Adapting to Monsoon Variability in India: the Case for Irrigation [1]

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Adapting to Monsoon Variability in India: the Case for Irrigation

Abstract

How will future changes in precipitation affect irrigation demand and supply in India? This paper provides econometric evidence for the demand side of the analysis by examining the relationship between monsoon changes and irrigation variability for one of the world's most water stressed countries, India. Using detailed crop-wise agriculture and weather data spanning 35 years, the econometric model isolates the historical impact of the distribution and total supply of monsoon precipitation on irrigation demand via the use of irrigated area for crops grown in the dry(Rabi) and wet(Kharif) seasons. We find differential impacts of the monsoon by crop, by season and by source of irrigation. In general, for crops grown in the wet season, irrigation is sensitive to both distribution and total monsoon rainfall but not to ground or surface water availability. For crops grown in the dry season, total monsoon rainfall matters most, and its effect is sensitive to groundwater availability. Over the historic period of analysis, the effect of the monsoon on irrigation has remained relatively stable. The econometric analysis, when combined with a process based hydrology model that accounts for the supply side response of water availability, can help quantify the (un)sustainable water use trajectory that different regions within India will face.

Keywords: climate change; adaptation; agriculture; irrigation; monsoon; India

JEL Codes: O13, Q15, Q54, Q56

1. Introduction

"Every cloud in the sky is watched, every symptom of rain checks irrigation…"

- The Calcutta Review, Volume 12, 1849

Given that global warming is now considered inevitable, there is a concern that climatic variability, through its impact on agriculture, is likely to add to the already high vulnerability of poor households (Skoufias et al., 2011). This is because most developing countries, like India, are more dependent on agriculture as the primary source of livelihood for majority of its people (52%) and agriculture is bound to be the most susceptible sector to climate change. In addition, the water needs of agriculture are tightly connected to the vagaries of the monsoon in India. Millions of farmers in India, who depend on agriculture for their livelihood, wait in anticipation every year to see what the rainy season will bring.[4] Rainfall realizations impact cropping decisions, irrigation decisions and ultimately agricultural profits.

India remains one of the most water stressed countries in the world. [5] 80% of India's water is used for irrigation, with canals and groundwater serving as the two main sources (Shah,2013). The expansion of irrigation, due to the Green Revolution in the early 1970s, and which marks the period under study from 1970-2004, was made possible by the use of subsidized power to extract groundwater and the emergence of *atomistic* or individual-led irrigation through use of tube wells. This was in contrast to state controlled canal-based irrigation that was prevalent from the early 1800s to 1970 (Shah, 2008, 2013)[6]. With declines in water tables raising concerns about aquifer depletion in north west India (Rodell, 2009) and evidence of climate change increasing the number of dry and wet spells during the monsoon season over the past 50 years(Singh et al, 2014), the sustainable use of irrigation into the future is a serious concern. According to the 2007 IPCC Report, "Of all sectoral water demands, the irrigation sector will be affected most strongly by climate change…. In areas facing water scarcity, changes in irrigation water use will be driven by the combined effects of changes in irrigation water demand, changes in demands for higher value uses (e.g., for urban areas), future management changes, and changes in availability."

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[4] "India's farmers pray for rain", Kazmin(2012) in Financial Times, July 25, 2012

[5] India's water situation can best be explained as 'anarchic': "When the balloon bursts, untold anarchy will be the lot of rural India."(Shah, 2008)

[6] The discourse on irrigation as a policy measure, started from the time of the British Raj. At that time, the colonial government undertook canal building on a massive scale ushering India as the "irrigation champion" of the world (Shah, 2011)

Much of the availability of water for irrigation is dependent on the monsoon. The annual occurrence of the monsoon between the months of June and September takes place under the influence of the south west monsoon. 85% of the annual rainfall occurs during this period. Some southern states, like Tamil Nadu, experience an extended monsoon, up to October and November, under the influence of the northeast monsoons. The degree of variation in the monsoon across the country is large, geographically and well as temporally. While average annual rainfall of the country is about 1170 mm, average rainfall in North East Region is as high as 10,000 mm per year whereas some parts of Western Rajasthan receive annual rainfall of about 100 mm only (Government of India, 2012). Figure 1 shows the spatial pattern of mean monsoon rainfall and mean frequency of rain days, defined as days with precipitation > 0.1mm of rain by the Indian Meteorological Department (Guhathakurta et al, 2011). The distribution of monsoon rainfall follows a similar pattern. The number of rainy days varies from about 5 in western deserts to 150 in the north-east (Jain et al, 2007). Figures 2, 3 and 4 show the different degrees of temporal variability in the monsoon. Figure 2 shows a large degree of short term inter-annual variation in the monsoon, spanning the years from 1870-2000. Some studies even indicate medium term inter-decadal variations in the monsoon, with thirty year wet and dry regime shifts, as in Figure 3, with the period after the Green Revolution in 1970 seeing rainfall drop below the long run mean historical average. Figure 4 shows large long run percentage changes in seasonal monsoon rainfall and the distribution of rainfall between the years 1970-2004.

In the econometric model, we focus on inter-annual variability in rainfall, since this impacts planting and cropping decisions, and subsequently irrigation requirements. Inter-annual variation in the monsoon is said to be affected by global features like *El Nino*, northern hemispheric temperatures and snow cover (Jain et al, 2007), as well as increases in tropical Indian Ocean and Pacific sea surface temperature (Meehl and Arblaster, 2003). While projections of the monsoon are wrought with uncertainty, recent studies indicate that there will be an increase in inter- annual variability as well as intra-seasonal variability of rainfall, along with increases in extreme rainfall (Menon et al, 2013; Menon, Levermann & Schewe, 2013). The effects of such precipitation changes will be seen directly for rain-fed agriculture, and indirectly for irrigated agriculture through impacts on water absorption in the soil and water storage capacity (Turral, 2010). 40% of global crop production is dependent on irrigation water. For India, the dependence on irrigation water out of the total water demand can be as high as 90%

(Fischer et al, 2007; Wada, 2013). Thus, how irrigation decisions in both the wet and dry seasons responds to the variability of rainfall needs to be understood. For the case of India, dry season (*Rabi*) irrigation occurs ex-post the monsoon season, while the wet season (*Kharif)* irrigation occurs concurrently with the monsoon season[7]. We focus on five major crops grown in different seasons: rice, sorghum, cotton and maize grown in the wet season, and rice, wheat and barley grown in the dry season. Crops grown in both seasons such as rice have different seasonal responses to changes in monsoon, and are therefore assessed separately by season.

Figures 5 and 6 show the aggregate changes in yield, production, crop area and irrigated crop area for rice and wheat over the period of study from 1970 to 2004. Of interest are irrigated area and production that have changed similarly over the sample period, although at different levels. Both saw a rapid rise from 1970 to 1995 and a slower rise from then on. Crop area remains more or less the same over the period, thus indicating the importance of irrigation in enabling consistent upward trend in yields. How a changing monsoon could impact irrigation outcomes, therefore has a direct bearing on food security for the country.

Several studies have evaluated the potential impacts of future climate change on irrigation water requirements in the hydrology literature but do so on a global scale based on static contemporary irrigated areas or monotonically changing irrigated areas. Dynamic irrigated areas are only now becoming important to the physical science modeling community, but these are not based on statistical analysis of historical data, and are first order estimates of water demand and supply through bio-physical models (Fischer et al, 2007; Konzmann et al, 2013; Elliott et al, 2014) Our study is unique in that the scope is regional and we use an economic framework to assess change in irrigated area by capturing behavioral responses to changing precipitation patterns. This is done by implementing panel data methods that are increasingly being used to assess links between climate and economic outcomes related to agriculture, health, conflict, mortality, migration among others (Dell, et al., 2013) due to their ability to control for unobserved and omitted variables that can confound the true impacts of climate change.

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[7] *Kharif* season coincides with the summer monsoon season, and lasts approximately from June to September or Mid-October. *Rabi* season lasts approximately from November to February. On average most *Kharif* and *Rabi* season crops, overlap with these months, across the different states in the country.

While using panel data methods certainly has benefits, it does not allow long term adaptation, and only captures short term adaptation exploiting year to year variability in weather outcomes. Focus on “medium-term” and “long-term” adaptation has started to emerge. Taraz’s study (2013) on farmer crop choices and irrigation investment in response to meridional rainfall regimes(30 to 40 year cycles of high and low rainfall) in India is an example of the former. Burke and Emerick’s study (2013) on adaptation of corn productivity to negative effects on temperature in the US using “long differences”, a panel data approach over longer periods(for instance, using the difference between two ten year averages), is an example of the latter. While the long differences approach comes closest to mirroring long run responses to climate, it is not clear how agents perceive changes over longer periods of time (Dell et al, 2013). This is especially true for irrigation use. When modeling extent of irrigated area, as in this paper, it is the short run variation in weather that matters most since applying irrigation, in a given agricultural year[8], does not occur ex-ante the monsoon, but while the monsoon and *Kharif* season are occurring (for the *Kharif* crops), and ex-post the monsoon while the *Rabi* season is on (for the *Rabi* crops). This is not true for planting decisions where prior to the monsoon, either ex-ante decisions are made based on expectations of monsoon regimes(Taraz, 2013), or based on skilled forecasts (Rosenzweig and Udry, 2013).

Earlier studies that focused on irrigation choices (Dinar and Zilberman, 1991, Dinar et al, 1992, Negri and Brooks, 1990) did so largely through the lens of economic factors(prices, income, access to capital), but ignored climate adaptation (Mendelsohn and Dinar, 2009). More recently, Fishman (2012) shows how his estimate of yield sensitivity to rainfall and temperature is moderated by spread of irrigation, an adaptation measure. While the well regarded property of irrigation as a buffer is not found to hold overall, his study points to the importance of evaluating irrigation in the face of rainfall variability. In a seminal study on risk and irrigation investment by Rosenzweig and Binswanger (1993), irrigation investment is found to be sensitive to monsoon onset dates for a risk-averse farmer. More recently, Taraz (2013) measures the sensitivity of irrigation investment to average decades of past rain and one-year lagged rainfall across India, and finds that investment is higher after decades that have been dry, emphasizing that farmers update their expectations over future weather.

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[8] Year refers to an agricultural year (not calendar year) that lasts roughly from May to June of the following year.

While investment decisions can be based on expectations about the future, decisions to apply water to a field, depend on the actual occurrence of the rainfall event. The few studies that look at inter-annual variation in monsoon rainfall to explain actual irrigation outcomes, through the use of irrigated area, have focused on groundwater irrigation on a local level. One study uses dry (*Rabi*) season irrigated areas as proxy for groundwater and finds that preceding monsoon season indicators as well as previous year precipitation play a crucial role on the state of groundwater at the beginning of the dry season in the Telanga region in South India(Siegfried et al ,2010). Focusing on the same region along with a region in North West India, Fishman et al (2011) take into account differences in hydro-geological structures in the two places, to show that the level of monsoon rainfall impacts wet (*Kharif)* irrigated areas directly, while it impacts dry (*Rabi*) irrigated area through its effect on the depth of water in the wells, differentially across the two regions.

Using detailed irrigation data in a panel of 311 districts between 1970 and 2004, our econometric model examines the link from monsoon to irrigation decisions, by teasing out the spillovers effects of in-season and preceding season rainfall as well as past irrigation outcomes, by disaggregating the link by crop and season, for the entire country. Statistical identification comes from the considerable variation in precipitation within the districts for the time period of study from 1970 to 2004. Our results show that, on average, irrigated area for crops grown in the wet season become sensitive to precipitation later in the monsoon season, while irrigated area for dry season crops are directly impacted by total precipitation in the preceding season conditional on number of rainless days. Irrigation for wet crops is not as sensitive to surface water or groundwater availability as it is so for dry crops. Over the historic period of analysis, we find that the effect of the monsoon on irrigation has remained quite stable

Our contribution to the literature is three fold. One, we contribute to the literature on adaptation to climate change, paying attention to behavioral responses like irrigation decisions. This is in contrast to studies that focus on biophysical outcomes such as yield responses to climate change (Burke and Emerick, 2012; Fishman, 2012; Krishnamurthy, 2011; Schlenker and Roberts, 2009; Guiteras, 2009). The econometric evidence about irrigation water demand we provide here will be integrated with a process based hydrology model that measures the supply side effects by tracking water use and exchange between the ground, atmosphere, runoff and stream networks to calculate water supply needs for irrigation, in the second step of our analysis. This will enable us to assess how far India can go with increased irrigation. Second, because our historical panel spans a little more than three decades, we are able to explore the relationship between weather and irrigation over a period that has seen dramatic changes in water availability and precipitation patterns in India. Lastly, we focus on a country that is at the epicenter of a water crisis, thereby contributing to urgent issues related to water scarcity, sustainability and adaptation.

The rest of the paper is organized as follows. Sections 2 explains the data used in the study, its strengths and weaknesses. Section 3 provides details on the empirical strategy. Section 4 discusses the results. Section 5 concludes.

2. Data

2.1 Agricultural data: The source of agricultural data comes from the Village Dynamics in South Asia database at the International Crop Research Institute for the Semi-Arid Tropics (ICRISAT)[9]. ICRISAT collates its data from State Directories of Agriculture, State Bureaus of Economics and Statistics, State Planning Departments, various Agricultural Censuses and government reports to create the dataset.

The data contains annual district level observations on a variety of variables like irrigated areas by crop and type of irrigation source(tanks, wells), production statistics, input use(fertilizer, agricultural implements), harvest prices, soil type, labor wages, livestock, for 311 districts and 19 states[10] for the agricultural years 1966-2006. The primary variables of interest are the irrigation statistics. Ideally, data on actual water use per hectare of crop area is preferred. However, since only irrigated area statistics by crop are available at the district level, we use irrigated area to proxy for actual water use. While this does not allow exploring the intensive effects of irrigation (the change in water applied per hectare), our analysis is still able to capture the extensive effects (the change in irrigated area).

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[9] A World Bank dataset covering years 1956-1987 called the Indian Agriculture and Climate Dataset has been widely used in a number of related studies (Kumar and Parikh, 2001; Sanghi et al., 1998; Guiteras, 2009; Duflo and Pande, 2007; Taraz, 2013; Miller, 2013). However, this dataset does not contain detailed information on irrigation related variables that are of primary interest to us.

[10] Three new states formed in India after 2000-Chhatisgarh, Jharkhand and Uttarakhand are given back to their parent states from where they were formed, for consistency. Therefore, in data analysis, the overall no. of states used is 16.

Data for a large proportion of the districts are available only from 1969 onwards and before 2005; we therefore use data from 1970-2004. The dataset covers both *Kharif*(wet) and *Rabi*(dry) season crops. In our analysis we focus on main cereals such as rice and wheat, coarse cereals such as sorghum, maize and barley, as well as a water intensive cash crop such as cotton. Wheat was the focus of the Green Revolution and has larger coverage of irrigated area than most other crops and is grown in the dry season. Rice is the main staple crop and accounts for 46% of cereal production, and is grown in both seasons. Sorghum, grown mostly in the wet season, remains a staple coarse cereal in India, due to its low sensitivity to drought, making it a preferred choice for poorer sections that reside in the semi-arid regions of India. Maize and barley are two other coarse cereals that make up a large share of diets for poorer sections of the country, each grown in the wet and dry seasons respectively. Cotton is widely grown as a cash crop, even in semi-arid regions, due to its high market value and is grown in the wet season. Not all districts grow all crops. Therefore for analysis purposes we focus on districts that grow a particular crop for all the years of our study.

We use districts as our unit of analysis. Districts are an administrative unit under the Indian state and are the lowest level of disaggregation at which longitudinal agricultural production data for the entire country is available. Since Indian district boundaries change over time and larger districts split into smaller ones (219 new districts were formed between 1966 and 2007), Districts in our data are as per the boundaries in the year of 1966. Data of districts formed after 1966 are given back to their parent districts (i.e. districts from which they were formed) based on the percentage of geographical area of the parent district that was transferred to the new district.

2.2 Weather Data: Our unique historical weather data for the years 1970-2006 comes from APHRODITE, a daily observationally gridded precipitation and temperature dataset. [11]

Since rainfall by its very nature is an "unusual discontinuous atmospheric phenomena" with high spatial and temporal variability (Mishra et al, 2011), the quality of precipitation data to be used is not trivial. We use a gauge-based observationally gridded daily dataset from APHRODITE(Asian Precipitation- Highly Resolved Observational Data Integration Towards Evaluation of the Water Resources) conducted at the Research Institute for Humanity and

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[11] Overview of the project, data set and algorithms are discussed in Yatagai et al (2012).

Nature (RIHN) and the Meteorological Research Institute of Japan Meteorological Agency (MRI/JMA). The data is compiled at a spatial resolution of 0.25 degree X 0.25 degree and 0.5 X 0.5 degree for the years 1951-2007. This is the only long-term (1951 onward) continental-scale daily product that contains a dense network of daily rain-gauge data for Asia including the Himalayas, South and Southeast Asia and mountainous areas in the Middle East(Yatagai et al, 2009). The dataset is interpolated using station gauge data obtained from a variety of sources: the World Meteorological Organization (WMO) Global Telecommunication System data, pre-compiled datasets, compilation of station data and monthly climatologies from a number of countries that included China and India (Yatagai et al, 2009). The higher resolution APHRODITE data captures the spatial trends in precipitation in more detail (Duncan et al, 2013) as well as the variability in each grid cell brought about by large scale dynamics and local forcings of monsoon rainfall due to changes in local emissions and landuse changes (Kharol et al, 2013). To our knowledge, this is the first study to use APHRODITE to study precipitation-agriculture linkages for India.

Temperature data in our analysis also comes from APHRODITE and is available for the period of 1973-2007, at a 0.50 x 0.50 degree grid resolution. Using GIS maps corresponding to district boundaries in the year 1966, we are able to convert gridded weather data to the district level, to make them consistent with the unit of analysis for agricultural data, by averaging over grid points falling within a given district.

2.3 Summary Statistics: Summary statistics of the key variables are presented in Table 1. Mean wheat and rice irrigated are the highest compared to the other crops. There is substantial variability in the extent of irrigation for all crops, as well as in the measures of monsoon rainfall. Table 2 shows that net irrigated area to net sown area is largest in the Northern regions of the country. These regions are also the ones that receive much lower monsoon rainfall than the rest of the country, and where the Green Revolution took off.

3. Empirical Strategy:

To recover estimates of the extensive elasticities of irrigation demand, we estimate reduced form fixed effects equations to quantify the change in irrigated area for kharif rice, sorghum, maize and cotton grown in the wet season, and rabi rice, wheat and barley grown in the dry season as a result of changes in precipitation patterns given by $R_{d,t-i}$, as under:

(1): $$\log Y_{dt} = \gamma_0 + \alpha\, logY_{d,t-1} + \beta\, log\, R_{d,t} + \gamma_1 logSDD + \gamma_2 \overline{A_{d,t-1,t-6}} + \rho_d + \lambda_t + A_s t + \epsilon_{dt}$$

Here d is the district index, t is the year index and s is the state index. We use conley corrected standard errors (Conley, 1999) adapted by Hsiang (2010) for panel data for our analysis. This allows for districts to be correlated as a function of distance. This technique ensures that we account for heteroscedasticity, district-specific serial correlation, and cross-sectional spatial correlations. The reduced form equation above, identifies the net effect of precipitation on irrigation outcomes and with the exogenous variation in precipitation explains the causal relationship from monsoon changes to irrigation changes.

Dependent variable: Y_{dt} is the crop irrigated area in district d at year t. We include a lag of the dependent variables since it is an important element of the data generating process. This is because investing in irrigation infrastructure has spillover effects into the future (to the extent that irrigation infrastructure is still in operation) that enable the application of irrigation in the first place[12]

Monsoon measures: $R_{d,t}$ are the contemporaneous rainfall measures. Following Fishman (2012) these are (a) total monsoon precipitation (rainfall that occurs between June-September), (b) total precipitation in the months of June, July, August and September separately and (c) a measure of the distribution of rainfall i.e no. of rain days (days with precipitation over 0.1mm). Using both the total monsoon rain and the no. of rain days helps to distinguish between cumulative impacts of rainfall and the associated impacts of its distribution over the months of June-September, by season. For example, during critical crop growth stages, too many days without rain, can reduce yields or lead to crop failure. While *Kharif* crops experience monsoon impacts as it happens since the *Kharif* and monsoon season are coincident; *Rabi* crops, experience the after- effects of the preceding monsoon season.

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[12] When using short panel data, including lags biases coefficient estimates called the Nickel bias. However, in long panels (here T=35), this bias can safely be considered second order as it declines at the rate of 1/T (Dell, 2013). Roodman (2006, pg. 42) notes that “If T is large, dynamic panel bias becomes insignificant, and a more straightforward fixed effects estimator works."

Temperature measure: Our focus in the paper is to isolate the effect of the monsoon on irrigation decisions. However, since historical precipitation and temperature are correlated, omitting temperature means that the coefficient on precipitation will measure the combined effect of the two variables. Therefore to obtain unbiased estimates of the effects of changes in precipitation, we include seasonal degree days in the regression equation as well (Auffhammer, et al, 2013).

Seasonal degree days (SDD) are a measure of heat exposure to predict crop yield, as per Schlenker et al. (2006) but by season. SDDs are a cumulative measure of temperature based on the minimum and maximum daily temperatures and measure the contribution of each day to the maturation of the crop. Each crop, depending on the specific seed type and other environmental factors, has its own heat requirements for maturity (Skoufias and Vinha 2011). Given the mixture of different crops grown in the districts, we follow Schlenker et al's (2006) generalized bounds of 8 and $32°C$. Here daily mean temperatures are converted to degree-days by the formula: $DDS = \sum_d D(T_{avg,d})$ where

- $T_{avg,d}$ is the average daily temperature in day d
- degree days are summed over the days of the growing season
- D(T) reflects ability of crops to absorb heat in the temperature range from 8℃ to 32℃

$$\begin{aligned} D(T) &= 0 && \text{if } T \leq 8°C \\ &= T - 8 && \text{if } 8°C < T \leq 32°C \\ &= 24 && \text{if } T \geq 32°C \end{aligned}$$

Controls: $\overline{A_{d,t-1,t-6}}$ is the previous five year average crop area. Since irrigation decisions occur in response to planting decisions, controlling for extent of crop area is necessary. This can help absorb residual variation and capture more precise estimates. However, inclusion of the contemporaneous cropping decision could create a potential source for endogeneity bias, especially if time varying unobservables that impact irrigation decisions also impact planting decisions or if these decisions occur almost simultaneously as in the case of the dry season. For instance, prior to the start of the dry season, farmers are known to check the post monsoon level of water in their wells. They then decide on acreage that can be safely irrigated, depending on how low the water tables are (Siegfried et al, 2010). Additionally, while the inclusion of time varying observables such as crop acreage is necessary, contemporaneous crop area is itself an outcome of weather changes. This creates an “over-controlling” problem, in that, we would be unable to estimate the true effect of weather on irrigation (Dell et al, 2013). To safeguard against the bias inference, we use previous five year average of crop area. This eliminates the bias at least contemporaneously, and is still able to capture the expectation to plant in the current period. ρ_d are controls for unobservable time invariant district specific characteristics(e.g. soil quality) Controlling for these district fixed effects, allows us to remove the heterogeneity between districts and make sure that the impact of monsoon rainfall on irrigated area is derived from differences in the monsoon across years, within any given district., λ_t are controls for unobservable year effects that controls for aggregate country specific effects (e.g. economic growth or growth in the real gross domestic product) , $A_s t$ are controls for state specific quadratic trends(e.g. technological progress that can differ from state to state).

Changes in precipitation and seasonal degree days affect the irrigated area proportionally; therefore it makes sense to estimate a logarithmic functional form, so that the coefficients are elasticities. The main coefficient of interest is β_i, since it measures the water stress on irrigation. More precisely, we capture the short-run elasticity of irrigation demand, in response to inter-annual variation in rainfall, assuming that further investment in irrigation infrastructure remains constant over time. To capture long run elasticity of irrigation demand, that encompasses changes in irrigation technology, we would need to model a dynamic multi-state model with forward looking agents. For the present analysis, we believe that such a short run elasticity measure captures the myopic decision making process farmers engage in, in India, with respect to actual irrigation use in the fields.

India has witnessed drastic changes in trends of groundwater and surface water use since 1970, form being surface water driven to being groundwater driven. The availability of well-drilling equipment, electrical pumps (Aeschbach and Gleeson, 2012) and large power subsidies that fuelled the green revolution (Shah, 2013), have changed the face of irrigation in the country but are also responsible for deteriorating water tables[13].Figure 7 shows the changing pattern of irrigation, by source. Therefore, we also estimate the sensitivity of irrigation outcomes to precipitation in presence of different types of irrigation infrastructure such as wells (shallow dug

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[13] Rodell et al. (2009) used GRACE satellite data and showed that during 2002-2008 India lost around 109 cubic km of water, leading to a decline in water table to the extent of 3-5 cm per annum.

wells and deep tube wells) and tanks, by interacting total rainfall in the monsoon season by dummies identifying districts where the source wise irrigated area is above the national average.

(2):

$$\log Y_{dt} = \gamma_0 + \alpha\, logY_{d,t-1} + \beta\, log\, R_{d,t} + \delta\, log\, R_{d,t} * high\ source_i + \gamma_1 logSDD + \gamma_2 \overline{A_{d,t-1,t-6}} + \rho_d + \lambda_t + A_s t + \epsilon_{dt}$$

$where\ i = tanks, dug\ wells, tube\ wells$

4. Results

4.1 Monsoon and Irrigation

Tables 3 and 4 present results from equation (1), for the kharif (wet season) crops and rabi (dry season) crops respectively, Column(2) includes the lag dependent variable, while Columns(3) and (4) also control for previous five year average crop area.

In general, irrigation demand responds negatively to more even distribution of rainfall over the monsoon season, keeping total amount of monsoon precipitation fixed. The coefficient on no. of rain days is negatively significant for most crop irrigated areas, both kharif and rabi. In other words, in face of increasing dry spells the demand for irrigation rises and a larger portion of crop area is irrigated. In contrast, irrigation demand can either rise or fall in response to increase in total monsoon precipitation, keeping the distribution of rain fixed. Total monsoon precipitation affects irrigation decisions separately for crops in the rabi and kharif seasons. This seasonal sensitivity is impacted by storage facilities for the total amount of rain, as well as the timing of the season. Rabi season occurs ex-post the monsoon, and therefore is mostly sensitive to total precipitation over the preceding season as collected in storage structures and the after- effects of monsoon on soil moisture. Kharif season occurs concurrently with the monsoon, and therefore the relationship between irrigation decisions and total monsoon precipitation is harder to tell. To alleviate this concern somewhat, we also look at intra-seasonal variation in the monsoon by examining the sensitivity of early (June), mid(July) and later rain (August and September) to irrigation use in Column (4).

Out of the kharif crops, only sorghum remains negatively sensitive to total monsoon precipitation. The demand for irrigation falls in response to an increase in total precipitation. This is in contrast to the insensitivity of sorghum irrigated area to the distribution of rainfall. This is probably because sorghum remains a relatively drought resistant crop (Brouwer and Heibloem, 1986) and is insensitive to increasing dry spells. When disaggregating by monthly rain, most of the kharif crops show a negative response of irrigation needs to higher early season rainfall. As the season progresses, the kharif crops show differential responses to increases in late season rainfall, except for sorghum where the irrigation response remains negative for most of the monsoon months. While monthly rainfall data allow estimating sensitivity of early season rainfall to irrigation, without accurate data on planting periods for crops grown in the monsoon season, it is harder to distinguish relation of mid and later season rainfall to irrigation. As the season progresses, from heavy rain in June to waning of the monsoon in September, the amount of water available in storage also changes, thereby making it harder to tell if it is the irrigation's sensitivity to rainfall or water storage that dominates.[14] We find no significant impacts of precipitation on rice; a surprising result but perhaps borne out of the concurrence of monsoon and kharif seasons, as well as to sensitivity of varying planting dates across different regions in the country.

All rabi irrigated areas respond positively to higher total precipitation in the preceding season since they depend on water accumulated in storage structures for irrigation. Among the monsoon months, mid to later monthly rainfall affect irrigated area the most, since the rabi season begins when the monsoon season ends, and rainfall collected in the latter months of the monsoon would impact water levels in storage structures and soil moisture conditions, the most.

To take stock of irrigation infrastructure spillovers into the long run and the irrigation potential of a district, we include lag of the dependent variables, to control for all economic factors that enable a farmer to irrigate. Since irrigation investment is an ex-ante self-insuring mechanism against precipitation shocks; the ex-post (rabi) and contemporaneous (kharif) application of irrigation that our results capture, require these investments to be functional and in place. At the same time, irrigation decisions are only made in response to planting decisions which we control

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[14] For instance, the Central Groundwater Board of India records pre-monsoon and post-monsoon water levels in different monitoring wells across the country.

for by using average of crop area over the last five years in each district. Coefficients on both variables remain positively significant for all crops, as expected.

Overall, we find that irrigation is able to counteract uneven distributions of rainfall through the monsoon season, but this is not the case for falls in total amount of monsoon precipitation. For dry crops, especially, this is of concern since recurring large falls in total precipitation could alter decisions to grow staple cereal crops such as wheat.

4.2: Monsoon and Source of irrigation

Table 5 present results from equation (2). As indicated earlier, total monsoon rainfall impacts on irrigation are mediated by surface and groundwater structures that hold monsoon rainfall. There exists large scale spatial heterogeneity in the type of irrigation infrastructure used and the extent of safety they afford in times of a bad rainfall. For instance, the southern states lie in the hard rock areas of peninsular India that are mostly dependent on tanks and dug wells, in contrast to north and north- west parts of India that are dependent on deep alluvial aquifers. Surface structures such as tanks that are prone to higher rates of evaporation provide least storage capacity, followed by shallow dug wells that offer better storage capacity, but are still vulnerable to rainfall variability. Therefore, both don’t serve as good buffers in the face of prolonged rainfall shocks (Shah et al, 2009)[15]. Deep tube wells, on the other hand, tap into pockets of deep groundwater, and are not as vulnerable to monsoon variability. We find that for a rabi crop such as wheat, sensitivity of irrigation to total precipitation falls in districts dominated by tube well irrigation, but increases in districts dominated by dug well irrigation. Tanks seem to play no role in mediating the sensitivity of irrigation to monsoon. For a kharif crop such as sorghum, none of the structures play a role in expanding or contracting irrigated area, except for dug wells. These estimates are at best suggestive, since exogenous variation in irrigation types is needed, to make conclusive assessments. However, they still point to the vulnerability of regions dominated by deep tube well irrigation, mostly in the north and north-west of the country that have now started to face drastic drops in water table levels due to excessive drawing of water (Rodell et al, 2009)

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[15] The 2002-2003 drought hit states in the hard rock peninsular region harder than states in the Indo Gangetic plain that are mostly dependent on tubewells. (Shah et al, 2009)

4.3: Monsoon and Evolution of irrigation

Finally, we examine the evolving nature of irrigation decisions by focusing on three decades separately, namely, the 1970s, 1980s and 1990s in Tables 6 and 7, since our data covers a large time period that saw marked changes in water availability (Rodell, 2009), the advent of "atomistic" irrigation propelled by individual investment in wells (Shah, 2010) and increase in extreme wet spells and frequency of dry spells (Singh et al, 2014). The estimates for coefficients on no. of rain days in the kharif season, and those on total monsoon in the rabi season are relatively stable. We find that for most of the kharif crops, irrigation acts as a buffer against uneven distribution of rainfall over different time periods, while for most rabi crops, irrigation remains positively and significantly sensitive to total amount of monsoon rainfall over time. The consistency in the direction of the signs for these two variables seems to indicate that irrigation decisions haven't undergone a massive shift in response to the monsoonal changes over time. What this means for future changes in monsoons, is questionable and needs to be explored.

5. Conclusion

This study attempts to estimate the differential effects of monsoon measures on irrigation outcomes for dry and wet season crops. Variation in the monsoon plays a substantial role in irrigation decisions. While irrigation is found to expand in response to lower rainy days keeping total precipitation constant, the effect of total monsoon precipitation is less clear for the kharif crops, although its effect remains and positively significant for the rabi crops. The vulnerability of rabi crops to falls in total monsoon precipitation is concerning. This vulnerability is somewhat counteracted in presence of deep tubewells, reflecting the importance of water storage structures. In presence of consecutive years of lower than normal monsoon rainfall, the role of irrigation, especially for dry season crops will be called into question. That this is true for crops such as wheat, a major crop in India and grown widely in the Indo-Gangetic plain, breadbasket of the Indian subcontinent and home to close to 280 million rural inhabitants, is a cause for concern. Dramatic changes in water availability over the course of the period, has not changed the way irrigation decisions are made. How sustainable this is into the future needs to be further investigated. Moving forward, this study will extend analysis to other crops, in addition to estimating future changes in irrigation with changes in the monsoon. Moreover, farm level data will be used to assess irrigation decisions at a more nuanced level which is not possible when using aggregate district level data. The study is the first step in linking estimates from an economy model to a hydrology process model such as the water balance model, with the goal of quantifying the sustainable or unsustainable water use trajectory India will face in the coming years.

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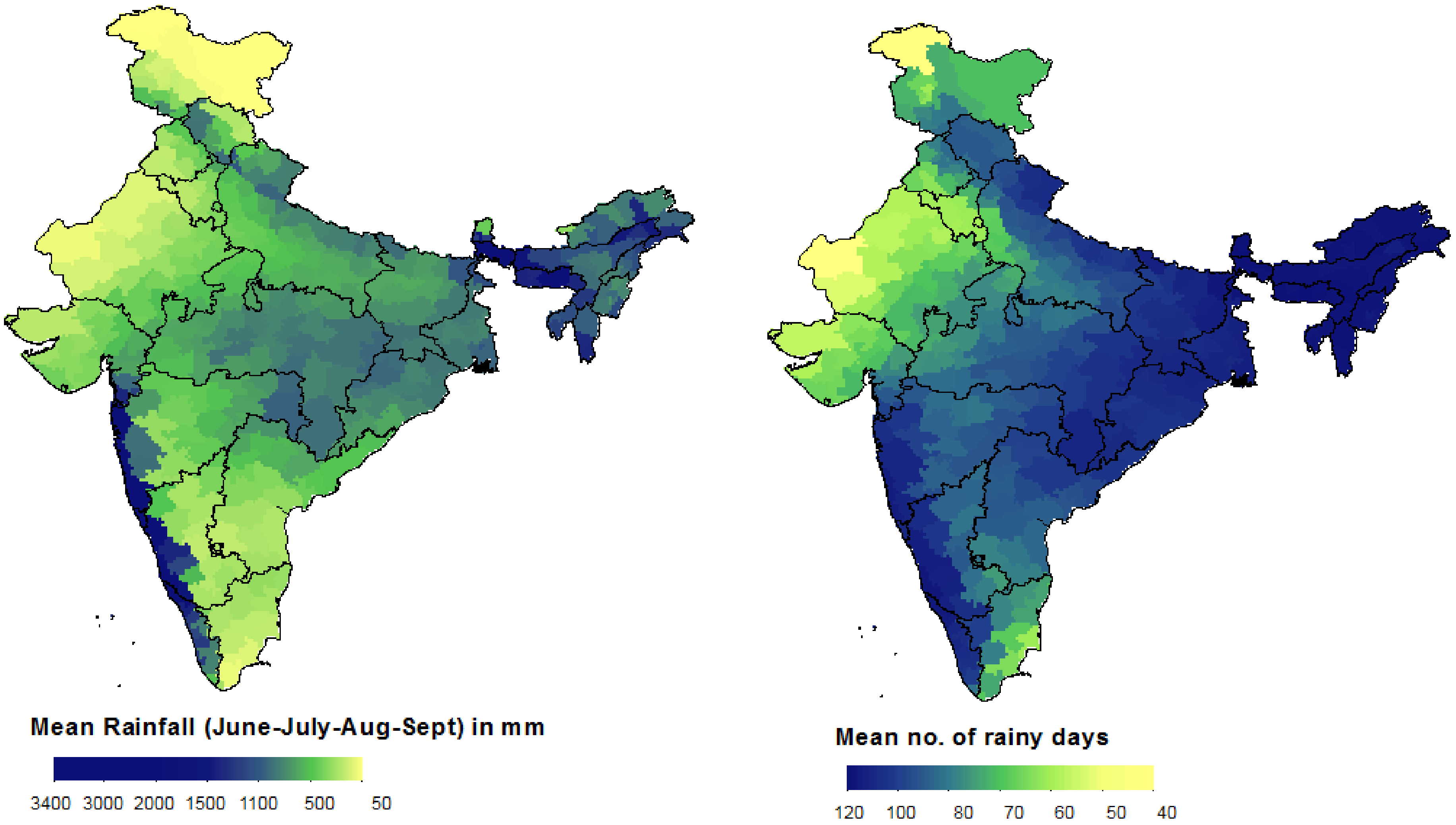
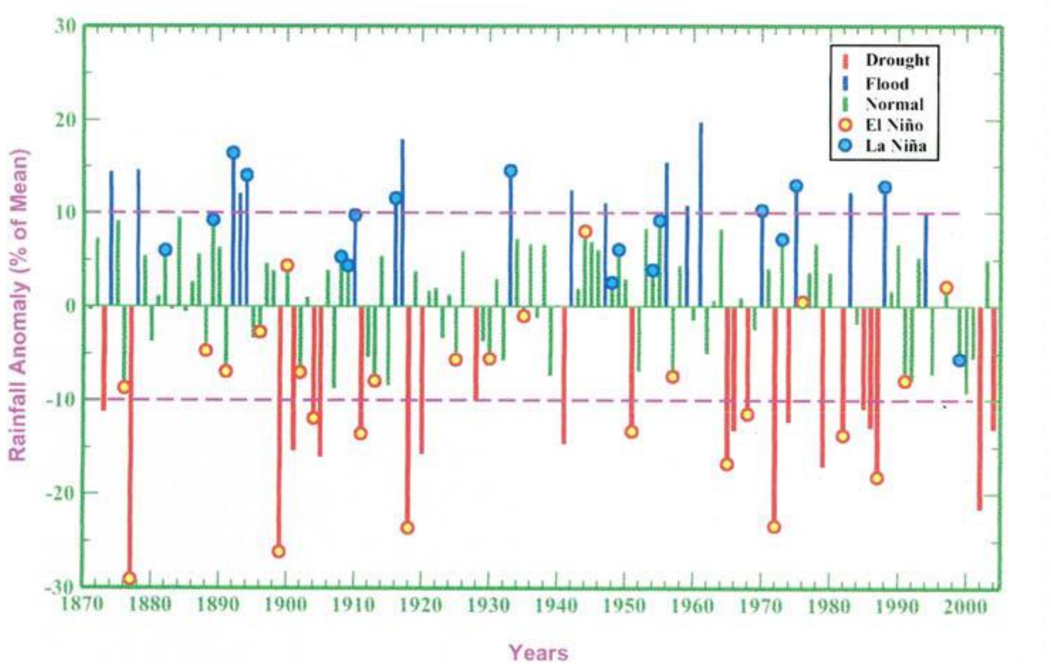
Figure 1 Spatial patterns of mean monsoon rainfall (a) and mean of rain days (b) from 1970-2004



(a) Monsoon rainfall

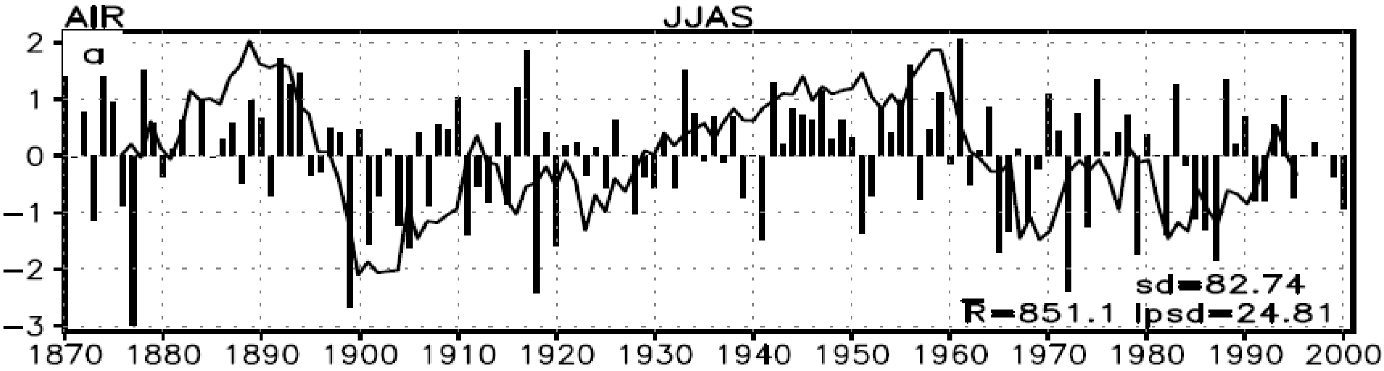
(b) No. of rain days

Figure 2: Inter-annual variation in monsoon rainfall corresponding to El Nino and La Nina (1871-2004)



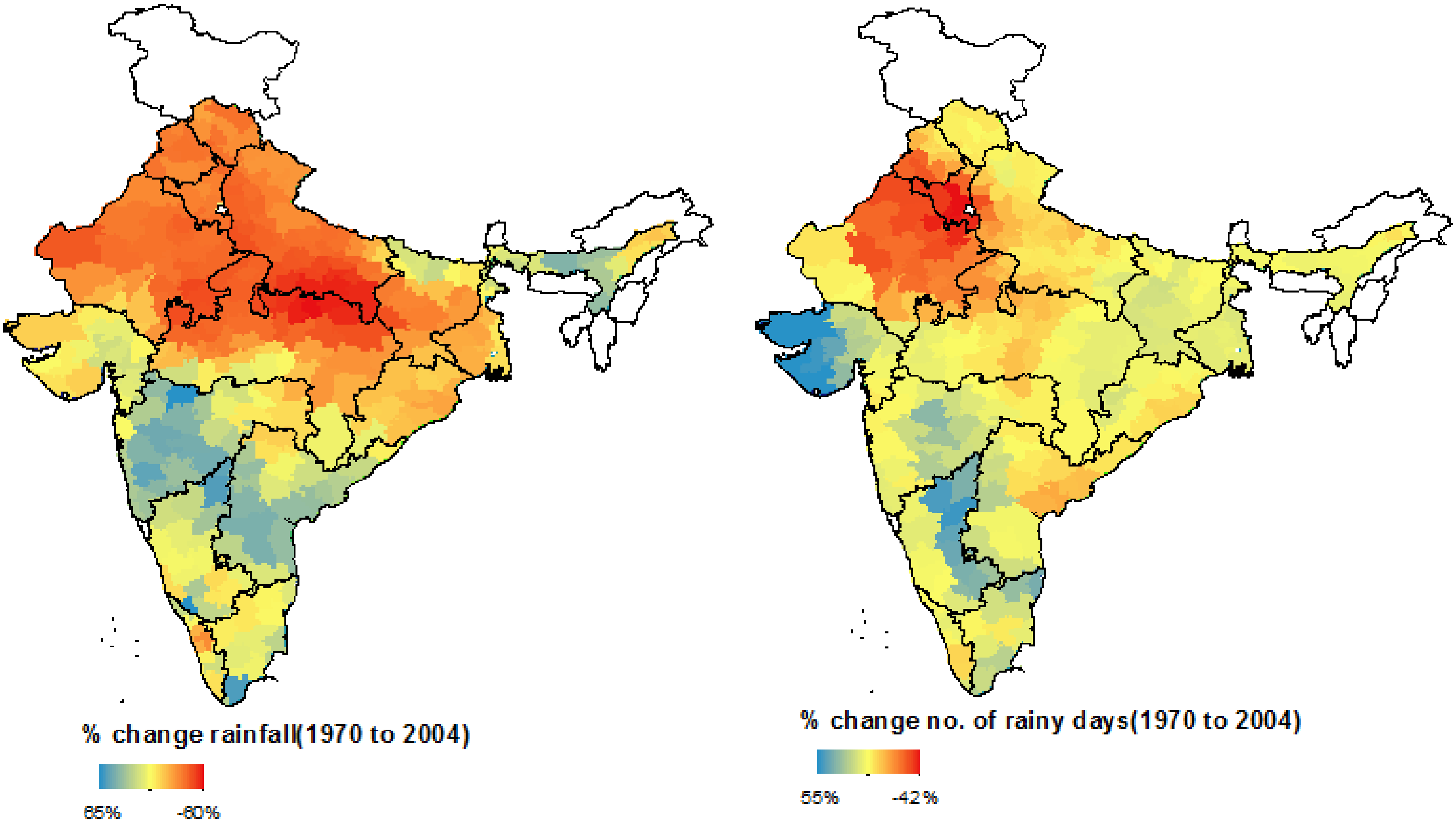
Source: Wang (2006)

Figure 3: Inter-annual (bar) and inter-decadal (solid) variability in All India Rainfall (AIR) during June-September(JJAS) (1871-2004)



Source: Wang (2006)

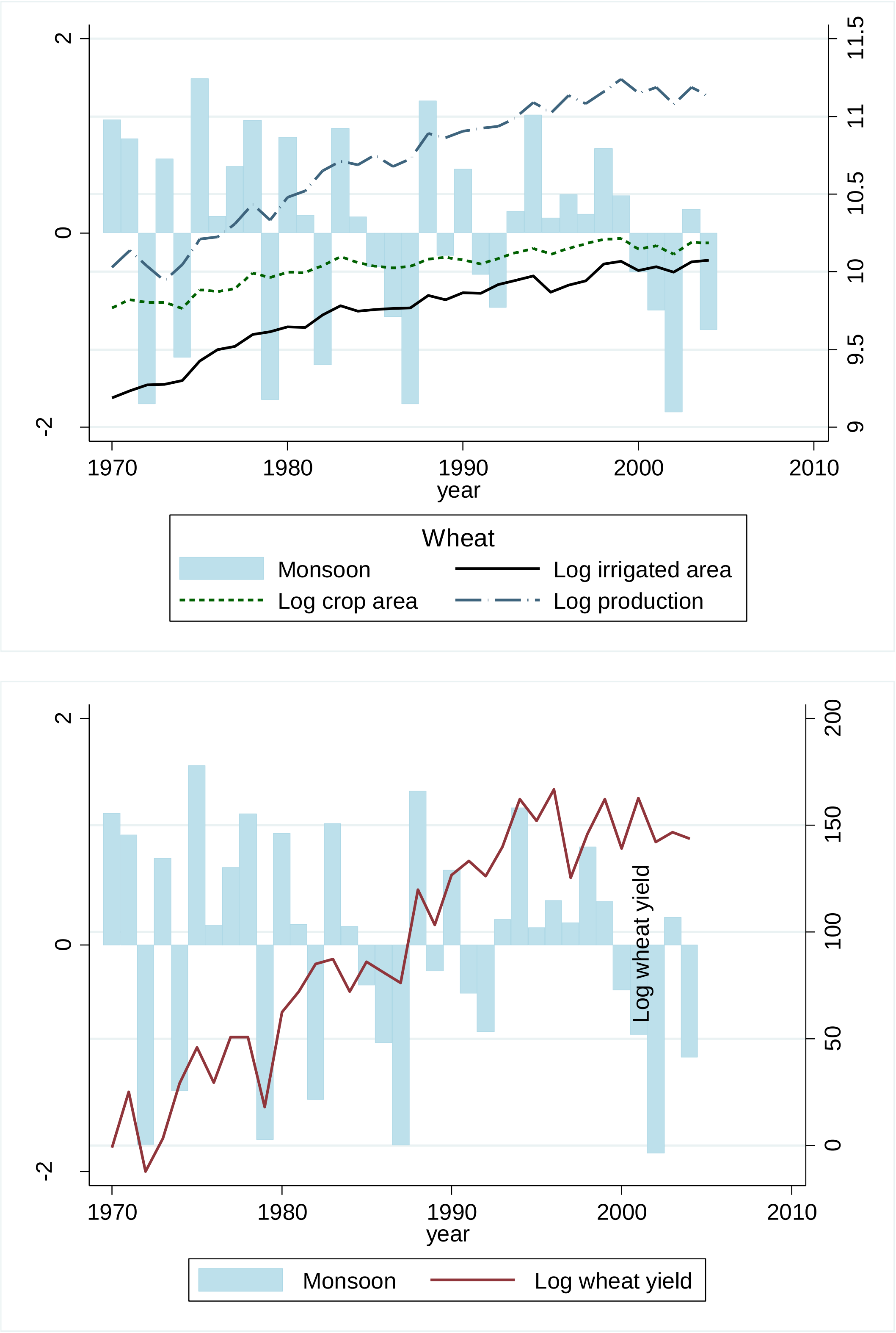
Figure 4: Percent change in monsoon rainfall (a) and no. of rain days (b) between 1970-2004. Negative (positive) percentage change indicate a drop (rise)



(a) Monsoon rainfall

(b) No. of rain days

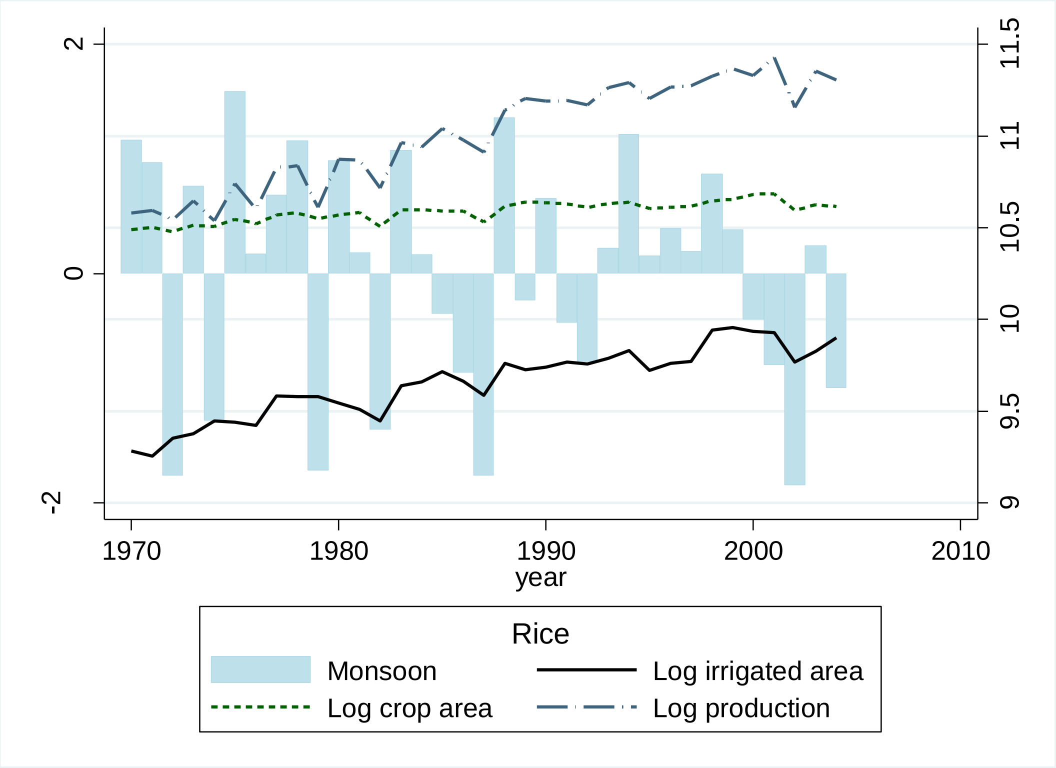
Fig 5: Aggregate changes in Wheat

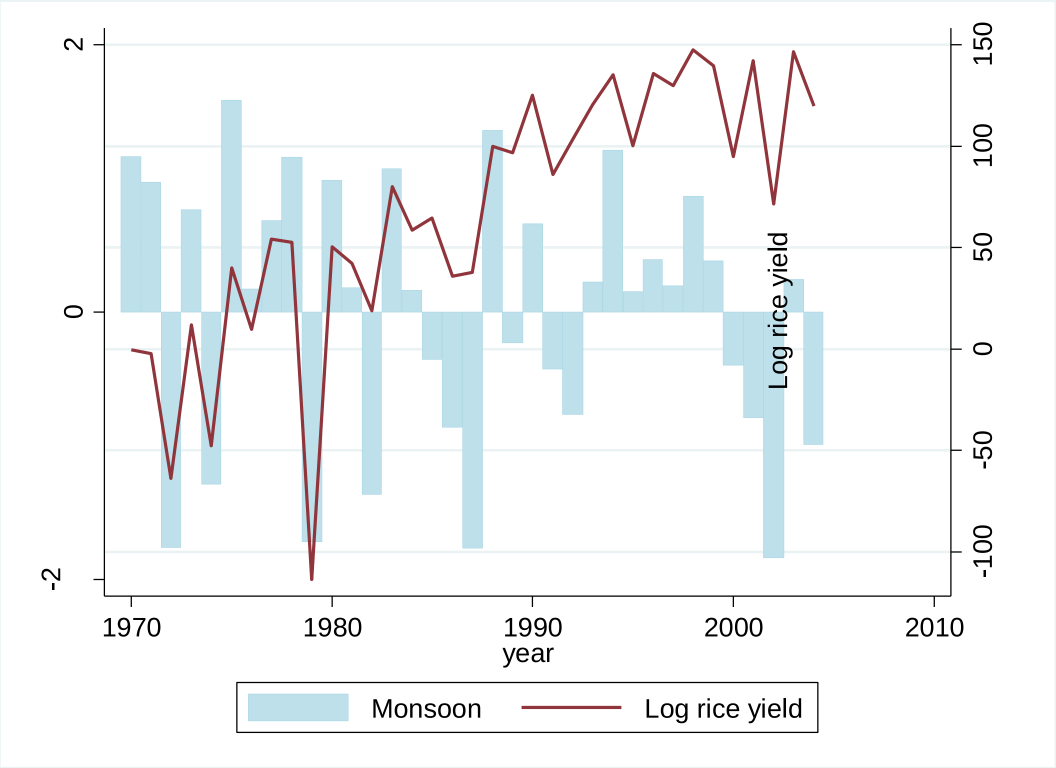


Note: Each panel reports values aggregated in each period over the district sample used in analysis.

Blue bars are the standardized deviation of monsoon rainfall (left axis)

Fig 6: Aggregate changes in Rice

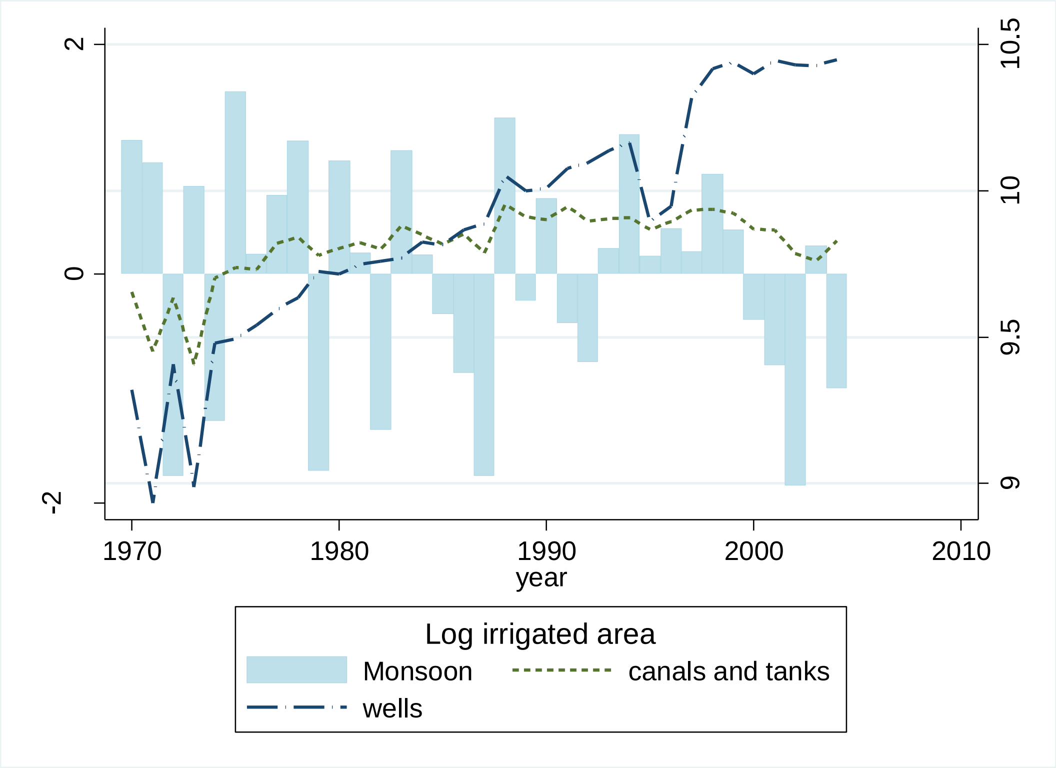




Note: Each panel reports values aggregated in each period over the district sample used in analysis.

Blue bars are the standardized deviation of monsoon rainfall (left axis)

Fig 7: Changing pattern of irrigation by source



Note: The panel reports values aggregated in each period over the district sample used in analysis. The blue and green lines correspond to log irrigated area by wells and surface water(canals and tanks). Blue bars are the standardized deviation of monsoon rainfall (left axis)

Table 1. Summary Statistics 1970-2004

Variable	**Obs**	**Mean**	**Std. Dev.**	**Min**	**Max**	**No. of districts**
Crop Irrigated areas (in 1000 hectares)						
Wheat	9822	62.68	92.57	0	742.98	301
Rice	9822	56.64	92.40	0	663.70	301
Sorghum	9820	2.65	10.11	0	109.10	301
Maize	9822	4.08	11.72	0	136.75	301
Barley	9788	2.70	7.68	0	109.70	301
Cotton	9781	8.36	37.60	0	541.56	301
Weather variables						
Monsoon rainfall (mm)	10885	783.60	471.86	18.46	4668.62	311
No. of rainy days (days)	10885	98.92	17.07	19	122.00	311
June rainfall (mm)	10885	145.75	145.36	0.38	1568.62	311
July rainfall (mm)	10885	252.15	182.19	1.46	1904.00	311
August rainfall (mm)	10885	239.20	147.02	0.68	1514.75	311
September rainfall (mm)	10885	146.50	102.79	0.01	981.23	311
Kharif(wet) degree days (degree days)	10885	2378.27	404.65	59.97	2925.04	311
Rabi(dry) degree days (degree days)	10885	1963.72	532.03	0	3193.11	311

Table 2. % net irrigated area to net sown area

Zone	**1985-86**	**1995-96**	**2001-02**	**2005-06**
North	60.305	69.795	82.17	84.175
East	33.265	27.345	37.67	46.5
Central & West	17.685	30.1	30.035	41.94
South	28.805	33.28	35.565	38.135

Notes: Net irrigated area is the area irrigated by any source once in a year.
Net sown area is the total area sown with crops and orchards.
Area sown more than once in the same year is counted only once

Table 3. Kharif (Wet Season) Irrigated Areas

	Rice				Sorghum				Cotton				Maize			
	(1)	(2)	(3)	(4)	(1)	(2)	(3)	(4)	(1)	(2)	(3)	(4)	(1)	(2)	(3)	(4)
No. of rain days	0.022	0.093	0.125	0.122	-0.071	-0.852	-0.872	-0.028	**-0.917+**	**-0.899+**	-0.841	**-0.944***	**-1.593***	**-1.611****	**-1.637****	**-1.408****
	(0.230)	(0.218)	(0.220)	(0.222)	(0.558)	(0.551)	(0.550)	(0.516)	**(0.514)**	**(0.530)**	(0.528)	**(0.469)**	**(0.462)**	**(0.429)**	**(0.425)**	**(0.432)**
Rainfall JJAS	0.118	0.060	0.068		**-0.955*****	**-0.853*****	**-0.881*****		0.258	0.202	0.188		0.224	0.142	0.145	
	(0.096)	(0.101)	(0.102)		**(0.203)**	**(0.204)**	**(0.204)**		(0.231)	(0.225)	(0.223)		(0.183)	(0.171)	(0.169)	
June Rain				0.057				**-0.161***				-0.097				**-0.110+**
				(0.036)				**(0.078)**				(0.117)				**(0.062)**
July Rain				0.059				-0.174				0.049				**0.222***
				(0.052)				(0.114)				(0.116)				**(0.089)**
Aug Rain				0.029				**-0.309****				0.142				0.052
				(0.054)				**(0.107)**				(0.093)				(0.077)
Sept Rain				-0.040				**-0.368*****				0.083				-0.062
				(0.031)				**(0.071)**				(0.083)				(0.057)
Kharif degree days	0.255	-0.187	-0.228	-0.195	**1.179****	0.532	0.652	0.664	**-0.622***	**-0.562***	**-0.687***	**-0.828****	-0.200	-0.271	-0.290	-0.362
	(0.253)	(0.250)	(0.249)	(0.250)	**(0.433)**	(0.636)	(0.633)	(0.611)	**(0.297)**	**(0.275)**	**(0.271)**	**(0.308)**	(0.545)	(0.797)	(0.791)	(0.794)
Lag log irrigated area		**0.502*****	**0.476*****	**0.475*****		**0.379*****	**0.372*****	**0.368*****		**0.463*****	**0.446*****	**0.449*****		**0.411*****	**0.401****	**0.400*****
		(0.050)	**(0.052)**	**(0.052)**		**(0.029)**	**(0.029)**	**(0.029)**		**(0.066)**	**(0.068)**	**(0.067)**		**(0.028)**	**(0.028)**	**(0.028)**
Log Previous 5 yr Avg Crop Area			**0.537*****	**0.534*****			**0.335*****	**0.348*****			**0.305*****	**0.303*****			**0.327****	**0.325*****
			(0.091)	**(0.091)**			**(0.069)**	**(0.068)**			**(0.075)**	**(0.075)**			**(0.057)**	**(0.056)**
N	8369	8004	8004	8004	5744	5559	5559	5559	3265	3150	3150	3150	7331	7031	7031	7031
R-sq	0.905	0.933	0.934	0.934	0.923	0.935	0.935	0.936	0.739	0.795	0.796	0.797	0.828	0.859	0.860	0.860

Notes: Column(1) reports model with only weather variables. Column (2) includes lag dependent variable. Column (3) includes previous 5 year average crop area. Column (4) is a variant of Column(3) and parses out Rainfall JJAS into its monthly components.   Includes district and year fixed effects, as well as state specific quadratic trends. Reported in parentheses are conley corrected standard errors. Conley standard errors are used to account for heteroscedasticity, district-specific serial correlation, and cross-sectional spatial correlation. Dependent variable is log crop irrigated area. All variables are in logarithmic form. + $p<0.10$ * $p<0.05$ ** $p<0.01$ ***$p < 0.001$.

Table 4. Rabi (Dry Season) Irrigated Areas

	Rice				Wheat				Barley			
	(1)	(2)	(3)	(4)	(1)	(2)	(3)	(4)	(1)	(2)	(3)	(4)
No. of rain days	__-0.134*__	__-0.081+__	__-0.077+__	-0.059	-0.182	-0.039	-0.036	-0.101	-0.468	-0.106	-0.119	-0.196
	__(0.053)__	__(0.045)__	__(0.045)__	(0.050)	(0.157)	(0.119)	(0.120)	(0.119)	(0.416)	(0.200)	(0.200)	(0.182)
Rainfall JJAS	__0.101***__	__0.124***__	__0.125***__		__0.242***__	__0.235***__	__0.237***__		__0.309+__	0.036	0.045	
	__(0.031)__	__(0.026)__	__(0.026)__		__(0.060)__	__(0.042)__	__(0.042)__		__(0.167)__	(0.079)	(0.080)	
June Rain				-0.001				0.014				-0.005
				(0.009)				(0.019)				(0.031)
July Rain				__0.027*__				__0.065**__				__0.093*__
				__(0.013)__				__(0.020)__				__(0.044)__
Aug Rain				__0.058***__				__0.084***__				-0.053
				__(0.014)__				__(0.022)__				(0.044)
Sept Rain				__0.014+__				__0.049***__				0.020
				__(0.007)__				__(0.013)__				(0.030)
Kharif degree days	-0.001	-0.017	-0.024	-0.055	__-0.290*__	-0.065	-0.037	-0.055	0.244	0.116	0.112	0.107
	(0.079)	(0.058)	(0.058)	(0.059)	__(0.142)__	(0.087)	(0.083)	(0.087)	(0.203)	(0.127)	(0.127)	(0.128)
Rabi degree days	0.164	0.024	0.027	0.056	-0.229	__-0.171+__	__-0.184+__	__-0.178+__	-0.107	-0.001	-0.004	-0.004
	(0.103)	(0.074)	(0.074)	(0.075)	(0.143)	__(0.096)__	__(0.098)__	__(0.102)__	(0.284)	(0.211)	(0.212)	(0.205)
Lag log irrigated area		__0.478***__	__0.473***__	__0.473***__		__0.593***__	__0.569***__	__0.568***__		__0.810***__	__0.801***__	__0.797***__
		__(0.103)__	__(0.104)__	__(0.103)__		__(0.066)__	__(0.073)__	__(0.073)__		__(0.043)__	__(0.047)__	__(0.047)__
Log Previous 5 yr Avg Crop Area			__0.067*__	__0.066*__			__0.164*__	__0.163*__			__0.075+__	__0.079+__
			__(0.027)__	__(0.027)__			__(0.067)__	__(0.068)__			__(0.041)__	__(0.041)__
N	8369	8004	8004	8004	7538	7266	7266	7266	4074	3911	3911	3911
R-sq	0.996	0.998	0.998	0.998	0.979	0.987	0.987	0.987	0.810	0.924	0.924	0.924

Notes: Column(1) reports model with only weather variables. Column (2) includes lag dependent variable. Column (3) includes previous 5 year average crop area. Column (4) is a variant of Column(3) and parses out Rainfall JJAS into its monthly components. Includes district and year fixed effects, as well as state specific quadratic trends. Reported in parentheses are conley corrected standard errors. Conley standard errors are used to account for heteroscedasticity, district-specific serial correlation, and cross-sectional spatial correlation. Dependent variable is log crop irrigated area. All variables are in logarithmic form. + $p<0.10$ * $p<0.05$ ** $p <0.01$ ***$p < 0.001$

Table 5. Sensitivity of Sorghum and Wheat Irrigated Areas to Source of Irrigation

	Sorghum				Wheat			
	(1)	(2)	(3)	(4)	(1)	(2)	(3)	(4)
	Baseline	Tube wells	Dug wells	Tanks	Baseline	Tube wells	Dug wells	Tanks
No. of rain days	-0.872	-0.863	-0.742	-0.831	-0.036	-0.044	-0.095	-0.018
	(0.550)	(0.547)	(0.535)	(0.553)	(0.120)	(0.118)	(0.124)	(0.115)
Rainfall JJAS	-0.881***	-0.790***	-0.568*	-0.991***	0.237***	0.338***	0.127**	0.215***
	(0.204)	(0.198)	(0.249)	(0.245)	(0.042)	(0.053)	(0.048)	(0.044)
Rainfall JJAS x high tubewell		-0.410				-0.298***		
		(0.355)				(0.054)		
Rainfall JJAS x high dugwell			-0.685**				0.256***	
			(0.247)				(0.070)	
Rainfall JJAS x high tanks				0.321				0.130
				(0.319)				(0.086)
Kharif degree days	0.652	0.668	0.664	0.673	-0.037	-0.050	-0.045	-0.033
	(0.633)	(0.638)	(0.607)	(0.636)	(0.083)	(0.083)	(0.082)	(0.083)
Rabi degree days					-0.184+	-0.162	-0.179+	-0.183+
					(0.098)	(0.101)	(0.099)	(0.098)
Lag log irrigated area	0.372***	0.372***	0.371***	0.372***	0.569***	0.568***	0.566***	0.568***
	(0.029)	(0.029)	(0.029)	(0.029)	(0.073)	(0.073)	(0.073)	(0.073)
Log Previous 5 yr Avg Crop Area	0.335***	0.336***	0.343***	0.338***	0.164*	0.168*	0.167*	0.163*
	(0.069)	(0.069)	(0.069)	(0.070)	(0.067)	(0.067)	(0.067)	(0.067)
N	5559	5559	5559	5559	7266	7266	7266	7266
R-sq	0.935	0.935	0.935	0.935	0.987	0.987	0.987	0.987

Notes: Column (1) reports model without interactions. Column(2) -(4) include interactions of total rainfall with dummies indicating districts with highest tube well, dug well and tanks irrigated area above the national average. Includes district and year fixed effects, as well as state specific quadratic trends. Reported in parentheses are conley corrected standard errors Conley standard errors are used to account for heteroscedasticity, district-specific serial correlation, and cross-sectional spatial correlation. Dependent variable is log crop irrigated area. All variables are in logarithmic form. + p<0.10 * p<0.05 ** p <0.01 ***p < 0.001.

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Table 6. Evolution of Monsoon Effects for Kharif(Wet Season) Irrigated Areas

	Rice			Sorghum			Cotton			Maize		
	1970s	1980s	1990s	1970s	1980s	1990s	1970s	1980s	1990s	1970s	1980s	1990s
No. of rain days	-0.209	0.189	0.333	-1.750	-2.402**	-0.502	-0.171	-1.440**	-3.730+	-1.861*	-1.874*	-0.873*
	(0.237)	(0.277)	(0.614)	(1.083)	(0.867)	(0.814)	(0.346)	(0.532)	(2.104)	(0.794)	(0.743)	(0.414)
Rainfall JJAS	-0.086	-0.107	-0.190	-1.053**	-0.727+	-0.346	0.098	0.574*	-1.194+	-0.360	0.262	-0.033
	(0.138)	(0.114)	(0.213)	(0.394)	(0.393)	(0.258)	(0.153)	(0.234)	(0.664)	(0.251)	(0.284)	(0.153)
Kharif degree days	-0.125	-4.349*	-1.361	0.264	-1.228	1.555	-0.134	-7.294+	-25.480+	0.226	2.474	-0.228
	(0.270)	(1.896)	(3.028)	(0.517)	(8.763)	(4.560)	(0.251)	(4.276)	(13.817)	(0.628)	(3.342)	(2.687)
N	2623	2430	2346	1821	1646	1633	1032	937	920	2336	2107	2038
R-sq	0.938	0.957	0.958	0.935	0.940	0.954	0.916	0.899	0.729	0.868	0.899	0.914

Table 7. Evolution of Monsoon Effects for Rabi(Dry Season) Irrigated Areas

	Rice			Wheat			Barley		
	1970s	1980s	1990s	1970s	1980s	1990s	1970s	1980s	1990s
No. of rain days	-0.215**	-0.060	-0.107	-0.215	-0.031	0.140	-0.243	-0.998+	0.175
	(0.082)	(0.101)	(0.072)	(0.187)	(0.257)	(0.175)	(0.210)	(0.550)	(0.350)
Rainfall JJAS	0.136*	0.076+	0.063*	0.115	0.230*	0.231***	0.017	0.339	-0.209*
	(0.061)	(0.043)	(0.028)	(0.081)	(0.093)	(0.061)	(0.095)	(0.274)	(0.095)
Kharif degree days	0.105+	-0.029	-0.606+	-0.241	-1.911	-0.139	0.234**	-7.888	-5.372*
	(0.063)	(0.564)	(0.351)	(0.165)	(1.191)	(0.554)	(0.090)	(5.191)	(2.464)
Rabi degree days	-0.082	0.681***	0.064	-0.275*	0.570	-0.148	-0.367**	-1.645	0.627**
	(0.091)	(0.171)	(0.121)	(0.138)	(0.424)	(0.115)	(0.123)	(1.496)	(0.194)
N	2623	2430	2346	2400	2148	2112	1308	1179	1112
R-sq	0.997	0.998	0.999	0.974	0.989	0.997	0.973	0.897	0.967

Notes: Includes district and year fixed effects, as well as state specific quadratic trends. Reported in parentheses are conley corrected standard errors.
Conley standard errors are used to account for heteroscedasticity, district-specific serial correlation, and cross-sectional spatial correlation.
Dependent variable is log crop irrigated area. All variables are in logarithmic form. + $p<0.10$ * $p<0.05$ ** $p<0.01$ *** $p<0.001$.