Way Down in the Hole: Adaptation to Long-Term Water Loss in Rural India *

David Blakeslee†

Ram Fishman‡

Veena Srinivasan§

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Abstract

Worsening environmental conditions threaten to undermine progress in reducing rural poverty. Little is known, however, about the prospects for farmer adaptations to mitigate this threat, in particular through opportunities for income diversification presented by recent non-agricultural growth. We study the effects of increasing water scarcity in India using quasi-random, geologically determined differences in access to groundwater. The drying up of wells results in a precipitous and persistent decline in farm income and wealth, with little evidence of agricultural adaptation. However, labor reallocation to off-farm employment appears successful in maintaining overall income, particularly in locations with a more developed manufacturing sector.

Key words: Adaptation, Environmental Change, Natural Resources, Smallholder Agriculture, Irrigation, Income Diversification, Migration *JEL code:* 013, 015, Q15, Q25, Q32

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†Email: david.blakeslee@nyu.edu. New York University (AD).

‡Email:ramf@post.tau.ac.il. Tel Aviv University.

§Email:veena.srinivasan@atree.org. ATREE.

1 Introduction

Worsening agro-climatic and environmental conditions are threatening the incomes of smallholder farmers in many parts of the developing world, casting a shadow over the prospects for continued progress in poverty eradication. Some scholars go so far as predicting a collapse of rural livelihoods and an exodus from afflicted rural areas (Morton, 2007; Brown, 2012), though such prognostications often fail to account for the possibility of adaptation, and may therefore overstate the likely economic and social impacts. In particular, whether non-agricultural development can help rural populations offset the impacts of deteriorating environmental conditions poses a fundamental question for sustainable development.

In this paper, we study this question in the important context of the growing water scarcity that is expected to threaten the livelihoods of hundreds of millions of farming households in coming decades (Vörösmarty et al., 2000; Rodell et al., 2018).

Our analysis exploits quasi-random, within-village variation in loss of access to groundwater in the Indian state of Karnataka. Like in many parts of India and the developing world, Karnataka's groundwater is a vital source of irrigation water, but has been depleted by a combination of a prolonged, multi-year drought and intensive extraction (Wada et al., 2010; Famiglietti, 2014). This severe drying trend is, however, taking place against a background of strong economic growth in the manufacturing and service sectors that is also reaching rural areas (Blakeslee et al., 2018).

Karnataka's groundwater is stored in small, scattered pockets located within a hard-rock sub-surface, which leads to substantial spatial variation in the volume of available groundwater at even very small distances. Importantly, this feature of the local aquifer has only become relevant with the recent drop in water levels, making continued access to groundwater subject to a high level of chance. Using this exogenous variation in groundwater supply, we show that the loss of groundwater causes a sharp and persistent decline in farm income, driven by abandonment of high-value horticulture and dry-season cultivation, and leads to a substantial loss of wealth. However, we also find that households are able to respond by shifting labor into off-farm employment, and ultimately suffer only a small, if any, drop in total income. These adaptation strategies are most successful where there are higher levels of local industrial development.

A substantial literature has studied the economic and social costs of short-term environmental change, generally in the form of annual weather variability, with a view to shedding light on the likely impact of climate change. This literature has consistently found severe detrimental effects on agricultural livelihoods and a host of social outcomes (Auffhammer et al., 2013; Dell et al., 2014; Carleton and Hsiang, 2016).[1] A related literature has docu-

[1]Many of the relevant studies are based in India, including: Guiteras (2009); Fishman et al. (2011);

mented households' coping strategies in response to such transient income shocks, including asset sales, income diversification, and migration (see reviews by Alderman and Paxson, 1992; Morduch, 1995; Dercon, 2002). Shifts to non-agricultural employment in response to transient weather shocks, in particular, are found by Kochar (1999), Macours et al. (2012), and Colmer (2016), among others.[2]

However, the literature also recognizes the conceptual limitations inherent in the use of transient, high-frequency environmental variation for the purpose of studying the impacts of long-term environmental shifts (Dell et al., 2014; Hsiang, 2016; Carleton and Hsiang, 2016). The issue of adaptation is central to this empirical ambiguity, as some coping strategies may only be feasible or effective in response to short-term shocks, while others may only be worth pursuing in response to more permanent shifts. The impacts of long-term environmental change may therefore be higher or lower than those of short-term variability, perhaps dramatically so.

There is relatively little causally interpretable evidence on the impacts of, and adaptations to, long-term environmental change, representing a fundamental gap in the literature (Hornbeck, 2012). The scarcity of such research is due in large part to the empirical challenges involved. In particular, identification of long-term responses by definition cannot rely on the high-frequency weather fluctuations which have proven so useful for causal identification in much existing research. Alternative approaches, especially those relying on spatial comparisons of long-term conditions, are highly susceptible to bias resulting from unobservable confounders. This problem is exacerbated by the fact that low-frequency environmental changes are typically spatially correlated over large distances, forcing the associated estimates to be based on comparisons of large and distant spatial units. The unique setting of the present paper addresses many of these limitations, as the variation we exploit in long-term loss of water is not only plausibly exogenous, but also occurs within villages, often between neighbouring farmers.

Our empirical strategy is based on *within-village* comparisons between households whose *first* borewell has failed and those for whom it is still operational. Focusing on the status of the first borewell helps address potential bias resulting from the ability of wealthier households to finance the drilling of additional wells, and thereby maintain access to water, in a context of pervasive credit constraints. The identifying assumption is that conditional on the year of drilling, the timing of the first borewell's failure is determined by exogenous geological attributes. In support of this assumption, we show that the first borewell's characteristics (including its depth and cost), as well as its present status (operational or failed), are un-

Auffhammer et al. (2012); Krishnamurthy (2012); Fishman (2016); Jayachandran (2006); Kaur (2014); Sekhri and Storeygard (2014); Blakeslee and Fishman (2018b).

[2] The literature on migratory response to weather shocks is extensive. See, for example, Feng et al. (2010); Gray and Mueller (2012); Cai et al. (2014); Bohra-Mishra et al. (2014).

correlated with households' pre-drilling characteristics. In addition, using data obtained by inserting specialized equipment into hundreds of failed and active borewells in a cluster of villages in our study area, we confirm that highly localized geological features are predictive of a borewell's lifetime; and that there is substantial spatial variability in these features and in borewell failure, even over short distances.

Farmers have two principal means of adapting to changes in environmental conditions. First, they may adopt new agricultural practices or technologies that can allow them to maintain their agricultural income under altered conditions. In the context of water scarcity, this may consist of the harvesting of rainwater, for example, or the more efficient application of irrigation. The adoption of such technologies may be hampered, however, by some of the same factors impeding the adoption of agricultural technologies more generally (Jack, 2013; de Janvry et al., 2016). Second, farmers may adapt by shifting labor to non-agricultural sources of income generation, or by migrating to areas with better employment opportunities. Here too, it is unclear whether the rural labor force possesses the necessary skills, or is sufficiently mobile, to take advantage of such adaptation strategies (Munshi and Rosenzweig, 2016; Blakeslee et al., 2018).

We report four main findings. First, we show that households suffer a dramatic decline in agricultural income following the loss of access to groundwater due to the drying up, or "failure," of their first borewell.[3] There is little evidence that households are able to adapt in such a way as to maintain agricultural incomes.

Second, we show that households are able to largely offset the income effects of losing groundwater through increased off-farm income, primarily in nearby areas and, to a much smaller extent, through the migration of household members. Since the average borewell failure in our sample occurred about 10 years prior to the survey, these should be understood as medium- to long-term adaptations rather than temporary, short-term coping mechanisms.

Third, we show that the effect is mediated by the presence of local industrial development. In areas with higher levels of employment in large firms, households are better able to increase off-farm income to offset losses on the farm. Where fewer large firms exists, total income declines.

Fourth, even when income is maintained, adaptation does not appear to be costless, as there is evidence for substantial asset decumulation and an increase in debt, which may undercut the ability of households to smooth consumption in the event of future income shocks. In addition, older children leave school and take up employment, potentially leading to long-term impacts on human capital accumulation and future income.

[3]A borewell is a well that is drilled into the sub-surface, unlike the traditional open dug wells which are much shallower. Borewells have become the more important source of irrigation water since water tables began to decline.

It is important to note that the form of water loss we study does not consist of isolated instances within an otherwise water-abundant economy, but of a veritable wave of borewell failures engulfing major portions of the community. As such, these findings are interpretable within a general equilibirum framework of large-scale water depletion. While they call into question sweeping projections of economic catastrophe and mass environmental migration, they also highlight the limited prospects for agricultural adaptation, and raise concerns about future food production.

This paper joins a young literature that attempts to make progress in understanding how households adapt to longer-term or slow-moving environmental change. Several papers have used lower-frequency (decade-scale) changes in weather to examine agricultural adaptation in the U.S. (Lobell and Asner, 2003; Burke and Emerick, 2016; Barrios et al., 2006; Henderson et al., 2017) and India (Taraz, 2017),[4] and urbanization in Sub-Saharan Africa (Barrios et al., 2006; Henderson et al., 2017). A smaller number of papers have employed identification strategies based on plausibly exogenous cross-sectional spatial variation in exposure to long-term environmental change. Hornbeck (2012), for example, studies the impacts of the dust-bowl in the U.S., and finds little evidence of agricultural adaptation, but strong evidence of migration. Fishman et al. (2017) study the impacts of cross-village variation in the rate of water table decline in Gujarat, India. They similarly find little evidence of agricultural adaptation, and substantial evidence for increased migration, particularly amongst young males.

Our paper also contributes to the rather thin literature providing quasi-experimental evidence on the effect of access to irrigation water. Duflo and Pande (2007) demonstrate the uneven distributional impacts of irrigation dams, with downstream users enjoying a boost in agricultural income, and upstream populations suffering from increased poverty. Hornbeck and Keskin (2014, 2015) show that access to the water of the Ogallala aquifer in the U.S. led to the adoption of high-value, water-intensive crops, but had no effect on long-run resilience to drought, and failed to generate a long-term expansion in non-agricultural activity. Sekhri (2014) finds that increases in the cost of access to groundwater in Uttar Pradesh, India, is correlated with higher poverty and conflict.

2 Background

Over the last few decades, groundwater has become the major source of irrigation for Indian agriculture, upending an era dominated by centralized surface irrigation projects. Ground-

[4]Taraz (2017) exploits decadal-scale variation in the Indian Monsoon and find evidence for shifts in crops and investment in irrigation, albeit of limited effectiveness. In the U.S., Lobell and Asner (2003) and Burke and Emerick (2016) employ "long-differencing" and find no evidence for agricultural adaptation to rising temperatures.

water pumped by millions of privately owned tube-wells now contributes 60% of the water used for irrigation, having grown by 105% since the 1970s, in contrast to a 28% increase for surface water (Roy and Shah, 2002). However, like other parts of the world where groundwater use has boomed, India is now facing a severe crisis of groundwater depletion, with widespread declines in water tables occurring in some of its most agriculturally productive regions.

Groundwater access, use, and depletion is to a large extent shaped by the characteristics of the subsurface hydro-geology. A geological map of the major aquifer systems of India is reproduced in the right panel of Figure 1. The middle panel of the same figure reproduces a map of the "stage of exploitation" of groundwater, which shows that over-extraction (i.e. in excess of local recharge) is largely concentrated in two parts of India: the Northwest, where aquifers are deep and alluvial; and a belt in central-southern India, where aquifers occur within a hard-rock geology. The area of our study, shown in the left panel of the same figure, is located in the latter region.

Studies of hard-rock areas in the Indian sub-continent have shown that below a highly weathered rock zone at the surface, the bulk of the sub-surface consists of impermeable rock interspersed with networks of fractures and pockets of permeable material, which is where groundwater is stored. The density of these water-bearing features declines with depth (Dewandel et al., 2006, 2010; Maréchal et al., 2007).

Borewells drilled into the hard rock yield water by tapping into these water-bearing pockets. A typical borewell will intersect 0–5 sources, each of which will be just a few decimeters thick. Importantly, the fractures have no "geomorphological expression," which means that their exact location and spacing cannot be determined by surface features, and that their patterns are highly heterogeneous and unpredictable (Krabbendam, 2018).

Until the 1960s, irrigation was confined to shallow, dug wells. A new borewell drilling technology called "down-the-hole" (DTH) drilling, developed in the late 1960s, enabled farmers to access deeper sources of water in the fractured zones, but at relatively high cost. It was not till the 1990s, however, that rising incomes enabled a proliferation of such deeper borewells.

The nature of the hard rock geology has several implications that are important to our study. First, the local aquifers have limited storage, and are therefore much more rapidly exhaustible than the alluvial aquifers of Northwestern India. As a consequence, water levels have dropped precipitously since the 1990s, and numerous wells, including deep ones, have dried up. Second, there is a very high degree of quasi-random spatial variation, even at small distances, in the prospects of hitting water and in the time a well can be operated before it dries up. Third, drilling a well is a very costly (more than double the median household annual cash income) and risky investment.

3 Data

Our study area consists of the highly arid eastern reaches of the state of Karnataka. In 2016, we administered a household survey in 102 villages that were randomly selected from the 31 sub-districts along Karnataka's eastern border that are not served by surface irrigation, and which are therefore primarily dependent on groundwater irrigation (Figure 1).[5] Within each village, we selected a random sub-sample of 150 land-owning households from official land records (or all households in smaller villages). Going through this list in random order, we checked whether households had: (1) never drilled a borewell; (2) had an operational borewell; or (3) had attempted to drill a borewell in the past but no longer had an operational borewell (i.e. all their borewells had failed). We then selected the first five households of each strata for surveying. Our analysis makes use of sampling weights reflecting the prevalence of each category within the village. The sample consists of 1,408 households in total, 893 of whom have ever attempted a borewell.

The survey instrument included a retrospective module that elicited information about every borewell the household had ever attempted to drill and its present status (operational or failed).[6] As Table 1 reports, about 61% of the (first) borewells in the sample have failed by the time of the surveys. The average well was drilled in 2001 at a cost of 75,000 Rs., and was 423 feet deep. For those that failed, failure occurred an average of 5 years after drilling.

The survey instrument also included a detailed module on the cropping patterns, income sources, and assets held by the household. Table 1 reports summary statistics of these variables disaggregated by ownership of an operational well. As is apparent, households with functioning borewells have much higher farm and total income, and own more land and other assets. Clearly, these differences cannot be interpreted as being caused by access to water, since in the presence of credit constraints greater wealth can enable households to retain access to water by drilling more and deeper wells. Our empirical strategy, described in the next section, will attempt to address this challenge.

We supplement these data sets with village-level administrative data from the 2013 Economic Census and the 2011 Demographic Census, which provide information on the number and size of firms within each village and the composition of the labor force.

[5]One village was selected randomly from each Hobli (an administrative unit below the sub-distrct) conditional on being more than 3 KM away from the Hobli's main town.

[6]The design of this module was motivated by the methodology employed by De Nicola and Giné (2014), who compare the year in which households in Tamil Nadu, India, report having purchased fishing boats to sales records showing the actual year in which the transaction occurred. They show that households have relatively precise recall over large asset purchases (in that case, fishing boats), but that recall deteriorates with time. Because borewells will generally be the largest investment that households in our survey make, this methodology is appropriate to this context. In addition, 90% of households will have drilled less than 3 borewells, reducing the cognitive demands involved. Nevertheless, robustness tests are performed to account for possible biases introduced by recall error.

4 Empirical approach

4.1 Identification Strategy

As explained above, a household's access to groundwater depends on highly irregular and quasi-random properties of the sub-surface beneath its land. In addition, however, it also depends on drilling "effort," and in particular the number of drilling attempts it can make (Blakeslee and Fishman, 2018a). In the presence of credit constraints, drilling effort is endogenous to household wealth, meaning that naive correlations between groundwater access and economic outcomes are likely to be biased. This is illustrated in Appendix Table A1, which reports regressions of various characteristics of a household's drilling history on indicators of the household's human and physical capital. In column (1), we see that households whose heads belong to higher castes, are better educated, or own more assets have attempted to drill more borewells (Blakeslee and Fishman, 2018a).

Our empirical strategy takes several steps to overcome this challenge. First, we only compare households that currently have a functional well to households which do not currently have one but had attempted to drill one in the past.

Second, we only compare households residing *within the same village*, a demanding specification that eliminates all village-level correlates of well failure and the outcomes of interest, and relies only on fine-scale geological variability for identification.

Third, and perhaps most importantly, we compare households on the basis of whether their *first* attempted borewell has failed or not, which addresses concerns about bias related to the number of borewells drilled over time.

One might still be concerned that other dimensions of drilling "effort" embodied in the characteristics of the first borewell could be correlated with household attributes that are predictive of the outcomes of interest. As seen in Appendix Table A1, however, there is no evidence of a correlation between (pre-drilling and time-invariant) household characteristics and the depth, cost, or initial flow strength of the first borewell, or the likelihood that it never delivered water to begin with (immediate failure). This pattern is consistent with farmers' anecdotal description of the the drilling procedure. Once a household decides to drill a borewell, drilling typically continues until an adequate supply of water has been achieved or the drilling equipment is in danger of becoming damaged; which suggests that the depth, cost, and initial flow are driven more by quasi-random features of the local geology than the characteristics of households. Nevertheless, we subject our analysis to robustness tests that also control for the cost and depth of the first borewell.

One variable that is likely to be (mechanically) predictive of failure, and which could potentially be correlated with outcomes of interest, is the year in which the first borewell was drilled. This is evident in results of regressions of failure on a well's age, depth, and cost, reported in Appendix Table A2. We therefore flexibly control for the age of the first borewell in all regressions by including fixed effects for the precise year of drilling. We also employ robustness tests in which we allow these fixed effects to vary geographically.

Formally, we estimate regressions of the form:

$$y_{i,v} = \alpha_1 + \alpha_2 F_i + \mathbf{X_i}\Phi + A_v + B_t + u_i, \quad (1)$$

where i is a household index and v a village index, $y_{i,v}$ is the outcome of interest, F_i is a binary indicator of whether the first borewell drilled by the household has failed by the time of the survey, $\mathbf{X_i}$ is a vector of household characteristics, A_v are village fixed effects, and B_t are fixed effects for the year t in which household i drilled its first borewell. The household characteristics include the age, caste, and literacy of the household head, as well as the total land inherited by the household. In robustness tests, the depth and cost of the first borewell are also controlled for, and the age of the first borewell is specified in alternative ways.

Because of our sampling strategy, all regressions incorporate sampling weights that reflect the relative share of households in the village that belong to each type (i.e., with or without a functional borewell).[7]

The identifying assumption is that, conditional on the year of drilling, the failure of the first borewell is exogenous, within villages, to any other correlates of the outcomes of interest. This assumption is motivated by the hypothesis that the remaining determinants of failure primarily depend on highly variable, and quasi-random, hydro-geological characteristics, such as the number of sources the well intersects. Below, we present evidence in support of this assumption.

4.2 Hydro-geological Justification

The impossibility of observing the location of sub-surface water sources from the ground provides strong motivation for our identification strategy, but it also makes it difficult to verify that geological factors actually influence well failure or to study their spatial distributions.

To do so, we inserted specialized cameras into all failed and functioning borewells ever drilled in a particular cluster of villages in the study region, encompassing several hundred borewells across an area of roughly 20 km^2. This allowed us to identify and enumerate water sources intersecting each well and the depths at which they occur. Figure A2 displays examples of images captured in this manner for four borewells.

Because the process is logistically demanding and expensive, it is infeasible to implement on scales encompassing our entire study area. Nevertheless, the data obtained in this particular cluster of villages offers two important insights.

[7] Our results turn out to be insensitive to the use of these weights.

First, the number of water sources intersected by a well is significantly predictive of the probability of failure, even when the well's age and depth are controlled for (Appendix Table A3). This association validates the hypothesis that normally unobservable geological characteristics influence a well's lifetime.

Second, Figure 3 presents a plot of all wells in the sample (n=450). In the left panel, we indicate the number of water sources intersected by each well, and in the right panel we indicate the well's current status (operational or failed). Both variables display substantial variation on fine spatial scales and do not appear to follow any particular pattern, further reinforcing our identifying assumption.

4.3 Balance

The most acute threat to our identification strategy is that the failure of the first borewell may be correlated with household characteristics, such as skill or wealth, that are also predictive of the outcomes of interest. The identifying assumption—that, conditional on location and age, well failure is only determined by exogenous geological factors—is motivated by the nature of local hydro-geology, as discussed above. However, we can also use observable time-invariant or pre-drilling household characteristics in order to test this assumption directly.

Table 2 reports such tests for a number of household characteristics. Columns (1) and (2) report the mean value of these characteristics for households that did and did not experience a first-borewell failure, respectively, with the sample restricted to households that ever attempted a borewell. In columns (3)–(5) we report estimates of differences between the two groups, with those reported in columns (4) and (5) accounting for village fixed effects, and those reported in column (5) also accounting for fixed effects for the year in which the first borewell was drilled.

The results show that the sample is well balanced in terms of first borewell failure. Failure is not correlated with the caste or educational attainment of the household head, or with the assets or type of cultivation reported by the household at the year preceding the drilling of the first borewell.

5 Results

In this section we report the impacts of failure of the first borewell on a range of household outcomes. Impacts on various categories of outcomes are reported in separate tables that are similarly formatted. In each table, each row is devoted to one outcome, indicated on the left. Column (1) reports the mean of the outcome variable for households whose first borewell did not fail. Columns (2) and (3) report the estimated impact of first borewell failure (i.e. the coefficient α_2 in specification (1)), with column (3) reporting estimates that include fixed effects for the year in which the first borewell was drilled.

5.1 Agriculture

Figure 4 plots the probability of having access to groundwater (i.e., having an operational borewell) against the years that have elapsed since the failure of the first borewell, disaggregated between households whose first well had failed or not.[8] Access to groundwater displays relatively similar levels and trends across the two groups in the years prior to failure. The failure of the first borewell, by construction, leads to a large and immediate decline in the probability of having a functioning borewell. What is more striking is the persistence of this loss. Though households could potentially drill additional wells, it seems that the cost and risk of doing so prevents most households from pursuing this adaptive response. Indeed, most respondents in our sample gave high subjective assessments of the risk that an attempted new borewell would fail to produce any water at all. Less than 25% of the respondents expressed an intention of attempting another borewell, with 93% of them blaming the high costs involved.

Table 3 reports the estimated effects of first borewell failure on water access and agricultural outcomes. Consistent with Figure 4, first-borewell failure leads to an approximately 63 percentage point (p.p.) decrease in the probability that a household has a functional borewell at the time of the survey (Panel A). Since irrigation plays different roles in the two main growing seasons—the rainy (*Kharif*) and dry (*Rabi*) seasons—we examine impacts on cultivation in these two seasons separately. We estimate a 46 and 34 p.p. decline in the probability that a household uses irrigation during the rainy and dry seasons, respectively.

There is no evidence of an impact on the total amount of land being cultivated during the rainy season (Panel B). However, we find evidence of a decline in the cultivation of horticultural crops (−0.30 acres, row 4), which require a more controlled, consistent, and reliable supply of irrigation water than most field crops, and a partially compensating increase in the cultivation of field crops (+0.18 acres, albeit imprecise, row 3).

Dry-season cultivation, in which irrigation is more important, displays a larger change in cropping patterns as a result of the first borewell's failure (Panel C). Land cultivated with horticultural and field crops declines by 0.19 and 0.29 acres, respectively, amounting to a decrease of 45%–50% in the cultivation of both types of crops. [9]

[8] For households whose first borewell has not failed, time is calibrated against the median year of first-borewell failure within the same village

[9] Households whose borewell has failed can continue to cultivate by relying on soil moisture or alternative sources of water, like open wells or surface water, explaining why the decline in irrigation is not total.

5.2 Household Labor Re-Allocation

We next assess whether households adapt to well failure through a re-allocation of labor resources. In Table 4, we report estimated impacts of first borewell failure on the fraction of adult household members that are employed in various categories of work, once again disaggregated by season (Panels A and B report estimates for the rainy and dry seasons, respectively).

In both seasons, first-borewell failure leads to a decline in own-farm cultivation (5 and 10 p.p. in the rainy and dry seasons, respectively) and a compensating increase in both agricultural (5 and 6 p.p.) and non-agricultural (3 and 4 p.p.) employment off the household's farm. The estimates are larger and more precise in the dry season. The estimated impacts on unemployment are positive (2 and 3 p.p.), and there is no change in the number of occupations per household member.

Panel C reports estimated impacts on the places of residence and work of household members. The probability that a household member has migrated increases by 1.4 p.p., representing more than a 100% increase. For those who reside in the household, the probability of working outside of the village increases by 2.7 p.p., representing a 45% increase.

In Appendix Table A4, we disaggregate these effects by gender. Labor reallocations are generally of larger absolute magnitude for men than for women. However, relative to mean levels in the control group, labor reallocations are proportionally similar across genders.

5.3 School Enrollment and Child Employment

Increases in child employment in response to transient income shocks have been documented in multiple contexts (Jacoby and Skoufias, 1997; Beegle et al., 2006). Consistent with this research, we find evidence (Table 5) that first borewell failure reduces enrollment and increases employment amongst children old enough to be employed (12–18 years old).

Interestingly, we also find that borewell failure *increases* enrollment rates amongst younger children (6–11 years old). One potential explanation is that borewell failure reduces the marginal returns to child labor on the farm, thereby reducing the opportunity cost of school enrollment. However, virtually no children of this age are reported as working by households whose wells are functional (though it is possible that parents under-report on-farm child labor). Another potential explanation is that borewell failure leads households to make greater investments in the human capital of their younger children in order to prepare them for non-agricultural employment. The latter interpretation is bolstered by the finding, shown below, that the increase in young-child enrollment is only occurring in areas with relatively abundant employment opportunities in large firms.

5.4 Income

The employment shifts reported above are also reflected in a diversification of household income sources. Table 6 reports estimated impacts on binary indicators (Panel A) and the amounts (Panel B) of income obtained from various income categories, mainly on-farm (including allied activities, such as livestock) and off-farm.

We find that first borewell failure leads to an 11 p.p. increase in the probability that a household derives income from off-farm employment. No other sources of income are affected. On-farm income experiences a roughly 14,000 Rs. decrease (row 6), equivalent to a 25% decline.[10] However, a compensating increase of similar magnitude (12,000 Rs.) in non-farm income (row 7) seems sufficient to leave total income little affected. Social insurance plays only a negligible role in this offset, with a small (approximately 500 Rs.) and imprecisely estimated increase in income from government sources (results not shown).

5.5 Assets

In Table 7, we test whether households respond to borewell failures through a liquidation of assets or the incurring of debt. We find no evidence that farmers sell off land in response to borewell failure (row 1). Self-assessed land values also show no evidence of a decline. It is important to note, however, that land prices in rural India rarely reflect agricultural value alone, and the thinness of land markets likely makes it difficult for farmers to assess the market value of their land.

The total value of non-land assets,Our analysis excludes agricultural machinery, whose liquidation might reflect a shift away from farming rather than a loss of wealth in contrast, is reduced by approximately 68,000 Rs. as a result of first borewell failure (row 5), amounting to more than a 24% loss, and almost equal to a full year's income.[11] An examination of the impact on specific asset categories (Appendix Table A5) reveals declines in livestock, bicycle, and refrigerator ownership, as well as a very large decline in gold holdings, which is responsible for much of the total lost asset value (approximately 45,000 Rs.).

There is also an 7.3 p.p. increase in the probability that a household whose first borewell failed has outstanding debt. This is associated with a 56,000 Rs. increase in the level of debt incurred, representing about a 60% increase.

The loss of assets and the taking on of debt by households whose first borewell has failed could be indicative of attempts to smooth consumption, perhaps during a transition period that may precede the eventual income-maintaining re-allocation of labor seen above.

[10] Income, asset, and debt values are winsorized at the 99th percentile.

[11] Total asset value was computed using reported numbers of asset unit and the typical monetary value of these assets.

It could also be due to the costs of attempting to drill another well, an action observed for about 58% of these households. Separating the estimation between households that did or did not attempt a second well reveals the increase in debt to be driven by the former type, which suggests that debt is incurred primarily to fund additional drilling attempts. Asset decumulation, on the other hand, is similar across the two types, suggesting it may indeed be driven by an attempt to smooth consumption, which is consistent with research showing that gold is commonly used in rural India (and elsewhere) to smooth consumption in the face of income shocks (Frankenberg et al., 2003).

5.6 Welfare Indicators

Table 8 reports the estimated impacts of borewell failure on several indicators of objective and subjective welfare.

We do not find evidence for an impact on poverty levels as indicated by official BPL ("below poverty line") status, possibly because 87% of households in the control group already belong to that category (row 1). We do find evidence of reductions in monthly expenditure on food (a decline of about 10%), but not on (annual) health or education.[12]

We estimate a small reduction (of about 0.2 on a scale of 1–10) in a standard measure of subjective life satisfaction (row 2), and a smaller and imprecise reduction in satisfaction with the household's financial situation.[13] Given the long lapse between the event of failure and the survey, and the tendency of these subjective assessments to recover from shocks (Galiani et al., 2015), these modest effects might potentially reflect larger initial declines.Anecdotal conversations with local farmers revealed substantial distaste for common forms of off-farm employment.

5.7 Additional tests

We employ several robustness tests and alternative specifications to address possible threats to identification. First, in Appendix Table A6 we re-estimate regressions for our main outcomes while controlling for the (log) age and (log) cost of the first borewell.

Second, in Appendix Table A9 we report estimates resulting from the use of alternative controls for the time of drilling. These include replacing fixed effects for the precise year of

[12] This lack of precision could be driven by the longer recall period used for health and education. It is also worth noting that the survey was administered just prior to the monsoon, during what would be part of the lean season.

[13] We used the standard subjective life satisfaction question phrased as: "All things considered, how satisfied are you with your life as a whole these days? Using this card on which 1 means you are 'completely dissatisfied' and 10 means you are 'completely satisfied' where would you put your satisfaction with your life as a whole?" The self-assessed financial situation is asked similarly: "How satisfied are you with the financial situation of your household?"

drilling with fixed effects for five-year intervals (which can address potential recall errors), and allowing both types of time fixed effects to flexibly vary geographically (interactions with district fixed effects). The pattern of the results is unchanged.

We have seen that observable pre-drilling household characteristics are uncorrelated with the failure of the first borewell. One might still be concerned that unobservable household characteristics could be influencing both borewell failure and the outcomes of interest. Some characteristics, such as greater financial capacity or higher returns to irrigation, may lead households to increase their investment in the initial drilling effort in ways not captured by our data. Other characteristics, such as being more forward-looking or skilled at water management, might affect post-drilling behavior and lead households to better conserve water. To examine the possibility that such unobservable characteristics are biasing our results, we estimate heterogeneities in treatment effects according to the *immediacy* of borewell failure—i.e., whether the borewell failed immediately or only after some time. The results are reported in Appendix Table A7.[14]

The first set of estimates, reported in column (2), restricts the sample of failed-borewell households to those which did not fail immediately, and can be thought of as the impact of failure conditional on initially hitting water. As such, it is less likely to be biased by unobservable farmer characteristics that can lead some farmers to persist longer in drilling until water is found. The similarity of these estimates to those obtained with the full sample suggests that the latter is little affected by potential biases of this nature.[15]

The second of the two sets of estimates, reported in column (3), restricts the sample of failed-borewell households to those that that failed immediately, and can be thought of as the impact of immediate borewell failure. As such, it is unlikely to be affected by any potential dimensions of post-drilling farmer behavior which might prolong a well's lifetime. Here too, the similarity of the estimated coefficients to those obtained with the full sample helps to allay concerns that such biases could be affecting our results.

Though we cannot conclusively rule out the possibility that the estimated impacts of well failure are biased by unobservable farmer characteristics, it is worth noting that the most plausible types of selection bias involve wealthier and more skilled farmers being less likely to experience borewell failure. This would most likely lead us to overestimate the negative effect of borewell failure on farm income, but would likely only strengthen the principal finding in this paper: namely, that total income is not reduced by borewell failure.

[14]Since, as we have seen in column 5 of Table A1, immediate failure is uncorrelated with observable (pre-drilling or time-invariant) household characteristics, these two estimates may be interpretable as the estimated impact of first borewell failure in these two sub-samples.

[15]The reduction in sample size results in reduced precision in the estimated impacts on income.

5.8 Heterogeneity by Local Rates of Economic Development and Groundwater Depletion

The adaptation strategies that we have documented through off-farm employment are likely to be mediated by employment opportunities in the household's vicinity. We therefore disaggregate the sample according to the availability of employment in relatively large firms in the area surrounding each village.[16] To do so, we use village-level data from the 2013 Economic Census, and determine the total number of workers employed by large firms (above 15 employees) that are situated within 5 kilometers of the village.[17] In Table 9 we separately estimate the impacts of first-borewell failure in "low-development" (column (1)) and "high-development" (column (2)) villages, defined as having above or below median (170 workers) values of this employment indicator. Column (3) reports the differences between the two estimates.[18]

Households in low- and high-development areas display a similar decline in on-farm employment. Households in high-development areas, however, display a larger shift towards both agricultural and non-agricultural off-farm employment, though the differences are imprecisely estimated. In low-development areas, on the other hand, there is a significantly larger increase in unemployment.

In addition, the increase in off-farm income is larger in high-development areas, as expected. As a result, households in high-development areas experience a substantial (but statistically imprecise) *increase* in total income, while households in low-development areas suffer a similarly sized decline in total income. These two income effects are significantly different from one another.

Finally, the increase in young-child (ages 6–11) school enrollment occurs primarily in high-development areas (Appendix Table A8), consistent with the thesis that it reflects increased investments in education as a means of preparing children for future off-farm employment. Similarly, the increase in employment by older children (ages 12–18) is more pronounced in high-development areas, where there are more employment opportunities.

We also explore heterogeneity in impacts of well failure on the basis of the aggregate rates of well failure in the village. Such an analysis can be suggestive of the extent to which widespread depletion might either exacerbate or ameliorate the impacts. For example, one might expect that widespread well failure could congest local labor market and restrict off-farm employment opportunities. However, we do not find significant indications of such

[16] We focus on large firms since small firms tend to rely on family labor, and therefore would be less viable as sources of employment.

[17] Our choice of a 5 km radius is motivated by the findings in Blakeslee et al. (2018).

[18] More precisely, estimates of an interaction term between first-borewell failure and an indicator of "high-development" villages. All household characteristics, as well as year indicators, are also interacted with the development indicator.

heterogeneity.[19]

6 Conclusion

This paper provides some of the first evidence on the medium- to long-term impacts of large-scale, permanent environmental deterioration on rural populations in developing countries.

The evidence suggests that loss of access to irrigation water, a critical input to farming in semi-arid regions, persistently reduces the viability of agricultural livelihoods. There is little indication that households are able to adapt to these losses through shifts in agricultural practices. Much of the affected land remains fallow, or cultivated with low-value field crops, raising concerns about the impacts on aggregate food production.

On the other hand, households seem to be relatively successful in off-setting agricultural income losses through a reallocation of labor to off-farm employment, which leaves total income little affected. The reallocation of labor is achieved without substantial resort to migration or even employment in nearby villages, arguing against the likelihood that worsening groundwater trends will result in large waves of "environmental refugees."[20]

The ability of households to adapt their income to water loss through non-agricultural employment, however, depends on the structure of the local economy. Where large firms are relatively common, individuals are more likely to take up off-farm employment, and there are indications of a slight increase in total income. Where such firms are relatively scarce, total income declines.

These results suggest that rural industrialization and non-agricultural economic development may enable rural populations to escape the worst income-related impacts of environmental degradation and the associated loss of agricultural production. However, these adaptations are not costless, as they entail the liquidation of assets and accumulation of debt, a decline in food expenditures, and a reduction of investments in the human capital of young adolescents.

[19]We divide the sample into villages in which the aggregate rate of well failure, calculated using the pre-survey census (see section 3), is below or above the median value (57%), and estimate impacts separately in each of the two groups (columns (1) and (2) of Appendix Table A10) and their difference (column (3)).

[20]It is important to acknowledge that we may not be able to observe households that have left the village altogether. However, data collected from a community survey indicates 3% of all households had migrated in the previous 5 years, with no correlation between migration and the village-wide groundwater situation.

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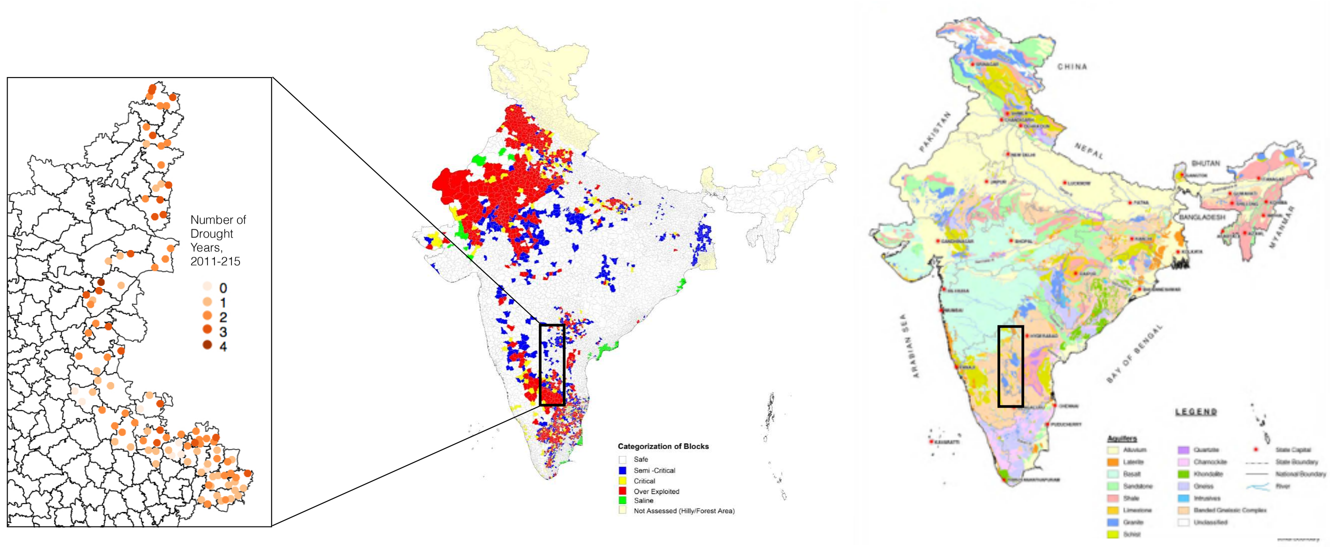
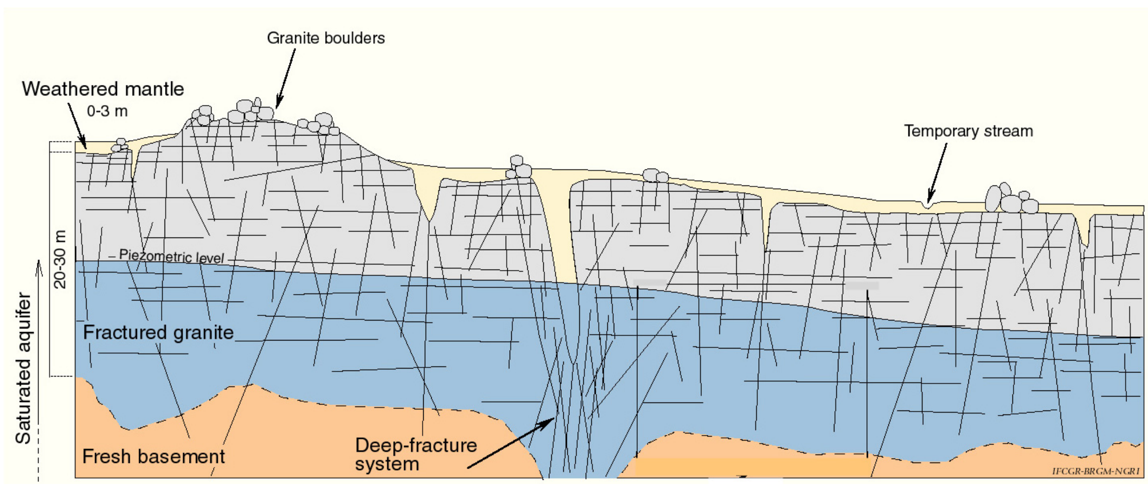
Figure 1: Location of the Survey Villages



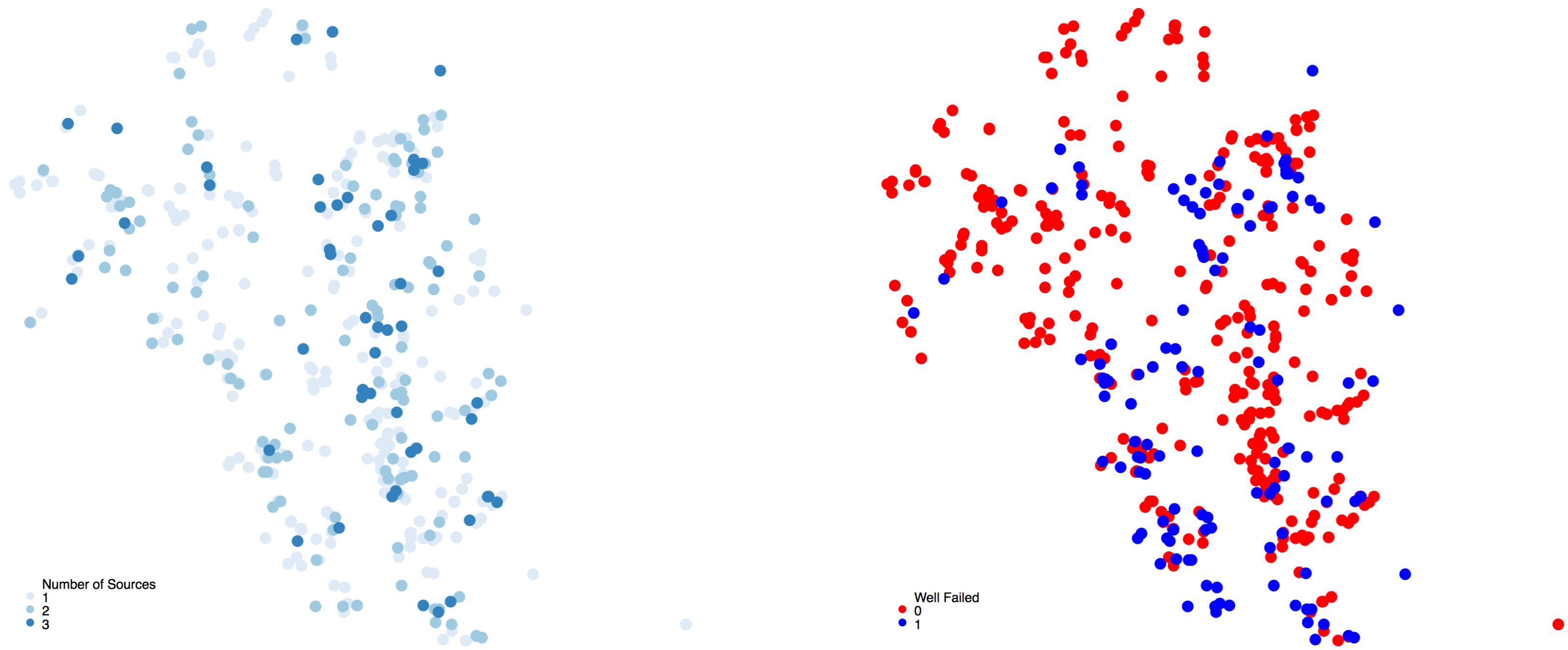
Right: Classification of the major aquifer systems of India. Alluvial aquifers are marked in yellow shades. All other colors signify hard-rock aquifers. The study area is marked by a rectangle. Source: Government of India (2012). **Middle**: Assessment of the state of utilization of groundwater resources across India in relation to natural recharge rates. Over-exploited / Critical / Semi-critical / Safe assessment units are defined as those in which withdrawals of groundwater are above 100% / 90%-100% / 70%-90% / below 70% of natural recharge rates. Source: Government of India (2013). **Left**: blow-up of the study area and sample villages in Eastern Karnataka. Each village is shaded to indicate the number of drought years experienced in the five years leading to the time of the survey. Lines represent sub-district boundaries.

Figure 2: Hard Rock Hydrogeology



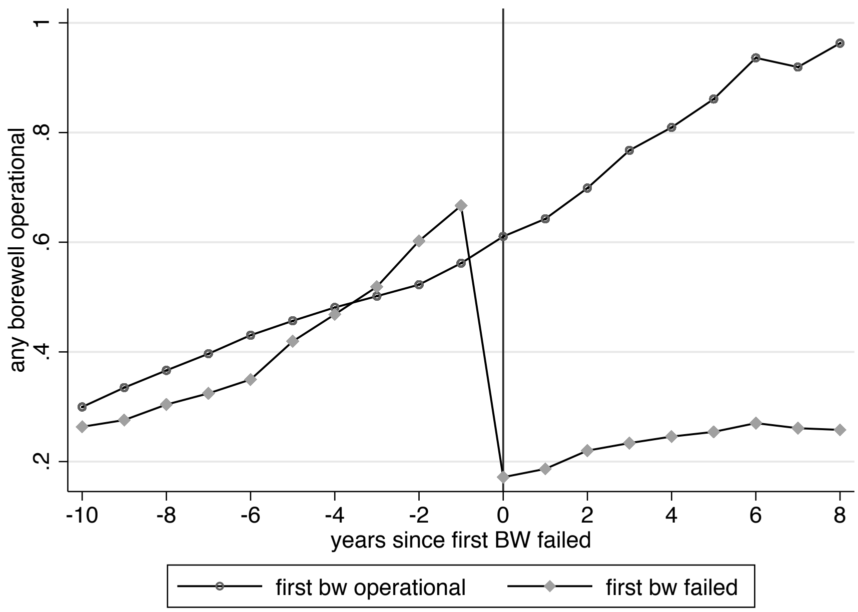
Notes: Simplified geological profile of a hardrock aquifer. Water accumulates in fractures (solid lines) that are interspersed within the sub-surface at varying locations and depth, and are being recharged from various sources. Source: Maréchal et al. (2004).

Figure 3: Hydrogeological Data



Plot of the number of water sources intercepted by each well, left, and borewell status (active, in blue / failed, in red), right, from a complete census of all borewells in a cluster of villages villages in the study area. The horizontal scale of the plot is about 5 KM.

Figure 4: Borewell Failure and Access to Water Over Time



Notes: The probability of having an active borewell against the years that have elapsed since the first borewell failed. The sample is disaggregated according to whether the first borewell drilled by the household had failed by the time of the survey. For households in which the first borewell did not fail, the year of first-borewell failure is defined as the median year in which first borewells failed within the village.

Table 1: Descriptive Statistics

Panel A: Sample Sizes			
Number Districts	10		
Number Villages	102		
Number Households	1408		
Number HHs Ever Drilled BW	893		
Panel B: First Borewell Characteristics			
Year Drilled	2001 [10]		
Depth (feet)	423 [225]		
Cost (10,000 Rs)	7.463 [5.690]		
Failed	0.615 [0.487]		
Year Failed	2006 [8]		
Panel C: Household Characteristics	Household Has Functional Borewell		
	Yes	No	Difference
HH Head Non-Marginal Caste	0.532	0.476	-0.055 [0.032]
HH Head Literate	0.643	0.577	-0.067 [0.027]
HH Head Age	51.961	51.548	-0.413 [0.809]
Brick House	0.437	0.340	-0.098 [0.028]
Electricity	0.974	0.968	-0.006 [0.010]
Below Poverty Line (BPL)	0.871	0.892	0.020 [0.020]
Inherited Land (acres)	5.720	4.554	-1.166 [0.408]
Asset Value w/o Land (10,000 Rs.)	28.529	17.465	-11.064 [2.044]
Income, 2015 (1,000 Rs.)			
Total	85.374	54.711	-30.663 [7.276]
On-Farm	61.005	24.817	-36.188 [4.775]
Off-Farm	24.369	29.894	5.525 [4.814]
Fraction of HH Members (Dry Season)			
Own-Farm	0.492	0.301	-0.191 [0.023]
Off-Farm, Agricultural Labor	0.126	0.229	0.103 [0.016]
Off-Farm, Non-Agricultural Labor	0.041	0.111	0.069 [0.011]
Not Working	0.097	0.147	0.050 [0.011]
Working Outside Village	0.074	0.098	0.024 [0.010]
Semi-Permanent Migrant	0.015	0.021	0.006 [0.005]

Notes: Summary statistics for sample size and household characteristics. Summary statistics for household characteristics are disaggregated into households with and without a functioning borewell at the time of the survey. Differences between the two groups are derived from regressions of the indicated variable on an indicator of not having a borewell. Error terms are assumed to be clustered at the village level.

Table 2: Balance

	First Borewell Operational	First Borewell Failed	Difference		
	(1)	(2)	(3)	(4)	(5)
HH Head					
Hindu	0.969	0.965	-0.004 [0.014]	0.001 [0.013]	-0.003 [0.014]
Non-Marginal Caste	0.497	0.565	0.068 [0.039]	0.023 [0.039]	0.014 [0.041]
Male	0.765	0.797	0.032 [0.030]	0.017 [0.027]	0.017 [0.027]
Age	51.377	51.682	0.305 [1.058]	0.013 [1.098]	-0.068 [1.184]
Literate	0.629	0.658	0.030 [0.034]	-0.009 [0.034]	-0.021 [0.036]
Education - none	0.371	0.339	-0.032 [0.034]	0.008 [0.034]	0.020 [0.036]
Education - primary	0.118	0.100	-0.018 [0.026]	-0.021 [0.030]	-0.009 [0.029]
Education - secondary	0.107	0.142	0.035 [0.023]	0.027 [0.025]	0.025 [0.027]
Education - post-secondary	0.298	0.331	0.034 [0.033]	0.015 [0.032]	-0.012 [0.036]
Number Children					
Aged 6-11	0.614	0.490	-0.124 [0.065]	-0.068 [0.066]	-0.038 [0.075]
Aged 12-18	0.718	0.711	-0.008 [0.069]	0.018 [0.072]	0.015 [0.077]
Adult Sons	0.767	0.795	0.027 [0.032]	0.015 [0.033]	0.030 [0.033]
Assets (at time 1st BW Drilled)					
Seed Drill	0.392	0.350	-0.042 [0.043]	0.029 [0.039]	0.029 [0.039]
Tractor	0.032	0.040	0.008 [0.013]	0.006 [0.014]	0.013 [0.014]
Thresher	0.004	0.009	0.005 [0.006]	0.001 [0.006]	-0.001 [0.007]
Motorcycle	0.123	0.121	-0.002 [0.023]	-0.019 [0.026]	0.006 [0.026]
Inherited Land (acres)	5.625	5.318	-0.307 [0.443]	0.480 [0.398]	0.184 [0.435]
Agriculture (at time 1st BW Drilled)					
Cash Crops	0.249	0.274	0.024 [0.037]	0.007 [0.039]	0.020 [0.039]
Irrigation	0.392	0.350	-0.042 [0.043]	0.029 [0.039]	0.029 [0.039]
Number Observations	305	587			
Village F.E.				Yes	Yes
First-BW Year-Drilled F.E.					Yes

Note: Comparisons of various characteristics (leftmost column) between households whose first borewell is still operational (column (1)) and those whose first borewell is not operational (column (2)). The sample is limited to households that have ever attempted to drill a borewell. Columns (3)–(5) report estimated differences derived from regressing each outcome on an indicator of first borewell failure. Columns (4)–(5) include village fixed effects, and Column (5) also include fixed effects for the year in which the first borewell was drilled. Error terms are assumed to be clustered at the village level. Standard errors in brackets.

Table 3: Water Access and Agriculture

	Control Mean	Impact of BW Failure	
	(1)	(2)	(3)
Panel A: Water Use			
Operational Borewell	1.000	-0.626	-0.634
		[0.027]	[0.026]
Irrigation, Rainy Season (any)	0.701	-0.443	-0.458
		[0.031]	[0.029]
Irrigation, Dry Season (any)	0.508	-0.332	-0.336
		[0.035]	[0.034]
Irrigation, Dry Season (pct. land)	0.317	-0.218	-0.210
		[0.028]	[0.028]
Panel B: Rainy Season			
Any Cultivation	0.993	-0.020	-0.021
		[0.009]	[0.009]
Total Land (acres)	4.451	-0.093	-0.124
		[0.219]	[0.266]
Field Crops (acres)	3.730	0.190	0.179
		[0.209]	[0.250]
Horticulture (acres)	0.720	-0.282	-0.303
		[0.096]	[0.099]
Panel C: Dry Season			
Any Cultivation	0.596	-0.286	-0.303
		[0.037]	[0.038]
Total Land (acres)	1.204	-0.466	-0.479
		[0.239]	[0.249]
Field Crops (acres)	0.826	-0.291	-0.286
		[0.182]	[0.211]
Horticulture (acres)	0.378	-0.175	-0.193
		[0.098]	[0.089]
Village F.E.		Yes	Yes
First-BW Year-Drilled F.E.			Yes

Note: Estimated impacts of first borewell failure on outcomes indicated at the leftmost column. Each estimate is derived from a separate regression. Column (1) reports the mean level of the outcome variable in households that drilled a borewell and did not experience a first-borewell failure. Columns (2) and (3) report estimates of the coefficient α_2 in specification 1. All regressions include controls for household head literacy, age, caste, and the amount of inherited land, as well as village fixed effects. Column (3) includes fixed effects for the year in which the first borewell was drilled. Error terms are assumed to be clustered at the village level. Standard errors in brackets.

Table 4: Labor Reallocation

	Control Mean	Impact of BW Failure	
	(1)	(2)	(3)
Panel A: Rainy Season			
Occupations per Member	1.380	-0.005	-0.013
		[0.047]	[0.044]
Fraction of HH Members			
Working on Own Farm	0.527	-0.040	-0.048
		[0.024]	[0.024]
Working Off-Farm, Agriculture	0.102	0.049	0.048
		[0.019]	[0.020]
Working Off-Farm, Non-Agriculture	0.038	0.026	0.027
		[0.011]	[0.012]
Not Working	0.100	0.014	0.019
		[0.012]	[0.012]
Panel B: Dry Season			
Occupations per Member	1.375	-0.025	-0.026
		[0.047]	[0.044]
Fraction of HH Members			
Working on Own Farm	0.489	-0.094	-0.104
		[0.025]	[0.025]
Working Off-Farm, Agriculture	0.119	0.061	0.064
		[0.021]	[0.021]
Working Off-Farm, Non-Agriculture	0.045	0.040	0.042
		[0.012]	[0.014]
Not Working	0.102	0.022	0.029
		[0.014]	[0.014]
Panel C: Location			
Fraction of HH Members			
Semi-Permanent Migrant	0.010	0.013	0.014
		[0.006]	[0.007]
Non-Migrant Working Outside Village			
Rainy Season	0.058	0.030	0.027
		[0.013]	[0.014]
Dry Season	0.060	0.028	0.028
		[0.013]	[0.014]
Village F.E.		Yes	Yes
First-BW Year-Drilled F.E.			Yes

Note: Estimated impacts of first borewell failure on outcomes indicated at the leftmost column. Each estimate is derived from a separate regression. Column (1) reports the mean level of the outcome variable in households that drilled a borewell and did not experience a first-borewell failure. Columns (2) and (3) report estimates of the coefficient α_2 in specification 1. All regressions include controls for household head literacy, age, caste, and the amount of inherited land, as well as village fixed effects. Column (3) includes fixed effects for the year in which the first borewell was drilled. Error terms are assumed to be clustered at the village level. Standard errors in brackets.

Table 5: Child Employment and Schooling

	Control Mean	Impact of BW Failure	
	(1)	(2)	(3)
Children, 6–11 Years Old			
Fraction Enrolled	0.542	0.120	0.122
		[0.058]	[0.060]
Fraction Employed	0.005	-0.002	-0.004
		[0.003]	[0.005]
Children, 12–18 Years Old			
Fraction Enrolled	0.817	-0.096	-0.110
		[0.043]	[0.042]
Fraction Employed	0.130	0.052	0.073
		[0.034]	[0.037]
Village F.E.		Yes	Yes
First-BW Year-Drilled F.E.			Yes

Note: Estimated impacts of first borewell failure on outcomes indicated at the leftmost column. Each estimate is derived from a separate regression. Column (1) reports the mean level of the outcome variable in households that drilled a borewell and did not experience a first-borewell failure. Columns (2) and (3) report estimates of the coefficient α_2 in specification 1. All regressions include controls for household head literacy, age, caste, and the amount of inherited land, as well as village fixed effects. Column (3) includes fixed effects for the year in which the first borewell was drilled. Error terms are assumed to be clustered at the village level. Standard errors in brackets.

Table 6: Income

	Control Mean	Impact of BW Failure	
	(1)	(2)	(3)
Any Income			
On-Farm	0.800	0.002	0.003
		[0.024]	[0.026]
Govt. Transfers	0.204	0.004	0.028
		[0.031]	[0.033]
Business	0.039	-0.004	-0.010
		[0.012]	[0.012]
Remittances	0.062	0.002	0.009
		[0.019]	[0.020]
Off-Farm Employment	0.291	0.084	0.118
		[0.038]	[0.038]
Income (1,000 Rs.)			
On-Farm	59.141	-16.684	-14.083
		[5.854]	[6.325]
Off-Farm	21.850	8.623	12.182
		[5.549]	[6.017]
Total	80.991	-8.061	-1.900
		[8.773]	[9.500]
Village F.E.		Yes	Yes
First-BW Year-Drilled F.E.			Yes

Note: Estimated impacts of first borewell failure on outcomes indicated at the leftmost column. Each estimate is derived from a separate regression. Column (1) reports the mean level of the outcome variable in households that drilled a borewell and did not experience a first-borewell failure. Columns (2) and (3) report estimates of the coefficient α_2 in specification 1. All regressions include controls for household head literacy, age, caste, and the amount of inherited land, as well as village fixed effects. Column (3) includes fixed effects for the year in which the first borewell was drilled. Error terms are assumed to be clustered at the village level. Standard errors in brackets.

Table 7: Assets and Debt

	Control Mean	Impact of BW Failure	
	(1)	(2)	(3)
Assets			
Total Land (acres)	5.510	0.091	0.045
		[0.216]	[0.226]
Land Value (10,000 Rs.)	316.816	-18.289	10.593
		[60.519]	[64.742]
Brick House	0.412	-0.055	-0.059
		[0.036]	[0.037]
Number Rooms	3.160	-0.062	-0.075
		[0.114]	[0.119]
Asset Value w/o Land (10,000 Rs.)	27.758	-6.523	-6.750
		[2.363]	[2.464]
Debt			
Any	0.352	0.074	0.073
		[0.032]	[0.031]
Size of Total Debt (10,000 Rs.)	9.270	4.599	5.572
		[2.271]	[2.294]
Village F.E.		Yes	Yes
First-BW Year-Drilled F.E.			Yes

Note: Estimated impacts of first borewell failure on outcomes indicated at the leftmost column. Each estimate is derived from a separate regression. Column (1) reports the mean level of the outcome variable in households that drilled a borewell and did not experience a first-borewell failure. Columns (2) and (3) report estimates of the coefficient α_2 in specification 1. All regressions include controls for household head literacy, age, caste, and the amount of inherited land, as well as village fixed effects. Column (3) includes fixed effects for the year in which the first borewell was drilled. Error terms are assumed to be clustered at the village level. Standard errors in brackets.

Table 8: Welfare and Expenditures

	Control Mean	Impact of BW Failure	
	(1)	(2)	(3)
Panel A: Objective Measures			
BPL household	0.871	-0.005	0.002
		[0.024]	[0.025]
Expenditure (1,000 Rs.)			
Food (last month)	4.779	-0.589	-0.507
		[0.262]	[0.251]
Education (last year)	21.154	-0.754	-1.471
		[2.832]	[2.937]
Health (last year)	26.257	1.271	-0.443
		[2.427]	[2.830]
Panel B: Subjective Measures			
Life Satisfaction (1–10)	4.814	-0.185	-0.177
		[0.104]	[0.114]
Financial Satisfaction (1–10)	4.463	-0.099	-0.062
		[0.113]	[0.113]
Village F.E.		Yes	Yes
First-BW Year-Drilled F.E.			Yes

Note: Estimated impacts of first borewell failure on outcomes indicated at the leftmost column. Each estimate is derived from a separate regression. Column (1) reports the mean level of the outcome variable in households that drilled a borewell and did not experience a first-borewell failure. Columns (2) and (3) report estimates of the coefficient α_2 in specification 1. All regressions include controls for household head literacy, age, caste, and the amount of inherited land, as well as village fixed effects. Column (3) includes fixed effects for the year in which the first borewell was drilled. Error terms are assumed to be clustered at the village level. Standard errors in brackets.

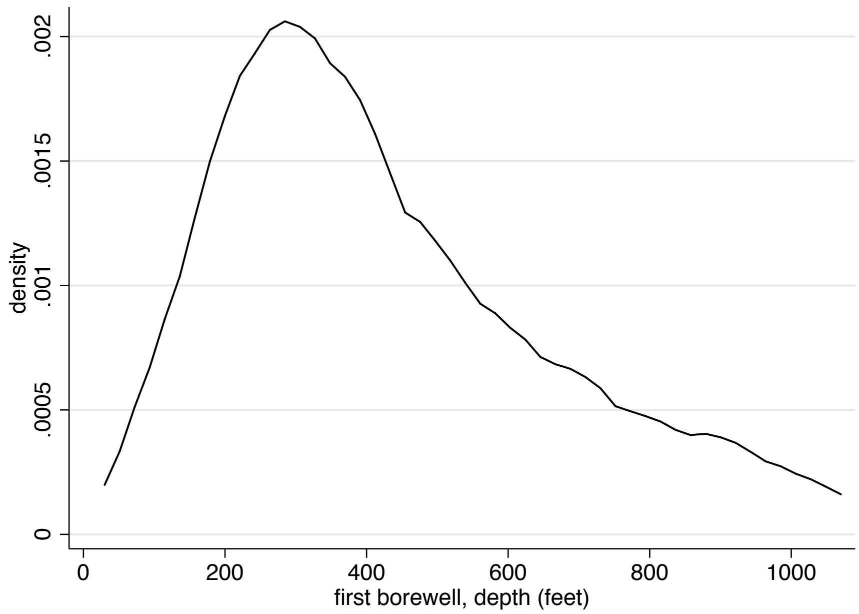
Table 9: Heterogeneous Treatment Effects by Economic Development

	Impact of BW Failure		
	Development		
	Low	High	Difference
	(1)	(2)	(3)
Fraction of HH Members (Dry Season)			
Working on Own Farm	-0.105	-0.105	-0.000
	[0.037]	[0.035]	[0.051]
Working Off-Farm, Agriculture	0.055	0.075	0.019
	[0.036]	[0.025]	[0.043]
Working Off-Farm, Non-Agriculture	0.034	0.062	0.028
	[0.018]	[0.019]	[0.026]
Not Working	0.054	0.001	-0.053
	[0.017]	[0.023]	[0.029]
Non-Migrant Working Outside Village	0.026	0.043	0.017
	[0.018]	[0.022]	[0.029]
Semi-Permanent Migrant (Annual)	0.026	0.008	-0.018
	[0.013]	[0.005]	[0.014]
Income (1,000 Rs.)			
On-Farm	-24.083	-5.502	18.582
	[8.480]	[10.903]	[13.765]
Off-Farm	3.428	27.462	24.033
	[8.244]	[10.732]	[13.486]
Total	-20.655	21.960	42.615
	[12.118]	[15.926]	[19.942]
Village F.E.	Yes	Yes	Yes
First-BW Year-Drilled F.E.	Yes	Yes	Yes

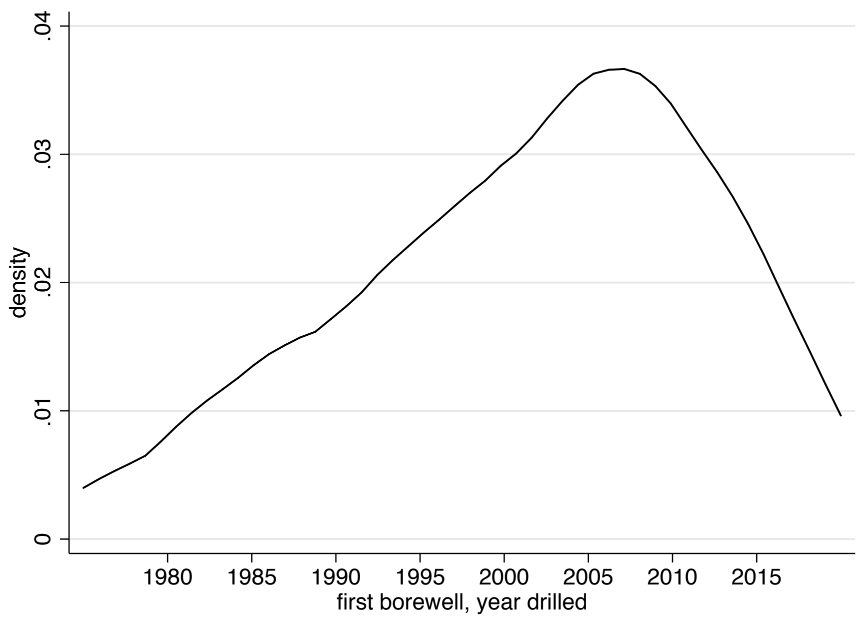
Note: Estimated impacts of first borewell failure on outcomes indicated at the leftmost column, segregated by local rates of economic development. Each estimate is derived from a separate regression. Column (1) reports estimates of the coefficient α_2 in specification 1 limiting the sample to villages in which fewer than 171 individuals work for firms with 15 or more employees within 5 kilometers ("low development"); and in Column (2) to villages with more than 171 individuals working for such firms ("high development"). Column (3) reports the coefficient for an intection term of first-borewell failure and a dummy indicating high development areas, where the sample includes all villages. All regressions include controls for household head literacy, age, caste, and the amount of inherited land, which are interacted with the high-development indicator in the Column (3) regressions. All regressions also include village fixed effects and fixed effects for the year in which the first borewell was drilled. Error terms are assumed to be clustered at the village level. Standard errors in brackets.

Appendix A

Figure A1: First Borewell, Depth and Year



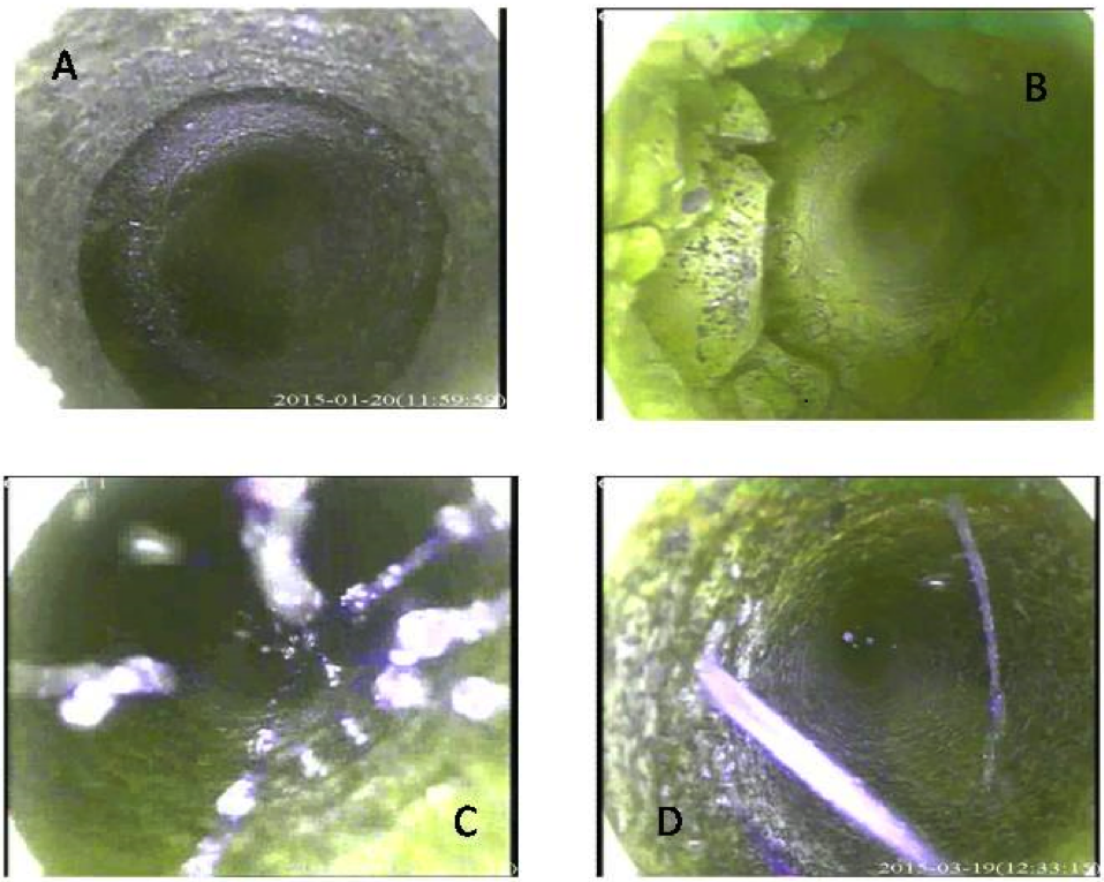
A1.1: Depth



A1.2: Year Drilled

Notes: Figure A1.1 shows the distribution of the depth of the first borewell. Figure A1.2 shows the distribution of the year in which the first borewell was drilled.

Figure A2: Borewell images



Notes: Figure A2 shows images taken from four borewells in the study area. A: Dry fracture in bedrock. B: Cavity formed in a fracture, now dried up. C: Fracture with cavity below the water level. D: Water-bearing shallow fracture, spout cascading down the well.

Table A1: Balance w.r.t. Borewell Characteristics

	All BWs	First BW			
	Number	Log Depth	Log Cost	Flow	Imm. Fail
	(1)	(2)	(3)	(4)	(5)
HH Head					
Hindu	-0.110 [0.300]	-0.096 [0.079]	0.081 [0.176]	-0.089 [0.283]	-0.144 [0.131]
Non-Marginal Caste	0.336 [0.143]	-0.004 [0.031]	-0.026 [0.065]	-0.038 [0.089]	0.018 [0.058]
Male	0.191 [0.122]	-0.070 [0.037]	-0.102 [0.059]	-0.086 [0.070]	0.071 [0.052]
Age	-0.003 [0.004]	-0.001 [0.001]	0.001 [0.002]	-0.000 [0.003]	0.001 [0.002]
Literate	0.184 [0.119]	-0.019 [0.030]	-0.066 [0.054]	0.058 [0.070]	-0.011 [0.051]
Education - none	-0.185 [0.119]	0.019 [0.030]	0.069 [0.055]	-0.064 [0.070]	0.011 [0.051]
Education - primary	-0.026 [0.158]	-0.027 [0.048]	0.004 [0.094]	0.037 [0.096]	-0.038 [0.082]
Education - secondary	0.217 [0.150]	0.002 [0.046]	-0.100 [0.066]	0.129 [0.092]	0.047 [0.078]
Education - post-secondary	0.067 [0.142]	-0.023 [0.036]	-0.048 [0.053]	-0.048 [0.074]	0.040 [0.056]
Number Children					
Aged 6-11	0.159 [0.065]	0.022 [0.016]	-0.009 [0.025]	-0.004 [0.030]	-0.000 [0.027]
Aged 12-18	0.125 [0.089]	0.026 [0.015]	-0.016 [0.026]	-0.022 [0.035]	0.006 [0.024]
Adult Sons	0.191 [0.125]	-0.044 [0.037]	-0.051 [0.057]	-0.116 [0.069]	0.070 [0.052]
Assets (at time 1st BW Drilled)					
Seed Drill	0.089 [0.149]	0.025 [0.040]	-0.002 [0.064]	-0.132 [0.074]	0.084 [0.063]
Tractor	1.284 [0.853]	0.077 [0.076]	0.129 [0.134]	-0.099 [0.175]	0.023 [0.125]
Thresher	1.536 [0.638]	-0.230 [0.272]	-0.164 [0.544]	-0.265 [0.245]	0.061 [0.407]
Motorcycle	0.315 [0.206]	0.034 [0.053]	0.021 [0.074]	0.023 [0.095]	-0.011 [0.069]
Inherited Land (acres)	0.065 [0.013]	-0.007 [0.003]	-0.014 [0.004]	-0.002 [0.005]	0.004 [0.004]
Agriculture (at time 1st BW Drilled)					
Cash Crops	-0.153 [0.148]	0.039 [0.036]	-0.015 [0.066]	-0.108 [0.073]	-0.034 [0.063]
Irrigation	0.089 [0.149]	0.025 [0.040]	-0.002 [0.064]	-0.132 [0.074]	0.084 [0.063]
Village F.E.	Yes	Yes	Yes	Yes	Yes
First-BW Year-Drilled F.E.	Yes	Yes	Yes	Yes	Yes

Note: Household characteristics and household drilling history. Each column reports estimates from a separate regression of the total number of borewells drilled (Column 1) and characteristics of the first borewell (depth, cost, initial flow in mm, and whether the well had failed immediately, Columns 2-5) on household characteristics indicated in the left column. All specifications include village fixed effects and fixed effects for the year in which the first borewell was drilled. Error terms are assumed to be clustered at the village level. Standard errors in brackets.

Table A2: Borewell Failure

	First Borewell Failed (binary)					
	(1)	(2)	(3)	(4)	(5)	(6)
Log Age First BW	0.127	0.103		0.118	0.088	
	(0.024)	(0.029)		(0.024)	(0.028)	
Log Depth First BW	0.080	0.049	0.054			
	(0.034)	(0.047)	(0.050)			
Log Cost First BW				-0.025	-0.044	-0.047
				(0.024)	(0.028)	(0.029)
HH Head Literate	-0.013	-0.024	-0.023	0.001	-0.025	-0.025
	(0.038)	(0.036)	(0.038)	(0.038)	(0.036)	(0.037)
HH Head Age	0.000	-0.001	-0.000	0.000	-0.001	-0.000
	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)
HH Head Non-Marginal Caste	0.045	0.016	0.012	0.055	0.017	0.014
	(0.039)	(0.042)	(0.044)	(0.038)	(0.042)	(0.043)
Inherited Land (acres)	-0.002	0.002	0.002	-0.004	0.001	0.001
	(0.003)	(0.003)	(0.003)	(0.003)	(0.003)	(0.003)
R-squared	0.059	0.193	0.239	0.055	0.195	0.242
N	892	891	876	892	891	876
Village F.E.		Yes	Yes		Yes	Yes
First-BW Year-Drilled F.E.			Yes			Yes

Note: Estimated correlates of first borewell failure. Each column reports estimates from a separate regression of an indicator of first borewell failure on the variables indicated in the left column. Columns (2), (3), (5), and (6) include village fixed effects, and Columns (3) and (6) include fixed effects for the year in which the first borewell was drilled. Error terms are assumed to be clustered at the village level. Standard errors in brackets.

Table A3: Borewell Failure (Well Census)

	Borewell Failed	
	(1)	(2)
Number of Sources	-0.068	-0.063
	[0.024]	[0.024]
Log Age	0.259	0.222
	[0.023]	[0.030]
Log Depth		-0.081
		[0.043]
Constant	0.277	0.494
	[0.081]	[0.140]
R-squared	0.212	0.237
N	434	434

Note: Estimates of a regression of a binary indicator of borewell failure on the number of sources intercepted by the well. In Columns 2 and 3 the age and depth of the well are controlled for. The sample consists of a census of all operational and failed borewells in a cluster of villages in the study region. See section 4.2 for details. Error terms are assumed to be clustered at the village level. Standard errors in brackets.

Table A4: Borewell Failure and Labor Reallocation by Gender

	Control Mean	Impact of BW Failure	
	(1)	(2)	(3)
Panel A: Fraction of Adult Males (Dry Season)			
Working on Own Farm	0.634	-0.112	-0.114
		[0.030]	[0.031]
Working Off-Farm, Agriculture	0.165	0.065	0.068
		[0.031]	[0.030]
Working Off-Farm, Non-Agriculture	0.070	0.056	0.059
		[0.021]	[0.023]
Not Working	0.080	0.029	0.040
		[0.015]	[0.014]
Non-Migrant Working Outside Village	0.083	0.031	0.028
		[0.019]	[0.020]
Semi-Permanent Migrant (Annual)	0.012	0.020	0.021
		[0.008]	[0.009]
Panel B: Fraction of Adult Females (Dry Season)			
Working on Own Farm	0.370	-0.065	-0.077
		[0.032]	[0.033]
Working Off-Farm, Agriculture	0.078	0.056	0.059
		[0.023]	[0.023]
Working Off-Farm, Non-Agriculture	0.014	0.022	0.025
		[0.008]	[0.010]
Not Working	0.108	0.012	0.012
		[0.017]	[0.018]
Non-Migrant Working Outside Village	0.028	0.016	0.015
		[0.010]	[0.011]
Semi-Permanent Migrant (Annual)	0.006	0.005	0.006
		[0.005]	[0.006]
Village F.E.		Yes	Yes
First-BW Year-Drilled F.E.			Yes

Note: This table shows the estimated impacts of first borewell failure on outcomes indicated at the leftmost column. Each estimate is derived from a separate regression. Column (1) gives the mean level of the outcome variable in households that drilled a borewell and did not experience a first-borewell failure. Columns (2) and (3) report estimates of the coefficient α_2 in specification 1. All regressions include controls for household head literacy, age, caste, and the amount of inherited land, as well as village fixed effects. Column (3) includes fixed effects for the year in which the first borewell was drilled. Error terms are assumed to be clustered at the village level. Standard errors in brackets.

Table A5: Individual Assets

	Control Mean	Impact of BW Failure	
	(1)	(2)	(3)
Number of Asset			
Cattle	1.728	-0.301	-0.297
		[0.160]	[0.179]
Bicycle	0.531	-0.074	-0.070
		[0.041]	[0.044]
Motorcycle	0.609	-0.028	-0.027
		[0.044]	[0.045]
Car	0.036	0.004	0.006
		[0.016]	[0.015]
Refrigerator	0.173	-0.077	-0.078
		[0.027]	[0.028]
TV	0.887	-0.030	-0.009
		[0.027]	[0.026]
Gold (ounces)	32.024	-20.816	-22.983
		[8.204]	[9.214]
Village F.E.		Yes	Yes
First-BW Year-Drilled F.E.			Yes

Note: This table shows the estimated impacts of first borewell failure (Columns 2 and 3) on outcomes indicated at the leftmost column. "Cattle" is the aggregation of bullocks, buffloes, and cows. Each estimate is derived from a separate regression. Column (1) gives the mean level of the outcome variable in households that drilled a borewell and did not experience a first-borewell failure. Columns (2) and (3) report estimates of the coefficient α_2 in specification 1. All regressions include controls for household head literacy, age, caste, and the amount of inherited land, as well as village fixed effects. Column (3) includes fixed effects for the year in which the first borewell was drilled. Error terms are assumed to be clustered at the village level. Standard errors in brackets.

Table A6: Controlling for Borewell Characteristics

	Impact of BW Failure			
	Benchmark	First Borewell Controls		
	(1)	(2)	(3)	(4)
Fraction of HH Members (Dry Season)				
Working on Own Farm	-0.104	-0.101	-0.095	-0.089
	[0.025]	[0.027]	[0.028]	[0.029]
Working Off-Farm, Agriculture	0.064	0.065	0.055	0.055
	[0.021]	[0.022]	[0.022]	[0.022]
Working Off-Farm, Non-Agriculture	0.042	0.042	0.041	0.038
	[0.014]	[0.014]	[0.014]	[0.014]
Not Working	0.029	0.028	0.024	0.025
	[0.014]	[0.014]	[0.015]	[0.015]
Non-Migrant Working Outside Village	0.028	0.027	0.028	0.025
	[0.014]	[0.015]	[0.015]	[0.015]
Semi-Permanent Migrant (Anuual)	0.014	0.014	0.017	0.017
	[0.007]	[0.008]	[0.007]	[0.008]
Income (1,000 Rs.)				
On-Farm	-14.083	-15.322	-12.473	-12.223
	[6.325]	[6.672]	[6.786]	[6.870]
Off-Farm	12.182	11.474	12.217	11.869
	[6.017]	[6.313]	[6.398]	[6.672]
Total	-1.900	-3.848	-0.256	-0.355
	[9.500]	[9.826]	[10.359]	[10.387]
Village F.E.	Yes	Yes	Yes	Yes
First-BW Year-Drilled F.E.	Yes	Yes	Yes	Yes
Log BW Depth	No	Yes	No	Yes
Log BW Cost	No	No	Yes	Yes

Note: Estimated impacts of first borewell failure on outcomes indicated at the leftmost column. Each estimate is derived from a separate regression (the coefficient α_2 in specification 1). Column (1) reports estimates from the benchmark standard specficiation. Column (2) controls for the depth of the first borewell, Column (3) controls for the cost of the first borewell and Column (4) controls for both. All regressions include controls for household head literacy, age, caste, and the amount of inherited land, as well as village fixed effects and fixed effects for the year in which the first borewell was drilled. Error terms are assumed to be clustered at the village level. Standard errors in brackets.

Table A7: Robustness Test: Immediate and Non-Immediate Failures

	Impact of BW Failure		
		Failed Borewell Sample:	
	Benchmark	Non-Immed.	Immediate
	(1)	(2)	(3)
Fraction of HH Members (Dry Season)			
Working on Own Farm	-0.104	-0.086	-0.117
	[0.025]	[0.033]	[0.029]
Working Off-Farm, Agriculture	0.064	0.053	0.068
	[0.021]	[0.024]	[0.030]
Working Off-Farm, Non-Agriculture	0.042	0.039	0.037
	[0.014]	[0.016]	[0.017]
Not Working	0.029	0.025	0.045
	[0.014]	[0.019]	[0.018]
Non-Migrant Working Outside Village	0.028	0.027	0.027
	[0.014]	[0.017]	[0.018]
Semi-Permanent Migrant (Annual)	0.014	0.013	0.012
	[0.007]	[0.005]	[0.011]
Income (1,000 Rs.)			
On-Farm	-14.083	-15.810	-11.470
	[6.325]	[7.879]	[7.085]
Off-Farm	12.182	7.693	14.461
	[6.017]	[6.261]	[10.263]
Total	-1.900	-8.118	2.991
	[9.500]	[9.914]	[13.639]
Village F.E.	Yes	Yes	Yes
First-BW Year-Drilled F.E.	Yes	Yes	Yes
Num of First-BW Failures	582	347	240
Num of First-BW Non-Failures	305	305	305

Note: Estimated impacts of first borewell failure on outcomes indicated at the leftmost column. Each estimate is derived from a separate regression (the coefficient α_2 in specification 1). Column (1) gives the benchmark estimates derived from the entire sample. Column (2) restricts the sample of failed first borewells only to those which did not fail within the first year; and column (3) restricts the sample of failed first borewells only to those which did fail within the first year. All specifications include controls for household head literacy, age, caste, and inherited land; as well as village fixed effects and fixed effects for the year in which the first borewell was drilled. Error terms are assumed to be clustered at the village level. Standard errors in brackets.

Table A8: Heterogeneous Effects by Local Economic Development

	Impact of BW Failure		
	Development		
	Low	High	Difference
	(1)	(2)	(3)
Children Aged 6–11			
Fraction Enrolled	0.016	0.220	0.204
	[0.081]	[0.078]	[0.113]
Fraction Working	-0.004	0.000	0.004
	[0.010]	[0.000]	[0.011]
Children Aged 12–18			
Fraction Enrolled	-0.063	-0.160	-0.097
	[0.053]	[0.077]	[0.093]
Fraction Working	0.017	0.150	0.133
	[0.046]	[0.063]	[0.078]
Village F.E.	Yes	Yes	Yes
First-BW Year-Drilled F.E.	Yes	Yes	Yes

Note: Estimated impacts of first borewell failure on outcomes indicated at the leftmost column, segregated by local rates of economic development. Each estimate is derived from a separate regression. Column (1) reports estimates of the coefficient α_2 in specification 1 limiting the sample to villages in which fewer than 171 individuals work for firms with 15 or more employees within 5 kilometers ("low development"); and in Column (2) to villages with more than 171 individuals working for such firms ("high development"). Column (3) reports the coefficient for an intection term of first-borewell failure and a dummy indicating high development areas, where the sample includes all villages. All regressions include controls for household head literacy, age, caste, and the amount of inherited land, which are interacted with the high-development indicator in the Column (3) regressions. All regressions also include village fixed effects and fixed effects for the year in which the first borewell was drilled. Error terms are assumed to be clustered at the village level. Standard errors in brackets.

Table A9: Robustness Test: Alternative Time Controls

	Impact of BW Failure			
	First BW Year-Drilled Controls:			
	Year F.E.		5-Year Intervals	
	(1)	(2)	(3)	(4)
Fraction of HH Members (Dry Season)				
Working on Own Farm	-0.104	-0.112	-0.099	-0.108
	[0.025]	[0.029]	[0.025]	[0.026]
Working Off-Farm, Agriculture	0.064	0.032	0.057	0.053
	[0.021]	[0.024]	[0.019]	[0.021]
Working Off-Farm, Non-Agriculture	0.042	0.058	0.038	0.043
	[0.014]	[0.015]	[0.013]	[0.014]
Not Working	0.029	0.034	0.026	0.024
	[0.014]	[0.019]	[0.013]	[0.014]
Non-Migrant Working Outside Village	0.028	0.037	0.029	0.029
	[0.014]	[0.018]	[0.013]	[0.015]
Semi-Permanent Migrant (Annual)	0.014	0.019	0.013	0.010
	[0.007]	[0.008]	[0.006]	[0.006]
Income (1,000 Rs.)				
On-Farm	-14.083	-17.639	-15.947	-14.746
	[6.325]	[6.892]	[6.126]	[5.808]
Off-Farm	12.182	18.635	9.284	11.719
	[6.017]	[7.754]	[5.652]	[5.830]
Total	-1.900	0.996	-6.663	-3.027
	[9.500]	[9.863]	[8.772]	[8.165]
Village F.E.	Yes	Yes	Yes	Yes
Year F.E.	Yes			
District F.E. X Year F.E.		Yes		
5-Year Bins			Yes	
District F.E. X 5-Year Bins				Yes

Note: Estimated impacts of first borewell failure on outcomes indicated at the leftmost column. Each estimate is derived from a separate regression (the coefficient α_2 in specification 1). Columns (1), (3), and (5) give the estimates when including, respectively, fixed effects for the year in which the first borewell was drilled, the log age of the first borewell, and fixed effects for 5-year bins in which the first borewell was drilled. Columns (2), (4), and (6) include interactions of the district fixed effects with the above three controls for the year in which the first borewell was drilled. All specifications include controls for household head literacy, age, caste, and inherited land; as well as village fixed effects. Error terms are assumed to be clustered at the village level.

Table A10: Heterogeneous Effects by Local Groundwater Situation

	Impact of BW Failure, BW Failure Rate: High	Impact of BW Failure, BW Failure Rate: Low	Difference
	(1)	(2)	(3)
Fraction of HH Members (Dry Season)			
Working on Own Farm	-0.139	-0.080	0.059
	[0.035]	[0.035]	[0.049]
Working Off-Farm, Agriculture	0.054	0.066	0.013
	[0.026]	[0.037]	[0.045]
Working Off-Farm, Non-Agriculture	0.049	0.045	-0.004
	[0.019]	[0.019]	[0.027]
Not working	0.013	0.030	0.017
	[0.024]	[0.015]	[0.028]
Non-Migrant Working Outside Village	0.047	0.019	-0.028
	[0.021]	[0.020]	[0.029]
Semi-Permanent Migrant (Annual)	0.009	0.025	0.015
	[0.006]	[0.014]	[0.015]
Income (1,000 Rs.)			
On-Farm	-18.034	-20.051	-2.016
	[9.148]	[8.929]	[12.735]
Off-Farm	16.542	9.432	-7.110
	[10.782]	[6.521]	[12.554]
Total	-1.492	-10.619	-9.127
	[14.591]	[11.526]	[18.525]
Village F.E.	Yes	Yes	Yes
First-BW Year-Drilled F.E.	Yes	Yes	Yes

Note: Estimated impacts of first borewell failure on outcomes indicated at the leftmost column, segregated by local rates of economic development. Each estimate is derived from a separate regression. Column (1) reports estimates of the coefficient α_2 in specification 1 limiting the sample to villages in which more than 57% of households ever drilled a borewell lacked an operational borewell at the time of the survey ("high failure"); and in Column (2) to villages in which less than 57% lacked an operational borewell ("low failure"). Column (3) reports the coefficient for an intection term of first-borewell failure and a dummy indicating low-failure areas, where the sample includes all villages. All regressions include controls for household head literacy, age, caste, and the amount of inherited land, which are interacted with the low-failure indicator in the Column (3) regressions. All regressions also include village fixed effects and fixed effects for the year in which the first borewell was drilled. Error terms are assumed to be clustered at the village level. Standard errors in brackets.