WATER RIGHTS AND AGRICULTURAL PRODUCTIVITY: EVIDENCE FROM INDIA

A Dissertation

Presented to

The Faculty of the Department

of Economics

University of Houston

In Partial Fulfillment

Of the Requirements for the Degree of

Doctor of Philosophy

By

Shreyasee Das

May, 2012

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Abstract

There is growing concern in the world to better manage water resources in order to sustain increased water demands. This heightened demand can be most importantly attributed to a rapid population growth and heightened development measures in the world. One way this has been tackled since centuries is by allocating water amongst the riparian parties. This dissertation examines a specific sector where water allocations are particularly vital, namely that of agriculture. I focus my analyses on two important basins in India, and attempt to estimate the causal effects of water allocations on agricultural productivity.

In my first chapter, I specifically look at the 1976 Krishna Water Dispute Tribunal that reallocated the rights of three Indian states (Maharashtra, Karnataka and Andhra Pradesh) over the Krishna River in the South of India. I exploit district-time variation in access to water to obtain causal effects of water reallocation on crop output and yield. I find that on average, the decision reduces district output by 7.7 percent and yield by 5.5 percent. I also find suggestive evidence that the decision amplified the reduction in productivity during drought periods; total production experiences an 8 percent decline and yield drops by 7.4 percent (however, the estimates are not statistically significant). The weak negative net effects of the decision are comprised of productivity gains for the most downstream state, Andhra Pradesh, that are more than offset by the productivity losses for the upstream states Maharashtra and Karnataka. The negative impacts for Maharashtra, which are especially pronounced during periods of drought, are significant at conventional levels of significance.

Thus, the 1976 reallocation of state rights over water from the Krishna Basin was redistributive and weakly reduced overall efficiency.

To assess if the same results are present in other basins, I look at the Cauvery Basin, also in the South of India, in my second chapter. I evaluate the effects of the 1991 Interim Order by the Cauvery Water Dispute Tribunal on agricultural productivity in the riparian states of Karnataka and Tamil Nadu by implementing a difference-in-differences strategy. On average, the decision does not significantly affect agricultural productivity. However, I find that output declines significantly during drought periods; total production falls by 24 percent (significant at the 5 percent level of significance) and yield reduces by 14.5 percent. I vary my analyses by states to investigate as to who bears incidence of the decision. Surprisingly, I find that both states experience losses during drought periods, but Tamil Nadu's losses are much higher than that of Karnataka's. The estimation results suggest an efficiency loss in the region and that the harmful effects of drought are amplified after the decision.

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to Ma (Kaberi), Daddy (Parichay) and Tulu Mashi (Krishna)

Chapter 1

State Rights over Water and Agricultural Productivity: Evidence from the Krishna Basin

"I have witnessed the conversion of my land from a water abundant country to a water stressed country." – Vandana Shiva, Water Wars: Privatization, Pollution and Profit

1.1 Introduction

River waters have long been the basis of conflict, both nationally and internationally. Usually the downstream parties demand more access to the river as their upstream counterparts tend to have more control over the river. Conflicts intensify when parties decide to build projects (canals, dams) on the rivers and/or their tributaries, thus blocking the water's natural flow (Iyer, 2007). In India, water wars have waged for centuries. The Cauvery River dispute has been going on since 1892, conflict over the Indus River between India and Pakistan began when India was partitioned right after its Independence in 1947, and the Farakka Water treaty between India and Bangladesh with respect to the Ganges River was brought up in the 1970s. Dispute over the Krishna River among the three riparian states has ensued since the early 1900s, and despite many attempts to settle it, a binding agreement was not in place until 1976; this 1976 agreement is the subject of this paper.

Rivers are examples of common pool resources: goods that are non-excludable but rival in consumption. There are a number of international doctrines pertaining to decisions solving water disputes, the most prominent being the Helsinki Rules on the Uses of the Waters of International Rivers of 1966, and the United Nations Convention on the Law of Non-Navigational Uses of International Watercourses of 1997.[1] These redistribution rules abide by the concept of *equitable appropriation* which states that the river is to be viewed as *common property* and that concerned parties will be allocated water on various factors that include the geography of the basin, the hydrology of the basin, climate, economic and social needs of the basin and population. India has its own set of doctrines to resolve disputes: the Interstate Water Disputes Act of 1956, which allows state governments to complain regarding river waters, and the National Water Policy of 1987 and 2002, which recognizes a river basin as the primary unit for water resources development and management.

Reallocating water among states involves redistribution, typically from upstream parties (who usually have better access to the water) to downstream parties. It is theoretically ambiguous whether on net, efficiency increases; this depends on whether the marginal productivity of water is higher upstream or downstream. Assessing which party has higher marginal productivity can be difficult, since incentives to invest can change after a water

[1] Helsinki Rules on the Uses of the Waters of International Rivers of 1966 spell out the principle of equitable sharing for beneficial uses while the United Nations Convention on the Law of Non-Navigational Uses of International Watercourses of 1997 details the utilization of water in an equitable and reasonable manner.

reallocation. In agriculture, for example, a change in water rights might change investments in irrigation and cropping patterns, among other things. Literature with respect to water allocation and water management is generally interdisciplinary and has been largely descriptive (Section 2.2 provides a discussion of the related literature). Though claims have been made about the depletion of water and the potential negative consequences for productivity, and case studies exist about productivity declines due to water reallocation[2], there are no studies that rigorously evaluate the effect of reallocation of state rights over water on agricultural productivity. This paper attempts to fill this gap by analyzing the impact of one particular water reallocation in India on agricultural productivity: the allocation of the Krishna Basin waters decided by the Krishna Water Dispute Tribunal (KWDT) in 1976. The evaluation of this water reallocation is of interest for several reasons. The Krishna Basin is one of the largest river basins in India, located in three states that collectively make up one-fifth of India's total population. Understanding the effect of the 1976 Tribunal decision is therefore important to the region, and could help policymakers design policies that raise food supplies, raise efficiency, or reduce poverty. The experience in Krishna Basin could illuminate issues in reallocation of water rights that others in India and outside it could learn from as they contend with their own water disputes.

To identify the effect of the 1976 water reallocation on agricultural productivity, I take advantage of district-time variation in exposure to the decision. In particular, only after 1976 is the water reallocation in effect, and moreover, it is the districts located adjacent to the Krishna Basin whose access to water could be changed due to the water reallocation. This

[2] In the matter of the Cauvery Water dispute, the downstream state of Tamil Nadu has always extensively used the river water for its irrigation, while Karnataka, the upstream state, started late with its irrigation and has extensively controlled the flow of water to the downstream areas. This has been associated with a productivity loss in the Thanjavore district in Tamil Nadu, which is one of the largest producers of paddy in the basin. However, it is difficult to attach a causal interpretation to this observed reduction in productivity, as there could be secular time changes in productivity unrelated to Karnataka's control of water upstream.

enables me to use a difference-in-differences strategy in which the change over time in agricultural productivity in the districts adjacent to the basin in excess of the change in districts located farther out is interpreted as the effect of the 1976 water reallocation. In the presence of differential trends in agricultural outcomes between the districts located closer and farther from the Krishna Basin, the difference-in-differences estimate would not give the effect of the water reallocation. Thus, in my preferred specification below, I control for district-specific time trends.

I apply this difference-in-differences strategy to a district panel data set covering all 63 districts of the three concerned states for the period of 1971-1999. My main finding is that the decision reduces agricultural productivity, though this is not significant at any conventional levels. I also look at the effect of the decision during drought periods, and find a negative (however not statistically significant) net effect on agricultural productivity; although the magnitude of the effect is higher than that of non-drought periods. When I allow heterogeneity in effect of the decision by state, I find that the decision increases productivity in the most downstream state, Andhra Pradesh, reduces productivity in the two upstream states, Maharashtra and Karnataka. The negative impacts for Maharashtra, which are especially pronounced during periods of drought, are significant at conventional significance levels. Taken together, these results indicate that the 1976 reallocation of state rights over water from the Krishna Basin was redistributive (with Andhra Pradesh gaining at the expense of its upstream neighbors) and weakly reduced overall efficiency.

The rest of the paper is organized as follows. Section 1.2 provides a background on the Krishna Water Dispute Tribunal, followed by a brief discussion of the related literature. Section 1.3 explains the theoretical framework for thinking about the impact of the water reallocation and elaborates on the empirical strategy. Section 1.4 describes the data. Section 1.5 presents the estimation results and I conclude in Section 1.6.

1.2 Background

1.2.1 The Krishna Water Dispute Tribunal

The Krishna River is the second largest river in Peninsular India. It rises from the Western Ghats near Mahabaleshwar and flows eastwards into the Bay of Bengal. The Krishna Basin spreads over 99,980 square miles (258,000 km^2) across three states: Maharashtra (upper riparian), Karnataka (middle riparian) and Andhra Pradesh (lower riparian).[3] The basin is further divided into 12 sub-basins. Figure 1.1 shows a map of the basin and the sub-basins. The Southwest Monsoon that spans from June to September/October is the main source of water in the basin. Canal irrigation is the primary method of irrigation, followed by tanks and wells. The soil in the region is primarily black soil and alluvial soil. The main crops of the basin are jowar, bajra, cotton, paddy and sugarcane.

The Krishna Basin has witnessed conflict between upstream and downstream parties for centuries. Most of the dispute has focused on which state has primary rights over the water, and also on various projects that were built on the river, thus curbing the natural flow of the river. There were contracts written between the states in 1933, 1944 and 1951, but arguments ensued about the validity of these agreements. Prior to the formation of the Krishna Water Dispute Tribunal in 1969, “the States were reduced simply to ‘parties to the disputes’, comparable to individual landowners quarrelling over withdrawals from

[3] Before the reorganization of states in 1956, the riparian provinces were Bombay, Madras, Hyderabad and Mysore.

watercourses that run through their properties" (D'Souza, 2006). Thus contracts regarding water sharing were difficult to enforce, with parties unhappy with the contract continuing to fight for a better allocation instead of abiding by it. To contest the 1951 agreement regarding the allocation of the Krishna waters, which Karnataka believed overly favored the downstream state Andhra Pradesh; Karnataka moved the central government to adjudicate the matters of the Krishna waters. The case was filed with the Indian Supreme Court in 1962 and a decision stipulating a new water allocation became effective in 1976.

After Karnataka filed the case in 1962, the Krishna Water Dispute Tribunal was set up in 1969 in accordance with Section 2(c) and Section 3 of the Interstate Water Dispute Act of 1956.[4] The Tribunal consisted of one former Indian Supreme Court judge, and two former judges from the highest court of two states not party to the dispute. The Tribunal sought advice and testimony from the concerned parties as well as technical experts. Karnataka was the main complainant and Andhra Pradesh the main opponent in the dispute. Maharashtra joined Karnataka as a complainant in this case. The primary point of dispute between the parties was to determine if the 1951 agreement remained valid. The upstream parties (Karnataka and Maharashtra) contended that the 1951 agreement was struck among entities that no longer existed due to the 1956 reorganization of states, and was based on many projects that had either been abandoned or modified, and thus was no longer valid. The downstream party (Andhra Pradesh) argued that the 1951 agreement was still valid.

The Krishna Water Dispute Tribunal announced its decision in 1973. The Tribunal concluded that the 1951 agreement was not valid and that the three states were not bound by that agreement. The Tribunal then stipulated a new water allocation: out of an estimated 2060

[4] Section 2(c) lays down the foundation that a "water dispute" implies that it is a dispute or difference between two or more state governments with respect to the use, distribution of the water of an inter-state river. Section 3 enables a state government to make a complaint regarding water disputes.

thousand million cubic feet (TMC) of total dependable flow[5] provided by the Krishna Basin, Maharashtra was allocated 565 TMC; Karnataka 695 TMC; and Andhra Pradesh 800 TMC. The decision was finalized in 1976 and henceforth became binding on the three states.[6] The intent of the Tribunal was to increase equity amongst the three states involved in the dispute, while maintaining individual state's efficient use of water in agricultural productivity as well as possible.

To regulate the implementation of the allocations, the Tribunal listed out a monitoring scheme. At all dams and weir sites (existing, under construction, and future projects) that utilize more than 1 TMC annually, discharge measurements were to be made three times a day.[7] In addition, the Central Water Commission (CWC) set up gauge sites on state rivers and interstate rivers and streams; these were to be monitored three times daily as well. All monitoring costs were to be borne by state governments. Water management techniques in the basin include dams, reservoirs, canals, and tube-wells.

Before turning to estimate the effect of the 1976 Tribunal decision reallocating states' rights over water in the Krishna Basin on agricultural productivity, it is useful to assess how the decision impacted water flows downstream. Data on discharge along the Krishna Basin

[5] Dependable flow is "the magnitude of river flow which may be assuredly expected at a given point on the river on some scientific or rational basis inspiring confidence" (Krishna Water Dispute Tribunal, 1973a, page 74). There are two approaches to calculate dependable flow; runoff and stream flow. Runoff is rainfall that is not absorbed by the soil finding its way into the river channel. River discharge (also sometimes called stream flow) is the volume rate of water flow (the residual amount available in a drainage basin). Stream flow was the preferred method of estimation since it also represents the integrated results of all meteorological and hydrological factors operative in the drainage basin and is the only phase of the cycle for which reasonably accurate measurements can be made of the volumes involved (Bruce and Clark, 1976). Discharge was calculated at the Bezawada (Vijayawada) site in Andhra Pradesh and the percentage dependability of the Krishna River at Vijayawada was calculated to be 75%, which works out to 2060 TMC.

[6] In addition to the above allocation (also known as Scheme A of the KWDT), Scheme B of the KWDT determined the distribution of the surplus water in the basin. The surplus was determined to be 330 TMC, and was to be divided thus, 25% to Maharashtra, 50% to Karnataka and 25% to Andhra Pradesh. However, the implementation of this Scheme required the constitution of the Krishna River Valley Authority, which was never realized. Thus, Andhra Pradesh was given access to use any surplus waters, but could not claim rights to it.

[7] The daily three times are 6 A.M., 12 Noon, and 6 P.M.

prior to the 1976 decision are not widely available; in fact, as mentioned above, it was not until after the decision that attention was paid to the collection of such data. For one station in Andhra Pradesh though—Vijayawada—I have managed to obtain monthly discharge data for 1965-2000 (Biggs et al., 2007 and 2008).[8] It is an important station since it was the site primarily used to make the rulings of the allocation, and moreover, it is where the river forms the Krishna Delta and flows into the sea. Figure 1.2 shows the location of the station.

To examine the effect of the Tribunal's decision on the flow of water, I perform a simple before-after analysis (unfortunately, given the data available, it is not possible to separate the true effect of the decision on water flow from changes in water flow that would have occurred over time irrespective of the decision). Figure 1.3, Panel A shows the mean discharge (averaged over 12 months of each calendar year) by year and Panel B shows the variance of the 12 months of discharge by year. Visually, it appears that the mean level and variance of discharge have decreased in the post-1976 period. This is corroborated by the regression analysis of Table 1.1. All specifications include rainfall as a control variable since rainfall is an important source of water in the basin. In Column 1, monthly discharge is the dependent variable, and I find that on average discharge significantly decreases after the Tribunal decision. In Column 2, I look at average monthly discharge over each calendar year and still find a significant decline in discharge in the post-water reallocation period.

Columns 3 and 4 relate to within-year fluctuations in discharge rather than the level of discharge. Column 3 shows that discharge significantly decreases in all months except the summer months.[9] The discharge significantly increases in the summer months after the decision (the point estimate is 1.189 = -7.492 + 8.681 and is significant at the 5% level of

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[8] I am grateful to Dr. Trent Biggs for sharing these data with me.
[9] Summer in India is typically between the months of March and May.

confidence). This suggests that during the drier part of the year, there is more water flow than what would be expected if the decline in level of discharge in Columns 1 and 2 applied uniformly across months. This is in line with the research by Biggs et al. (2007, 2008) and Venot et al. (2007). The KWDT had defined a typical *water year* as June 1st to May 31st each year. One potential explanation of the increase in discharge during the summer months could be that the upstream states were trying to meet the allocations towards the end of the water year, which coincidentally falls during the summer months. However, it is also consistent with upstream states releasing more water when the downstream is drier for other reasons, such as increased pressure to release water when supply is naturally low downstream. Column 4 explicitly shows that the variance of discharge declines in Vijayawada after the Tribunal decision.

While the results of Table 1.1 do not say anything about what happened in the upstream states, they do suggest a decrease in the level and variance flow to Vijayawada. Hydrology research suggests that the Krishna Basin is facing water shortage (hence the lower flows perhaps), however during times of higher demand for water (in the analysis, the summer months) it appears that more water is being released from upstream, leading to more stable water flows throughout the year.

1.2.2 Related Literature

A large literature has focused on the provision of common pool resources and public goods. Broadly, these papers focus on two things: the need for cooperation among parties who are beneficiaries to the resources and the control aspect of it. Ostrom (2003) finds that some ownership rights towards common pool resources can result in effective governing and managing of systems.[10] Boucher and Branoillé (2010) provide evidence of cooperation at the country level. They argue that, under uncertainty, contributors to a public good increase participation, however there is a subsequent decrease in their level of efforts.

The other set of literature has highlighted provision of public goods based on who controls these goods. Banerjee and Somanathan (2006) discuss how public goods are allocated by a centralized state and note that politically disadvantaged groups have also been able to extract public resources from the state; however, it is not the same across all minority groups. Besley and Coate (2003) suggest that sharing costs in a centralized system clouds efficient policy making since it does not keep local needs into account.[11] A handful of other studies examine the relationship between property rights allocation and economic efficiency. Besley and Ghatak (2010) theorize that for a non-binding resource constraint, improving property rights of an insecure asset involved in the production process (e.g. land) can improve economic efficiency. Banerjee, Gertler and Ghatak (2002) find evidence of an increase in agricultural productivity when tenants have more secure land rights. Bardhan (2000) finds that usually, rich farmers violate water allocation rules within an irrigation community. He also points out that obedience might not be an indicator of cooperation among farmers since they might be better off without the rules.

Also related to my study is research in the area of hydrology that has been done on the Krishna Basin.[12] One focus of this research has been about the *closing* of the river, i.e., it can no longer sustain any large irrigation projects since its efficiency has reached a maximum. In addition to the research presented by Venot (2008), Biggs et al. (2007) and Venot et al.

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[10] Also see Ostrom and Gardner (1993), Ostrom, Gardner and Walker (1994), Steins and Edwards (1999).

[11] See Bardhan and Mookherjee (2006), Besley et al. (2003) and Besley et al. (2004) for more on this topic.

[12] D'Souza (2006) provides a detailed description of the history on the Krishna Water Dispute and a thorough insight into the Tribunal's decision.

(2007) find that the stream flow in the Krishna Basin has dramatically decreased, with the effects aggravated during drought years. Gaur et al. (2008) estimate cropping pattern and water supply changes during the drought of 2000-2003 and formulate methods to sustain such shocks. However, these papers have largely focused on the Lower Krishna Basin and the Krishna Delta (two lower sub-basins of the Krishna Basin) and usually use a short panel dataset.

Adding to the problem of overuse is the issue of low quality irrigation techniques in the Krishna Basin. Wallach (1984) points out that in the Krishna Basin, although cultivated land grew over 80% (post-independence in 1947 to the 1970s), water had not reached most parts due to leaky canals. Shah (2005) finds that groundwater irrigation is being heavily exhausted because of lack of good canals, tube wells and irrigation and hence allocation schemes are by and large wasted because of faulty irrigation methods. A handful of studies have also focused on the efficiency of dam constructions on rivers. Duflo and Pande (2007) find that dams increase agricultural productivity and reduce vulnerability against rainfall shocks in the districts downstream from where dams are built. On the other hand, Gamage and Smakhtin (2009) suggest that large-scale expansion of dams and barrages over the rivers have reduced flow into the sea. They focus on the Krishna Basin and note that upstream reservoir storage developments are to blame for this.

The main contribution of my paper is that I quantify the effects of redistribution of state rights over water within an entire basin, over an extended period of time. In particular, I look at the impact of the 1976 Krishna Water Dispute Tribunal decision that shifted state rights over water from the Krishna Basin. My research tries to link the literature on the use of water in agricultural production and the research on property rights (in my case water rights).

To my knowledge, it is the first study on the effects of court-ordered water distributions on agricultural outcomes.

1.3 Empirical Framework

1.3.1 Conceptual Framework

A simple model where states are treated as profit-maximizing firms can provide a useful framework for understanding what could be the impact of a redistribution of state rights over water.[13] Consider two states (upstream and downstream) that share a river basin. Suppose the total amount of water in the river is $\bar{w}$. Each state maximizes profit with respect to water

$$\max_{w} \pi = f(w) * p - c(w)$$

where π is the profit, $f(w)$ is a concave production function ($f'(w)>0$, $f''(w)<0$), p is output price and $c(w)$ is the cost function and is non-decreasing in water. For simplicity, let us assume that the cost of production is just the net cost of controlling the water. To maximize profits, each state will produce output where marginal revenue equals marginal cost, i.e., $f'(w) * p = c'(w)$. Upstream has first access to water, and so it will use water until the marginal profit from using the additional unit of water is zero; let w^u denote the profit-maximizing amount of water for the upstream state. Assuming that the downstream state had the same technology, costs, and price, then downstream would also like to choose w^u to maximize its profits. However, there will not be enough water to permit downstream to also choose w^u, when $2w^u > \bar{w}$; in this case the resource constraint is binding and the best downstream can do is to choose $w^d < w^u$ where $w^u + w^d = \bar{w}$.

[13] State governments and their politicians may well have other objectives, but profit maximization nevertheless provides a useful reference point.

Without any allocation rules, each state maximizes its own profits, and $f'(w^u) < f'(w^d)$, i.e., the marginal product of an additional unit of water is less in the upstream state than in the downstream state. This is inefficient, as reallocating a unit of water from upstream to downstream would increase output and profit. Indeed, if the two states were to jointly make production decisions (e.g., a social planner acting on behalf of the two states, trying to maximize total profit), then water would have been allocated such that the last unit of water provides the same extra profit in the two states. Generally, this means that the new profit-maximizing amount of water used by the upstream state decreases from w^u to w^{u2}, and the amount available to the downstream state increases from w^d to w^{d2}. In the case where the states are identical in technology, costs and price, and where the resource constraint binds, then each state should use $\frac{\overline{w}}{2}$.

Let y denote the total output in the region. Without any allocation rules, each state maximizes its own profit, and the total output is:

$$y_{alone} = f(w^u) + f(w^d)$$

If states behaved jointly, total output would be:

$$y_{joint} = f\left(\frac{\overline{w}}{2}\right) + f\left(\frac{\overline{w}}{2}\right),$$

and given the concavity of the production function it can be seen that $y_{joint} > y_{alone}$. Thus, for the region as a whole, there is an increase in output.

Figure 1.4 illustrates the above arguments in graphical form. Panel A shows the effects on the upstream state, and Panel B shows the effects on the downstream state. I use a linear marginal benefit curve for simplicity (the results are similar for a non-linear marginal benefit curve). At point A, the upstream maximizes its total profit where marginal benefit is zero, given the current amount of water it uses, w^u. Point B is where downstream produces given w^d amount of water. If they were to jointly make the output decision, i.e., where marginal benefits are equalized, they would produce at point C, with upstream using w^{u2} and downstream using w^{d^2}. Thus, the upstream state decreases output moving from stand-alone to joint profit maximization, the downstream state increases output, and output increases overall.

To summarize, in the case where the resource constraint is binding, a reallocation of water from an area of lower marginal productivity of water to an area of higher marginal productivity of water is predicted to raise overall output and yield (with the higher marginal productivity area gaining in output and the lower marginal productivity one losing in output). However, it is theoretically possible that water reallocation might lead to lower output. This would happen if water were reallocated from a higher marginal productivity area to a lower marginal productivity area. While this is not something a profit maximizing decision-maker would intentionally do, this could arise for sensible reasons. For example, the equitable appropriations guideline for solving water disputes stipulates that decision-makers consider equity as an important goal, and decision-makers who weigh equity heavily in their social welfare function more may well redistribute water in favor of the lower marginal productivity party. Also, allocation decisions are being made under imperfect information about each state's marginal productivities, hence even decision-makers who care only about efficiency could ex post have reallocated to lower productivity areas.

Additionally, in theory, the effect of the water reallocation could have zero impact on output. This is consistent with several scenarios. First, the resource constraint may not be binding—the water that the upstream state left for downstream use may exceed the optimal amount demanded by the downstream state. In my empirical analysis below, I allow the effect of the allocation to vary between drought and non-drought periods in the region; the rationale is that the resource constraint is more likely to be binding during a drought period than a non-drought period. Second, the allocations may not be enforced, in which again nothing changes from the pre-decision situation of each state maximizing its own profit. Also, if there were already some private bargaining in place prior to the 1976 water reallocation, then this reallocation would not achieve any efficiency increase and the net effect of the allocation would be zero.

Given the foregoing discussion, it is theoretically ambiguous what the effect of the reallocation of states' rights over the Krishna Basin is on agricultural productivity. Next, I describe my methodology for identifying the causal effect of water reallocation.

1.3.2 Identification Strategy

The decision of the Krishna Water Dispute Tribunal redistributes rights over water from the Krishna River among the three states bordering it. There are two sources of variation in exposure to this water reallocation. On the one hand, there is time variation: the decision is effective in 1976. On the other hand, there is cross-sectional variation, with the water reallocation affecting the water access of districts located closer to the Krishna River. Using time variation alone would not permit identification of the causal effect of the water allocation because agricultural outcomes would have differed before and after 1976 even without the reallocation. As well, using the cross-district variation alone would not permit identification of the causal effect because the districts adjacent to the Krishna River are different from the farther away districts in ways that affect the outcomes (e.g., water availability, soil type, topography). Therefore, I exploit both sources using a difference-in-differences identification strategy.

Specifically, I estimate the effect of water reallocation by taking the after-before difference in outcomes for the districts located inside the Krishna Basin (i.e., adjacent to the basin; below, I refer to these as "inside" districts), and subtracting out the after-before difference in outcomes for districts located outside the basin to remove the secular time effect. This strategy is summarized by the following equation:

$$y_{dt} = \alpha + \beta(inside_d * post_t) + \rho(rainfall_{dt}) + \delta_d + \theta_t + \varepsilon_{dt} \quad (1)$$

where y_{dt} is a measure of agricultural productivity of district d in time t, $post_t$ is a dummy variable for observations in years post 1976, $inside_d$ is a dummy variable for the districts located inside the Krishna Basin, $rainfall_{dt}$ is the rainfall shock, δ_d is district fixed effects, θ_t is year fixed effects, and ε_{dt} is the error term. The coefficient of primary interest is β_1, which is the difference-in-differences estimate.[14] In order to interpret this coefficient as the effect of the 1976 decision reallocating states' rights over the Krishna Basin, the parallel trend assumption must hold: in the absence of the water reallocation policy, the change over time in productivity in the inside districts would have been the same as the change over time in productivity in the outside districts.

The district panel data I use for my empirical analysis has several years of pre-1976 data to permit explicitly controlling for differential trends. One method I use is to control for a time trend that is specific to the inside districts:

[14] Compared to the raw difference-in-differences estimate, which is (mean *y* for inside districts after 1976 minus mean *y* for inside districts before 1976)- (mean y for outside districts after 1976 minus mean y for outside districts before 1976), this one controls for main effects more fully (time dummies are more detailed than controlling just for a "post" dummy, and district dummies are more detailed than controlling for just an "inside" dummy) and for rainfall.

$$y_{dt} = \alpha + \beta(inside_d * post_t) + \rho(rainfall_{dt}) + \delta_d + \theta_t + \lambda(inside_d * year_t) + \varepsilon_{dt}. \quad (2)$$

A second method controls for district-specific time trends, which is a more exhaustive control for differential trends than what is encapsulated by Equation 2:

$$y_{dt} = \alpha + \beta(inside_d * post_t) + \rho(rainfall_{dt}) + \delta_d + \theta_t + \lambda_d(year_t) + \varepsilon_{dt}. \quad (3)$$

The difference-in-differences estimates in Equations 2 and 3 provide the effect of the water reallocation even if there is a differential trend between districts closer to and farther from the Krishna Basin, so long as the differential trend that would have applied in the post-1976 period mirrors the recent historical trend. Gradual expansion of irrigation, or gradual adoption of new agricultural technologies like high yield variety seeds, are two important forces underlying trends in agricultural productivity in Maharashtra, Karnataka and Andhra Pradesh over this time period, hence these inside-specific and district-specific time trends credibly capture much of the differential time effects between inside and outside districts.

If the water allocations stipulated by the 1976 decision are not binding, then we do not expect the decision to have any impact. For example, there may be enough water for everyone, and so productivity does not change. During droughts, there is likely to be excess demand for water, and the allocations are more likely to be binding. Therefore, I modify the previous models to incorporate heterogeneity in effect by drought and non-drought periods. A district-year is classified as under drought if the rainfall shock in that year falls below the 20th percentile of rainfall shock in the three states. When a district's own rainfall is below expectation, then demand for water from other sources (such as the Krishna Basin) is especially high. It is an empirical question whether the water reallocation on the whole mitigates or amplifies the harmful effects of drought on agricultural productivity. For downstream districts, the harmful effects could be mitigated because the water reallocation assures a steady release of water from upstream (subject to the annual and monthly flows stipulated in the decision). However, for upstream districts, the very same steady releases of water could amplify the harmful effects of drought because at their highest time of need for non-rain sources of water, they may need to release some water to abide by the decision. To assess whether the water reallocation on net changes the effect of droughts on agricultural productivity, I estimate the following equation:

$$y_{dt} = \alpha + \beta_1(inside_d * post_t) + \beta_2(inside_d * post_t * drought_{dt}) + \gamma_1(post_t * drought_{dt}) + \gamma_2(inside_d * drought_{dt}) + \gamma_3(drought_{dt}) + \beta_3(rainfall_{dt}) + \delta_d + \theta_t + \varepsilon_{dt} \quad (4)$$

where $drought_{dt}$ is a dummy variable for district d having a drought at time t. β_1 gives the effect of the water reallocation on agricultural productivity during non-drought periods, and β_2 gives the differential effect during drought periods. A positive β_2 would suggest that on net, the water reallocation mitigates the harm of droughts, while a negative β_2 would suggest that on net, the water reallocation amplifies the harm of droughts (which would be an unintended consequence.

The analysis has thus far focused on estimating net effects of the water redistribution across the three states involved in the decision. This is of primary interest because this answers the question of whether the policy raised efficiency. However, given that the decision basically redistributes water from upstream state Maharashtra to downstream states Karnataka and Andhra Pradesh, it is also of interest to assess which states gain and which lose (if any). Therefore I modify Equations 1 to 4 to allow for state-specific effects of the water reallocation.

1.4 Data

I implement my identification strategy using a district panel dataset that is used by Duflo and Pande (2007).[15] The dataset is an extension of the Evenson and McKinsey India Agriculture and Climate dataset (Evenson and McKinsey, 1999).[16] The dataset contains variables related to agricultural production collected from various Indian government publications as well as rainfall[17] for 271 Indian districts in 13 Indian states from 1956-2004. I restrict this data to the three states in the Krishna Basin, namely Maharashtra, Karnataka and Andhra Pradesh. There are 63 districts in total, with 24 districts falling within the Krishna Basin ("inside" districts) and 39 outside. My main analysis uses data for 1971-1999; this restriction is made for practical reasons the rainfall variable is available only for these years; but still provides a good number of before and after years of data.

The two main measures of agricultural productivity that I use are total production and total yield. Total production, measured in Rupees (per thousand tons), is the value of the production of the main crops (at average crop prices in 1960-65). Total yield, measured as Rupees per hectare, is total production divided by cultivated area. The main crops consist of water-intensive crops (rice, sugarcane, cotton and wheat) and non-water intensive crops (bajra, jowar and pulses).

Table 1.2 provides descriptive statistics of the district panel data that I use for my main empirical analysis. Figures 1.5 and 1.6 show mean output and yield, respectively, by state and year in inside and outside districts**.** The average log of total production is 9.67

[15] Data downloaded from Institute for Quantitative Social Science at Harvard University, http://dvn.iq.harvard.edu/dvn).

[16] These data are available for download from the BREAD website, http://ipl.econ.duke.edu/dthomas/dev_data/index.html.

[17] Rainfall in this dataset is the district's fractional deviation from its mean over the 1971-1999 period.

Rupees per thousand tons and average log of total yield is 4.12 Rupees per hectare. While output is higher in inside districts at the outset of the water reallocation, yield is similar between inside and outside districts.

1.5 Estimation Results

1.5.1 Effect on Agricultural Productivity

I first estimate the overall net effect of water reallocation on total production and total yield. These results are presented in Table 1.3. The difference-in-differences estimate of the effect of water reallocation is given by the coefficient for the "Post*Inside" interaction term.

Column 1 reports the results of estimating Equation 1 with log total production as the dependent variable using ordinary least squares. I obtain a difference-in-differences estimate of 0.035; the coefficient is not statistically significantly different from zero at conventional confidence levels. In order to interpret this coefficient as the effect of water reallocation, the parallel trend assumption must hold: in the counterfactual where the decision did not happen, the change in output over time would have been the same in the inside districts (located adjacent to the Krishna Basin) and the outside districts (located further away). In Column 2, I add a control for a time trend specific to inside districts (i.e., Equation 2) and obtain an adjusted difference-in-differences estimate of -0.077.[18] In Column 3, I add district-specific time trends (i.e., Equation 3), and obtain an adjusted difference-in-differences estimate of -0.076, though neither of these estimates is significant at conventional levels of significance.[19] Thus there is weak evidence that the decision reduced output. The point estimate in Column

[18] It is interesting that the coefficient decreases after adjusting for a differential trend between inside and outside districts—this suggests that in the absence of the decision, output would have grown faster in the inside region.

[19] Also, the standard errors I use are rather conservative, robust not only to arbitrary heteroscedasticity but also arbitrary serial correlation within districts.

3 indicates that the 1976 reallocation reduced annual district output by an average of 7.6 percent. The 95% confidence interval is [-0.186, 0.034], which means that I can rule out output gains greater than 0.034 and output losses less than -0.186 at the 5% significance level. In the right panel of Table 1.3, I conduct a similar analysis with log of total yield as the dependent variable. The difference-in-differences estimate is -0.008 in Column 4. The difference-in-differences estimate is -0.055 when I control for inside-specific and district-specific linear trends (Columns 5 and 6), indicating that the 1976 reallocation reduced annual district yield by an average of 5.5 percent. The 95% confidence interval is [-0.131, 0.021], which means that the yield losses will not be less than -0.131 and yield gains are limited to 0.021.

The main finding from Table 1.3 is that the water reallocation weakly reduced agricultural output and yield on net within the three states involved in the Tribunal's decision. In Table 1.4, I explore whether the net effect of water reallocation differs during drought and non-drought periods. The first row shows the coefficient for the "Post*Inside" interaction, and reflects the net effect of water reallocation during non-drought periods. The second row shows the difference in effect between drought and non-drought periods (thus, the effect of water reallocation during drought periods is the sum of these two coefficients; this figure is displayed in the bottom row of the table). Column 1 (Column 4) shows the results of estimating Equation 4 with log total production (log total yield) as the dependent variable, Column 2 (Column 5) adds a time trend specific to inside districts, and Column 3 (Column 6) adds district-specific time trends.

I find that during non-drought periods, the net effect of water reallocation is negative, though not significantly different from zero (Table 1.4, first row). During drought periods, the net effect becomes more negative (second row gives the difference in effect, bottom row reports the total net effect during drought periods), though neither the effect during drought periods nor the difference in effect between drought and non-drought periods is significant. These results are suggestive of the decision amplifying the harmful effects of drought, however, due to the imprecision of the estimates we cannot rule out that the effect of water reallocation is no different between drought and non-drought periods.

Did the redistribution lead to some winners and losers in terms of agricultural productivity, or did it have a uniform effect on all three states? I re-estimate the preceding models allowing the effects of water reallocation to vary by state. Table 1.5 presents these results. The odd columns use basic difference-in-differences estimation (as in Equation 1), and the even columns control for district-specific trends (as in Equation 3). The results in Table 1.5 indicate that the decision was redistributive—it reduced output and yield in Maharashtra and Karnataka, and increased output and yield in Andhra Pradesh. The decision reduces output by 14.8 log points and yield by 14.0 log points in Maharashtra (Columns 2 and 6, first row), and these estimates are significant at the 10 percent level of significance. Much of the negative impact of the decision in Maharashtra comes during drought periods. The bottom of Column 8 indicates that for Maharashtra during drought periods, the water allocation reduced total yield by 24 log points and production decreased by 20 log points (bottom of column 4); both the results are significant at the 5% level. These results of lower productivity especially during drought periods due to the decision is consistent with Maharashtra having to release water downstream at a steady pace, regardless of its own water needs. The gain in output that Andhra Pradesh experiences can be attributed to the discharge results presented in Table 1.1 – there is a decrease in variance of water flow, and water flow during summer months was higher than expected after the 1976 decision.

Although the estimated effects are not in general significant for Karnataka and Andhra Pradesh, the pattern of results in Table 1.5 suggest a redistribution of water in favor of the downstream state, with the cost borne by upstream neighbors. Such a redistribution may well have been intended by the Tribunal, who were trying to adhere to the equitable appropriations doctrine. However, it is not clear whether reducing overall efficiency and amplifying the harm of droughts for Maharashtra in the magnitudes shown in my tables were the cost the Tribunal was willing to pay for the increased equity—perhaps some of these effects were unintended consequences.

1.5.2 Robustness Checks

1.5.2.1 Severity of Droughts

My analyses thus far have shown that the decision hurts agricultural productivity during drought periods (at least weakly; the estimates are imprecise, so often they are not significant at the conventional levels). However, a potential confounding factor is the severity of droughts in the drought periods. The drought dummy variable I use takes on the value one for 20% of the sample by construction; hence one could argue that the intensity of the drought could vary, and if by chance the post-1976 has a larger share of severe droughts in the inside districts, this could cause large negative estimated effects in output and yield for reasons having nothing to do with the decision. To check if this is indeed the case, I make the following adjustments to my estimations. First, I add a control for severity of drought (an interaction between the drought variable and the rainfall deviation variable) to Equation 3.

This allows for rainfall shock to have a different effect during drought and non-drought periods. Columns 1, 2, 5 and 6 of Table 1.6 report these results. A second way I account for the drought severity is by dropping the worst drought seasons, which I construct as the bottom 5% of the rainfall shock. This precludes the possibility of a few devastating droughts driving the results. Columns 3, 4, 7 and 8 present these results. The estimation results controlling for severity of the drought in these two ways are basically the same as the original results in Table 1.3 and 1.4, suggesting that differential severity of droughts is not biasing my estimates of the effect of the water reallocation. Table 1.7 reports results for the state-wise estimations and the results are similar to Table 1.5.

1.5.2.2 Other Robustness Checks

Duflo and Pande (2007) show that dams increase agricultural productivity and reduce susceptibility to rainfall shocks in districts that are downstream from where the dams are built. To the extent that dam construction is correlated with the interaction term "Post*Inside", then the coefficient for this variable would not be interpretable as the effect of the water reallocation, as it could also be capturing effects of dam construction. To address this concern, I control for number of dams using the variable from Duflo and Pande (2007) and my results are basically unchanged.[20]

An additional concern is that with a long post-decision time window (my analysis extends from 1971-1999, so the post-decision period is 24 years), there could be other policies, not just the construction of dams, that are correlated with the "Post*Inside" dummy.

[20] The district-time data on the number of completed dams by Duflo and Pande (2007) is derived from the World Registry of Large Dams.

Therefore, I narrow the time window around the decision and find qualitatively similar results.

1.6 Conclusion

This paper estimates the effect of redistributing water rights among states on agricultural productivity. The 1976 decision of the Krishna Water Dispute Tribunal provides district-time variation in access to water from the Krishna River. I exploit this variation using a difference-in-differences strategy to identify the effect of water reallocation on agricultural productivity. I find that, on net, there is weak evidence that the water reallocation lowers agricultural productivity. I also find that the decision significantly lowered output and yield in Maharashtra, especially during drought periods. Additionally, the decision lowers productivity in Karnataka and raises it in Andhra Pradesh. These state-wise effects taken together clearly indicate that a redistribution away from the two upstream states toward the downstream state.

Various international and Indian doctrines governing the resolution of water disputes have often pushed for "equitable appropriation", i.e., increasing equity amongst parties without compromising much on individual riparian's efficient use of water. My results are consistent with following this principle: equity is improved (downstream party benefits), though there is an efficiency cost. The point estimates suggest a 7.7% decline in output and 5.5% decline in yield (these effect sizes are not economically significant). It is impossible to know whether the entirety of these net productivity losses were part of the tradeoff that the Tribunal intentionally made to gain more equity, or whether at least some of the losses were unintended consequences. However, unintended or not, efficiency losses are associated with the 1976 agreement, and it is worth considering whether there are more efficient ways to improve equity than water reallocation. Evaluating the KWDT's decision is important because the Krishna Basin is a water source for many people and is an important region for agricultural production. However, the external validity of these estimates may be limited. Each basin is different with respect to its inherent characteristics, but more importantly they are different with respect to the nature of the dispute, so what is found for the Krishna Basin may not necessarily apply elsewhere. Moreover, my analysis is restricted to a particular allocation- that stipulated by the 1976 Tribunal decision. It is likely that some other allocation for the same basin would have had different consequences.[21]

My work is the first to highlight the effects of a water reallocation decision on agricultural productivity. My results indicate the vagueness of the 1976 decision and the need to make future allocations more precise. In particular, that the upstream state Maharashtra and middle riparian Karnataka are worse off, while the downstream state of Andhra Pradesh is better off, especially during drought periods, suggest that there might be need for flexible allocations; state-contingent allocations might be better than having rigid allocations. This will allow for some flexibility when a state is experiencing an extreme rainfall shock, to achieve their goals.

[21] A new decision regarding the Krishna Waters was reached in 2010; it will be interesting to evaluate the new allocation and see how the effects compare to what is estimated here.

Figure 1.1: Map of Krishna Basin

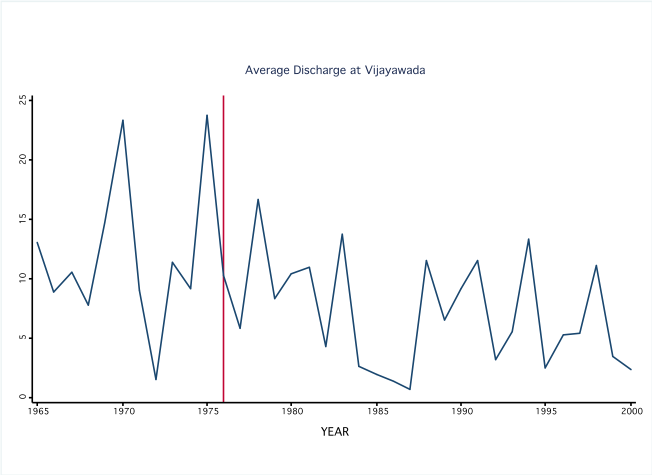
Source: International Water Management Institute

Figure 1.2: Vijayawada Station in the Krishna Basin

Source: Integrated Hydrological Data Book, Central Water Commission, 2009

Figure 1.3: Discharge at Vijayawada

Panel A



Panel B

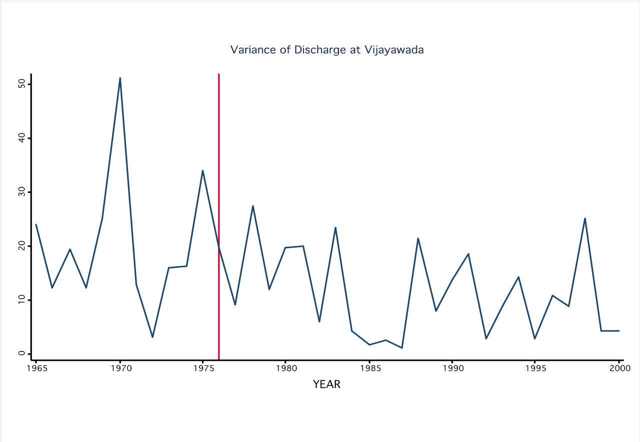


Figure 1.4: Effect of Redistribution of Water on Marginal Benefit of Upstream and Downstream States

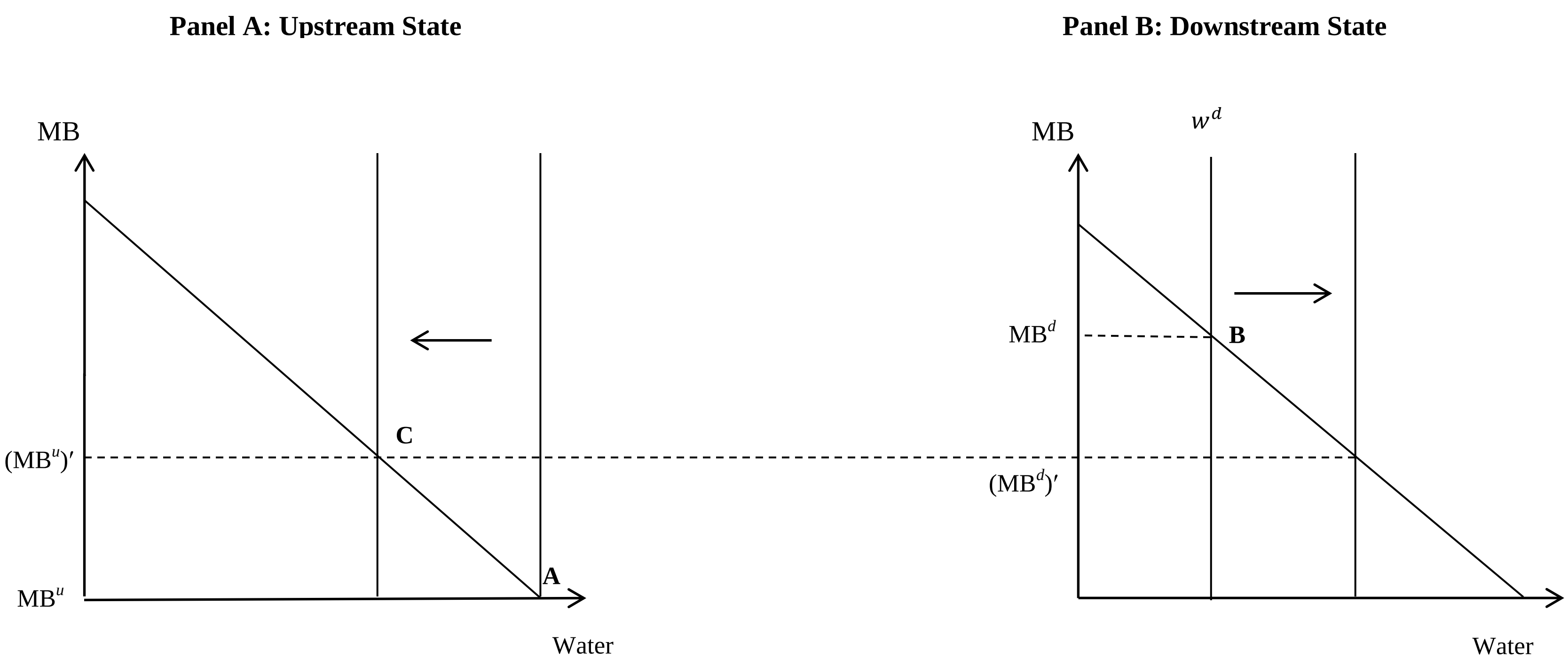


Figure 1.5: Mean Log of Total Production by State, Year and Inside/Outside Districts

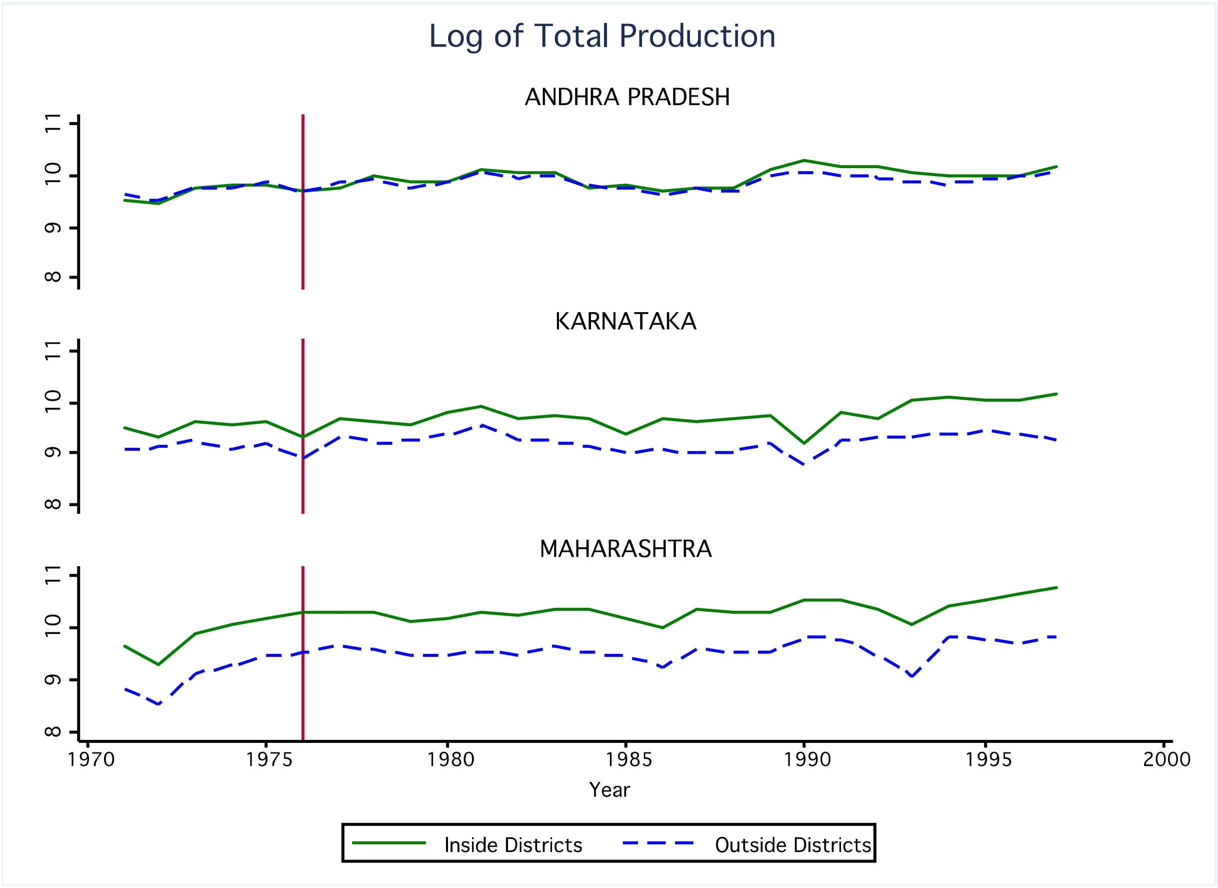


Figure 1.6: Mean Log of Total Yield by State, Year and Inside/Outside Districts

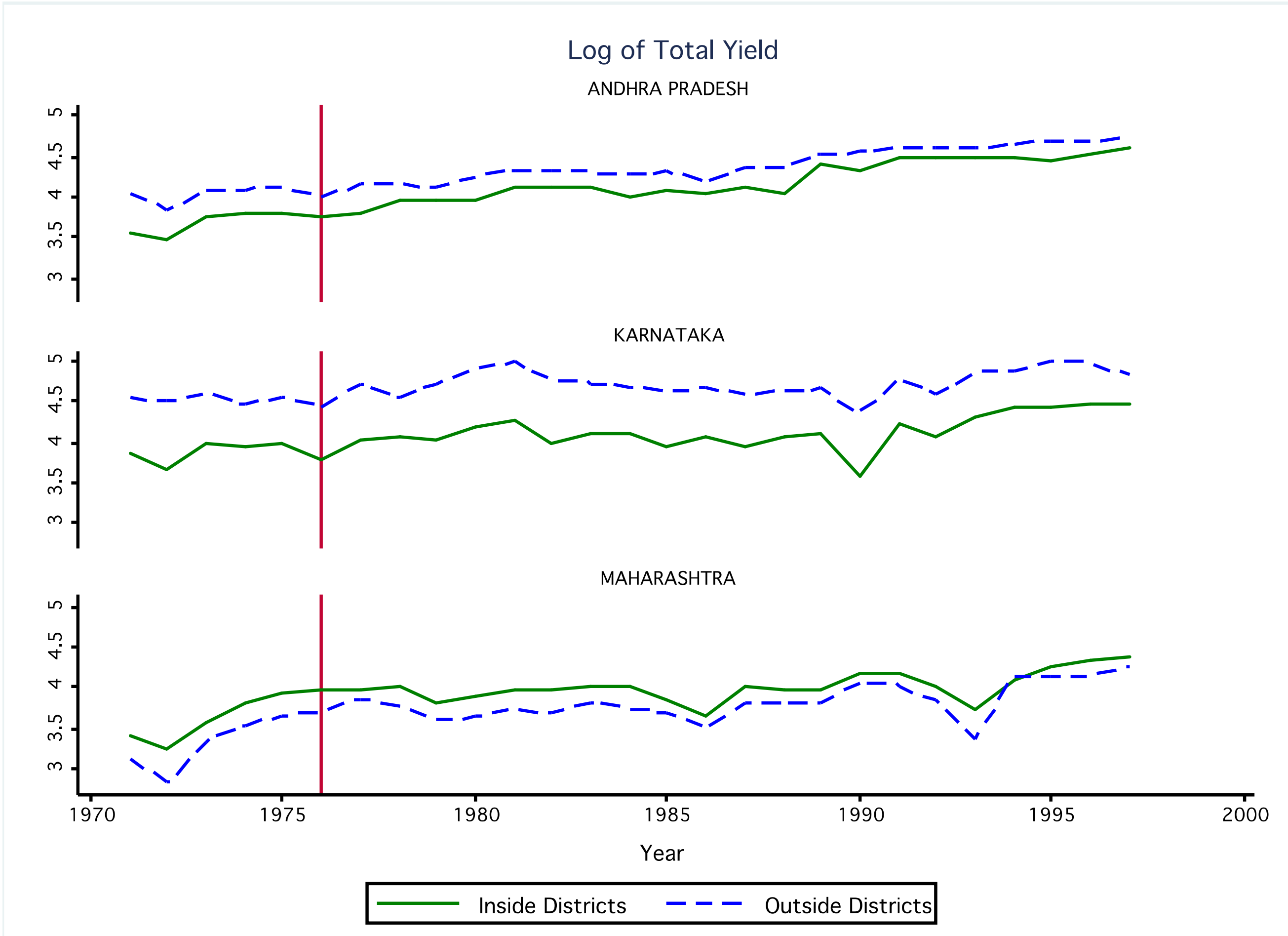


Table 1.1: Discharge at Vijayawada After the Decision

	Monthly Discharge	Average Discharge	Monthly Discharge	Variance of discharge
	(1)	(2)	(3)	(4)
Post	-5.321***	-6.636***	-7.492***	-9.789***
	(1.870)	(1.264)	(2.472)	(3.122)
Post*Summer			8.681***	
			(2.517)	
Summer	-2.545***		-8.309***	
	(0.704)		(1.763)	
Monthly Rainfall	0.0819***		0.0821***	
	(0.013)		(0.013)	
Average Rainfall		0.366***		
		(0.046)		
Variance of Rainfall				0.387***
				(0.053)
Number of Observations	432	36	432	36
R^2	0.240	0.640	0.250	0.500
Mean of dependent variable	*8.678*	*8.680*		*14.469*
(S.D.)	*(17.963)*	*(5.619)*		*(10.556)*

Notes: Robust standard errors in parentheses. ***, **, * denotes significance at 1%, 5% and 10% respectively. Discharge is measured as mm/month and rainfall is measured in mm.

Table 1.2: Descriptive Statistics

			Inside				Outside			
	Full Sample		Before		After		Before		After	
		Obs		**Obs**		**Obs**		**Obs**		**Obs**
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
Log of Total Production	9.670	1827	9.658	144	9.981	552	9.288	234	9.573	897
	(0.691)		(0.573)		(0.712)		(0.579)		(0.644)	
Log of Total Yield	4.120	1827	3.750	144	4.159	552	3.835	234	4.250	897
	(0.643)		(0.629)		(0.605)		(0.696)		(0.606)	
Rainfall Deviation	<0.001	1827	-0.094	144	0.025	552	-0.081	234	0.021	897
	(0.256)		(0.280)		(0.305)		(0.218)		(0.218)	
Drought	0.200	1827	0.319	144	0.219	552	0.278	234	0.149	897
	(0.400)		(0.468)		(0.414)		(.449)		(0.357)	

Notes: Observations are at the district-year level for all districts located in Maharashtra, Karnataka and Andhra Pradesh. Inside districts (24) are those located adjacent to the Krishna Basin, and outside districts (39) are the remaining districts. Production is measured in Rupees per thousand tons using average crop prices of 1960-1965. Yield is measured in Rupees per hectare. Rainfall deviation is the fractional deviation of rainfall from the mean at the district level (over 1971-1999). Drought is a dummy indicating that the observation is in the bottom quintile of rainfall deviation.

Table 1.3: Difference-in-Differences Estimates of the Effect of Water Reallocation on Agricultural Productivity

	Log of Total Production			Log of Total Yield		
	(1)	(2)	(3)	(4)	(5)	(6)
Post*Inside	0.035	-0.077	-0.076	-0.008	-0.055	-0.055
	(0.065)	(0.056)	(0.056)	(0.048)	(0.039)	(0.039)
Inside*Drought	0.127***	0.133***	0.130***	0.039	0.042	0.030
	(0.047)	(0.046)	(0.035)	(0.034)	(0.034)	(0.029)
Post*Drought	0.205***	0.205***	0.194***	0.117**	0.118**	0.109***
	(0.058)	(0.057)	(0.043)	(0.046)	(0.046)	(0.039)
Drought	-0.213***	-0.219***	-0.201***	-0.131***	-0.134***	-0.114***
	(0.053)	(0.053)	(0.035)	(0.041)	(0.041)	(0.036)
Rainfall Deviation	0.135*	0.122*	0.134***	0.024	0.019	0.046
	(0.069)	(0.065)	(0.044)	(0.047)	(0.047)	(0.041)
Number of Observations	1,827	1,827	1,827	1,827	1,827	1,827
R^2	0.770	0.771	0.817	0.865	0.866	0.891

Notes: Standard errors are clustered at the district level and reported in parentheses below the estimated coefficient. ***, **, * denote significance at 1%, 5% and 10% respectively. All regressions include year and district fixed effects. Columns (2) and (5) control for linear time trends specific to inside districts. Columns (3) and (6) control for district - specific time trends. The first row of coefficients gives the difference-in-differences estimate of the effect of water reallocation.

Table 1.4: Effect of Water Reallocation by Drought/Non-Drought Periods

	Log of Total Production			Log of Total Yield		
	(1)	(2)	(3)	(4)	(5)	(6)
Post*Inside	0.038	-0.073	-0.074	0.017	-0.031	-0.047
	(0.067)	(0.066)	(0.061)	(0.054)	(0.038)	(0.038)
Post*Inside*Drought	-0.011	-0.012	-0.005	-0.091	-0.091	-0.027
	(0.094)	(0.094)	(0.066)	(0.084)	(0.084)	(0.069)
Inside*Drought	0.135	0.141	0.134**	0.106	0.109	0.051
	(0.088)	(0.088)	(0.059)	(0.074)	(0.075)	(0.066)
Post*Drought	0.209***	0.209***	0.196***	0.154***	0.154***	0.120***
	(0.067)	(0.066)	(0.052)	(0.043)	(0.043)	(0.045)
Drought	-0.216***	-0.223***	-0.202***	-0.156***	-0.158***	-0.122***
	(0.059)	(0.058)	(0.040)	(0.042)	(0.042)	(0.041)
Rainfall Deviation	0.135*	0.122*	0.134***	0.023	0.018	0.045
	(0.069)	(0.065)	(0.045)	(0.048)	(0.047)	(0.042)
Observations	1,827	1,827	1,827	1,827	1,827	1,827
R^2	0.770	0.771	0.817	0.865	0.866	0.891
Overall effect during drought	*0.027*	*-0.085*	*-0.079*	*-0.074*	*-0.122*	*-0.074*
	(0.101)	*(0.078)*	*(0.068)*	*(0.076)*	*(0.083)*	*(0.074)*

Notes: Standard errors are clustered at the district level and reported in parentheses below the estimated coefficient. ***, **, * denote significance at 1%, 5% and 10% respectively. All regressions include year and district fixed effects. . Columns (2) and (5) control for linear time trends specific to inside districts. Columns (3) and (6) control for district - specific time trends. The first row of coefficients gives the effect of water reallocation during non-drought periods, and the second row gives the difference in effect between drought and non-drought periods; the sum of these two coefficients gives the total effect during drought periods, and is reported in the bottom row.

Table 1.5: Effect of Water Reallocation by State

	Log of Total Production				Log of Total Yield			
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Post*Inside*MH	-0.028	-0.148*	0.009	-0.120	-0.105	-0.140*	-0.078	-0.086
	(0.076)	(0.081)	(0.086)	(0.080)	(0.065)	(0.081)	(0.081)	(0.076)
Post*Inside*KT	0.142	-0.089	0.141	-0.106	0.041	-0.126**	0.058	-0.130**
	(0.113)	(0.079)	(0.126)	(0.091)	(0.051)	(0.051)	(0.046)	(0.059)
Post*Inside*AP	0.072	0.139	0.110	0.136	0.126*	0.105	0.138*	0.103
	(0.091)	(0.088)	(0.097)	(0.094)	(0.065)	(0.064)	(0.076)	(0.064)
Post*Inside*Drought*MH			-0.124	-0.079			-0.087	-0.154**
			(0.081)	(0.063)			(0.097)	(0.067)
Post*Inside*Drought*KT			0.005	0.067			-0.066	0.016
			(0.149)	(0.113)			(0.142)	(0.133)
Post*Inside*Drought*AP			-0.166	0.016			-0.051	0.012
			(0.193)	(0.136)			(0.112)	(0.098)
Rainfall Deviation	0.113**	0.127***	0.112**	0.126***	0.016	0.041	0.015	0.039
	(0.051)	(0.046)	(0.051)	(0.046)	(0.043)	(0.043)	(0.043)	(0.043)
Observations	1,827	1,827	1,827	1,827	1,827	1,827	1,827	1,827
R^2	0.780	0.820	0.780	0.820	0.871	0.894	0.871	0.894
Overall effect during drought								
MH			*-0.115*	*-0.199***			*-0.166***	*-0.240***
			(0.079)	*(0.095)*			*(0.075)*	*(0.101)*
KT			*0.146*	*-0.040*			*-0.009*	*-0.115*
			(0.141)	*(0.098)*			*(0.138)*	*(0.114)*
AP			*-0.056*	*0.152*			*0.087*	*0.115*
			(0.178)	*(0.133)*			*(0.095)*	*(0.107)*

Notes: Standard errors are clustered at the district level and reported in parentheses below the estimated coefficient. ***, **, * denote significance at 1%, 5% and 10% respectively. AP represents Andhra Pradesh, MH represents Maharashtra, KT represents Karnataka. All regressions also control for year and district fixed effects, inside*drought, post*drought and drought. Even columns also control for district-specific time trends.

Table 1.6: Robustness Check –Controlling for Severity of Droughts

	Log of Total Production				Log of Total Yield			
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Post*Inside	-0.075	-0.077	-0.078	-0.069	-0.054	-0.049	-0.059	-0.053
	(0.056)	(0.060)	(0.059)	(0.060)	(0.039)	(0.037)	(0.037)	(0.038)
Post*Inside*Drought		0.006		-0.055		-0.015		-0.035
		(0.064)		(0.079)		(0.070)		(0.075)
Inside*Drought	0.146***	0.141**	0.104***	0.148**	0.047	0.058	0.012	0.039
	(0.034)	(0.057)	(0.036)	(0.061)	(0.029)	(0.064)	(0.027)	(0.065)
Post*Drought	0.182***	0.180***	0.110**	0.127**	0.096**	0.102**	0.054	0.065
	(0.043)	(0.052)	(0.045)	(0.056)	(0.040)	(0.044)	(0.040)	(0.052)
Drought*Rainfall Deviation	0.375*	0.376*			0.428**	0.426**		
	(0.214)	(0.212)			(0.186)	(0.186)		
Drought	-0.094	-0.093	-0.123***	-0.136***	0.007	0.002	-0.059	-0.067
	(0.069)	(0.070)	(0.041)	(0.048)	(0.063)	(0.066)	(0.040)	(0.049)
Rainfall Deviation	0.095*	0.095*	0.105**	0.105*	0.0009	0.0007	0.019	0.019
	(0.053)	(0.053)	(0.052)	(0.053)	(0.047)	(0.048)	(0.048)	(0.049)
Observations	1,827	1,827	1,735	1,735	1,827	1,827	1,735	1,735
R^2	0.817	0.817	0.816	0.816	0.892	0.892	0.889	0.889
Overall effect during drought		*-0.071*		*-0.123*		*-0.064*		*-0.088*
		(0.068)		*(0.090)*		*(0.074)*		*(0.076)*

Notes: Standard errors are clustered at the district level and reported in parentheses below the estimated coefficient. ***, **, * denote significance at 1%, 5% and 10% respectively. Columns (3), (4), (7) and (8) drop the drought observations falling in the lowest 5 percent of rainfall deviation. All regressions also control for year and district fixed effects, and district-specific time trends.

Table 1.7: Robustness Check – State-wise Estimates Controlling for Severity of Droughts

	Log of Total Production				Log of Total Yield			
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Post*Inside*MH	-0.144*	-0.121	-0.147*	-0.122	-0.137	-0.088	-0.117	-0.089
	(0.081)	(0.079)	(0.084)	(0.088)	(0.082)	(0.076)	(0.074)	(0.083)
Post*Inside*KT	-0.093	-0.113	-0.108	-0.099	-0.130**	-0.137**	-0.141***	-0.136**
	(0.081)	(0.090)	(0.082)	(0.085)	(0.053)	(0.060)	(0.052)	(0.059)
Post*Inside*AP	0.136	0.129	0.126	0.125	0.099	0.092	0.097	0.092
	(0.085)	(0.091)	(0.086)	(0.092)	(0.061)	(0.063)	(0.063)	(0.062)
Post*Inside*Drought*MH		-0.065		-0.153		-0.143*		-0.176
		(0.065)		(0.126)		(0.077)		(0.118)
Post*Inside*Drought*KT		0.079		-0.054		0.029		-0.031
		(0.110)		(0.125)		(0.135)		(0.117)
Post*Inside*Drought*AP		0.035		0.007		0.030		0.029
		(0.128)		(0.125)		(0.081)		(0.076)
Rainfall Deviation	0.089	0.087	0.098*	0.097*	0.001	-0.0008	0.014	0.012
	(0.053)	(0.053)	(0.054)	(0.054)	(0.049)	(0.049)	(0.049)	(0.050)
Observations	1,827	1,827	1,735	1,735	1,827	1827	1,735	1,735
R^2	0.820	0.820	0.819	0.819	0.895	0.895	0.891	0.891
Overall effect during drought								
MH		*-0.186**		*-0.275***		*-0.230***		*-0.264****
		(0.098)		*(0.119)*		*(0.110)*		*(0.089)*
KT		*-0.033*		*-0.152*		*-0.108*		*-0.167*
		(0.099)		*(0.134)*		*(0.118)*		*(0.102)*
AP		*0.163*		*0.132*		*0.122*		*0.122*
		(0.124)		*(0.122)*		*(0.086)*		*(0.092)*

Notes: Standard errors are clustered at the district level and reported in parentheses below the estimated coefficient. ***, **, * denote significance at 1%, 5% and 10% respectively. Columns (3), (4), (7) and (8) drop the drought observations falling in the lowest 5 percent of rainfall deviation. All regressions also control for year and district fixed effects, and district-specific time trends.

Chapter 2

The Interim Order of 1991 and Agricultural Productivity in the Cauvery Basin

"It is not without significance that the word rival derived from rivus, a stream"

– H M Seervai, (Indian Constitutional Law Expert)

2.1 Introduction

Water disputes have increased globally, with incidents aggravated in the arid regions of the world. Increased demand for water resources due to continuing development, population growth and unsustainable methods of resource utilization has intensified these water conflicts (Folke, 1998). India has seen its fair share of water conflicts over the centuries; the Krishna Waters Dispute began in the early 1900s, the Narmada Water Dispute was finally resolved in 1970s, the Indus River conflict between India and Pakistan began post-independence in 1947, and the famous Cauvery Waters Dispute that has ensued since 1892. There have been four major agreements relating to the allocation of the Cauvery River waters: in 1892, 1924, 1991 (an interim agreement) and 2007. In this paper, I estimate the effect of the 1991 Interim Order on agricultural output and yield in Karnataka and Tamil Nadu, the two main parties of the dispute.

Various international doctrines set guidelines on how to resolve water disputes. The Helsinki Rules on the Uses of the Waters of International Rivers of 1966, and the United Nations Convention on the Law of Non-Navigational Uses of International Watercourses of 1997 are the most widely referenced guidelines. In India, the Interstate Water Disputes Act of 1956, allowing for state governments to be able to present their water grievances, and the National Water Policy of 1987 and 2002, allowing for river basin to be recognized as a unit of development and management, guide the resolution of water conflicts. Water sharing accords try to resolve disputes through the concept of *equitable appropriation* – that the river is a *common property* and that allocations to the riparian states will be determined by the geography, demography, crop cultivation and other characteristics of the basin.

However, in the Cauvery dispute, equitable appropriation has been difficult to achieve because Karnataka has long believed in the Harmon doctrine, i.e., it has sovereign rights over the Cauvery water because it originates in its state.[1] Tamil Nadu believes that since its irrigation started much earlier than Karnataka's, it has prescriptive rights over the water, which could potentially hurt Karnataka. Moreover, both states have been guilty of increasing their irrigation and cultivation more than can be sustained, further complicating

[1] The Harmon doctrine was proposed by U.S. Attorney General Judson Harmon in 1885. The doctrine states that a country holds absolute sovereignty when it comes to the portion of international watercourse within its borders. Thus that country would be free to divert all of the water from an international watercourse, leaving none for downstream states. This was issued in response to Mexico's claim for damage for diverting the waters of the Rio Grande.

the task of deciding allocations. A unique feature of the Cauvery dispute is also that there are a lot of cultural, linguistic and political differences that have been associated with the river and hence a decision that satisfies both parties is all the more difficult to attain.

Though the Cauvery Waters Dispute has been widely studied by researchers, the literature related to the Cauvery Basin has been largely descriptive, or has focused on the experience of a few villages.[2] The contribution of this paper is to estimate the impact of one of the Cauvery water allocation agreements on regional agricultural productivity. In particular, I evaluate the effect of the 1991 Interim Order; though the other three orders are of interest, for data availability reasons I focus on the 1991 Interim Order.[3] The 1991 Interim Order guaranteed a set amount of water releases from Karnataka to Tamil Nadu and marked a change in allocation from the 1924 agreement, as I describe in Section 2.

Evaluating the effect of the 1991 Interim Order is of interest for several reasons. On the one hand, there is not much existing knowledge about the effects of court-ordered water reallocations on agricultural productivity in general. Only other paper that rigorously evaluates a court-ordered water reallocation on agricultural productivity is Das (2012), who evaluates the effect of the 1976 Krishna Water Dispute Tribunal, which redistributed the Krishna Basin waters among Maharashtra, Karnataka and Andhra Pradesh. She finds evidence suggesting that equity increased but efficiency decreased in the area around the Krishna Basin due to the 1976 water reallocation—the gains to the most downstream state, Andhra Pradesh, were not as large as the total losses to the other two states. Do these results hold for other water reallocations in India too, which presumably would be based on the

[2] See Epstein (1962, 1973 and 2007), Folke (1998), and White and Janakarajan (2004).

[3] The 1892 and 1924 agreements occur before the district-wise data series on agricultural productivity I use begins, and the 2007 is too recent for sufficient years of post-agreement data.

same guiding principles? The Cauvery Basin is heavily cultivated with paddy and sugarcane, both important components in the region's economies of the concerned states. It also provides a source of livelihood for many, though in recent decades there has been a vast migration out of agricultural communities into urban communities, paving the way for some traditional agricultural communities to die out (Epstein 1962, 1973 and 2007). Understanding factors that impact agricultural productivity in the area, such as through water allocation policy, therefore has important consequences for the well-being of the region's population.

Following Das (2012), I take advantage of the district-time variation in exposure to the decision to identify the effects of the 1991 Interim Order on agricultural productivity. I apply a difference-in-differences strategy to a district panel data set on the 31 districts of the two main riparian states (Karnataka and Tamil Nadu) over 1971-1999.[4] To preview the findings, I find that while on average, the decision does not significantly affect agricultural productivity, during drought periods there is a significant decline in agricultural productivity. I also find that while both Karnataka (upper riparian) and Tamil Nadu (downstream riparian) experience losses during drought periods due to the 1991 Interim Order, Tamil Nadu's losses are considerably higher. These results taken together suggest an efficiency loss for the region without any party gaining. In fact, both states are worse off—the harmful effects of the water reallocation are amplified after the Interim Order.

The rest of the paper is organized as follows. Section 2.2 offers a background on the Cauvery Dispute and the Cauvery Water Dispute Tribunal. Section 2.3 explains the

[4] The Cauvery dispute had originally been between Karnataka and Tamil Nadu; Kerala and Pondicherry became parties to the dispute only after the reorganization of states. The main river primarily flows through Karnataka and Tamil Nadu, and the majority of the area of the basin lies within these two states, hence I restrict my analysis to these two states.

identification strategy I use to estimate the causal effect of the water reallocation pursuant to the 1991 Interim Order on agricultural productivity. Section 2.4 describes the data. Section 2.5 presents the results of my estimations and I conclude in Section 2.6.

2.2 Background

The Cauvery River rises in the Western Ghats in India and flows eastwards into the Bay of Bengal. Spreading over an area of 31,319 square miles (81,155 km^2), it covers the three states of Karnataka, Tamil Nadu, Kerala and the Union Territory of Pondicherry.[5] Crops grown in the region are primarily sugarcane and rice (which are highly water-intensive crops) and some areas also cultivate ragi and millets (non-water intensive crops).[6] The Cauvery Basin is unique in terms of rainfall; the part above the delta (the region before the river flows into the sea) gets its rain through the Southwest Monsoon (from June to Sept) while the delta region sees rainfall during the Northeast Monsoon (Oct to Jan).[7] Figure 1.1 shows a map of the Basin.

Like most other water disputes, the Cauvery Dispute has primarily been about which state has primary right over the river water. Moreover, apart from the economic reasons for water sharing, namely that of agriculture, farmers also associate the river with a lot of customs and traditions. The case has also been marred by politics with Chief Ministers in the

[5] Before the reorganization of states, the riparian provinces were Mysore and Madras. Kerala became a riparian in 1972 and the UT of Pondicherry was part of the basin from 1978.
[6] Thanjavore (also known as Thanjavur) district in Tamil Nadu is known as the “Rice Bowl of India”.
[7] One of the points in the dispute has been Karnataka’s contention that Tamil Nadu gets water from the NE Monsoon, while TN has maintained that the rainfall from the NE Monsoon can hardly be tapped since its usually erratic, helps only the delta region and sometimes flows immediately into the sea.

riparian states hardly ever agreeing to the terms of stipulated decisions.[8] Interestingly, however, scholars involved in understanding the dispute have increasingly maintained that the dispute is not about finding a solution with the surplus amount of water in the river but in fact is about how to re-share a river that is heavily used (Iyer 2003, Pani 2009), primarily because the Cauvery Basin is already overused, with no surplus.

The first agreement in terms of water sharing was in 1892 when the Princely States of Mysore (Karnataka today) and the Presidency of Madras (Tamil Nadu today) had come to conclusion with respect to the use of water and construction of irrigation projects.[9] The 1924 agreement on the other hand specifically listed the extent of irrigation take-ups and reservoir constructions. Mysore was allowed to construct the Krishnarajasagar reservoir, restricted to a total capacity of 44.8 TMC (thousand million cubic feet), with an ayacut of 125,000 acres and have other reservoirs of an effective capacity of 45 TMC with an additional ayacut of 140,000 acres.[10] Madras was permitted to construct the Mettur Dam with a capacity of 93.5 TMC and have new irrigation limited to 301,000 acres. The agreement was set to expire in 50 years in 1974.

In 1972, after a request from Tamil Nadu for a new allocation, the Government of India formed a Cauvery Fact Finding Committee (CFFC) that was in charge of collecting factual details with respect to the Cauvery River. They fixed the availability of the Cauvery River at 671 TMC; usage was set at 489 TMC for Tamil Nadu, 177 TMC for Karnataka and

[8] This has made it very difficult for any standing decision for the water sharing; the 2007 decision was finally taken after a 33 year impasse.
[9] One of its provisions was that any project that Mysore wanted to construct on the main river would have to be consulted with Madras.
[10] An ayacut is an area served by an irrigation project such as a canal, dam, or a tank.

5 TMC for Kerala.[11] The CFFC also called for an establishment of the Cauvery Valley Authority, which would be in charge of overseeing the implementation of the agreement. Unfortunately, Tamil Nadu was under Presidential Rule and so the decision was deemed "too early" and was never implemented.[12] The Cauvery Water Dispute Tribunal was formed in 1990 after Tamil Nadu had requested for the formation of the Tribunal in 1986.[13] The point of the dispute was the validity of the 1924 agreement; Karnataka maintained their stand that the 1924 agreement had expired in 1974 and that a new decision with respect to the current agricultural situation in the states was needed. On the other hand, Tamil Nadu maintained that for the state to sustain the existing agricultural production and irrigation, the *status quo* needs to be maintained, i.e., the 1892 and 1924 agreement needed to be in place.[14]

To stall the then current impasse, the Tribunal produced an Interim Order in 1991, which stated that Karnataka was to release 205 TMC of water until a final decision was announced. To make sure the releases were not erratic; the Tribunal also listed monthly release schedules. In addition to the release details, the Tribunal had also specified irrigation area restrictions on Karnataka. Karnataka was ordered not to increase irrigation over a limit of 11.2 lakh acres in the Cauvery Basin.[15] The Interim Order was met with resistance from Karnataka, but eventually it was published in the Gazette of the Government of India and the

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[11] The CFFC also specified savings limits; Tamil Nadu could save 100 TMC and Karnataka 25 TMC over a period of 15 years, which was to be redistributed as 4 TMC to Tamil Nadu, 87 TMC to Karnataka and 34 TMC to Kerala.

[12] Presidential Rule, in India, is when a federal rule is imposed on a state. One of the main reasons for this to be imposed is when a state legislature fails to elect a Chief Minister.

[13] A farmers' association from the Thanjavur district in Tamil Nadu was responsible for that initiative.

[14] The water sharing would be: 566 TMC for Tamil Nadu and Pondicherry; 177 TMC for Karnataka and 5 TMC for Kerala. This is slightly different from the CFFC's assessment. Also, there was no stringent amount of water that Karnataka was asked to release before.

[15] A final decision in the matters of the Cauvery Waters was made in 2007. The details of the decision can be found from the Ministry of Water Resources website, India http://wrmin.nic.in/. However the 4 riparian states have not implemented it thoroughly. The 2007 decision also specified that Karnataka would have to release 192 TMC of water (this is different from the 205 TMC that the 1991 agreement stipulated)

order became binding in December of 1991[16]. Following the Interim Order, the two states witnessed some of the worst backlashes ever; thousands of Tamilian families had to flee Bangalore, Karnataka in fear of being attacked.[17] A Cauvery River Authority (CRA) with the Prime Minister as the head and the Chief Ministers of the four riparian states as members was to be established to implement the Interim Order, but that was not formed until 1998.[18]

2.3 Empirical Strategy

Das (2012) presents a theoretical framework for the potential effects of water reallocation on agricultural production due to the water reallocation. The main conclusion is that it is theoretically ambiguous what the net impact of a water reallocation on agricultural productivity is. A redistribution of water from an area with higher marginal productivity of water to one with a lower one would lead to a net efficiency loss (and vice versa) accompanied by gains and losses for individual parties to the agreement. Therefore, it is ultimately an empirical question what is the impact of the 1991 Interim Order on agricultural output.

The interim decision by the Cauvery Waters Dispute Tribunal assured a steady flow of the river water to Tamil Nadu from Karnataka until a final adjudication was reached. There are two sources of variation in exposure to this water reallocation. The decision is effective in 1991, which is the source of the time variation. Also, there is cross-sectional variation, with the water reallocation affecting the water access of districts located closer to

[16] Karnataka had set up an Ordinance to attack the decision of the Tribunal but The Supreme Court of India had deemed it unconstitutional, and Karnataka had to abide by the decision.
[17] For a detailed insight into the 1991 riots, refer to Guhan (1993).
[18] Another body, the Cauvery Monitoring Committee, consisting of engineers, technocrats and officers who would collect the data was also formed. It was to report all its findings periodically to the CRA.

the Cauvery River. Using the time variation alone would not permit identification of the causal effect of the water allocation because agricultural outcomes would have differed before and after 1991 even without the reallocation. As well, using the cross-district variation alone would not permit identification of the causal effect because the districts adjacent to the Cauvery River are different from the farther away districts in ways that affect the outcomes (e.g., water availability, soil type, topography). Therefore, I exploit both sources using a difference-in-differences identification strategy.[19]

Specifically, I estimate the effect of water reallocation by taking the after-before difference in outcomes for the districts located inside the Cauvery Basin (i.e., adjacent to the basin; below, I refer to these as "inside" districts), and subtracting out the after-before difference in outcomes for districts located outside the basin to remove the secular time effect. This strategy is summarized by the following equation:

$$y_{dt} = \alpha + \beta(inside_d * post_t) + \rho(rainfall_{dt}) + \delta_d + \theta_t + \varepsilon_{dt} \quad (1)$$

where y_{dt} is a measure of agricultural productivity of district d in time t, $post_t$ is a dummy variable for observations in years 1992[20] or later, $inside_d$ is a dummy variable for the districts located inside the Cauvery Basin, $rainfall_{dt}$ is the rainfall shock, δ_d is district fixed effects, θ_t is year fixed effects, and ε_{dt} is the error term. The coefficient of primary interest is β_1 which is the difference-in-differences estimate.[21] In order to interpret this coefficient as the effect of the 1991 decision reallocating states' rights over the Cauvery Basin, the parallel trend assumption must hold: in the absence of the water reallocation policy, the change over time

[19] Das (2012) presents a theoretical framework for the potential effects of water reallocation on agricultural production due to the water reallocation.
[20] Since the decision became effective only in December 1991, I include 1991 in my pre-decision years.
[21] Compared to the raw difference-in-differences estimate, which is (mean y for inside districts after 1991 minus mean y for inside districts before 1991) - (mean y for outside districts after 1991 minus mean y for outside districts before 1991), this one controls for main effects more fully (time dummies are more detailed than controlling just for a "post" dummy, and district dummies are more detailed than controlling for just an "inside" dummy) and for rainfall.

in productivity in the inside districts would have been the same as the change over time in productivity in the outside districts.

The district panel data I use for my empirical analysis has a sufficiently long series of pre-1991 data to permit explicitly controlling for differential trends. One method I use is to control for a time trend that is specific to the inside districts:

$$y_{dt} = \alpha + \beta(inside_d * post_t) + \rho(rainfall_{dt}) + \delta_d + \theta_t + \lambda(inside_d * year_t) + \varepsilon_{dt}. \quad (2)$$

A second method controls for district-specific time trends, which is a more exhaustive control for differential trends than what is encapsulated by Equation 2:

$$y_{dt} = \alpha + \beta(inside_d * post_t) + \rho(rainfall_{dt}) + \delta_d + \theta_t + \lambda_d(year_t) + \varepsilon_{dt}. \quad (3)$$

The difference-in-differences estimates in Equations 2 and 3 provide the effect of the water reallocation even if there is a differential trend between districts closer to and farther from the Cauvery Basin, so long as the differential trend that would have applied in the post-1991 period mirrors the recent historical trend. Gradual expansion of irrigation, or gradual adoption of new agricultural technologies like high yield variety seeds, are two important forces underlying trends in agricultural output and yield in Karnataka and Tamil Nadu over this time period, hence these inside-specific and district-specific time trends credibly capture much of the differential time effects between inside and outside districts.[22]

If the water allocations stipulated by the 1991 decision are not binding, then we do not expect the decision to have any impact. For example, there may be enough water for everyone, and so productivity does not change. During droughts, there is likely to be excess demand for water, and the allocations are more likely to be binding. Therefore, I modify the previous models to incorporate heterogeneity in effect by drought and non-drought periods. A district-year is classified as under drought if the rainfall shock in that year falls below the

[22] This is consistent with the concern in the literature that both states have rapidly increased their production.

20th percentile of rainfall shock in the two states. When a district's own rainfall is below expectation, then demand for water from other sources is especially high. It is an empirical question whether the water reallocation on the whole mitigates or amplifies the harmful effects of drought on agricultural productivity. For downstream districts, the harmful effects could be mitigated because the water reallocation assures a steady release of water from upstream (subject to the annual and monthly flows stipulated in the decision). However, for upstream districts, the very same steady releases of water could amplify the harmful effects of drought because at their highest time of need for non-rain sources of water, they may need to release some water to abide by the decision. To assess whether the water reallocation on net changes the effect of droughts on agricultural productivity, I estimate the following equation:

$$y_{dt} = \alpha + \beta_1(inside_d * post_t) + \beta_2(inside_d * post_t * drought_{dt}) + \gamma_1(post_t * drought_{dt}) + \gamma_2(inside_d * drought_{dt}) + \gamma_3(drought_{dt}) + \beta_3(rainfall_{dt}) + \delta_d + \theta_t + \varepsilon_{dt} \quad (4)$$

where $drought_{dt}$ is a dummy variable for district *d* having a drought at time *t*. β_1 gives the effect of the water reallocation on agricultural productivity during non-drought periods, and β_2 gives the differential effect during drought periods. A positive β_2 would suggest that on net, the water reallocation mitigates the harm of droughts, while a negative β_2 would suggest that on net, the water reallocation amplifies the harm of droughts (which would be an unintended consequence).

The analysis has thus far focused on estimating net effects of the water redistribution across the two main states involved in the decision. Given that the decision basically redistributes water from upstream state Karnataka to downstream state Tamil Nadu; it is also of interest to assess which state, if at all, bears greater incidence of the water redistribution.

Therefore I modify Equations 1 to 4 to allow for state-specific effects of the water reallocation.

2.4 Data

I implement my identification strategy using a district panel data set that is used by Duflo and Pande (2007).[23] The dataset is an extension of the Evenson and McKinsey India Agriculture and Climate dataset (Evenson and McKinsey, 1999).[24] The dataset contains variables related to agricultural production collected from various Indian government publications as well as rainfall[25] for 271 Indian districts in 13 Indian states from 1956-2004. I restrict this data to the two states in the Cauvery Basin, namely Karnataka and Tamil Nadu.[26] There are 31 districts in total, with 12 districts falling within the Cauvery Basin ("inside" districts) and 19 outside. My main analysis uses data for 1971-1999.

The two main measures of agricultural productivity that I use are total production and total yield. Total production, measured in Rupees per thousand tons, is the value of the production of the main crops (at average crop prices in 1960-65). Total yield, measured as Rupees per hectare, is total production divided by cultivated area. The main crops consist of water-intensive crops (rice, sugarcane, cotton and wheat) and non-water intensive crops (millets and pulses). Supplemental analysis examines the effect of the water allocation on water-intensive crop production as well.

[23] Data can be downloaded from the Institute for Quantitative Social Science at Harvard University, http://dvn.iq.harvard.edu/dvn).
[24] These data are available for download from the BREAD website, http://ipl.econ.duke.edu/dthomas/dev_data/index.html.
[25] Rainfall in this dataset is the district's fractional deviation from its mean over the 1971-1999 period.
[26] In addition to the reasons mentioned above, the data set does not have data for Kerala and Pondicherry, so I focus my analysis to Tamil Nadu and Karnataka.

Table 2.1 provides descriptive statistics of the district panel data that I use for my main empirical analysis. The number of observations should be 899 (31 districts x 29 years), but due to missing observations for Tamil Nadu, I am restricted to only 886 observations. Figures 1.2 and 1.3 show output and yield, respectively, by state and year in inside and outside districts. The average log of total production is 9.65 Rupees per thousand tons and average log of total yield is 4.54 Rupees per hectare.

2.5 Estimation Results

2.5.1 Effect on Agricultural Productivity

I first estimate the overall net effect of the interim water allocation on total production and total yield. These results are displayed in Table 2.2. The difference-in-differences estimate of the effect of water allocation is given by the coefficient for the "Post*Inside" interaction term.

Column 1 reports the results of estimating Equation 1 with log total production as the dependent variable using ordinary least squares. I obtain a difference-in-differences estimate of -0.172 and is significant at the 10% level. In order to interpret this coefficient as the effect of water reallocation, the parallel trend assumption must hold: in the counterfactual where the decision did not happen, the before-after change in output would have been the same in the inside districts (located adjacent to the Krishna Basin) and the outside districts (located further away). To relax the identifying assumption, I allow for differential trends by controlling for inside specific linear trend (i.e., Equation 2) and for district-specific linear trend (i.e., Equation 3). These adjusted difference-in-differences estimates suggest a small, insignificant effect of water reallocation on net productivity in the Cauvery Basin region.

In the right panel of Table 2.2, I conduct a similar analysis with log of total yield as the dependent variable. The difference-in-differences estimate is around -0.058. The difference-in-differences estimate is -0.002 and -0.005 when I control for inside specific and district-specific linear trends respectively, however the results are not statistically significant. The results from Table 2.2 suggest there is no impact of the 1991 Interim Order on net. Next, I explore if there is a differential effect of the water reallocation between drought and non-drought periods. During times of water shortage, the water allocations stipulated by the 1991 Interim Order might be especially likely to bind. Moreover, both Karnataka and Tamil Nadu have criticized the Tribunal's interim decision for not having dealt with distress years (Meenakshisundaram et al., 2010), suggesting that the decision is consequential for water flow, especially during drought periods. The first row of Table 2.3 provides the coefficient for the "Post*Inside" interaction, and reflects the net effect of water reallocation during non-drought periods. The second row shows the additional effect of water allocation during drought periods relative to non-drought periods. Thus, the overall effect of the allocation during drought periods is the sum of the coefficients from these first two rows (presented in the bottom row of Table 2.3). I estimate Equation 4 with log of production and log of yield as dependent variables, the results are presented in Columns 1 and 4 respectively. Columns 2 and 5 add time trends specific to inside districts while Columns 3 and 6 add district-specific time trends. The net effect during non-drought periods is not statistically significantly different from zero. During drought periods though, I find that there is an output loss of 24 log points significant at the 5% level of confidence (reported at the bottom of Column 3), and this is statistically different from the effect during non-drought periods. Total yield reduces by 14.5 log points; however the result is not statistically significant at conventional levels.

Are the gains for one state exactly offset by the losses from the other state responsible for the net zero effects presented in Table 2.2? What is the incidence of the productivity losses during drought periods due to the water reallocation found in Table 2.3? Motivated by these questions, I proceed by re-estimating the models allowing for heterogeneity in effect of the water reallocation by state.[27] Table 2.4 presents these results; the odd columns use the basic difference-in-differences estimation (as in Equation 1), and the even columns control for district-specific trends (as in Equation 3).

The results in Table 2.4 indicate that Tamil Nadu bears greater incidence of the allocation than Karnataka, especially during drought periods. On average across all periods (both drought and non-drought), Karnataka experiences a growth of 10.6 percent in production and a reduction of 5.9 percent in yield (Columns 2 and 6, first row) due to the water reallocation, however these results are not statistically significant. Tamil Nadu experiences a loss of 18 percent in output (significant at the 10% level) and yield increases by 7.6 percent (not statistically significant) (Columns 2 and 6, second row). During non-drought periods, the water reallocation does not have any significant impacts on agricultural productivity for either state. However, during drought periods, the effect is always negative, with the impact on output for Tamil Nadu significant at the 5 percent level. Thus, consistent with anecdotal reports and complaints from the states, the decision failed to mitigate the situation during distress years.

The results described above suggest that there is a net efficiency loss due to the 1991 Interim Order, with both Karnataka and Tamil Nadu experiencing decreases in agricultural productivity during drought periods, and Tamil Nadu bearing the bulk of these losses. While

[27] As mentioned before, this is particularly interesting in the case of the Cauvery Basin since both states have made claims that their best interests have not been taken into consideration and has resulted in output losses in each of the regions.

one of the reasons for this could be the obvious reason scarcity of water in the river during drought periods: there could also be other potential reasons. One of the crops that Tamil Nadu grows is the *kuruvai* crop (grown in about 33% of the paddy lands in the delta region of Cauvery Basin), which is heavily dependent on the Southwest Monsoon for its cultivation (June-September). Tamil Nadu has regularly complained against Karnataka's sugarcane cultivation, a water-intensive crop that uses more water than paddy, in the Cauvery Basin. In the district of Mandya in Karnataka, for example, sugarcane cultivation has expanded because of increased demand from the sugar industry and could be one of the causes for lower amounts of water reaching Tamil Nadu (Folke, 1998). This has allowed for a tug of war for water, heightened especially during drought periods. Also true in the region is that even though the Cauvery Dispute is inter-state, there are issues within the states that have prevented a solution from being reached. For example, Folke (1998) reports that illegal lifting of water has been prevalent in both states. Instances of rich/higher caste farmers taking control over the public goods, in this case, water resources, have been reported in both Karnataka and Tamil Nadu. This is in line with Bardhan (2000) in which he reports that rich farmers often violate allocation rules within irrigation communities. Literature has also described an overexploitation of groundwater resources in this region, making it exceptionally hard for surface water to be sufficient to sustain irrigation (Shah, 2005).

To examine if the water-intensive crops in the region are in fact hurt by the allocation decision and are the ones driving my results in Tables 2.3 and 2.4, I estimate Equation 3 (controlling for district-specific time trends) with the log of water-intensive crops and the share of water-intensive crop as the dependent variables. Columns 1, 2, 5 and 6 of Table 2.5 present the results for the whole region, while the others present state-wise results. The results for log of water intensive crops follow a similar pattern to the previous tables. I find that there is a significant decrease, by 36%, in water-intensive crop production during drought periods (Column 2, bottom row). State-wise results show that Tamil Nadu again is the one more affected during drought periods (a loss of 58% significant at the 1% level) relative to Karnataka, which also suffers a decrease in water-intensive crop production (though the result is not statistically significant). These results corroborate the concerns both states have shared over having less water to sustain their irrigation.

Finally, I examine the share of water-intensive crops (as a fraction of total crop) to examine if there were changes in cropping patterns during drought periods which could be driving the results in the left hand side panel of Table 2.5. Do those findings merely reflect a pattern of productivity losses that is common to all crops, or is there a systematic shift away from water-intensive crops? The overall effects do not show that there was any significant change in the share of water-intensive crops. However, the share of water-intensive crops in Karnataka decreases by 7.5% (significant at the 5% level of confidence) during drought periods, while Tamil Nadu sees an increase in the ratio, although the result is statistically not significant. This could suggest the following: that due to the allocation decision, Tamil Nadu increases the ratio of water-intensive crops, while Karnataka scale back to abide by the decision, especially during drought periods. However, because of failed monsoons, the realized output of water intensive crops is reduced dramatically, shown in the results above.

The analyses thus far have shown the following: First, on net, there is no significant effect of water reallocation on agricultural output and yield in the Cauvery Basin. I also find that there is a significant reduction in output during drought periods with Tamil Nadu bearing greater incidence of the loss in the region. Finally, a main concern in the dispute has been insufficient water to sustain irrigation, which is reflected in the results for water-intensive crops.

2.5.2 Robustness Checks

2.5.2.1 Severity of Droughts

My analyses thus far have shown that the decision hurts agricultural productivity during drought periods. However, a potential confounding factor is the severity of droughts in the drought periods. My current drought variable is 20% of the sample by construction; hence one could argue that the intensity of the drought could vary, and if by chance the post-1991 has a larger share of severe droughts in the inside districts, this could cause large negative estimated effects in output and yield for reasons having nothing to do with the decision.[28] To check if this is in fact the case, I make the following adjustments to my estimations. First, I add a control for severity of drought (an interaction between the drought variable and the rainfall deviation variable) to Equation 3. This allows for rainfall deviation to have a different effect during drought and non-drought periods. Columns 1, 2, 5 and 6 of Table 2.6 report these results. A second way I account for the drought severity is by dropping the worst drought seasons, which I construct as the bottom 5% of the rainfall deviation. This precludes the possibility of a few devastating droughts driving the results. Columns 3, 4, 7 and 8 present these results. The estimation results controlling for severity of the drought in these two ways are basically the same as the original results in Table 2.2 and 2.3, suggesting that

[28] The monsoons had failed in 1995-1996 in Karnataka and it found it difficult to release water to Tamil Nadu as per the Interim Order. Tamil Nadu had asked the Supreme Court for 30 TMC of water to be released. The Supreme Court referred the state to the Tribunal that had scaled it back to 11 TMC. The issue finally reached the then Prime Minister who ordered Karnataka to order 6 TMC of water to Tamil Nadu, and Karnataka had to comply with.

differential severity of droughts is not biasing my estimates of the effect of the water reallocation.

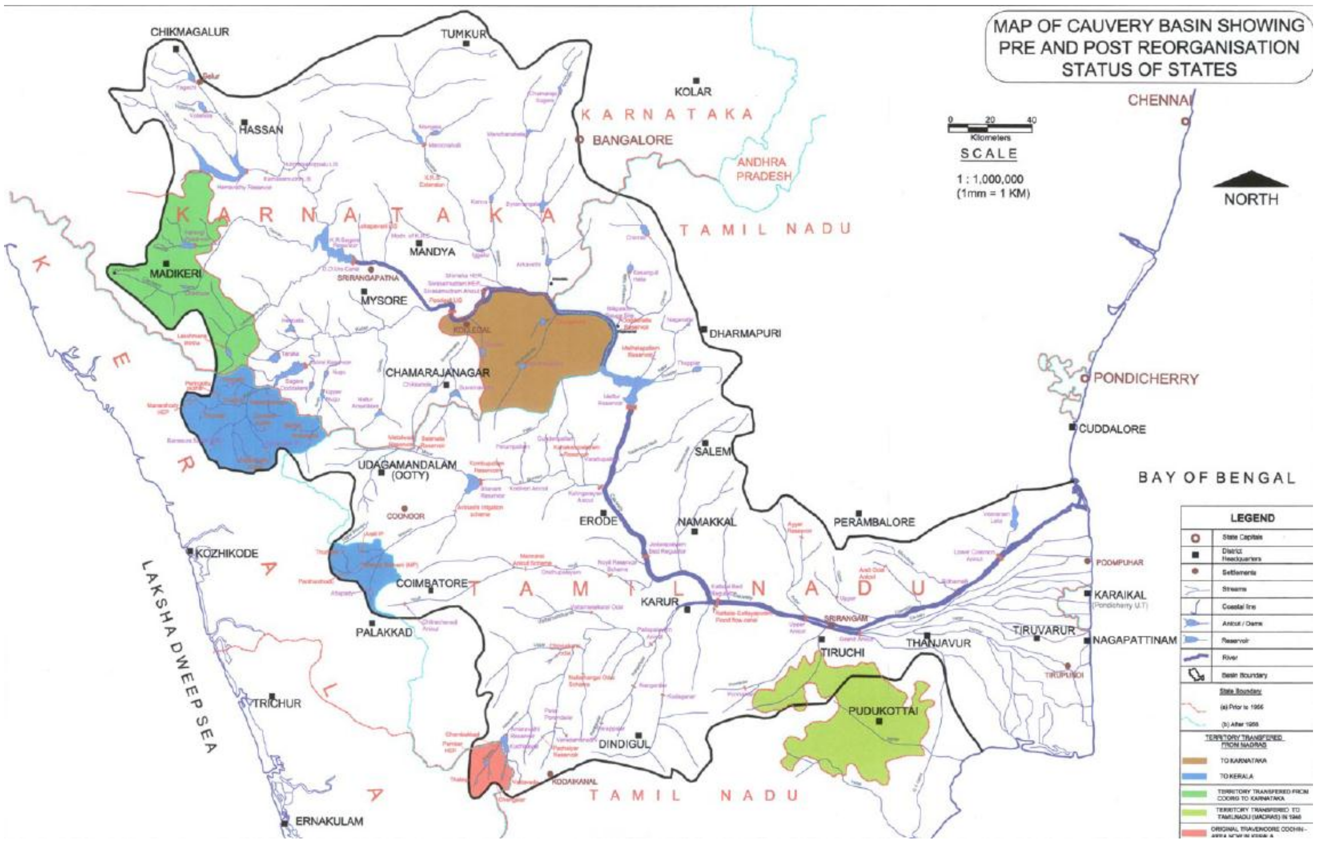
2.6 Conclusion

The matters of the Cauvery Waters have been ongoing for centuries; however a final decision with regards to the water sharing was not reached until 2007. Research has focused on understanding why the dispute has ensued this long, and also on individual villages' responses due to the dispute. This paper adds to that literature by evaluating the effects of one of the allocation decisions; that of the Interim decision of 1991, on agricultural outcomes in the region as a whole.

The 1991 Interim Order of the Cauvery Water Dispute Tribunal guaranteed some amount of secure flow of the river from Karnataka to Tamil Nadu. I exploit this variation in amount of water allocated by implementing a difference-in-differences strategy to identify the causal effects of the decision on agricultural productivity. On average, I find that the decision does not significantly change output in the region. However, during drought periods, I find that the 1991 Interim Order reduces output 24 percent (significant at the 5% level) and reduces yield by 14 percent. I also find a significant reduction in the water-intensive crop production due to the decision. Redistributions often have winners and losers, and in my state-wise results I find a surprising result—there are no winners in this redistribution, as both Karnataka and Tamil Nadu experience bigger losses during drought periods due to the decision, though Tamil Nadu's losses larger. Thus, there is a net efficiency loss for the Cauvery Basin region, with both parties sharing in the loss—surely this is an unintended consequence of the 1991 Interim Order.

Various doctrines governing resolution of water disputes quite often focus on equity and not compromising efficiency. My results suggest that neither has been achieved in this case. It will be interesting to examine the 2007 decision and see if the states are better off than the 1991 decision.

Figure 2.1: Map of Cauvery Basin



Source: Ministry of Water Resources, India

Figure 2.2: Mean Log of Total Production by State, Year and Inside/Outside Districts

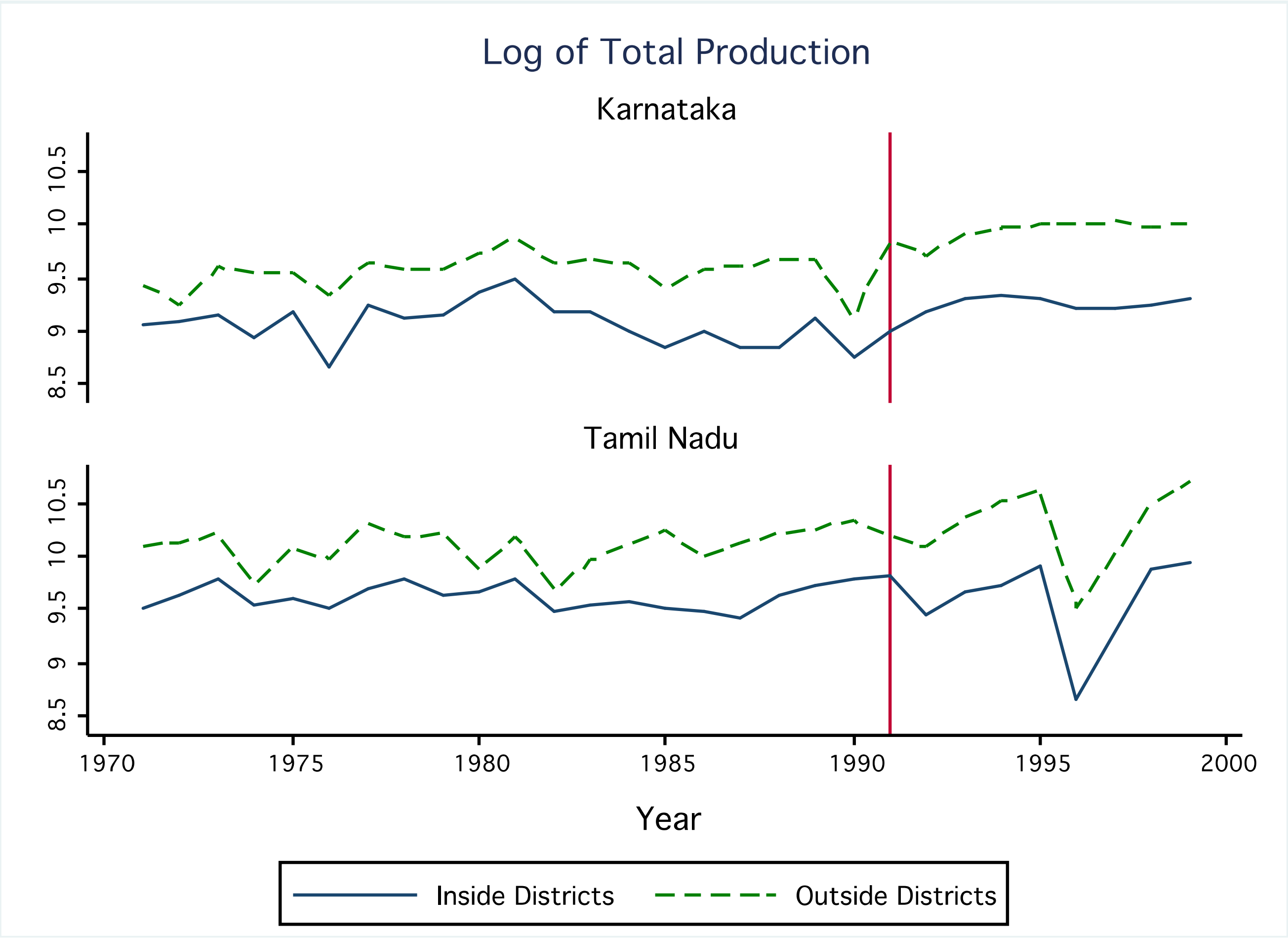


Figure 2.3: Mean Log of Total Yield by State, Year and Inside/Outside Districts

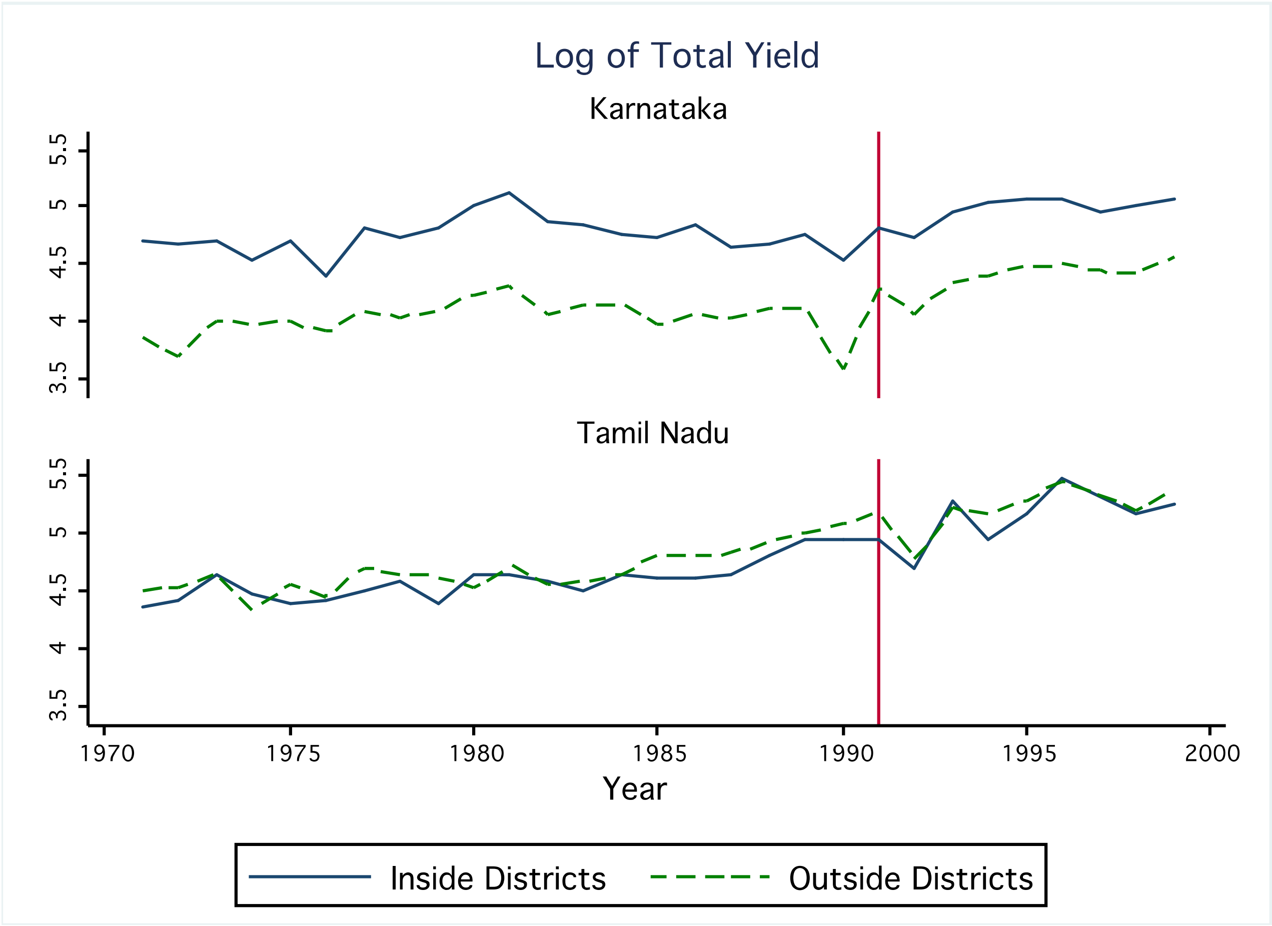


Table 2.1: Descriptive Statistics

	Full Sample		Inside				Outside			
			Before		After		Before		After	
		Obs		**Obs**		**Obs**		**Obs**		**Obs**
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
Log of Total Production	9.648 (1.096)	886	9.298 (1.420)	252	9.397 (1.549)	91	9.768 (0.685)	399	10.084 (0.766)	144
Log of Total Yield	4.541 (0.580)	885	4.692 (0.346)	252	5.045 (0.341)	90	4.284 (0.608)	399	4.676 (0.607)	144
Log of Water-Intensive Crops	9.405 (1.148)	886	9.187 (1.404)	252	9.326 (1.543)	91	9.418 (0.888)	399	9.799 (0.871)	144
Share of Water-Intensive Crops	0.821 (0.199)	886	0.899 (0.085)	252	0.934 (0.059)	91	0.757 (0.233)	399	0.790 (0.215)	144
Rainfall Deviation	-0.004 (0.254)	886	-0.070 (0.177)	252	0.173 (0.289)	91	-0.039 (0.235)	399	0.097 (0.314)	144
Drought	0.203 (0.403)	886	0.230 (0.422)	252	0.099 (0.300)	91	0.221 (0.415)	399	0.174 (0.380)	144

Notes: Observations are at the district-year level for all districts located in Karnataka and Tamil Nadu. Inside districts (12) are those located adjacent to the Cauvery Basin, and outside districts (19) are the remaining districts. Production is measured in Rupees per thousand tons using average crop prices of 1960-1965. Yield is measured in Rupees per hectare. Rainfall deviation is the fractional deviation of rainfall from the mean at the district level (over 1971-1999). Drought is a dummy indicating that the observation is in the bottom quintile of rainfall deviation.

Table 2.2: Difference-in-Differences Estimates of the Water Reallocation on Agricultural Productivity

	Log of Total Production			Log of Total Yield		
	(1)	(2)	(3)	(4)	(5)	(6)
Post*Inside	-0.172*	0.003	0.002	-0.058	-0.002	-0.005
	(0.098)	(0.090)	(0.094)	(0.069)	(0.062)	(0.063)
Inside*Drought	0.037	0.044	0.078	0.076	0.079	0.061
	(0.057)	(0.054)	(0.049)	(0.051)	(0.051)	(0.049)
Post*Drought	0.522***	0.519***	0.402***	0.161**	0.160**	0.105**
	(0.060)	(0.059)	(0.062)	(0.074)	(0.075)	(0.047)
Drought	-0.185***	-0.180***	-0.180***	-0.129***	-0.128***	-0.108***
	(0.039)	(0.038)	(0.039)	(0.027)	(0.026)	(0.035)
Rainfall Deviation	-0.039	-0.018	-0.002	0.024	0.031	0.079
	(0.060)	(0.057)	(0.047)	(0.071)	(0.069)	(0.053)
Observations	886	886	886	885	885	885
R^2	0.934	0.935	0.947	0.857	0.858	0.888

Notes: Standard errors are clustered at the district level. ***, **, * denote significance at 1%, 5% and 10% respectively. All regressions include year and district fixed effects. Columns (2) and (5) control for linear time trends specific to inside districts. Columns (3) and (6) control for district - specific time trends. The first row of coefficients gives the difference-in-differences estimate of the effect of water reallocation.

Table 2.3: Effect of Water Reallocation by Drought/Non-Drought Periods

	Log of Total Production			Log of Total Yield		
	(1)	(2)	(3)	(4)	(5)	(6)
Post*Inside	-0.132	0.026	0.027	-0.035	0.013	0.009
	(0.101)	(0.094)	(0.097)	(0.070)	(0.063)	(0.062)
Post*Inside*Drought	-0.291***	-0.242***	-0.267***	-0.172*	-0.157*	-0.154*
	(0.095)	(0.087)	(0.094)	(0.084)	(0.083)	(0.076)
Inside*Drought	0.086	0.085	0.122**	0.106**	0.105**	0.086
	(0.063)	(0.061)	(0.057)	(0.051)	(0.049)	(0.052)
Post*Drought	0.590***	0.577***	0.468***	0.202**	0.197**	0.143**
	(0.062)	(0.062)	(0.069)	(0.081)	(0.081)	(0.053)
Drought	-0.206***	-0.198***	-0.200***	-0.142***	-0.139***	-0.120***
	(0.041)	(0.039)	(0.042)	(0.028)	(0.028)	(0.037)
Rainfall Deviation	-0.047	-0.025	-0.011	0.019	0.026	0.074
	(0.060)	(0.057)	(0.047)	(0.072)	(0.070)	(0.054)
Observations	886	886	886	885	885	885
R^2	0.934	0.935	0.947	0.858	0.858	0.888
Overall effect during drought	*-0.423****	*-0.217***	*-0.240***	*-0.207**	*-0.144*	*-0.145*
	(0.121)	*(0.095)*	*(0.107)*	*(0.104)*	*(0.092)*	*(0.094)*

Notes: Standard errors are clustered at the district level. ***, **, * denote significance at 1%, 5% and 10% respectively. All regressions include year and district fixed effects. . Columns (2) and (5) control for linear time trends specific to inside districts. Columns (3) and (6) control for district - specific time trends. The first row of coefficients gives the effect of water reallocation during non-drought periods, and the second row gives the difference in effect between drought and non-drought periods; the sum of these two coefficients gives the total effect during drought periods, and is reported in the bottom row.

Table 2.4: Effect of Water Reallocation by State

	Log of Total Production				Log of Total Yield			
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Post*Inside*KT	-0.146	0.106	-0.106	0.121	-0.123	-0.059	-0.099	-0.052
	(0.134)	(0.097)	(0.132)	(0.104)	(0.080)	(0.077)	(0.079)	(0.079)
Post*Inside*TN	-0.218*	-0.180*	-0.183	-0.145	0.032	0.076	0.059	0.092
	(0.115)	(0.105)	(0.129)	(0.108)	(0.051)	(0.092)	(0.048)	(0.092)
Post*Inside*Drought*KT			-0.286**	-0.151			-0.170	-0.073
			(0.109)	(0.108)			(0.110)	(0.069)
Post*Inside*Drought*TN			-0.283**	-0.458***			-0.221**	-0.215*
			(0.135)	(0.108)			(0.089)	(0.121)
Rainfall Deviation	0.010	0.059	0.002	0.053	0.041	0.112**	0.036	0.109**
	(0.061)	(0.054)	(0.062)	(0.055)	(0.058)	(0.052)	(0.059)	(0.052)
Observations	886	886	886	886	885	885	885	885
R^2	0.936	0.949	0.936	0.949	0.865	0.890	0.866	0.890
Overall effect during drought								
KT			*-0.392***	*-0.030*			*-0.270**	*-0.125*
			(0.179)	*(0.107)*			*(0.135)*	*(0.080)*
TN			*-0.465****	*-0.603****			*-0.161*	*-0.123*
			(0.110)	*(0.130)*			*(0.109)*	*(0.160)*

Notes: Standard errors are clustered at the district level. ***, **, * denote significance at 1%, 5% and 10% respectively. All regressions include year and district fixed effects. KT denotes Karnataka, and TN denotes Tamil Nadu. All regressions also control for year and district fixed effects, inside*drought, post*drought and drought. Even columns also control for district-specific time trends.

Table 2.5: Effect of Water Allocation on Water-Intensive Crop Production

	Log of Water Intensive Crops				Share of Water- Intensive Crops			
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Post*Inside	-0.036	-0.003			-0.003	0.001		
	(0.106)	(0.108)			(0.017)	(0.017)		
Post*Inside*Drought		-0.357***				-0.045*		
		(0.088)				(0.024)		
Post*Inside*KT			0.024	0.052			-0.021	-0.015
			(0.127)	(0.133)			(0.022)	(0.022)
Post*Inside*TN			-0.155	-0.120			0.023	0.023
			(0.116)	(0.120)			(0.018)	(0.018)
Post*Inside*Drought*KT				-0.275**				-0.059*
				(0.115)				(0.031)
Post*Inside*Drought*TN				-0.456***				-0.005
				(0.113)				(0.012)
Rainfall Deviation	0.047	0.035	0.125	0.115	0.031**	0.029**	0.035**	0.033**
	(0.062)	(0.061)	(0.077)	(0.077)	(0.013)	(0.013)	(0.015)	(0.015)
Observations	886	886	886	886	886	886	886	886
R^2	0.919	0.919	0.921	0.921	0.931	0.931	0.932	0.933
Overall effect during drought								
Full region		-0.360***				-0.043		
		(0.114)				(0.026)		
KT				-0.223				-0.075**
				(0.134)				(0.032)
TN				-0.576***				0.019
				(0.138)				(0.025)

Notes: Standard errors are clustered at the district level. ***, **, * denote significance at 1%, 5% and 10% respectively. Share of water-intensive crops is calculated as the ratio of water-intensive crops to total production. All regressions include year and district fixed effects. KT denotes Karnataka, and TN denotes Tamil Nadu. All regressions also control for year and district fixed effects, inside*drought, post*drought, drought and district-specific time trends.

Table 2.6: Robustness Check - Controlling for Severity of Droughts

	Log of Total Production				Log of Total Yield			
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Post*Inside	-0.009	0.011	-0.019	0.004	-0.054	-0.044	-0.054	-0.040
	(0.096)	(0.099)	(0.099)	(0.102)	(0.057)	(0.056)	(0.059)	(0.059)
Post*Inside*Drought		-0.261**		-0.290***		-0.138*		-0.169**
		(0.097)		(0.096)		(0.077)		(0.081)
Inside*Drought	0.076	0.120*	0.091*	0.149**	0.0541	0.077	0.078	0.112**
	(0.050)	(0.059)	(0.052)	(0.064)	(0.049)	(0.052)	(0.046)	(0.049)
Post*Drought	0.402***	0.466***	0.368***	0.446***	0.103**	0.136**	0.079	0.125**
	(0.063)	(0.069)	(0.070)	(0.077)	(0.046)	(0.050)	(0.049)	(0.056)
Drought*Rainfall Deviation	-0.006	-0.018			-0.022	-0.028		
	(0.231)	(0.227)			(0.193)	(0.191)		
Drought	-0.181***	-0.204***	-0.164***	-0.188***	-0.113**	-0.125**	-0.101**	-0.115***
	(0.059)	(0.059)	(0.041)	(0.045)	(0.051)	(0.052)	(0.038)	(0.040)
Rainfall Deviation	-0.002	-0.008	0.003	-0.006	0.081	0.078	0.073	0.068
	(0.066)	(0.066)	(0.069)	(0.069)	(0.064)	(0.065)	(0.064)	(0.065)
Observations	886	886	841	841	885	885	840	840
R^2	0.947	0.947	0.948	0.948	0.888	0.888	0.883	0.883
Overall Effect During Drought		*-0.250***		*-0.286****		*-0.182**		*-0.209**
		(0.102)		*(0.096)*		*(0.093)*		*(0.104)*

Notes: Standard errors are clustered at the district level. ***, **, * denote significance at 1%, 5% and 10% respectively. Columns (3), (4), (7) and (8) drop the drought observations falling in the lowest 5 percent of rainfall deviation. All regressions also control for year and district fixed effects, and district-specific time trends.

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