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Sustaining Groundwater: Role of Policy Reforms in Promoting Conservation in India*

ABSTRACT Groundwater depletion has become an increasingly important policy concern in many countries around the world, especially in India, which is the largest user of groundwater for irrigation. Groundwater is contended to have ushered Green Revolution in the country. However, a downside to this pattern of development is that it is not sustainable. As in other countries, the stocks of groundwater are rapidly depleting in India. Against this backdrop, it is important to understand what policies can help conserve this vital resource. This study uses data from observation and monitoring wells of the country to identify depletion hot spots and evaluate the impact of two policies—rainwater harvesting mandates and delaying of paddy transplanting time—on water tables. Rainwater harvesting mandates did not have beneficial effects on water tables in the short run and delayed transplanting of paddy resulted in increased use of groundwater.

Keywords: *Groundwater Conservation, Sustainable Development*

JEL Classification: *O13, O38, Q15, Q25*

1. Introduction

India is the largest user of groundwater for irrigation in the world. The amount of groundwater drawn is estimated to be 230 billion cubic meters per year (in 2004) compared to 101 billion cubic meters in China and 108 billion cubic meters in US in 2005 (Food and Agriculture Organization, Aquastat dataset). Indian agriculture is sustained by groundwater. According to the 2005–06 Agricultural Census of the country, 60.4 percent of the net irrigated area is irrigated using groundwater. Agriculture is the source of livelihood for majority of Indian population. In 2009–10, agriculture

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employed 52.9 percent of the working population (National Sample Survey Office, 2011). In addition, around 80 percent of the rural population relies on groundwater for meeting their drinking water needs.

Groundwater is contended to have ushered Green Revolution in the country (Repetto 1994; Shah et al. 2007). Groundwater irrigation has ensured food security in times of deficit rainfall and facilitated a manifold increase in agricultural productivity. The country has become a net exporter of food grains. However, this pattern of development is not sustainable. As in other countries, the stocks of groundwater are rapidly depleting in India. According to the central groundwater board, 15 percent of the administrative blocks are overexploited (more water is extracted than is replenished each year) and are growing at a rate of 5.5 percent per annum.

India's legal framework allows for unchecked open access to groundwater. Riparian rights govern extraction of groundwater. Any person who owns land can extract groundwater free of cost. In addition to this, most states provide huge electricity subsidies to the farm sector. In large agricultural states such as Punjab and Tamil Nadu, farmers get free electricity. In other states, electricity is not metered but provided at a flat rate based on horse power of the pumps used for groundwater extraction. The central governments assured minimum support pricing policy distorts the prices of food grains such as wheat, and more importantly, paddy incentivizing growing paddy in areas not conducive for it. These factors compound the depletion problem.

Against this backdrop, it is important to understand what policies can help conserve this vital resource. There are more than 27 million private tube wells in the country (Shankar et al. 2011). Pervasive usage of individual wells makes monitoring and enforcement extremely difficult, and hence impedes conventional policy design to check overextraction. Therefore, public policy focus has mostly been on supply side interventions. This study uses data from observation and monitoring wells to evaluate the impact of two policies—rainwater harvesting mandates and delaying of paddy transplanting time—on water tables.

This paper has three objectives. First, the paper highlights the depletion hot spots and trends in water table decline in these hot spots. Second, the paper summarizes the literature to establish the expected welfare costs of groundwater depletion. Third, the paper presents detailed evaluation of three policies targeted toward reversing water table decline in various parts of the country. The paper is organized as follows: Section 2 discusses current groundwater situation and trends in groundwater decline in the entire country. Section 3 discusses potential welfare implications of declining groundwater levels. In section 4, I provide detailed discussion of the three policies being evaluated in this paper. Section 5 provides concluding remarks including comments on the characteristics of policies that can effectively address the issue of declining groundwater levels.

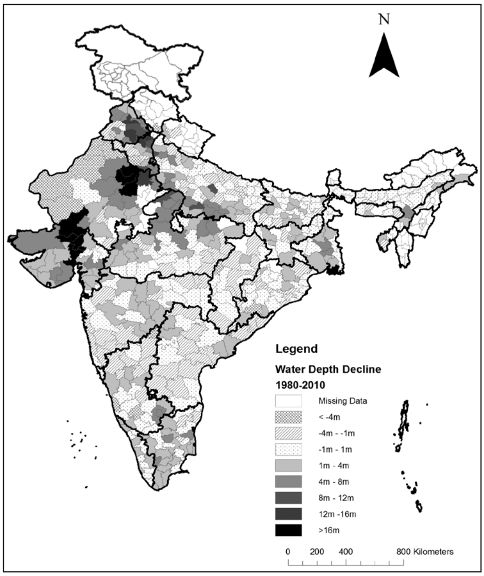
2. Current Groundwater Scenario and Depletion Trends

In this section, I highlight the spatial distribution of the current groundwater situation in the country and the trends in the depletion rates. For the purposes of this assessment, I use the monitoring wells (observation wells) level data for each well from 1980 onwards and the spatial boundaries of Indian districts from Census of India 2001. Monitoring wells data contains 4 quarterly observations on level of groundwater in meters below ground level (mbgl). Annual averages are constructed for each district for each year using this data.

Figure 1 shows the changes in the stock of groundwater over a period of 30 years between 1980 and 2010 (negative numbers indicate rises in the water level). The most substantial decline in groundwater level is observed in northwestern India. In parts of Gujarat and Rajasthan, groundwater level fell more than 16 meters over this period. In central Punjab and Haryana, the groundwater level declined between 12 and 16 meters. Other pockets of Punjab, Haryana, Rajasthan, Gujarat, Western Uttar Pradesh, and New Delhi also experienced noticeable declines between 8 and 12 meters. A few districts in coastal Gujarat, central Rajasthan, Madhya Pradesh, Uttar Pradesh, West Bengal, Karnataka, and Tamil Nadu saw a decline of 4 to 8 meters. In addition, a 1 to 4 meters' decline over this period was widespread, extending to many other states. Figure 2 panels A, B, and C show the patterns of decline by decade. Groundwater depletion had already commenced between 1980 and 1990. But in the following decades, there was a sharp downward trend in the northwestern region of the country. Trends in groundwater level for states in the top quartile of absolute water table decline and top quartile of percentage change are shown in Figure 3, panels A and B. Punjab, Gujarat, and Delhi experienced the largest quantum of change. Figure 4 shows the area within states that experienced different degrees of decline. Delhi has the largest area experiencing the worst decline, followed by Punjab.

The cost of extracting groundwater depends on the depth of water table. There is a sharp rise in the fixed cost of extracting groundwater at around 8 meters. At 8 meters, surface pumps become infeasible to extract water and farmers have to invest in more expensive technologies such as submersible

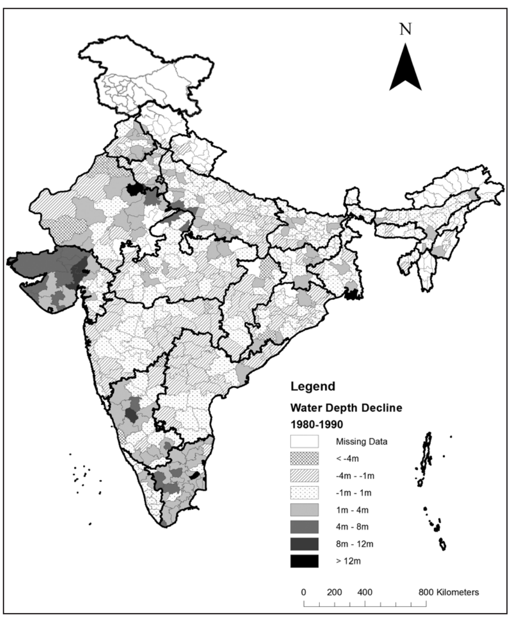
FIGURE 1. Changes in India District Groundwater Depth, 1980–2010



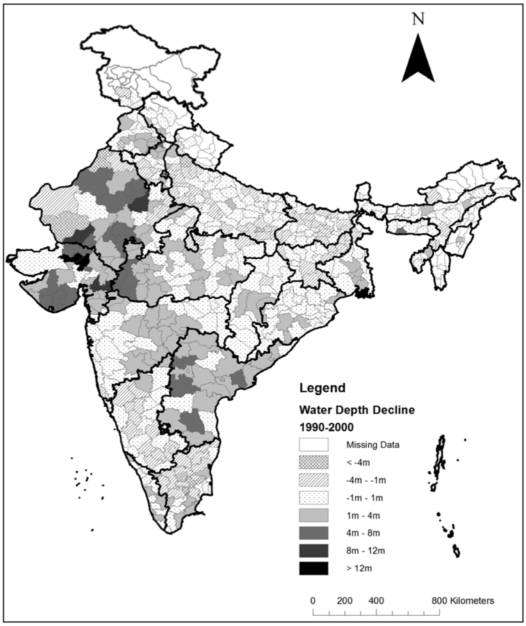
Source: Based on author's calculations.

FIGURE 2. Decadal Changes in Indian District Groundwater Depth

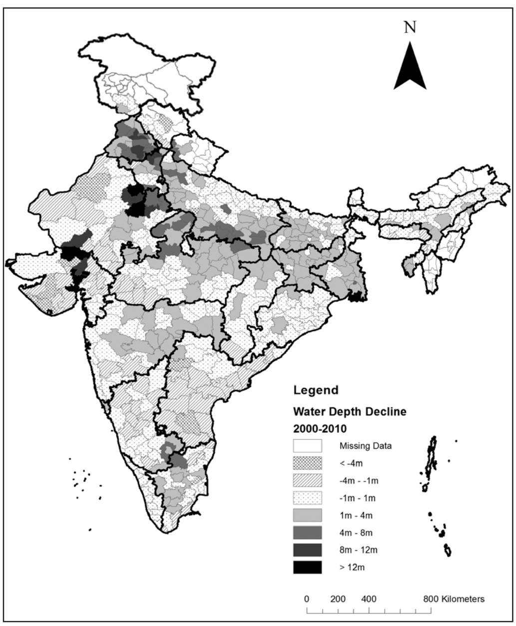
Panel A: Changes in Indian District Groundwater Depth, 1980–1990



Panel B: Changes in Indian District Groundwater Depth, 1990–2000



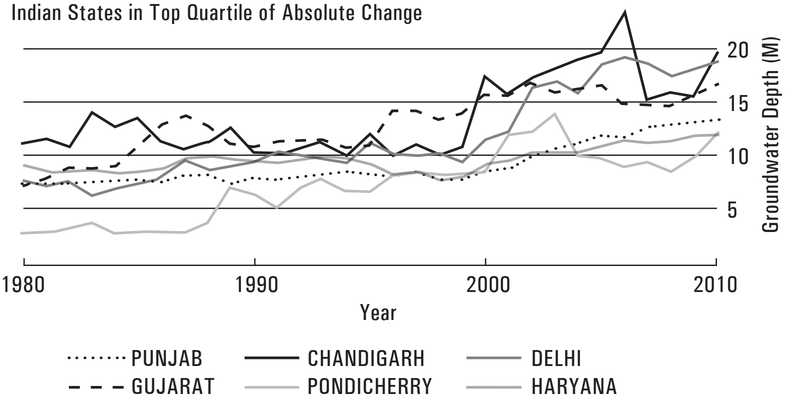
Panel C: Changes in Indian District Groundwater Depth, 2000–2010



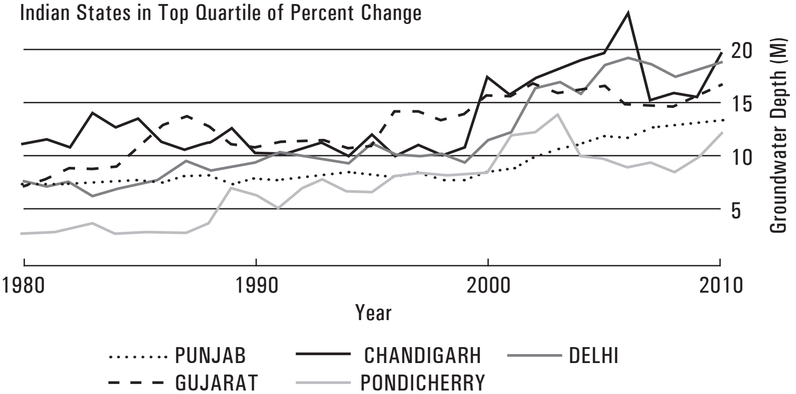
Source: Based on author's calculations.

FIGURE 3. District Groundwater Depth in Selected States, 1980–2010

Panel A: Groundwater Depth, 1980–2010
Indian States in Top Quartile of Absolute Change



Panel B: Groundwater Depth, 1980–2010
Indian States in Top Quartile of Percent Change

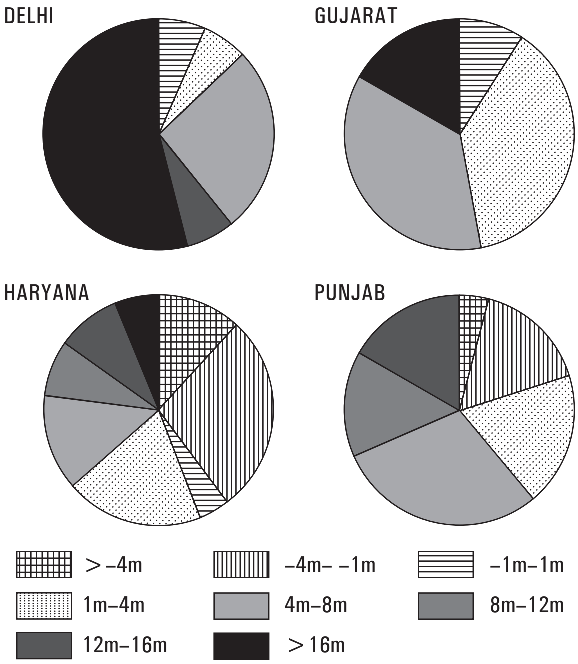


Source: Based on author's calculations.

pumps to extract groundwater.[1] From social and economic perspective, it becomes important to determine the extent of depletion where water tables fall from over 8 meters to below 8 meters. Figure 5 shows the proportion of districts in selected states where the water table has fallen below 8 meters between 1980 and 2010. Most districts in Punjab have experienced such patterns of decline. Other states including Haryana, New Delhi, Gujarat, Rajasthan, Madhya Pradesh, Maharashtra, Uttar Pradesh, Bihar, Jharkhand, West Bengal, Andhra Pradesh, Pondicherry, Kerala, and Tamil Nadu also

1. Surface pumps use atmospheric pressure to draw water. Atmospheric pressure can practically support the weight of a column of water of height 8 meters.

FIGURE 4. District Groundwater Depth Changes Selected States, 1980–2010



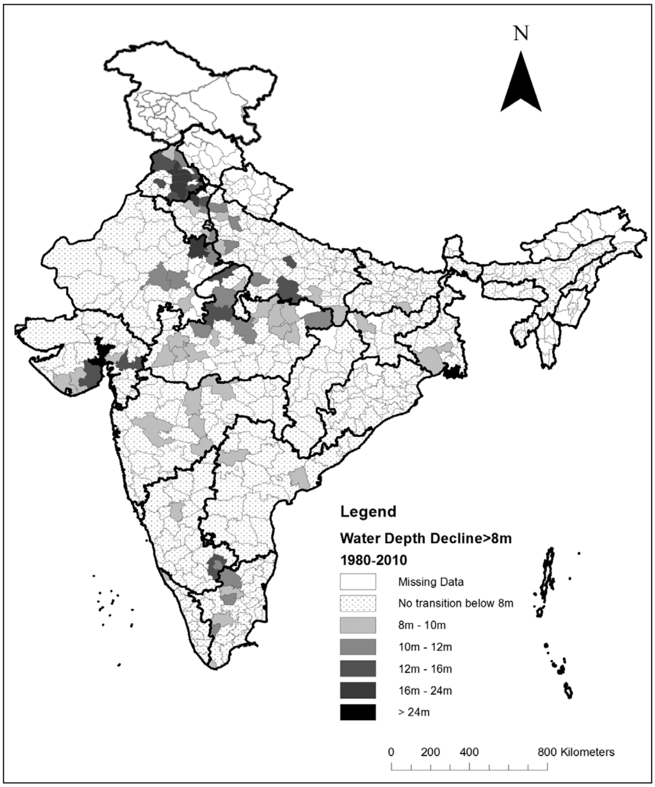
Source: Based on author's calculations.

have pockets where declines of water table are costly to the farmers. Figure 6 shows the trends over time in the top five states—Punjab, Gujarat, Delhi, Pondicherry, and Madhya Pradesh—where average groundwater depth went from above 8 meters to below 8 meters. Figure 7 shows the area of the states that experienced decline from above 8 to below 8 meters. Punjab had the largest area experiencing such decline, followed by Pondicherry, Madhya Pradesh, Haryana, New Delhi, and Gujarat.

Three important facts emerge from these figures. One, the decline in water tables in India is spatially heterogeneous with northwestern region affected the most.[2] Two, the bread basket states, including Punjab and Haryana with endowments of thick aquifers, are experiencing significant declines in water tables. These states are the role models of Green Revolution. Three, the decline has accelerated over time.

2. This is consistent with other findings using recent satellite based data. Data from NASA's GRACE satellites shows significant depletion of groundwater levels in Northern India. Non-renewable aquifers are being mined over large areas (NASA 2009).

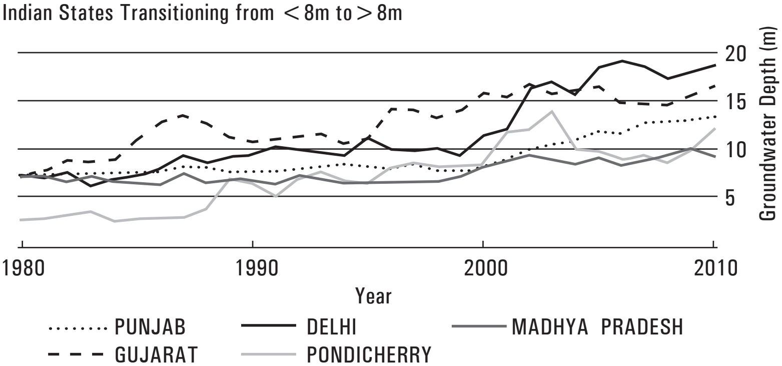
FIGURE 5. Costly Changes in Indian District Groundwater Depth, 1980–2010



Source: Based on author's calculations.

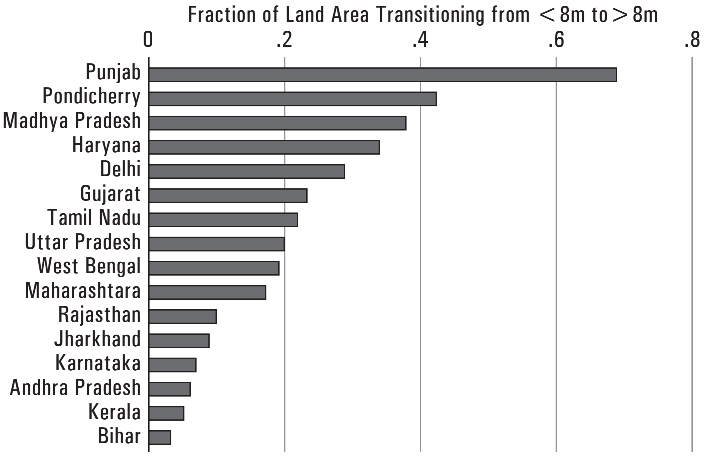
FIGURE 6. Groundwater Depth, 1980–2010

Indian States Transitioning from < 8m to > 8m



Source: Based on author's calculations.

FIGURE 7. Costly Changes in Indian State Groundwater Depth, 1980–2010



Source: Based on author's calculations.

3. Why Is Conservation Vital? Poverty and Other Implications

From welfare perspective, rapid decline in water tables can result in significant social cost. Case studies have documented that access to groundwater can reduce poverty and ensure food security (Moench 2001; Moench 2003; Mukherji 2008). Sekhri (2011a) uses groundwater data in conjunction with annual agricultural output data at the district level to show that a 1-meter decline in groundwater from its long-term mean can reduce food grain production by around 8 percent. Controlling for district fixed effects, year fixed effects, and district-specific trends, this paper uses the plausibly exogenous fluctuations in groundwater depth from long-term means to estimate the effect of groundwater scarcity on food grain production. A 1-meter decline of groundwater depth results in very large reduction in food grain production. Given that groundwater irrigation is the main stay of irrigation in India, this is not unexpected. Consistent with previous field studies, this paper shows that groundwater depletion can have significant effect on food security in the country.

Sekhri (2012) identifies the causal impact of groundwater scarcity on poverty. Using village-level data from Uttar Pradesh, and exploiting the fact that there is a nonlinearity in cost required to access groundwater at 8 meters, this study shows that poverty rate increases by around 11 percent as groundwater depth falls below 8 meters. The full sample estimation controls for other village characteristics that may be correlated with poverty rate and hence, generate omitted variable bias. These include geographical controls like rainfall and temperature; geological controls like elevation and slope; demographic characteristics like population, literacy rate, total female population; infrastructure including availability of schools, medical facilities, access to electricity, distance to nearest town, village council expenditure on public goods, banking facility and bus service. This study uses a regression discontinuity design for identification. Both parametric and nonparametric techniques have been used to show that the results do not depend on the estimation method. The study provides a variety of tests to substantiate the findings. This study also shows that self-reported conflict over irrigation water increases substantially near the cutoff. The findings echo the results of field studies. Groundwater scarcity increases poverty. On the flip side, uncontrolled access can lead to very rapid depletion. Therefore, sustainable access to groundwater is required to curb poverty in rural areas of the country. One limitation of this study is that is provides a static estimate. How poverty dynamically evolves with groundwater depletion is not well-understood. More work is required to understand and estimate the optimal level of depletion in the long term.

In Gujarat, where the water tables are falling almost at a rate of 3 meters a year, Narula et al. (2011) estimate that water savings of 30 percent can free up 2.7 billion units of electricity for nonagricultural use. Department of Drinking Water Supply, Government of India, estimates that in 2010, approximately 15 percent of the total habitations in the country went from full coverage of drinking water to partial coverage due to drying up of sources. These findings indicate that the welfare costs of groundwater depletion are very large in magnitude, and thus groundwater depletion warrants an appropriate policy response.

4. Policy Response

State governments have introduced policies with the objective to reverse these trends of rapidly falling groundwater. One of the first policies that has been introduced across many states is mandated rainwater harvesting. States opted into selecting various measures for mandating rainwater harvesting. These measures included construction of rainwater harvesting structures on the roofs of buildings which met specific size criterion. Delhi was the first to pass this mandate in 2001. The other states that mandated rainwater harvesting include Andhra Pradesh, Tamil Nadu, Kerala, Madhya Pradesh, Rajasthan, Bihar, and West Bengal. Table 1 provides details of the mandates along with the dates on which the mandates were passed. In this paper, I conduct a district-level analysis to examine whether such mandates have had any short-run impact on water table decline.

TABLE 1. Rainwater Harvesting Mandates

State	*Year passed*	*Description*
Delhi	2001	RWH mandatory for all new buildings with more than 100 sq m roof area and all newly developed plots of land larger than 1,000 sq m. Also,mandated RWH by March 31, 2002 for all institutions and residential colonies in notified areas (south and southwest Delhi, and adjoining areas) and all buildings in notified areas that have tubewells
Andhra Pradesh	2002	Andhra Pradesh Water, Land and Tree Act, 2002 stipulates mandatory provision to construct RWH structures at new and existing constructions for all residential, commercial and other premises and open space having area of not less than 200 sq m in the stipulated period, failing which the authority construct such RWH structures and recover the cost incurred along a prescribed penalty
Tamil Nadu	2003	Vide Ordinance No. 4 of 2003 dated July 2003 mandates RWH facilities for all existing and new buildings. Like Andhra Pradesh, the state may construct RWH facilities and recover the cost incurred by means of property taxes
Kerala	2004	Roof top RWH is mandatory for all new buildings as per Kerala Municipality Building (Amendment) Rules, 2004
Madhya Pradesh	2006	The State Govt. vide Gazette notification dated 26.8.2006, has made roof top RWH mandatory for all buildings with plot size larger than 140 sq.m. Also there is a 6 percent rebate in property tax to individuals for the year in which the individual installs roof top RWH structures
Rajasthan	2006	Roof Top RWH is mandatory in state-owned buildings and all buildings with plots larger than 500 sq m in urban areas
Bihar	2007	The Bihar Groundwater Act, enacted in 2007, mandates privions of RWH structures for buildings with plots larger than 1000 sq m
West Bengal	2007	Vide Rule 171 of the West Bengal Municipal (Building) Rules, 2007, mandates installation of RWH system on new and existing buildings

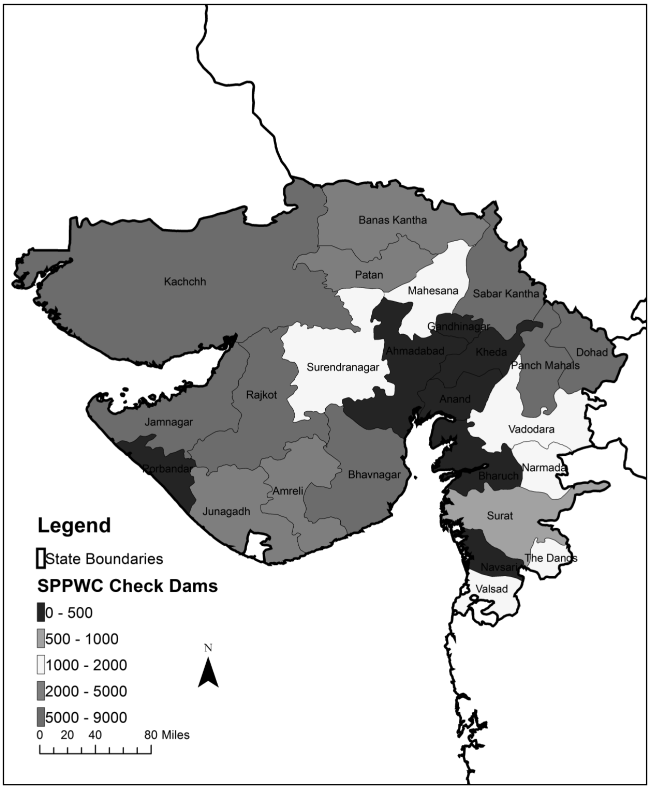
Sources: http://www.rainwaterharvesting.org/Policy/Legislation.htm#
State profiles at http://cgwb.gov.in/gw_profiles/st_ap.htm
http://www.cseindia.org/content/legislation-rainwater-harvesting.

I also examine the impact of a policy pursued by the Gujarat government that promoted decentralized rainwater harvesting. Concentrated efforts to recharge groundwater began in the Saurashtra region of Gujarat after the drought of 1987 (Mehta 2006). Initial efforts to divert run-off to groundwater wells led to widespread adoption of the practice by farmers throughout Saurashtra without government intervention. Over time, farmers experimented with new technologies and farmers began constructing check dams in streams and rivers to reduce water speed and to allow the river water to seep into the ground and replenish the groundwater supply (Mehta 2006). Farmers continued constructing check dams through the 1990s with assistance from nongovernmental organizations (NGOs) who bore some of the costs.

In January2000, Gujarat government introduced the Sardar Patel Participatory Water Conservation Project in response to the work of farmers and NGOs in the Saurashtra, Kachchh, Ahmedabad, and Sabar Kantha regions (Government of Gujarat 2012b). The first phase of the program ran from January 17, 2000 to February 20, 2001, and 10,257 check dams were constructed by September 1, 2000. The program initially funded 60 percent of the estimated cost of new check dams, and beneficiaries/NGOs financed the remaining 40 percent. By early 2004, almost 24,500 check dams had been constructed, of which roughly 18,700 were in the Saurashtra region (Pandya 2004). In 2005, the government increased its financing to 80 percent of the estimated cost, and the pace of construction increased outside of the Saurashtra region. According to statistics from the Gujarat government, 70,719 check dams had been constructed in total under the project by the end of March, 2012. Of these, 26,799 (38 percent) are in the Saurashtra region, and 22,257 (31 percent) are in Kachchh or North Gujarat (Government of Gujarat 2012a). Figure 8 shows the geographic distribution of check dams constructed under the Sardar Patel Participatory Water Conservation Project.

As discussed above, Punjab and Haryana are experiencing very rapid decline in water tables (see Figure 8). This can threaten future food security in the country. Punjab did not mandate rainwater harvesting. One of the key initiatives undertaken in Punjab to decelerate water table decline is mandated delay of paddy transplanting. In 2006, the state government influenced the date of paddy transplanting by changing the date on which free electricity is diverted to the farm sector for operating mechanized tube wells for groundwater extraction. The date was pushed to June 10, thereby reducing the amount of intensive watering that the crop can receive during its production cycle (Tribune News Service 2006). The delayed date was mandated in 2008 via an ordinance. This was later turned into a law: The Punjab Preservation of Sub-Soil Water Act, 2009. The main purpose of the law is to preserve groundwater by prohibiting sowing paddy before May 10 and transplanting paddy before June 10. In addition, the law creates the

FIGURE 8. SPPWC Check Dams in Gujarat, March 2012



Source: Based on author's calculations.

authority to destroy, at the farmer's expense, paddy sowed or transplanted early, and the law assesses a penalty of ₹10,000 per month, per hectare of land in violation of the law (Government of Punjab 2009).

Haryana followed suit and mandated delay in paddy transplanting in 2009. Haryana passed its Preservation of Sub-Soil Water Act in March 2009, and it is very similar to the Punjab act. Its main provisions prohibit sowing paddy before May 15 and transplanting paddy before June 15. The law also contains punitive provisions similar to Punjab. These include destruction of paddy sowed or transplanted early and a penalty of ₹10,000 per month, per hectare of land in violation of the law (Government of Haryana 2009). The law took immediate effect for the 2009 paddy season.[3] In this paper, I make

3. Singh (2009) provides more details.

use of the timing of the introduction of this policy in Punjab and Haryana to isolate the causal effect of the policy on water tables. Because of the de facto prohibition of transplanting paddy before June 10 in Punjab, I treat 2006 as the effective year for Punjab's policy rather than 2008.

4.1. Data

Data from several sources have been combined to analyze the trends in Indian groundwater levels since 1980, and to evaluate the impact of various policies on water table decline. The groundwater level data are from the Indian Central Groundwater Board. Individual monitoring well data has been used to construct measures of district groundwater depth from 1980 through 2010. The precipitation data from the University of Delaware Center for Climactic Research have been used to calculate district annual average monthly precipitation through 2008. The district precipitation data from the India Meteorological Department has been used for the years 2009 to 2010. In addition, district demographic and socioeconomic characteristics are from the 2001 Census of India. Area under various crops by districts is from the Directorate of Economics and Statistics, Department of Agriculture and Cooperation, Ministry of Agriculture. This has been used to classify districts as high rice growing districts as explained later.

4.1.1. Groundwater Data The Indian CGWB measures groundwater depth throughout each year at approximately 16,000 monitoring wells across India. In this paper, I use observations from 1980 to 2010 to construct district-level measures of groundwater depth. Groundwater depth is typically measured in January, May, August, and November although some wells have more or fewer observations within a given year. The number of wells in the sample increased greatly over the years. There were 3,305 wells in 1980; 11,063 in 1990; 15,782 in 2000; and 13,683 in 2010. The density of wells in states increased to cover more geographical area and more states started coverage. In the policy analysis conducted later, I use observations from year 2000 to 2010. During this time, the number of wells was, by and large, stable. The monitoring wells are spread over the entire country and not concentrated in any particular area. Wells have not been located in places where the groundwater has been depleting the most. For these reasons, endogenous well placement will not be a concern in the policy analysis.

In addition to groundwater depth, the data include latitude and longitude for each well, and I use this information to match each well to the spatial boundaries of the Indian districts in 2001 and construct a district-level panel of monthly and annual groundwater depth. These district-level measures of groundwater levels are the primary outcomes studied in this paper.

4.1.2. Precipitation Data I use precipitation data from the University of Delaware and the India Meteorological Department to control for annual variation in precipitation which greatly affects groundwater depth. The Center for Climactic Research at the University of Delaware compiled monthly weather station data from 1900 to 2008 from several sources.[4] From this data, all grid points within India's administrative boundaries were extracted to construct district-level annual average and monthly precipitation in each year. Since the Center for Climactic Research's data only cover years through 2008, I use data from the India Meteorological Department for 2009 to 2010. The India Meteorological Department collects monthly rainfall data for all Indian districts and publishes tables for each district containing monthly rainfall for the past five years (India Meteorological Department 2012). For 2009 to 2010, district-level annual average and monthly precipitation was calculated from these tables.

4.1.3. Demographic Data The 2001 Indian census data has been used to control for district demographic and socioeconomic characteristics. Specifically, district population, percentage of the district population with at least some college education, district literacy rate, district employment rate, and the percentage of the district population that is female have been controlled. Because these variables have not been observed in intercensal years, these have been interacted with indicators for each year in the sample to control for these characteristics non-parametrically in regression analysis.

4.1.4. Crop Production Data Data on area under various crops by district has been used to construct high rice production and low rice production district groups in the analysis of Punjab's and Haryana's policies to delay paddy transplanting before the middle of June. Specifically, the fraction of

4. These sources include the Global Historical Climatology Network, the Atmospheric Environment Service/Environment Canada, the Hydrometeorological Institute in St Petersburg, Russia, GC-Net, the Automatic Weather Station Project, the National Center for Atmospheric Research, Sharon Nicholson's archive of African precipitation data, Webber and Willmott's (1998) South American monthly precipitation station records, and the Global Surface Summary of Day. After combining data from various sources, the Center for Climactic Research used various spatial interpolation and cross-validation methods to construct a global 0.5 degree by 0.5 degree latitude/longitude grid of monthly precipitation data from 1900 to 2008 (Matsuura and Wilmott 2009).

cultivated area under rice for each district in Punjab and Haryana has been calculated. I then classify districts in Punjab and Haryana above the median as "high rice growing districts."

4.2. Conceptual Framework

The change in the depth of groundwater is a function of demand side variables, supply side variables, and natural recharge rate.

The change in depth can be modeled as:

$$W_t - W_{t-1} = R_t - D_t + S_t + E_t$$

where R_t is the rate of recharge. This would be influenced by the geology of the place including soil characteristics, slope, elevation, and such features. These features are time invariant. The recharge will also be affected by precipitation. D_t represents the demand side variables which may include population, type of industry or sector that is dominant in the district, crops grown, area under various crops, number of pumps being used, availability of alternate form of irrigation, prices of crops, and inputs such as electricity and diesel. The supply side variables S_t include management policies and prevalent institutions. E_t represents an error term. Most of the policies that have been designed change the factors in the set S_t. In what follows, I examine a subset.

A few comments on relating this model to the policy analysis conducted are in order. I use panel data and the methodologies used control for time invariant characteristics of districts. I also control for rainfall and temperature in every regression to account for the recharge. I do not have data on very comprehensive set of variables that can affect the demand for groundwater. I do control for a set of demographic and economic variables. But to the extent that these variables have not influenced policy choices or implementation logistics differentially in treated and control areas, the estimation yields unbiased results.

The following analysis is carried out at the level of districts. Districts are administrative units under states. Most program allocations and monitoring of government programs are delegated to districts. Hence, they are a natural choice for unit of analysis. One concern may be that the underlying aquifers are interconnected. The lateral velocity of groundwater is very low (Todd 1980). Hence, over this time frame spatial externalities may not have arisen. I address this more specifically in the analysis, where I allow spatial correlation between standard errors.

4.3. Identification Strategy

Rainwater harvesting mandates the states selected into mandating rainwater harvesting. Hence, comparing the outcomes in the states that mandated rainwater harvesting with the ones that did not, will result in biased estimates. Therefore, I compare groundwater levels in districts in the states that passed the mandates earlier to the states that passed them later in order to circumvent selection concerns. The identifying assumption is that the timing of such mandates is plausibly exogenous.

The empirical model is as follows:

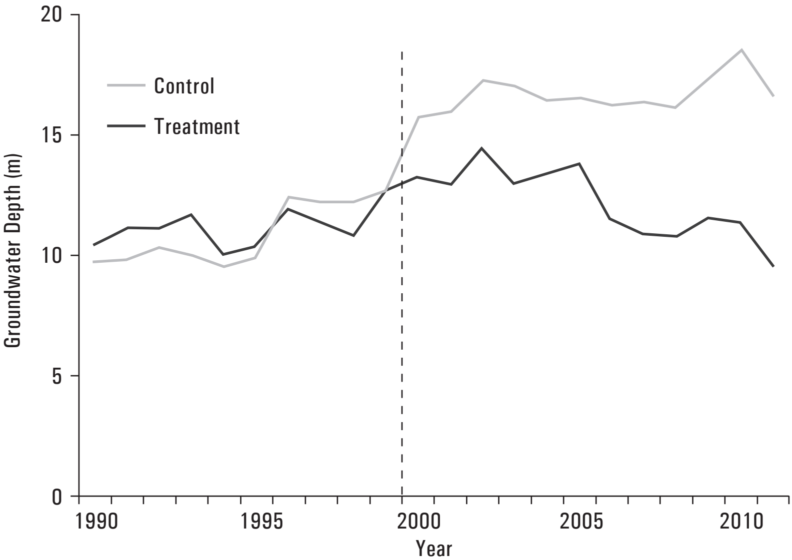
$$Y_{ist} = \alpha_0 + \alpha_1 T_t + \alpha_2 d_{is} + \alpha_3 Post * d_{is} + \alpha_4 X_{ist} + \varepsilon_{ist} \tag{1}$$

where Y_{ist} is the groundwater level in district i in state s at time t, T_t are the year fixed effects, d_{is} is the treatment indicator which takes the value 1 if the district is in a treated state, and X_{ist} is a vector of time varying district specific controls. *Post* is an indicator variable that switches to 1 after the rainwater harvesting mandates were passed in the states. The coefficient α_3 is the parameter of interest. ε_{ist} is the error term. Robust standard errors are clustered at the level of states. Year specific common shocks to all districts are absorbed by the time fixed effects. Time invariant district specific omitted variables that affect the likelihood of treatment are controlled for by including the treatment indicator. The interaction $Post * d_{is}$ yields the effect of the treatment on the treated post treatment where the treatment is passing of rainwater harvesting mandates.

4.3.1. Decentralized Rainwater Harvesting: Sardar Patel Participatory Water Conservation Project I compare the groundwater levels of districts in the regions that received the subsidy program earlier in January 2000 (treatment regions: Saurashtra, Kachchh, Ahmedabad, and Sabar Kantha regions) to the districts that received the program later in 2005 when it expanded (control regions).[5] Figure 9 plots the average groundwater level in the treated and the control districts from 1990 to 2011. The pretreatment groundwater levels prior to 2000 are similar across these districts and the two groups do not exhibit differential trends. The following empirical model is estimated using the data from 1990 to 2011:

5. Districts in treated group include Rajkot, Junagadh, Bhavnagar, Porbandar, Jamnagar, Amreli, Surendranagar, Ahmedabad, Kachchh, and Sabar Kantha. Control group includes Banas Kantha, Patan, Mahesana, Gandhinagar, Kheda, Anand, Panch Mahals, Dahod, Valdora, Narmada, Bharuch, Surat, Navsari, the Dangs, and Valsad.

FIGURE 9. Groundwater Depth in Gujarat Treatment and Control Districts, 1990–2011



Source: Based on author's calculations.

$$Y_{drt} = \theta_0 + \theta_1\ T_t + \theta_2\ \tau_{dr} + \theta_3\ Post * \tau_{dr} + \theta_4\ X_{drt} + \theta_5\ R_r + \varepsilon_{ist} \qquad (2)$$

where Y_{drt} is the groundwater level in district d in region r at time t, T_t are the year fixed effects, τ_{dr} is the treatment indicator which takes the value 1 if the district is in a treated region, and X_{drt} is a vector of time varying district specific controls. Post is an indicator variable that switches to 1 after 1999. The coefficient θ_3 is the parameter of interest. ε_{ist} is the error term. Robust standard errors are clustered at the level of districts. Year specific common shocks to all districts are absorbed by the time fixed effects. Time invariant district specific omitted variables that affect the likelihood of treatment are controlled for by including the treatment indicator. Region specific time invariant unobservables are absorbed by the region fixed effects R_r in certain specifications. It is important to note that the areas where the subsidy was initiated first were the ones where such decentralized initiatives were successful with the help of NGOs and donor funding. Hence, the estimated coefficient cannot be interpreted as causal. Although pretrends in groundwater level are controlled for, there can be other potential time varying factors that influenced early initiation of the program and are unobserved. An example could be a gradual change in people's attitude toward groundwater conservation or awareness about implications of water depletion.

4.3.2. Delayed Paddy Transplanting In the estimation procedure, I employ a difference-in-difference methodology comparing the paddy growing areas in Punjab to the bordering Haryana. Since both states adopted measures to ensure delayed transplanting of paddy at different time, I use the variation in the timing of introduction of the policy to evaluate its impact on groundwater levels. As mentioned before, in Punjab, the de-facto change in date of transplanting happened in 2006 and in Haryana, the mandate was passed in 2009. The rice growing districts were identified using the area under various crops. The districts where the ratio of area under rice to the total cultivated area exceeded the sample median in 2003 for all districts in Haryana and Punjab are considered the high rice growing districts. Since the policy delayed transplanting rice, the policy should have affected the water use in rice growing districts, and hence impact water tables in these districts. Figure 10 maps the high rice production districts (treatment) and low rice production districts (control) in Punjab and Haryana.[6] I compare the high rice growing districts with low rice growing districts before and after the policy change.

The empirical specification is given by:

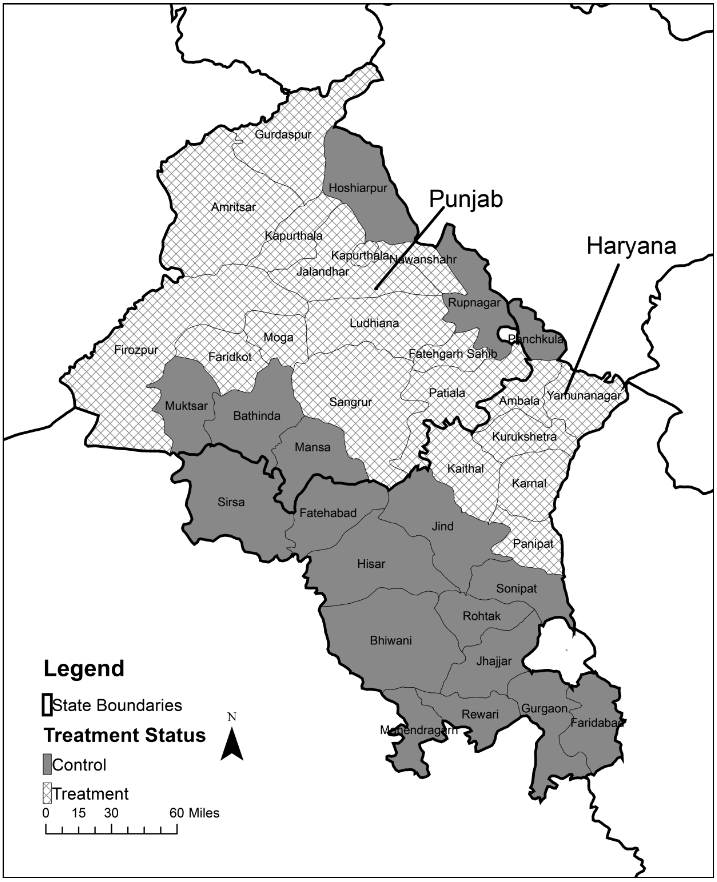
$$\begin{aligned} Y_{its} = \beta_0 + \beta_1 T_t + \beta_2 R_{is} + \beta_3 \, Post * R_{is} \\ + \beta_4 X_{its} + \beta_5 S_s * R_{is} + \beta_6 R_{is} * T_t + \varepsilon_{its} \end{aligned} \tag{3}$$

where Y_{its} is the groundwater level in district i at time t. T_t are the year fixed effects, R_{is} is an indicator variable which takes value 1 if the district is rice growing district and 0 otherwise, and X_{its} is a vector of time varying district specific controls. *Post* is an indicator variable that switches to 1 after the paddy transplanting was delayed and is equal to 0 before that. The coefficient β_3 is the parameter of interest. The regressions include full sets of interaction between state and rice growing districts, and rice growing districts and year indicators. ε_{its} is the error term. Robust standard errors are clustered at the level of districts. I also report Conley (1999) errors to account for spatial correlation in groundwater levels of neighboring districts.[7] Year specific

6. High rice production districts are Gurdaspur, Amritsar, Firozpur, Faridkot, Moga, Kapurthala, Jalandhar, Nawanshahr, Ludhiana, Sangrur, Fatehgarh Sahib, Patiala, Kaithal, Kurukshetra, Ambala, Yamunanagar, Karnal, and Panipat. The low rice production districts are Hoshiarpur, Rupnagar, Muktsar, Bathinda, Mansa, Panchkula, Sirsa, Fatehabad, Hisar, Jind, Sonipat, Rohtak, Bhiwani, Jhajjar, Mahendragarh, Rewari, Gurgaon, and Faridabad.

7. The aquifers could be interconnected. The lateral velocity of groundwater is very low. In the short run, cross district externalities are not likely to arise. Conley's standard errors correct for such externalities.

FIGURE 10. Rice Paddy Treatment and Control Districts



Source: Based on author's calculations.

common shocks to all districts are absorbed by the time fixed effects. Time invariant rice growing district specific omitted variables are controlled for by including the rice growing indicator. The specifications allow for high rice growing districts in the two states to be different by including state times rice growing fixed effects. Differences in high rice growing and low rice growing districts over years are also accounted for by including high rice growing districts times year fixed effects. The vector Y_{its} includes average annual rainfall in the district and demographic controls including percentage of females, percentage of working population, percentage of literate population, percentage of population with some college, and total population.[8] The interaction term *Post* * R_{is} yields the difference-in-difference estimator. In robustness checks, I also allow for state specific trends that non-parametrically account for time varying state specific factors that may have influenced timing of treatment.

4.3.3. Results Tables 2 and 3 report the results for the impact of rainwater harvesting mandates on groundwater levels. Table 2 reports the effect on groundwater levels for four different months—January, May, August, and November. Each specification includes treatment and year fixed effects. I do not find evidence of beneficial effects of rainwater harvesting mandates on groundwater levels at least in the short run. The coefficients on the interaction term are statistically insignificant.[9] In Table 3, this analysis is repeated for annual groundwater levels. Each specification controls for state and year fixed effects. In column (ii), annual average district precipitation is added to the empirical specification and in column (iii), demographic controls interacted with year indicators are added in addition to the precipitation. Although, the interaction term is marginally significant at 10 percent in the columns (i) and (ii), this is not robust to including demographic controls in column (iii). These results do not bear out any evidence of a beneficial effect of rainwater harvesting mandates on water tables in the short run.

Table 4 reports the results for the impact of the Sardar Patel Participatory Water Conservation Project on annual groundwater levels. The subsidy program had an ameliorative effect on groundwater levels. Column (i) reports

TABLE 2. The Impact of Rainwater Harvesting Mandates on Seasonal Groundwater Levels

	(i) January	*(ii) May*	*(iii) August*	*(iv) November*
Post * Treatment	0.84*	0.86*	0.51	0.35
	(0.44)	(0.37)	(0.42)	(0.24)
Observations	2,206	2,153	2,060	2,118
R-squared	0.435	0.433	0.405	0.433

Source: Based on author's calculations.

Notes: Robust standard errors are clustered at the state level.

*** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$

Sample is restricted to states which implemented Rainwater Harvesting legislation by 2010. Sample includes observations from 2000 to 2010. Each specification includes year and treatment fixed effects.

8. These variables are available for the year 2001 from the Census of India. These are interacted with year indicators to control for trends in these variables starting at the 2001 initial values.

9. The number of observations change across specifications because of missing data in some of the district year cells.

TABLE 3. The Impact of Rainwater Harvesting Mandates on Annual Groundwater Levels

	(i)	*(ii)*	*(iii)*
Post * Treatment	0.62*	0.83*	0.64
	(0.29)	(0.41)	(0.36)
Observations	2,230	2,204	2,196
R-squared	0.431	0.456	0.497
District Precipitation	No	Yes	Yes
Demographic Controls	No	No	Yes

Source: Based on author's calculations.

Notes: Robust standard errors are clustered at state level.

*** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$

Sample is restricted to states which implemented Rainwater Harvesting legislation by 2010. Sample includes observations from 2000 to 2010. Each specification includes year and treatment fixed effects. Precipitation is district average monthly precipitation in mm. Demographic controls include 2001 district demographics interacted with year dummies and include percent female, percent literate, percent working, percent with some college, and total population.

the baseline specification. The coefficient is negative but statistically insignificant. In column (ii), I add region fixed effects. Columns (iii) and (iv) control for annual precipitation levels with and without region fixed effects. The effect continues to be statistically insignificant. In columns (v) and (vi), demographic controls are added interacted with year indicators are added in addition to the precipitation. Both specifications—with and without region fixed effects—yield a negative and highly statistically significant effect of the program. The point estimate of 9.3 is 0.82 of a standard deviation and very large in magnitude. The subsidy program had a huge effect on the annual groundwater level in treated areas. However, these results should be interpreted with caution as the areas that received the early treatment were the areas where decentralized rainwater harvesting was very effective prior to the subsidy program. The government focused the subsidy in regions where NGOs and other donor-funded projects were successful. Hence, I cannot rule out selection bias. As mentioned before, previous experience with such projects may have gradually changed the attitudes toward conservation which is unobserved. Controlling demographic characteristics in column (v) of Table 4 relative to column (iv) changes the results substantially. This strongly suggests that program was targeted selectively in certain types of areas. Figure 9 shows that there are no differential trends in groundwater level prior to the program. Hence, it is likely that the results emerge as a result of this program alone. On the other hand, it is possible that such programs may not be successful in randomly chosen areas, where people do not have prior experience with such projects. More research is required to address selection and establish the causal impact of such subsidy programs.

TABLE 4. The Impact of Sardar Patel Water Conservation Subsidy Program on Annual Groundwater Level

	(i)	*(ii)*	*(iii)*	*(iv)*	*(v)*	*(vi)*
Treatment × Post-1999	–4.744 (2.918) [2.847]	–4.744 (2.932) [2.847]	–3.742 (2.661) [2.586]	–4.593 (2.974) [2.882]	–9.318*** (1.540) [1.309]	–9.314*** (1.593) [1.347]
Observations	550	550	550	550	550	550
R-squared	0.056	0.597	0.249	0.598	0.762	0.810
Year FE	YES	YES	YES	YES	YES	YES
Treatment FE	YES	YES	YES	YES	YES	YES
Region FE	NO	YES	NO	YES	NO	YES
Precipitation (mm)	NO	NO	YES	YES	YES	YES
Census Controls	NO	NO	NO	NO	YES	YES

Source: Based on author's calculations.

Notes: Robust standard errors clustered at district level are in parenthesis and Conley (1999) standard errors correcting for spatial correlation are in brackets.

*** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$

Sample restricted to districts in Gujarat and includes observations from 1990 to 2011. All regressions include a Treatment dummy for districts which received early check dam construction from the Sardar Patel Participatory Water Conservation Program. These include the Saurasthra region, Kachchh, Ahmedabad, and Sabar Kantha. Regions in Gujarat include Kachchh, North Gujarat, Central Gujarat, Saurashtra, East Gujarat, and South Gujarat. Precipitation is district average monthly precipitation in mm. Census controls include 2001 district demographics interacted with year dummies and include percent female, percent literate, percent working, percent with some college, and total population.

Tables 5 and 6 report the results of the impact of delayed paddy transplantation on groundwater levels. The outcome variable is depth to groundwater in meters below ground level (mbgl). Paddy transplantation occurs in June. Table 5 reports the effect of the policy on post-transplanting groundwater level in August and Table 6 reports the results for annual depth to groundwater. Column (i) in Table 5 shows the coefficient of the interaction term from a specification which includes year fixed effects, state × rice fixed effects, and rice × year fixed effects. In column (ii), precipitation is added to the regression specification. Column (iii) controls for trends in demographic variables, and column (iv) includes state specific time trends in addition to the above mentioned controls. In all specifications, the policy increases depth to groundwater. The coefficient is marginally significant at 10 percent significance level is the most conservative specification in column (iv). The August groundwater levels declined in response to the policy. The depth to groundwater level in high rice growing districts post the policy change was 1.17 meters deeper than the low rice growing districts. Similar specifications are repeated for the annual depth to groundwater in Table 6. In each specification, the coefficient on the interaction term is positive and highly statistically significant. In the last column, we observe a decline in depth of 1.60 mbgl and it is significant at 1 percent level. This effect is 0.28 of

TABLE 5. The Impact of Delay in Paddy Transplantation on Groundwater Levels Post-transplanting (Groundwater Level Measured in August)

	(i)	*(ii)*	*(iii)*	*(iv)*
Post * High Rice Producing Districts	1.30**	1.28**	1.13	1.17*
	(0.53)	(0.53)	(0.70)	(0.64)
	[0.51]	[0.51]	[0.62]	[0.57]
Observations	324	321	321	321
R-squared	0.100	0.101	0.252	0.254
State × Rice FE	Yes	Yes	Yes	Yes
Year × Rice FE	Yes	Yes	Yes	Yes
District Precipitation	No	Yes	Yes	Yes
Census Controls	No	No	Yes	Yes
State Specific Time Trend	No	No	No	Yes

Source: Based on author's calculations.

Notes: Robust standard errors clustered at district level are in parentheses. Conley (1999) standard errors correcting for spatial correlation are in brackets.

*** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$

Sample is restricted to districts in Punjab and Haryana. Each regression controls for year fixed effects.

Sample includes observations from 2003 to 2011. Districts with rice area as a fraction of total cultivated area above the median in Punjab and Haryana (.30) are classified as rice-producing.

Punjab began limiting paddy water supply in 2006 (two years before its legislation) by way of rationing electricity, and Haryana passed legislation in 2009. Precipitation is district average monthly precipitation in mm.

Census controls include 2001 district demographics interacted with year dummies and include percent female, percent literate, percent working, percent with some college, and total population.

TABLE 6. The Impact of Delay in Paddy Transplantation on Annual Groundwater Levels

	(i)	*(ii)*	*(iii)*	*(iv)*
Post * High Rice Producing Districts	1.25***	1.13**	1.58***	1.60***
	(0.45)	(0.46)	(0.54)	(0.53)
	[0.44]	[0.45]	[0.48]	[0.47]
Observations	324	321	321	321
R-squared	0.090	0.097	0.248	0.249
State × Rice FE	Yes	Yes	Yes	Yes
Year × Rice FE	Yes	Yes	Yes	Yes
District Precipitation	No	Yes	Yes	Yes
Census Controls	No	No	Yes	Yes
State Specific Time Trend	No	No	No	Yes

Notes: Robust standard errors clustered at district level are in parentheses. Conley (1999) standard errors correcting for spatial correlation are in brackets.

*** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$

Sample is restricted to districts in Punjab and Haryana. Each regression controls for year fixed effects.

Sample includes observations from 2003 to 2011. Districts with rice area as a fraction of total cultivated area above the median in Punjab and Haryana (0.30) are classified as rice-producing.

Punjab began limiting paddy water supply in 2006 (two years before its legislation) by way of rationing electricity, and Haryana passed legislation in 2009. Precipitation is district average monthly precipitation in mm.

Census controls include 2001 district demographics interacted with year dummies and include percent female, percent literate, percent working, percent with some college, and total population.

a standard deviation and is economically moderate. The findings indicate that the annual groundwater level situation worsened in rice growing areas after the policy change.[10] It is possible that the farmers responded to the policy by increasing the number of irrigations applied or using more water per irrigation after the mid-June transplanting.[11]

What Do We Learn from the Experience with These Policies?

The rainwater harvesting mandates were unsuccessful in reversing the depletion rates whereas the decentralized experience in Gujarat has been more positive. From this comparison, it appears that technical or engineering limitations or short duration that has elapsed since the program commencement are not the principal explanations for success or failure of these policies. The effective policies will need to be decentralized in nature. Engagement of the stakeholders is an important ingredient for these policies to work. Bottom-up rather than top-down policy tools are more successful. None of these policies are pricing mechanisms. In Sekhri (2011b), I show that public wells provision can reduce the rate of depletion. If an optimal price is charged it can also reverse depletion. But this can work only where cost of groundwater extraction is high, or in other words in areas where water tables are deep. In Sekhri and Foster (2008), we find evidence that bilateral trade arrangements between farmers who sell and buy groundwater also decelerate depletion rates. The benefit of promoting these is that these arrangements do not require top down monitoring. Introduction of pricing mechanisms may be another important lever to reduce overextraction.

Future Directions with Policy Choices

What kind of policies—direct or indirect—can or cannot work? Reducing electricity subsidies can potentially affect groundwater extraction rates (Badiani and Jessoe 2011). West Bengal and Uttarakhand have recently adopted metering of electricity for tube wells. Gujarat, under the flagship Jyotirgram Yojana, has separated agricultural feeders from nonagricultural

10. In contrast to these findings, Singh (2009) estimates a 30 cm water-saving effect of the policy but the estimate is based on simulations using historic data from central Punjab and does not account for selection issues.

11. In the absence of farm-level data on applied number of irrigations and water use, it is not possible to establish the mechanism.

feeders, improved the quality of the power supply and rationed the number of hours of electricity to agriculture to eight hours a day. Important policy lessons can be learnt from the experience of these states.[12] Other possibilities include promoting water-saving infrastructure and agricultural practices. More research is required to understand the effect of policies that promote such practices, and is a very promising area of future research.

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Comments and Discussion

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I made several comments on the original draft of this paper at the July 2012 IPF Conference. Unfortunately, they have gone unanswered in the final version. Therefore, in the following, I restate some of the most important reservations I continue to have on the paper.

When India became independent it inherited the world's largest *surface* irrigation infrastructure. Since then, however, the trends in Indian agriculture have made India the *groundwater* champion of the world, in the sense that surface irrigation systems, tanks, surface reservoirs, and canal systems in which India made huge public investments for 250 years have increasingly became irrelevant in Indian agriculture, and their place has been taken by some 25 million private wells and tube wells mounted with small mechanical pumps that irrigate the bulk of India's crops. There are many factors that have driven this transformation of Indian irrigation. By far the most important has been the compulsion for a small farmer to eke out a living from one acre or one and half acres of farm holding, which makes it imperative for him or her to use that land very intensively, cropping it two or three times a year. Having a private captive source of irrigation is critical to do that, which explains the obsessive preoccupation of Indian farmers with well irrigation and the insatiable demand for wells, pumps and power to irrigate.

I have argued that but for this revolution in groundwater irrigation in India, areas that are today considered to be very dry, like the Telangana region, or the Saurashtra region in Gujarat, which had no public sources of irrigation, would have experienced much greater social instability than is the case today. One major reason why one-third of Indian districts are suffering the Naxalite movement, in which tribal farmers are trying to take on the State, is primarily because there is very little development of irrigation here. So agriculture with diminishing landholdings in these regions has become increasingly unviable.

In contrast, in regions where groundwater development has taken place, although it has not made farmers rich, it has made it possible for them to continue subsisting. That is also part of the reason why many Indian states have pursued policies that appear so irrational. For example, there are four or five Indian states that supply totally free electricity to farmers so that the latter can run their pumps as long as the electricity is available and they can keep drawing the water. The other states do not meter the power that they sell to farmers, so that farmers are basically subject to a pricing regime in which the incremental cost of pumping is virtually zero. That means that as long as the power supply is on, the pumps are on and groundwater keeps being drawn.

These distortions have now led to a very vibrant debate. Water is a field in which economists have been conspicuous by their absence in India but this particular subfield seems to be one in which we have seen their greater participation leading to a lively debate.

The paper that professor Sekhri has presented dwells on three or four very important experiments. For the past 50 years the Indian farmers as well as states have been preoccupied with developing and exploiting groundwater as if it were oil. But unlike oil, groundwater is a renewable resource and it is possible to manage it so that you can use it forever, especially in a subcontinent like ours where there is a very substantial amount of annual rainfall to recharge the depleted aquifers. So we should be able to manage our aquifers like we manage our surface reservoirs. A reservoir gets emptied every year and it gets refilled in the monsoon. We could do pretty much the same with the aquifers if we just understood the management of aquifers properly, but we still have not got into that game. Throughout the past 40 or 50 years, the focus of government policy, as well as the focus of the farmers' efforts, has essentially been on making punctures in the earth, making more boreholes, putting up more pumps and pumping more groundwater. There was no attention paid to managing the resource for sustainable use and the three or four efforts that Professor Sekhri's paper studies are among the first efforts in India to actually bring a sustainability dimension to the groundwater economy of India.

I have a number of questions and suggestions on identification. I also find it hard to reconcile Professor Sekhri's conclusions with a growing literature of local studies, based on different datasets (not studying district level groundwater movements) that seek to understand the impact of groundwater demand management in Punjab and rainwater harvesting in Saurashtra. Personally, I would not expect the rainwater harvesting laws—even when implemented and enforced fully, which they are not currently—to have a significant impact even in urban areas let alone rural areas. So, I do not expect the author's model to produce positive outcomes from the mandates studied.

But additionally, there remains the serious problem of implementation of the laws. Although the Punjab water laws were enacted as early as 2001, the actual enforcement in Punjab started in 2009. In Haryana, the law is not enforced even today. So it is just a paper law that has actually not changed behavior. In Punjab, you might find significant impact on farmer behavior in 2009 and thereafter.

Second, I really wonder whether it is possible to control for electricity pricing and supply. These are powerful drivers of farmer incentives. In Punjab, in the opinion of many, more important than the water law is the progressive whittling down of the power supply to farmers and the increasing need for farmers to use very expensive diesel to supplement electricity. If behavior has changed recently, it is probably this partial shift to expensive diesel that probably accounts for the change. To be convincing, the model needs to control for this important change.

Many of the studies that I have seen of Punjab are based not on farmer level data but block level data that show very significant savings in groundwater as well as in electricity use in Punjab as a result of shifting the transplantation of paddy from middle of May to the middle of June.

When it comes to Gujarat, I think that the impact is much stronger than what the author's study suggests. Perhaps if the author were to use block level data in Gujarat, which is available, it might actually provide a much more textured analysis. Also the groundwater or water harvesting structures in Gujarat are orders of magnitude larger in numbers than the paper suggests. The author has probably captured data on the number of structures constructed by just one department, but there are several other departments that are involved. And many more non-government rain harvesting structures have been constructed by diamond merchants in Surat or NGOs or religious movements like the *Swaminarayan Sampraday* and *Swadhyay Parivar*, which have huge followings of farmers. These structures are probably not included in the data, and this is worth checking.

Finally, Andhra Pradesh is another state where there is a very interesting experiment on demand management that should be looked at. This is an FAO supported project in which a group of NGOs have tried to work with 750 to 800 villages educating farmers, women, and children in taking measurements of groundwater level, assuming that greater knowledge of the understanding of hydrological processes would eventually change their behavior. The results of this experiment should definitely be worth a look.

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Before I go to my Power Points let me begin with some general remarks. First is a point made by Mr Shah that we have been involved in irrigation for 250 years. But out of those 250 years in my reading of the literature, for 190 years, that is, before independence in 1947, the irrigation objective was primarily protective, that is to say to ameliorate the effects of famines and droughts and so the irrigation systems were created mainly to address those issues, and not particularly to raise the productivity of the land. So, in protective irrigation the major dimension was to minimize to the extent feasible of the risk due to drought and famine. Second point is that at that time, there were taxes called cesses on crops like rice, sugarcane, or whatever, which were water-intensive, to prevent farmers from using large share of their land for cultivating water-intensive crops and devote more land to less-water–intensive subsistence crops. Third, from that regime, in the post independence period we shifted to returns from irrigation though productivity increases and the land tax, which used to be the dominant source of government revenue and the crop cesses were allowed to wither away. Finally, as Kirit mentioned in his introduction property rights over water in India was associated with property rights over land thereby generating incentives excessive use of groundwater. I mention all these points because they relate to what Sekhri is doing in the paper. Further and unfortunately there is no mention anywhere of the major element of farming, namely risk (from weather, pests and others) in her analysis. This is unfortunate since farmers are, and have always been, making risk return trade-offs in the use of groundwater as well as other inputs and as the groundwater levels become more and more uncompetitive with respect to pumping what is going to happen is related also to how the farmers decisions are going to be made in this regard.

I distributed an op-ed by a very distinguished expert in water policy whom Mr Shah knows very well. He is Professor Asit Biswas, my colleague LKY School, and in the op-ed he was talking of Delhi's ongoing water crisis and this is a drinking water crisis. I want to focus only on one point he makes. The Delhi Jal Board apparently has no information for making critical decisions on water use. It does not have information as to how many consumers it has, what their per-capita water use is, how much water it loses due to leakages and unauthorized connections and how much staff it has per thousand connection. None of that information that Delhi Water Board has and this is the agency that is managing water in Delhi. This is an example of the nature of water management in many aspects of India's irrigation system as well. So, this has to be kept in mind that with no data there is no way you can analyze a problem empirically even if you had a reasonably good analytical model.

Now let me start with Sekhri's paper. Of course the scarcity of water as a resource and near universal inefficiencies and inequities in its allocation are well known. The latest issue of *Global-is-Asian* at LKY School is devoted to the global dimension of this water scarcity issue. I mentioned Mr Biswas's op-ed but there are also examples within India of 24×7 potable water supply that individual towns have been able to mange. Amaravati is an example of such a town, whose remarkable success Isher Ahluwalia in one of her op-eds in the Indian Express has examined. So, it is possible in India with the right institutions and the right incentives to supply 24×7 drinking water to consumers. This again suggests that the failure to do so is not so India-specific. What is India specific are policies that India and regions of India have (or have not) adopted among those that are in principle feasible to adopt.

The literature on issues of water used for irrigation is huge. The distortions in the allocation of water for irrigation are many and a large share of these distortions have been created by public policy. So clearly public policy reform in this area is urgently needed. The impact of distortions of prices of agricultural output and inputs, such as fuel for pumping groundwater including electricity and fossil fuels, distribution of land, and others on the allocation of water and distribution of income and wealth have been discussed extensively in the literature. Issues of pricing of un-priced water have also been discussed.

Closer to the topic of the present paper is the discussion of the conjunctive use of surface and groundwater in India. So, there is a vast literature and I do not see any reference to any of this literature in the paper. For this reason, I had great difficulty in understanding much of the paper. It is quite likely I have misunderstood it, so my comments should be understood as possibly reflecting my misunderstanding.

Let me start with one example, if estimates of groundwater use of China's geological survey which published two years ago in 2009 are to be believed, China is using 250 billion cubic meters of water, not the 105 that is cited in the paper. In any case, in my view, the estimates for such aggregates as India's use or China's use are subject to possibly large and unknown measurement errors and possibly even biases. The paper estimates that there are 27 million pump users in India. I have no doubt there is a band of error around that 27 million. Sekhri does not mention anything about the locations of monitoring wells which provide the data on water pumped on which her entire analysis depends. I have no idea, and Sekhri provides no information, on where the monitoring wells were located. If you want to estimate the average groundwater level in a particular district and you are using data from monitoring wells to do so, if the wells are not randomly distributed over the district but are concentrated in specific areas, the estimates that you get would be biased. As I said, I do not have any idea where these wells are located. Without some idea of the representativeness of the well locations in each district I found it hard to make sense of the reliability of the Figures 1 to 8 in the paper.

The sharp increase at 8 meter in pumping cost, if I understand it, arises from the simple fact that 8 meters of water is equivalent of 30 inches of mercury in a barometer; so if you make the appropriate adjustments for density of mercury and you get this 8-meter figure and so at that level that the usual pumps do not work and you need to go down to submersible pumps or whatever other technology straightforward and as you have rightly said, the fixed cost and the investment that you have to make—so this non-linearity that arises from this physics of atmospheric pressure there is no mystery. It is well-known although Sekhri does not mention it.

The paper has a very short Section on welfare implications. It is evident that there are many intermediate links between the depth of groundwater and long-term food production and between food production and poverty level. Unless they are modeled, both theoretically and in the form econometric estimating equations, it is hard to assess the very striking results about the impact on poverty and impact on food production. Simply running the poverty against level of groundwater is not an appropriate or convincing way of estimating the effect of groundwater on poverty.

In the section on policy reform, the econometrics is focused on just two policies, one on rainwater harvesting and the other on the delay in the transplanting and the two work, if through the water recharge mechanism of groundwater, either from the rainfall water being pumped back into the ground or alternatively by delaying the flow of water in rivers and thereby increasing the recharge. Now, this is not the entire policy regime that one would want to think about when you want to analyze, not just groundwater issues, but also the general issue of water policy.

Sekhri starts the whole analysis from the estimating equations. On equations 1, 2 and 3, the econometric issues of identification and selection bias take significant amount of space. But they are discussed in a routine and familiar fashion and I have no quarrel with it. The discussion in Table 4 on the other hand suggests that the identification procedure used, namely the delay in the policy imposition, did not work as well as one thought. Sekhri herself has mentioned in her discussion under Table 4.

Sekhri starts with estimating equations and proceeds thereafter to discuss the econometric issues that arise in them. I am afraid this is the conventional procedure in empirical analysis these days, where the analyst starts from some estimating equation from somewhere and spends all his/her time discussing how to identify it or what to do with it but not spend enough time on where the equation came from, that is the relevant economic or physical theory underlying it. For me such a procedure is of dubious analytical value, if it has any value at all.

The average groundwater level in a district is the average of the levels of more than one aquifer in the district. If there is diversity of aquifers, as is very likely, the districts may differ in water pumped out as well as recharged. It is simply being assumed that the average groundwater in a district is a good proxy for the stock of water remaining in the aquifers in that district. It need not be, I will present simple model thinking about it where these issues are brought out.

The results presented, and I don't have the tables with me, are rightly of the interaction variable, a product of the dummy for the timing of introduction of policy and a dummy on whether the district is a treated region or not. While it is certainly the coefficient of interest, the other coefficients such as those of time-varying district-specific controls are of interest as well. These and the controls used are not fully described and the phrase "salutary effects of rainwater harvesting," is not defined anywhere though it is said that there were no significant salutary effects from rainwater harvesting.

Sekhri in her presentation went through the tables and explained the coefficients. I found some of these coefficients puzzling. One of those is relating to Table 4. The orders of magnitude were quite large in regressions in columns (v) and (vi) of Table 4 and may be the units of measurement used for the same variable were different in different regressions. In regressions (i) to (iv) of Table 4, the treatment has no significant effect, but in regressions (v) and (vi) not only the magnitude of the treatment effect is large and almost the same in the two, but also both effects are statistically significant at 1 percent level. Regression (v) includes all controls while (iv) omits only the region fixed effects. The first four regressions omit differing set of controls. The argument that differences in the inclusion or omission of particular controls across regressions explains the particular difference in the magnitude and the statistical significance of the treatment effect is not convincing at all, besides raising possible endogeneity issues.

In my last section, firstly, I am going to focus on a single aquifer. For simplicity think of an aquifer as a rectangular tank of water of average height "H(t)" and an unknown base area "A(t)" in year "t." By definition the area is not changing so the "A(t)" is a constant A. Then the stock of water S (t) is AxH (t) since the aquifer it is a rectangle, so height x area is the volume. Its change between end of period t-1 and t is A [H (t).- H(t-1)]. This is the "delta" change in S(t). Delta S(t) is by definition is the net effect of the volume of water P(t) pumped out during the period and the volume of water that was added, that is the recharge in period, R(t) of aquifers plus any random errors for measurement. So, delta S(t) is R(t)-P(t)+ epsilon(t) or H (t)-H(t-1) This change in groundwater level is what I have written in (3). The constant A does not matter, it is simply a scaling coefficient and so this is the story.

The variable P(t), that is the pumped out water, would include for example on the demand side either area sown for various crops or alternatively expected harvest presence for crops in this region and irrigated by water from the aquifer, availability of non-groundwater sources of irrigation, number of pumpers, pumping cost proxy such as fossil fuel, electricity prices, and groundwater use, and service cost of other sources of irrigation, etc, all of these will be included in the function P(t) as other variables besides t.. Similarly I can list s whole list of variables for R(t) besides t. Now, the point is that it is easy to list variables as I have done but given the limited extent available of time series data and groundwater levels, not too many variables can be quoted. This is where your modeling judgment comes in. What you are going to include, what you are going to keep out and then do later the robustness checks about your modeling assumptions. So my only purpose in listing it out all this is to say that you start from a theory and a model and not from just some equation pulled out from somewhere and think about econometrics of that equation. Thank you.

General Discussion

Indira Rajaraman opened the discussion by noting that groundwater use was not just an agricultural phenomenon. There is a huge mineral water industry, which also draws groundwater.

Abhijit Banerjee said that he was baffled by the author's conclusion that there was no impact. In his reading, the impact was actually negative. Banerjee also noted that he was puzzled by the author's comment that people do not want water markets because water is not to be marketed. Irrigation water is sold all the time, people just buy water from pumps. There is no issue of water markets not existing. They are everywhere. But it is not clear why the market would help. The market makes the problem worse. This is an un-priced resource, why wouldn't anyone sell it more if more people want it and the equilibrium occurs where everyone tries to overdraw because everyone thinks that the water will exhaust by the next year. Banerjee said he saw no reason why market would help here.

Devesh Kapoor said that he thought that by far the most relevant to the problem at hand is the procurement price of rice. This is the wrong crop being grown in the wrong place, period. And everything else is dwarfed by the procurement policy.

Another speaker noted that in India 70 percent of water was used for irrigation and the rest for drinking and industrial use. The paper had not discussed industry use, how it could be managed.

Sheetal Sekhri responded that policy other than those directly targeting water use in agriculture were relevant and would definitely include discouraging paddy growing where it should not be grown. Agricultural scientists have been making this point for more than two decades. But given the power of farmer lobbies, this is not going to happen any time soon.

Regarding the point by Banerjee about a negative effect in Table 3, Sekhri said she was not sure where he was looking since the results did show that the situation was getting worse. On the point about why households would want to sell more water, thus, exacerbating the problem was a very intriguing one. Regarding the point by Indira Rajaraman, Sekhri said that about 91 percent of the groundwater that India extracted was used in irrigation. So, agriculture was the main culprit. It was not really industry even though we might routinely bash the industry. Regarding interconnectedness of aquifers, Sekhri said that the point is well taken but it is undermined by the fact that the lateral velocity of groundwater is very low. The first order concern is really depletion over time in a specific place rather than spatial externalities. For surface water those externalities are much more prominent because surface water flows very quickly. So, recharging something in Saurashtra and Gujarat is not likely to have a perceptible effect on Kutch anytime soon.

Turning to the comments by Tushaar Shah, Sekhri said they were very instructive and she was thankful to him for them. The first point that Shah raised was that rainwater harvesting mandates had no effect and that he did not expect them to have any effects because they were in urban areas. But this did warrant a policy analysis because the policies have been enacted and the States are spending significant amount of state money on monitoring and evaluating these policies. They do have staff that gets paid to evaluate the policies.

The second Shah had raised was about Punjab delaying the implementation of the law relating to paddy till 2009 and it then that having salutary effects. Sekhri noted that she had used 2009 as the implementation date and carried out the same analysis and found the same type of effects. Also, Shah had mentioned that there could not have been a change in paddy transplanting prior to 2009. But the statistics say that paddy transplanting in May 2008 declined from 14 percent to 0.2 percent. So, there does seem to be some action before 2009. Shah also noted that electricity prices should be in the model. Sekhri said she thought this was very important for the analysis but the analysis of how the marginal cost of extracting groundwater would affect groundwater extraction rates was a paper in its own right. Shah also mentioned some existing papers finding positive effects of Punjab policy. Sekhri said she had looked at that literature but was not convinced by the methodologies used there. Shah also mentioned that she (Sekhri) had not investigated the effects of check dams or other types of rainwater harvesting initiatives that were being promoted by NGOs and several other types of donors. She felt that the analysis of these dams was fraught with selection issues. Since she could not estimate anything cleanly there, she refrained from it.

Moving on to the comments by T. N. Srinivasan, Sekhri said that he had made several points about the inclusion of certain variables and exclusion of others in the regression analysis. She said that to the extent that the excluded variables were unrelated to the policy implementation in any particular way, their omission would not impact the analysis. Srinivasan mentioned something about statistical significance jumping from column 3 to 4, 5 to 6 in Table 6. But there were only four columns in Table 6. As we move across columns, neither the point estimate nor the statistical significance in Tables 4 and 6 change very much. Srinivasan had mentioned that the paper was confined to only two policies. This was true since the paper did not aim to survey all the policies. There are not too many carefully done empirical studies evaluating any of the policies relating to groundwater so that the paper represented some progress over the existing literature. The welfare implications section is brief but I think it draws out at least the main implications of depletion.

At the invitation of the chair to say a few words on water markets, Tushaar Shah stated that markets were not something to be created. They have been in operation in every nook and corner of South Asia for nearly 30 or 40 years. If anything, we are now shrinking because of falling groundwater levels and greater difficulty in accessing groundwater and because the number of tube wells and pumps has grown so much that every third or fourth farmer in the region has his own bore well. Water markets are very vibrant in the early stages of groundwater development where in a village you would have 15 or 20 tube wells and pumps and 100 to 200 farmers who wanted to use the groundwater and are willing to pay for irrigation service but now with increasing number of farmers acquiring their own tube wells, the scope for large scale water selling is actually declining.

The Chair, Kirit Parikh, concluded with two short observations. One, there is a Working Group report or an Expert Group report by the Planning Commission on Groundwater Management that he chaired and Tushaar was a member of. The author might find it useful. Two, T. N. Srinivasan had mentioned the Delhi Jal Board. In that context, it might be of some interest to know that in 2006 there was a proposal to have a French firm come and do some auditing and help Delhi Jal Board to provide 24×7 water to its customers. The point is that Delhi's total per-capita water availability is more than what is available in Paris for example but the water is available for only two hours or less than that to customers largely because the system is not properly managed. That was torpedoed by lots of activists who are concerned about this foreigners' firm coming and meddling into our affairs.