Each regression includes a set of well/project characteristics (if well is a shallow tubewell, pump horsepower, log of water table depth, log of time to irrigate, log of distance from well to plot, buyer discount rate, buyer and seller outside options, if buyer and seller are related, and if the seller has a good reputation). Cluster corrected robust standard errors are reported in parentheses (* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$).