# Agricultural Trade and Depletion of Groundwater*

Paul Landefeld Sheetal Sekhri†

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**Abstract**

Globalization can lead to either conservation or depletion of natural resources that are used in the production of traded goods. Rising prices may lead to better resource management. Alternatively, stronger incentives to extract these resources may exacerbate their decline- especially in open access institutional frameworks. We examine the impact of agricultural trade promotion on the groundwater extraction in India using nationally representative data from 1996-2005. We find evidence that trade promotion led to increased extraction of the reserves. In areas deemed over-exploited by the government, groundwater depleted by an additional 2.5 meter or 1 within district standard deviation. This large decline had economically significant distributive consequences. While large and marginal farmers did not experience any real welfare changes, we detect a 1 standard deviation decline in real mean per capita expenditure for small farmers in such areas. We also quantify the social cost of groundwater depletion due to increased agricultural trade. Our findings indicate that the monetized value of depleted groundwater could be atleast as high as 1 billion US dollars in 1991 dollar terms.

JEL classification: O13, Q25, Q56

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†Paul Landefeld-Joint Committee on Taxation, Email: paul.landefeld@jct.gov and Sheetal Sekhri-University of Virginia, PO Box 400182, Department of Economics, Monroe Hall, Charlottesville, VA 22904-4182, Email: SSekhri@virginia.edu.

# 1 Introduction

Promoting the trade of goods that use natural resources as factors of production can have consequences for these resources. However, the nature of these consequences is not well established. Prominent theories investigating the linkage between trade and natural resources indicate that access to world markets may generate strong incentives to improve resource management (Copeland and Taylor, 2009). Non-market institutions that promote resource conservation may emerge (Ostrom, 1990; Ostrom, 2010).[1] On the other hand, trade promotion in economies with an open-access property rights regime may exacerbate extraction. These competing effects make the impact of trade promotion on resource stocks theoretically unclear. Rigorous empirical examination of this relationship is especially important in poor and predominantly agricultural economies that use agricultural trade promotion as a policy lever to improve standards of living. In this paper, we explore whether promotion of agricultural trade leads to conservation of groundwater.

Groundwater is mined for irrigation use in many industrialized and developing countries including India, Pakistan, China, Yemen, and the United States. Access to this resource can lead to manifold increases in agricultural productivity but also raises the risk of its depletion. Declining water tables can threaten food security and compromise the ability to mitigate droughts.[2] Groundwater is also used to meet drinking water needs in many parts of the world. Concerns about changing precipitation patterns due to global warming have made sustaining groundwater reserves even more critical. Thus, from a policy perspective, understanding how groundwater can be used in a sustainable manner is vital.

We explore the introduction of agricultural trade promotion zones in India and make three contributions. First, our study identifies the causal impact of an increase in international trade on renewable resources in an economy with open-access property rights. We present novel evidence on the impact of agricultural trade promotion on groundwater resources used as a factor of production in agriculture. In addition, we estimate reduced-form effects on real mean per capita expenditure and rural wages. In areas deemed over-exploited by the government of India, we examine distributive effects for farmers by land holding size. Finally, we put a lower bound on the social cost (monetized value) of groundwater depletion by calculating

[1] In her influential work on the emergence of non-market institutions to promote conservation of open-access resources, Ostrom has provided many case studies highlighting when and where these institutions emerge.

[2] Water table is the depth below surface of earth where water is first encountered at atmospheric pressure.

the cost of desalinizing a volume of seawater equivalent to depleted groundwater as per our estimates.

India is a pertinent setting in which to explore the relationship between agricultural trade promotion and depletion of groundwater for a number of reasons. India extracts the largest amount of groundwater in the world, almost twice as much as the United States. Around 60 percent of Indian agriculture is sustained by groundwater. Between 1980 and 2010, water tables declined by more than 12 meters in many parts of India, and the depletion rates have been accelerating since 2000 (Rodell at al., 2009; Sekhri, 2012). According to the satellite-data-based study conducted by NASA, the rate at which aquifers are being mined in India is unsustainable (Rodell at al., 2009). Sekhri (2013 a) finds that a 1 meter decline in district water tables below its long-term mean in India reduces production of food grains by 8 percent. Groundwater scarcity increases rural poverty by almost 12 percent (Sekhri, 2013 b). According to an estimate of the International Water Management Institute, the current patterns of extraction in India could lead to a 25 percent decline in food production by 2025 (Seckler et al, 1998). Given that malnutrition, especially among children, is high in India,[3] conserving groundwater and ensuring food security are first-order policy goals.

The Government of India introduced Agricultural Export Promotion Zones (AEZs) in its exim (export-import) policy of 2001. These AEZs provide integrated services such as packaging, agricultural extension, quality control, and upgrading to geographically concentrated clusters of administrative jurisdictions (districts) to promote export of government-approved crops. We use geographical neighbors of the AEZs as the counterfactual in our empirical analysis. We compare treated districts that comprise a specific AEZ to their geographical neighbors and pool all AEZ cases. Thus, the identification comes from the comparison of treated districts specific to an AEZ cluster to their neighbors over time. [4] To carry out our empirical analysis, we collated a unique dataset that includes nationally representative groundwater data from 1996 to 2005 covering 16,000 observation wells in the country.

The major determinant of selection was suitability for the approved crop, which is affected

[3] Almost 40 percent of the world's malnourished children live in India (Von Braun et al., 2008).

[4] We do not compare the set of districts that received an AEZ to the set of districts that comprise geographical neighbors of these districts. The control set in such a comparison may not be in proximity to the treated districts and thus may be less comparable in crop suitability. Rather, we compare districts in a specific AEZ to its geographical neighbors. Greenstone et al. (2010) make this type of dyadic comparison between winner and loser counties to identify the effect of million-dollar plants on local economies.

by characteristics of districts that do not change in the short-run, such as geology and geography. The inclusion of district fixed effects in our regression analysis accounts for differences in suitability for various crops. Our long panel data allow us to establish that pre-policy trends in groundwater depth do not confound our results. Our identifying assumption is that conditional on district fixed effects and these pre-trends, the neighboring districts form valid counterfactuals for the treated districts. We show that prior to AEZ establishment, treated districts have similar trends in most economic and demographic variables compared to the neighboring districts.

We find that the introduction of AEZs leads to an increase in exports but accelerates the extraction groundwater more rapidly. Notably, groundwater is being depleted at a very large rate in areas classified as over-exploited by the Central Groundwater Board of India. Following Brander and Taylor (1997) and Taylor (2011), we conjecture that the underlying mechanism is entry of more farmers into growing APEDA approved high value crops. Using Taylor's framework, we illustrate that such entry can lead to depletion of groundwater. We bolster the mechanism by showing that price of cereals in export zones that exported cereals, which comprise the largest exported crops by volume, went up subsequent to the policy change. We also show that area under rice and yield of rice increased in cereal AEZs, whereas yield of pulses went down.

To corroborate our study design and address the concern that other investments can be driving our results, we conduct a placebo test to show that AEZ clusters with zero exports did not experience any changes in depth to groundwater. In addition, we show that the results are robust to controlling investment specific time trends and state time trends. We also examine spill-over effects. To do so, we carry out our analysis on a restricted sample of treated districts that are on the geographical boundaries of the clusters. Our results in this restricted sample are similar to those in the full sample, indicating the absence of spatial spill-over effects.

Our empirical estimates imply that an additional decline of 0.45 meters (0.17 of a within standard deviation) in groundwater depth results from setting up of AEZs. In over exploited areas (where extraction exceeds recharge by 100 percent), there is an additional depletion of 2.5 meters or 1 standard deviation. A concern is that these areas might be endogenously determined based on groundwater depth. In carrying out the analysis by different classification of state of exploitation, we control for treatment times classification specific pre-trends to allay concerns over endogeneity and compare districts that are treated to the controls within the classification- that is, within overexploited group, both treated and control districts that they are compared to, are overexploited.

Finally, we estimate reduced-form effects on welfare. We do not detect statistically significant effect on real wages. Following the literature, we use real mean per capita expenditure as a proxy for income to measure welfare effects. We find evidence that agricultural trade promotion had distributive consequences in over exploited areas. While large and marginal farmers are not hurt in over exploited areas, the real mpce of small farmers with holdings between 1 to 2.1 hectare falls by 74 percent (1 standard deviation). This effect is economically large and significant at 1 percent. Marginal farmers do not tend to own wells and large farmers are wealthy so that they are able to absorb the cost of well deepening. Hence, the welfare of large farmers does not go down. By contrast, the small well owning farmers would have to expend significant resources to deepen wells, which could lower their welfare. We provide evidence that probability of well ownership and well deepening increases with land holding size. To bolster the credibility of our estimates, we conduct a falsification test and show that there is no differential change in the real mpce of small farmers in treated and control district in periods prior to the treatment.

We use our estimates of groundwater depletion in deemed overexploited and critical areas to determine the social cost of replenishing groundwater using desalinization. [5]Under different assumptions about the extent of aquifers in the treated districts and different capacities of plants and methods for desalinization, we show that the cost of desalinization alone can range between 1.1 to 9.4 billion dollars in 1991 dollar terms. This does not include the energy costs required to pump water out of the oceans and desalinization plants and the cost of distribution infrastructure.

This paper contributes to the literature on trade promotion and depletion of natural resources. Current theoretical insights offer mixed findings depending on how increased exports alter the trajectory of prices. Copeland and Taylor (2009) develop a model that lays out the conditions under which trade can lead to conservation of renewable resources. They argue

[5]Rain water harvesting is another alternative. Sekhri (2012) shows that policies mandating rain water harvesting are not effective at recharge. In addition, the volume of water needed to be replenished is less likely to be feasible with rain water harvesting. An additional concern is that this method relies on weather patterns and therefore cannot deliver desired volume with certainty.

that an increase in the price of the product resulting from favorable terms of trade may lead to the emergence of institutions that help conserve natural resources. Property rights that promote conservation can emerge as a result of increased trade. Foster and Rosenzweig (2003) present empirical evidence to demonstrate that increased prices for forest products between 1977 and 1999 in India, albeit resulting from increase in local demand for forest goods, led to a revival of the forests and decelerated deforestation. [6] Chichilnisky (1994) and Brander and Taylor (1997) present theoretical arguments that improved terms of trade can generate unsustainable entry resulting in overuse of the resource. Taylor (2011) and Lopez (1997, 1998) develop theories and offer supporting evidence from the historical extinction of buffalo in US and African agriculture respectively.[7] However, lack of available data has contributed to the paucity of careful causal analysis on how trade in goods using renewable resources influences the stock of those resources due to the evolution or lack thereof of pertinent institutions. Another pressing empirical problem for such analysis is that the availability or abundance of the renewable resource might influence policies that promote trade making the identification of causal effects difficult. Our comprehensive data and study design allow us to circumvent these issues. To the best of our knowledge, our study is the first to present evidence on the effects of agricultural trade promotion on groundwater and examine distributive consequences of groundwater over-exploitation.

The rest of the paper is organized as follows: Section 2 provides background on AEZs in India and their selection process. Section 3 discusses the data we use in our empirical work. Section 4 presents our estimation Strategy. Section 5 discusses the main results and results from several robustness tests. Section 6 explains the mechanism relying on a model of entry into high value added crops. In Section 7, we examine alternative explanations for our findings and present evidence in support of our theory and conceptual framework. Section 8 presents the reduced-form effects on real wages and mpce. Section 9 presents a cost-analysis of groundwater depletion in critical and over-exploited areas. Section 10 provides concluding remarks.

[6] Kremer and Morcom (2000) develop a model in which open-access resources are used for production of storable goods, and show that both survival and extinction equilibria are likely to arise.

[7] Bulte and Barbier (2005) review the literature on trade and property rights.

# 2 Background

## 2.1 Agricultural Export Promotion Zones

The government of India created the concept of AEZ under its exim Policy of 2001 to promote the export of high value added crops. It nominated the Agricultural and Processed Food Products Export Development Authority (APEDA) as the nodal agency to oversee the creation and operations of these zones. In establishing an AEZ, the government designates a potential product for export and a contiguous geographical region in which this product can be grown. Subsequently, production, packaging, and transportation of APEDA-approved crops, which have a high return on investment, are integrated within the zone. The government provides financial assistance for training and extension services, research and development, quality upgrading, and international marketing. At the time of establishment, the government anticipated that these zones would increase value addition, improve quality, increase competitiveness, bring down the cost of production due to economies of scale, increase research and development for trade promotion, and increase employment. Individual states nominated clusters, comprising either a single district or a block of districts, and products for centralized approval. Each cluster was envisioned to have research and development support from a nearby agricultural university. States are also expected to provide institutional support for smooth day-to-day functioning of the zone. Importantly, pricing or provision of electricity did not change due to setting up of an AEZ.[8] As of 2008, 60 AEZ clusters had been created. [9] In our empirical analysis, we use 36 out of the 60 AEZs. We drop 18 AEZs due to a lack of groundwater data for some or all districts involved. We also drop clusters where AEZ resulted in 0 exports. Hoever, we use the remaining excluded AEZs for which we have groundwater data to conduct a falsification test and validate that an increase in exports of

[8]Many states in India already subsidize electricity for agriculture; thus the marginal cost of extraction is negligible. No concurrent changes in agricultural electricity pricing occurred that can drive the results. For example, Punjab (a major agricultural state experiencing significant declines in groundwater) went from flat tariffs for agricultural electricity usage to free provision in 1997. The free provision was reversed in 2002 and then instituted again in 2005. Relative to the previous decade, groundwater depth in Punjab did not drop significantly after 1997, but rather after 2001, when two AEZs had been established. Furthermore, the depleting trend did not reverse between 2002 and 2005, when free provision was reversed. In addition, electricity pricing would have to change differentially for a districts receiving AEZs and neighbors within a state to drive the results. But within-state pricing policies are uniformly applied to all districts.

[9] Districts in our sample can be a part of more than one AEZ cluster established at different times.

crops due to AEZ establishment drives our results.

## 2.2 Selection of Agricultural Export Zones

The states had to choose feasible crops and clusters of areas that could grow these cash crops. Thus, an important criterion in selecting the AEZ cluster sites was suitability for growing the crops. Suitability for growing crops in a geographical area is largely determined by static factors such as soil characteristics, long term climate, and geographical characteristics such as elevation and slope. Support from an agricultural university was also deemed important and proximity to such universities influenced the selection of cluster locations.

States also had to provide substantial financial support for the AEZs. Appendix Table 1 shows the details of government expenditures, the product for which AEZ was launched, the state and districts of establishment, and the date of approval and commencement. Suitability influenced the location, whereas institutional and financial constraints of the states influenced the timing of creation. Appendix Figure 1 shows the distribution of the dates of establishment of these zones. Among the AEZs established by 2008, the median number were established by December, 2002. We provide more details in Section 7.4.

To address endogeneity concerns, we use neighboring districts that did not receive an AEZ as counterfactuals. We compare the groundwater depths for these districts before and after the AEZ creation using a long panel of groundwater data. Our identifying assumption is that neighboring districts provide a good counterfactual in terms of potential to grow the crops. The geographical neighbors we use as controls are comparable in crop suitability to the treated districts and are in close proximity to agricultural universities. Figure 1 maps the districts that were in an AEZ by 2008 along with their neighbors and locations of agricultural universities to highlight that the agricultural universities were equidistant.[10] We discuss selection into treatment and its implications in detail in section 4.2.

[10]We do not have data for some of the geographical neighbors. In addition, some universities were established after 2001 by the time the exim policy had been already announced. Appendix Figure 2 maps the districts that were in an AEZ and indicates neighbors for which we do not have data. This map also indicates the locations of universities by the establishment date.

# 3 Data

The groundwater data comes from individual monitoring wells of the Indian Central Ground Water Board. These data are collected from around 16,000 monitoring or observation wells that are spread through out the country. Groundwater measurements are taken four times a year at these monitoring wells, once in each quarter – in May/June, August, November, and January. These well data have been aggregated spatially to the district level using the spatial boundaries of Indian districts corresponding to the 2001 Census of India. We use both quarterly and annual average district -level data in the empirical analysis.

Precipitation and temperature data from the University of Delaware Center for Climactic Research are used to calculate district annual average monthly precipitation and temperature. The Center for Climactic Research at the University of Delaware compiled monthly weather station data from 1900 to 2008 from several sources.[11] After combining data from various sources, the Center for Climactic Research used various spatial interpolation and cross-validation methods to construct a global 0.5 degree by 0.5 degree latitude/longitude grid of monthly precipitation and temperature data from 1900 to 2008 (Matsuura and Wilmott, 2009). From these data, all grid points within India's administrative boundaries were extracted to construct district-level annual average and monthly precipitation and temperature in each year. In addition, we take district demographic and socioeconomic characteristics from the 2001 Census of India. Table 1 reports the summary statistics. Our sample contains 232 districts, of which 133 districts received an AEZ and 112 constitute neighboring controls.

Table 1 reports the summary statistics. Overall average depth to groundwater in the sample is 7.2 meters below ground level (mbgl). The average is 6.8 mbgl for the treated districts and 7.6 mbgl for the control districts. The sample median is 6 mbgl. The overall standard deviation is 6.1 mbgl. The standard deviation in the treated group is smaller at 3.7 than the control group at 7.8 mbgl. The average annual rainfall is 34.5 mm per annum. The treated areas on average receive more rainfall but the variability in rainfall is also higher. The average annual temperature is 25 degree centrigrade and is comparable across the treated and

[11] These sources include the Global Historical Climatology Network, the Atmospheric Environment Service/Environment Canada, the Hydrometeorological Institute in St. Petersburg, Russia, GC-Net, the Automatic Weather Station Project, the National Center for Atmospheric Research, Sharon Nicholson's archive of African precipitation data, Webber and Willmott's (1998) South American monthly precipitation station records, and the Global Surface Summary of Day.

control areas. The treated areas are more populous as per the Census of India 1991. In the sample, 38 percent of the population is employed in 1991. Around 48 percent is female and 16 percent is scheduled castes.[12] These characteristics are very similar across treated and control group districts. Average Literacy rate is 44 percent. In levels, the treated areas have higher literacy in 1991. But we later show that these variables do not exhibit differential trends.

Table 2 shows the summary statistics for the depth to groundwater by year. In 1996, the average depth was 6.9 mbgl, whereas in 2001, the average depth was 7.5 mbgl. This further fell to 7.9 mbgl in 2002. The average depth to groundwater in treated districts was 6.4 mbgl in 1996, whereas it was 7.6 in the control areas. The variability in depth is also lower in the treated areas. Overall depth to groundwater in both the treated and control areas was declining over this time period. In the treated areas, depth to groundwater fell by 1 meter and in control areas, it fell by only 0.2 meters. Prior to treatment, the treated areas had shallower water tables. In what follows, we show that much of this rapid decline in treated areas resulted from promotion of AEZs.

# 4 Estimation Strategy

## 4.1 Empirical Model

The main empirical challenge in estimating the effects of the establishment of AEZs on groundwater decline is that districts for AEZs were not randomly chosen. As mentioned before, in order to address endogeneity concerns, we use neighboring districts that did not receive an AEZ as counterfactuals. We compare the groundwater depths for AEZ districts and neighbors before and after the AEZ's establishment, using a long panel of groundwater data.[13]

The empirical model for each AEZ is as follows:

$$W_{dt} = \alpha_0 + D_d + Q_t + trend_t + \alpha_1 \, Post * T + \alpha_2 \, X_{dt} + \epsilon_{dt} \tag{1}$$

where $W_{dt}$ is the depth to groundwater in district d at time t. Post is an indicator that

[12] Scheduled Castes are historically marginalized population group in India.

[13] We do not have district specific data on production of all APEDA-approved crops. Hence, we do not estimate a 2SLS model in which the first stage would show the effect of the policy shift on area under cultivation and the second stage would show how increased area under cultivation shifts water tables.

takes value 1 after an AEZ has been established in a district and 0 before. T is an indicator that takes the value 1 if a district is a part of the AEZ cluster. $Q_t$ is an indicator for the quarter of the year in which groundwater measurement is taken to account for the seasonality in depth of groundwater. $trend_t$ is a linear time trend and controls for any secular changes in depth over time. $X_{dt}$ are time-varying characteristics of the districts that may vary across treatment and control districts and influence selection into treatment. $\epsilon_{dt}$ is the standard error. Robust standard errors are clustered by district.

We make dyadic comparisons between treated and neighboring districts in each AEZ case and our analysis pools these cases. We use this paired-group difference to ensure we compare the districts that receive a specific crop-based AEZ to their immediate neighbors who are also suitable for growing that crop. In addition, we control for $D_d$, the complete set of district fixed effects. Hence, any fixed characteristics of districts that are used for selection of districts for locating the AEZ are controlled for and do not confound our results.[14] As we discussed earlier, the main criterion was suitability for cultivation of a specific APEDA-approved crops. We control for this criterion by including the district fixed effects in our specifications.[15] The coefficient of interest is $\alpha_1$, which captures the effect of AEZ establishment on treated districts post treatment.

In additional specifications, we also include AEZ case specific pre-trends and both AEZ case specific pre- and post-trends. Controlling pre-trends further allays concerns regarding bias resulting from endogenous placement of AEZs. These pre-trends control for any time-variant characteristics of districts that may have influenced selection. Thus, conditional on district fixed effects and AEZ case specific pre-trends, the neighboring districts form a valid counterfactual for the districts that received an AEZ. The AEZ case specific post-trends allow us to examine if a trend break occurs in the groundwater depth in addition to a level effect.

## 4.2 Selection into Treatment

We compare the observable characteristics of treated districts (districts that received AEZ) with the neighboring control districts to examine if the neighboring controls are comparable

[14] Control districts are shared across different AEZ clusters, and in some cases treated districts received more than one AEZ.

[15] We discuss the crop suitability data in section 4.2. Suitability measures are available for some, but not all, of the APEDA crops. Hence, we are unable to control for suitability measure in our regressions, and allow it to have a differential effect before and after the introduction of AEZs.

to the treated districts. In particular, we explore how demographic characteristics of the districts might have influenced selection. We use demographic information from the 1991 and 2001 Census of India. We also examine whether geographical characteristics of districts such as elevation, rainfall, and temperature are balanced across the treated and control districts. Table 3 reports the means of the observable characteristics by treatment status. Column (i) presents the average values for the control districts that did not receive an AEZ. Column (ii) reports the averages for the treated districts, and column (iii) reports the difference. We compare the pre-treatment 1991 levels of demographic characteristics. Only total population and percentage of literate population are statistically significantly different. Although these differences are marginally statistically significant at the 10 percent significance level. We also include the changes in demographics from 1991-2001 rather than the 1991 levels to examine if these factors are trending differently. We observe a small difference in changes over time in total population. Hence we control for trends in total population in our empirical analysis. We find no difference in percentage working and percentage literate, implying the standard of living was trending in a comparable way in treated and control districts. Looking at geographical characteristics of districts, treated areas are at a higher elevation, though the difference between treated and control districts is statistically insignificant. Treated areas also receive more rainfall and we control for rainfall in our regressions.

Two important determinants of selection were access to agricultural universities and suitability for growing cash crops. We determined the geographical coordinates of all agricultural universities and the date of their establishment. Using spatial software tools, we calculated the shortest distance between the location of the nearest agricultural universities and the centroid of treated and control districts of the AEZ clusters. We calculated both the distance from universities that were already established before the exim policy of 2001 was announced and distance from all universities irrespective of the date of establishment. We report both these average distances of the treated and the control districts from the agricultural university in Table 3. Distances from agricultural universities and from pre-existing agricultural universities are balanced in the treated and control districts.[16]

To assess if suitability for cultivation is balanced across treated districts and our control sample, we analyze the suitability for growing a subset of the crops specified for AEZs in

[16] Appendix Table 2 reports the names and years of establishment of various agricultural universities in the country.

the treatment and control districts. We use geo-spatial data from the Food and Agriculture Organization of the United Nations. These data come from module 6 “Land Productivity Potential” of the Food Insecurity, Poverty, and Environmental Global GIS Database (FGGD). The data are organized as a raster dataset covering the entire global land area in a grid of blocks of five arc-minutes each. Each block is then assigned ratings for its suitability for production of crops under various farming regimes, based on soil and terrain characteristics as well as a number of other biophysical factors that influence production. We aggregate blocks to the district level and use the median rating for a district as a measure of that district’s suitability to growing the crops specified in the AEZ agreement. We do not have these data for all the APEDA-approved crops. Hence we are not able to control for suitability directly in our regression analysis. However, with the crops data we do have, we use the neighbor controls and show that suitability for cultivation of the APEDA-approved cash crops across the treated AEZ districts is modestly higher than these neighboring districts. For example, looking specifically at the case of onions, which are covered by four separate AEZs affecting 20 districts, making it one of the most widely targeted crops is instructive. The FAOs suitability ratings for onions fall between 0 to 10, with higher scores meaning an area is more suitable for cultivation. Across the AEZs covering onions, the average median suitability index rating was 5.75, whereas among their 18 near neighbors, it was slightly lower at 5.0. These measures indicate that both treatment and control groups are well suited to growing onions, but the treatment districts are slightly more productive. This is in line with the selection methodology outlined by APEDA. Thus we report the average suitability for the treated and the control districts for the subset of cash crops for which we do have the suitability data. The average for the treated is 5.74 and that for the controls is 5.48. As expected, the difference is positive but small and statistically insignificant.

We also include the change in depth to groundwater from 1999-2000 and the level of depth in 2000, the year prior to the announcement of the AEZ policy. Neither of these are statistically different. The difference in the change in depth is negative though statistically insignificant. If anything, this finding would imply depth was falling less rapidly in the treated places before the program.[17] Hence, if we detect an increase in depth to groundwater after the program, it is not likely to be attributed to pre-existing declining trends in groundwater depth.

[17]Depth has a lower value when groundwater is closer to the surface.

In our empirical implementation, district fixed effects control for the time-invariant determinants of selection. Distance from universities and suitability for growing crops are purged, as these are time-invariant features of the districts. We include time-varying demographic characteristics of districts including population in our regression specifications to address any concerns about selection based on these observables. We also control for annual average temperature and rainfall in our analysis. Our difference-in-differences estimator will be biased if the parallel-trends assumption does not hold. In order to allay concerns about differential trends prior to treatment, we also control for AEZ case specific pre-trends in depth to groundwater from 1996 to 2000 in the analysis.

# 5 Results

## 5.1 Impact of Agricultural Trade on Groundwater

We examine whether establishment of Agricultural Export Zones influences groundwater depths by comparing districts that receive an AEZ with immediate neighbors that do not. Quarterly groundwater depth is measured in meters below the surface, so that a positive coefficient implies a worsening of the groundwater situation.

We first show that volume of cash crop exports from India did increase in response to the AEZ policy. Figure 2 shows the volume of exports in metric tonnes over time. Before 2000-01, there is the data reveal no systematic pattern. After the announcement of the policy in 2000-01, the volume of APEDA- approved cash crops increases systematically. APEDA does not provide cluster or district-specific export figures over time. Hence we are unable to perform district-level regression analysis. [18]

Next, we turn to exploring the effect of AEZs on groundwater depth. We use approval dates as the time of treatment, but results are similar if we use the date of signing of the MOU with the national government as the treatment date.

We report the results from the regression analysis in Table 4. Each specification controls for demographic, economic, and geographical characteristics of districts including total population, literate population, fraction of working population, fraction of scheduled caste population, and average annual rainfall and temperature.[19] Each specification also includes

[18] Also, due to data limitations on crop-production data for specific crops, we are not able to estimate district-specific changes in APEDA approved crop production.

[19] We have the demographic and economic data for the Census years and interpolate these variables for the

AEZ-case indicators, quarter fixed effects, and district fixed effects. Column (i) is the most parsimonious specification, where we include a simple policy indicator equal to 1 in the post-treatment period for treated districts. The coefficient estimate suggests that AEZ approval results in a level shift of groundwater in the treated districts of about 0.4 meters away from the surface. The coefficient is highly statistically significant. Because the within district standard deviation is 2.6 meters, this effect represents 0.12 of a standard deviation increase in the depth to groundwater.

We add a linear trend in column (ii) to account for any secular changes in groundwater over the period. The point estimate for the policy dummy does not change. In column (iii), we examine the possibility that groundwater trends were different in the control group prior to the policy introduction, but we do not find any evidence for differential pre-trends. The point estimate is robust to controlling for pre-trends in groundwater data. In the final column of Table 4, we investigate the possibility that, in addition to a level shift in groundwater, a break in the trend occurred. In column (iv), we estimate both a AEZ case specific pre-trend and post-trend, which are small and insignificant, and including them increases the policy coefficient by about 0.05. The point estimate on the policy dummy is remarkably stable across specifications ranging from 0.4 to 0.45 meters.

## 5.2 Response by Groundwater Over Exploitation Status

We test if the effects vary by groundwater over exploitation. Central Ground water Board of India classifies districts as over-exploited if more groundwater is extracted than is replenished by precipitation. The groundwater estimation committee has established a hydrological model to determine the rates of extraction and recharge and classify the administrative jurisdictions based on these. Districts are over-exploited if extraction exceeds precipitation by 100 percent and critical if extraction rate is between 85 to 99 percent of recharge rate. We use this classification and estimate the heterogenous effect of agricultural trade by classification status. Panel A in Figure 3 shows the over-exploited and critical districts. Panel B shows the treatment status for these districts. Table 5 reports the results of our analysis. The sample size is slightly smaller than Table 4 as we could not find the status of 1 district. Hence, the first two columns replicate the last two specifications used in Table 4. The results are similar to those reported in Table 4. Columns (iii) and (iv) report the triple interaction terms

remaining years.

for critical and over-exploited districts. Both these columns include additionally full set of non-collinear double interactions. Column (iv) includes post-treatment trend. An increase in trade led to 0.7 meters additional decline in critical areas with the estimate being marginally significant at 10 percent. However, in over-exploited areas this effect is additional depletion of 2.5 meters which is significant at 1 percent significance level. This effect is large and is equal to one within standard deviation of groundwater depth.

There might be two empirical concerns. First, the classification is defined as a function of the groundwater depth and hence might be endogenous. Second, we might be picking up the effects of the time varying characteristics of the districts that led to over-exploitation in the first place and attributing to increase in agricultural trade. The first concern is allayed because we are comparing treatment districts to control districts within over exploited areas and critical areas and only treatment districts have received agricultural export zones. Also, we show in Table 3 that trends in groundwater depth were not a determinant of selection of districts. In order to address the second concern, we include in column (iii) and (iv) pre-trends in groundwater depth interacted with treatment and classification status. In other words, we control for treatment times classification specific pre-trends. We discuss the economic consequences of this large effect in a later section.

### 5.3 Falsification Test - AEZs with no exports

A total of six AEZs reported zero exports over the sample period. If the AEZ operations that resulted in increased agricultural exports from the districts drive our results, we should not discern any effects in districts that had zero exports. We compare the hypothetical treated sample (AEzs with zero exports) with the neighbors in a similar way as our main Table 4. The results are reported in Table 6. Column (i) reports the estimate from a simple difference-in-difference estimation with district fixed effects, and quarter-of-year fixed effects in addition to annual average rainfall and temperature. In column (ii), we add a linear time trend. The coefficient if anything is negative and is significant at 10 percent. But when we account for AEZ case pre- or post-trends in the remaining columns, the coefficient is statistically insignificant. Unlike our main results, we observe a negative coefficient except in column (iv). These findings illustrate that an increase in crop exports resulting from operations of AEZ are driving our results. One concern might be that the AEZs with 0 exports might be different than AEZs with positive exports. We compare the observable characteristics of districts with zero to non zero exports and document our results in Appendix Table A5. They look comparable on most observables including suitability for crops and distance from agricultural universities. The time varying factors that are statistically different are population and literacy rate although the difference in literacy rate is small (0.02 percent). Results are robust to inclusion or exclusion of these factors. [20]

### 5.4 Are There Any Spill-Over Effects?

One possibility is that there are spatial spill-overs in our frame work. Economic spill-overs can arise if increased returns to agricultural inputs in treated areas resulting from an increase in exports changes the behavior of the farmers in the control areas. For example, there is a movement of factors of production into treated areas from control areas. Also, hydrological spill-overs from treated areas to their neighbors might occur. Given that lateral velocity of groundwater is low (Todd, 1980), this scenario is less likely though still possible. In order to examine these possibilities, we restrict our sample of treatment districts to those on the cluster boundaries sharing a geographic border with the neighboring districts. If factors of production move to the treated areas from the neighbors, we should see a larger effect in this sample. If, on the other hand, the treated areas attract the groundwater from the control areas, we should see a muted effect in this sample, and the magnitude should be smaller than in the main sample. We report the results from this exercise in Table 7. Our most preferred specification in column (iii) , where we report the results from a specification controlling district fixed effects, quarter fixed effects, linear trend, and AEZ case specific pre-trend in addition to annual average rainfall and temperature, finds that AEZs lead to a decline of 0.501 m in the boundary sample. The coefficient from the same specification in Table 4 yields an estimate of 0.403 which is also significant at 5 percent. These estimates are not statistically distinguishable from each other. The test statistics testing for equivalence of the interaction coefficients across Table 4 and 7 yield p-values of 0.53, 0.62, 0.37 and 0.17 across the four columns of the tables. Hence we cannot reject the null hypothesis that these estimates are equal, and we do not find any evidence for spatial spill-overs.

[20]Some of these AEZs with 0 exports int he time period in our sample, are exporting crops now but were delayed for logistic reasons. For example- the delays in exports from cereal AEZ in Uttranchal resulted from logistic problems of the state being carved out of Uttar Pradesh only in 2001.

### 5.5 Robustness Tests: Controlling Investment-Specific and State-Specific Trends

One concern may be that AEZ represents bundled investments. Thus, what we find is the effect of these investments (not price or other effects of trade)on outcomes. In Table 6, we already demonstrated that areas with no exports despite positive investments in some cases did not result and positive and significant decline in groundwater depth. This provides strong evidence that our results are not driven by investments per se. In other words, other than the trade channel, these investments did not have an independent effect on outcomes. To allay such concerns, we further performed two tests and report the results in Table 8. First, we interact the total investment with time trends and control for this investment specific trend. Second, we allow for state-specific trends. Columns (i) and (ii) show that our results are still similar to those reported in Table 4. We also perform these tests for a sample where the treated districts are on the cluster boundary. These are reported in columns(iii) and (iv). These coefficients are remarkably similar to the ones reported in Table 7 without the investment specific and state specific trend controls. This further gives us confidence that these investments are not independently affecting outcomes.

### 5.6 Spatial Correlation across Districts

Geographical proximity of districts may result in spatial correlation in our application. Hence, following Conley (1999), we allow for spatial correlation in our main empirical analysis. Districts in India cover an expanse of around 66 kilometers on the average. Thus, we first allow the spatial correlation to fall to 0 at a cutoff of 0.25 degree (latitude and longitude). This is equivalent to around 27.825 kms. The results from this estimation are reported in column (i) of Appendix Table 3. As a sensitivity check, we also use 0.5 degrees (55.65 km) as the cutoff in column (ii), 1 degrees (111.3 km) as the cutoff in column (iii), and 1.5 degrees (166.95 km) in column (iv). The results are identical across these columns using different cutoffs. The estimated coefficient of 0.45 is statistically significant at 5 percent in the first two columns and at 10 percent in columns(iii) and (iv). These results are the same as those reported in Table 4. Thus, our findings are robust to allowing for spatial correlation.[21]

[21]We demeaned our data to carry out this analysis in order to control for district specific heterogeneity. Conley's (1999) algorithm to account for spatial correlation was implemented on the demeaned data.

# 6 Mechanism

Most APEDA approved crops are high-risk, high-reward crops. Although returns to irrigation are high, there is a tacitness to growing these crops; hence not all farmers grow these crops. The introduction of AEZs increases the returns to growing such crops. Farmers on the intensive margin, who previously grew these crops, are likely to increase their production. But the strong incentives driven by an increase in prices, may also lead to entry into cultivating. When a large fraction of farmers enter this market, resource extraction increases. The model presented here formalizes this hypothesis. We use the framework previously developed and used by Brander and Taylor (1997) and Taylor (2011) to examine extraction of renewable resources in the following model of entry and exit in Indian crop production to explain our empirical findings.

In the model, the farmers either decide to grow the crops being targeted by the AEZ or traditional crops that they have experience growing. This implies that there is entry and exit into the export crop markets.[22]

Farmers' land is differentially suited to growing export crops but assumed to be equally suitable for growing conventional crops. If the farmer decides to grow export crops, they earn $pw$ in time $dt$, where p is the relative price of the export crops and w is the amount of water extracted. If they do not grow export crops, they earn $I$. Suppose $GW(t)$ is the stock of groundwater available at time t and the productivity of land for export crops is proportional to the available stock. Then, a farmer with land productivity $\alpha$ will earn $pw = p\,\alpha\, GW(t)$ per unit time. Assume that the distribution of productivity is $F(\alpha)$ where $\alpha \in [0, \widetilde{\alpha}]$ . Farmers compare income from growing export crops to income from growing conventional varieties to determine whether they should enter the export crop market and extract groundwater.

The marginal farmer who grows export crops is given by: $p\,\alpha^*\,GW = I$

Farmers with productivity $\alpha \geq \alpha^*$ grow export crops. Note that $\frac{d\alpha^*}{dGW} < 0$.

If the mass of farmers growing export crops is N, and the total number of farmers growing high value added crops is $N[1 - F(\alpha^*)]$, then $NF(\alpha^*)$ must grow conventional crops. Since $\alpha^* > 0$ , the conventional crop is always produced. Assuming constant returns in the

[22] We make a simplifying assumption that farmers have already sunk a well. We can endogenize the decision to sink a well. The qualitative predictions would remain the same. Therefore, we abstain from introducing well sinking as a choice in the model for the sake of brevity. The purpose of our model is to provide insights about the mechanism driving our empirical findings, and our simple model captures the underlying mechanism.

conventional crop, and choosing units such that output equals labor input, $I = 1$ at all times.

Define $\triangle W$ as the amount of groundwater extracted per unit time when the stock size is $GW$, and farmers with land productivity greater than $\alpha^*$ are engaged in growing export crops.

$$\triangle W = N\ GW \int_{\alpha^*}^{\widetilde{\alpha}} \alpha f(\alpha) d\alpha \tag{2}$$

where the density of land productivity for farmers growing export crops is $F'(\alpha) = f(\alpha)$. The price p and the stock of groundwater GW determine the marginal farmer at every time. Hence, $\triangle W$ is a function of p and GW.

The extraction is increasing in stock of groundwater.

$$\frac{d\triangle(p, GW)}{dGW} = N \int_{\alpha^*}^{\widetilde{\alpha}} \alpha f(\alpha) d\alpha - N\ GW\ \alpha^*(\alpha^*) \frac{d\alpha^*}{dGW} > 0 \tag{3}$$

When the stock increases, the use of water by the inframarginal farmer increases, and farmers in the extensive margin enter the export crop market. The combination of these two implies that the extraction rate increases with the groundwater stock. When the stock declines, farmers exit and average use falls. The farmer with the highest productivity of land will extract groundwater even when it is not abundant. The highest productivity is given by $\widetilde{\alpha}$. Thus, lowest level of groundwater from which extraction will take place satisfies:

$$p\ \bar{\alpha}\ GW^L = I \tag{4}$$

Thus, extraction will not take place if $GW < GW^L$. Therefore, the extraction function is given by:

$$\begin{aligned} \triangle W &= 0 && if\ \ GW < GW^L \\ &= N\ GW \int_{a^*}^{\widetilde{\alpha}} \alpha f(\alpha) d\alpha && if\ \ GW \geq GW^L \end{aligned} \tag{5}$$

Natural recharge G(GW) is assumed to be a positive and concave function of groundwater stock. Recharge is zero when the bottom of the confined aquifers are reached; that is, $G(0) = 0$ and zero when the aquifer's capacity is reached; that is, $G(C) = 0$. The evolution of groundwater is given by:

$$G\dot{W} = G(GW) - \triangle W(p, GW) \tag{6}$$

### 6.1 Steady-State Solution

Appendix Figure 3 (a), shows the typical steady state. Natural Recharge $G(GW)$ starts at $GW = 0$, rises, and then goes to 0 recharge when the aquifer reaches capacity C. The extraction function $\triangle W(p, S)$ is also shown. The extraction rate is 0 when stock of groundwater is low. Extraction commences at $GW^L(p)$ and grows in intensity.

We characterize the solution in the theory appendix.

### 6.2 Influence of the AEZ

Appendix Figure 3 (b) shows two extraction functions. Before the AEZs were introduced, the value of a groundwater was given by p, and hence the extraction function $\triangle W(p; GW)$ intersects the horizontal axis at $GW^L(p)$. The steady state corresponding to this price is given by A. In this case, suppose that the economy is moving along $\triangle W(p, GW)$ towards A from the right. Groundwater depth was falling, but slowly. Without the AEZs, the economy would have moved closer to A over time, with falling groundwater stock but fewer farmers growing export crops.

The AEZs change this movement to the steady state. The AEZs result in a price shock. When this price shock is realized, the extraction function shifts to $\triangle W(\acute{p}; GW)$, resulting in a significant increase in extraction. The productivity of land required to grow export crops discreetly drops and more area is devoted to them (new farmers start growing export crops and farmers already growing them increase the amount of land dedicated to these crops). This change in patterns increases the rate of extraction sharply and water tables begin to decline. The results are formalized in the theory appendix.

## 7 Additional Evidence

### 7.1 Evidence Supporting the Model

The proposed mechanism is that the terms of trade for APEDA approved crops improve which incentivizes more extraction. While we do not have crop production and price data for all crops, we have consumption price data for a subset of crops which constitute 79.5 percent of exports of APEDA approved crops from India. Using this data, we establish that real prices of the exported crops (for which we have data) increased in the crop specific AEZ treated districts after the policy change.

We have comprehensive data on consumption prices of cereal and cereal substitutes which comprise 3/4ths of the APEDA approved exports from the country. We use the pooled sample of AEZs where treated and control districts form the dyads.

We test if terms of trade improve specifically in treated districts of the AEZs for cereals. In order to empirically investigate this, we interact the main interaction effect with an indicator for crop category cereal. The excluded reference group has other crop groups that were exported (including pulses, vegetables,fruits, and medicinal plants).

$$P_{cdt} = \beta_0 + D_d + Post + \beta_1 \ Post * T + \beta_2 Post * \text{Cereal} + \beta_3 \ \text{Post*Cereal*T} + \beta_4 \ X_{dt} + \nu_{cdt} \quad (7)$$

where $P_{cdt}$ is the price of cereals and cereal substitutes normalized by the consumer price Index for Agricultural Labor (CPI-AL) base year 1999. We estimate the model using district fixed effects ($D_d$) and the period fixed effect ($Post$). We account for common macro shocks affecting all districts. The district fixed effects control for time-invariant characteristics of districts that make them suitable for both placement of an AEZ and agriculturally productive. We show results both- with and without $X_{dt}$- controlling for demographic and economic characteristics. Here, the parameter of interest is $\beta_3$ which illustrates the effect of cereal exports on real prices of cereals in AEZs that were approved for cereal. If exports bid up the price, we should expect $\beta_3 > 0$.

We use the nationally representative expenditure survey conducted by the National Sample Survey Organization (NSSO) to estimate the effect on prices. The NSSO conducts "thick rounds" every five years.[23] We use the 1999 and 2009 rounds to conduct our analysis.[24] The AEZ policy was announced in 2001. Thus, we use 1999 as the pre-year. We use repeated cross-sections to create a district-level panel. Weights as specified by NSSO have been applied for each of the two rounds. Expenditure data has detailed prices of several food items. We match these data to district level temperature, rainfall, and other demographic data.

Table 9 shows the effect of the AEZ implementation on real prices of cereal and cereal substitutes. Column (i) is our basic specification with controls for district average temperature and rainfall and district and time fixed effects, and column(ii) additionally controls for total population, employed population, and literacy rate interacted with post. Our results indicate

[23]Thick rounds have larger sample sizes compared to thin rounds that are conducted every year.

[24]These rounds have same recall periods, hence we restrict our analysis to these two rounds.

that the price of approved cereals increased post AEZ implementation. We interact the main effect with an indicator for AEZs approved for cereals. Two facts emerge from these results. First, the price effect on cereals (which comprise the largest exported crop item) is driven by changes in prices in the specific geographical AEZs approved for cereal relative to other crops. The main effect is negligible and insignificant but the interaction of the main effect with indicator for AEZs approved for cereal export is positive and significant at 1 percent significance level. Second, the change in real price is large at around 33 percent increase. Hence, terms of trade improved significantly in areas that export the approved crops.

For examining the effects on production of crops, we use the crop production data collected by Directorate of Economic Policy, Ministry of Agriculture, India. The directorate collects district wise annual data on production and sown area for 49 crops.[25] We can calculate crop specific yields yields from this data. One limitation is that this data does not cover all APEDA approved crops and also does not differentiate between qualities or varieties such as Basmati or short grain rice. For example, it does not cover most fruits and vegetables that were approved by APEDA. Hence, we focus on production of cereals approved for exports (rice and wheat) and examine the production in cereal AEZs. In panel A of Table 10, we show that area under rice increased significantly in cereal AEzs. In panel B, we show that yield of rice increased in cereal AEZs post AEZ introduction. Correspondingly, yield of pulses declined suggesting switching of inputs across crops.

### 7.2 Can Domestic Demand Have Driven the Results?

Because the Indian economy went through a period of rapid growth in the last decade, an alternate explanation can be that domestic demand for agricultural products rose due to factors unrelated to agricultural exports and thereby accelerated groundwater decline. However, this explanation is not consistent with a number of facts. First, the timing is inconsistent with this alternate hypothesis. The groundwater depth declined in treated areas post AEZ establishment compared to years prior to AEZ establishment. Not all AEZs were introduced at the same time. On the other hand, growth rates over this period were high but steady and did not exhibit sharp temporal increases (Virmani, 2009). Hence, increased domestic demand, unrelated to exports (resulting from increase in GDP) can have caused a gradual uniform shift in groundwater depth but cannot explain a difference pre and post AEZ establishment

[25] The crop details are provided in the Appendix Table 6.

over multiple years. Second, we include linear time trends in our specifications to control for universally experienced growth shocks. Thus, universal increases in demand cannot explain our results. From Table 2, we see that treatment is uncorrelated with the change in rate of employment. Standard of living in treated areas is similar to the control areas. Thus, local growth shocks specific to the treatment areas cannot have generated demand for the goods in question.[26] Finally and most importantly, in Table 6, we show that the AEZs that did not result in any exports, did not affect groundwater depth. If local demand unrelated to agriculture exports were driving the results, we would see an effect in this case as well. In addition, we show in Table 8, that controlling for AEZ investment specific trends does not alter the results.

### 7.3 Can Investments have had an Independent Effect?

One concern is that AEZs were established with investments directed towards improving research, quality control, transportation, all of which could have an effect on outcomes independent of the export channel. There are two findings that cast doubt on this. First, in Table 6, we show that AEZs with 0 exports (despite investments in some cases), do not result in a positive and significant effect. Second, if investments were driving these results then controlling the investment specific time trend should explain the main result. In contrast, we find that our results our robust to controlling for investment specific trends (columns (i) and (iii) in table 8). Thus, it is less likely that the results are driven by these investments alone.

### 7.4 Changes in State Infrastructure May Have Influenced the Outcomes

Changes in state infrastructure could potentially affect outcomes. States opting to set up AEZs might also be improving road networks or liberalizing transportation. We compare districts that are treated to the geographical neighbors that are not treated. So these districts should equally benefit from state infrastructure improvements. In order to further allay this concern, we show in Table 8 that the results are robust to including state specific trends.

[26] Local agriculture markets are spatially fragmented. Farmers from 2 to 3 villages sell to a wholesaler in a nearby market called the 'mandi'. These sales are often mediated by a middleman called the 'artia'. The wholesaler then sells to retailers. Produce is also sold at local village markets called the 'haats'.

### 7.5 Investments May have Benefitted Water Intensive Industries Increasing the Industrial Use of Groundwater

Another concern might be that investments benefitted water intensive industries in the treatment areas and the groundwater depletion occurred as a result of increase in use by such industries. Irrigation uses 92 percent of groundwater in India (Jha and Sinha, 2009). But large water intensive industries could have increased their use. Two tests cast doubt on this possibility. In Table 8, we already show that our results are unchanged if we include investment specific trends in our specifications. We did an additional test to allay this concern further. We geo-coded the hubs of 6 major water intensive industries -thermal power, textiles, sugar, metals, fertilizers, paper and pulp. [27] Out of 66 such districts with water intensive industries, 37 are in the treatment group and 29 are in the control group. We examine if the results are driven by the water intensive industries. We interact the treatment times post interaction with an indicator for water intensive industries hub and report the results in Table 11. The main double interaction is still positive and significant at 5 percent level. The triple interaction is negative and statistically insignificant. Therefore, it is unlikely that are results are driven by an increase in use of groundwater by water intensive industries. Appendix Table A4 shows the results by classification status excluding water intensive industries hubs in columns (i) and (ii) and restricting to such hubs in columns (iii) and (iv). We cannot statistically reject that results from column (i) and (iii) and columns (ii) and (iv) respectively are similar. We continue to observe large increases in depletion in over-exploited areas in both samples further indicating that industrial use is not the driver of our results.

### 7.6 Trade Increased the Local Demand for Water Intensive Products due to an Income Effect

Increase in trade could increase the purchasing power of households. This could have increased the demand for water intensive products and could be driving our results. If this were true, supply of such products would increase and we would see larger effects in districts which are hubs of water intensive industries. As Table 11 indicates, the effects are not larger in hubs of water intensive industries. In fact, the triple interaction coefficient with the indicator for water intensive industries has a negative sign although it is not statistically significant.

[27] These industries were identified by Center for Science and Environment and details can be found in CSE(2004). Appendix Figure 4 maps the hub districts of these water intensive industries.

## 8 Income and Wages

The decline in depth to groundwater resulting from the establishment of AEZs could effects income and wages of individuals engaged in agriculture. In this section, we examine the effect on real wages and per capita expenditure by land distribution of farmers.

We analyze the impact on real wages using the following specification:

$$W_{dt} = \beta_0 + D_d + Post + \beta_1 \ Post * T + \beta_2 \ X_{dt} + \nu_{dt} \tag{8}$$

We estimate the model using district fixed effects ($D_d$) and period fixed effect ($Post$) for each AEZ case pooling all AEZs. We show results both- with and without- controlling for demographic and economic characteristics. We also identify distributive effects on farmers. We examine the differential impact on log real mean per capita expenditure for land-owning farmers by percentiles of 1999 land distribution.

Direct measures of income are not available or reliable. Following the literature (Deaton and Paxson, 1998 ; Topolova, ; Atkins, 2013), we use mean per capita expenditure (MPCE) as a proxy for income. We use the nationally representative expenditure survey conducted by the National Sample Survey Organization (NSSO) to estimate the effect on per capita expenditures. The NSSO conducts "thick rounds" every five years.[28] We use the 1999 and 2009 rounds to conduct our analysis. The AEZ policy was announced in 2001. Hence, we use 1999 as the pre year. We use repeated cross-sections of the surveys to create a district-level panel. The NSSO data provide rural wages, landholding status, occupation, and monthly mean per-capita expenditure. We match these data to district level temperature and rainfall, and the groundwater depth data. We use CPI-AL base year 1999 to normalize the per capita expenditure.[29] CPI-AL 1999 is also used to normalize wages in agricultural sector. CPI-IW 1999 is used normalize the wages in non-agricultural sector.

### 8.1 Real Wages

We examine the effect on real agricultural and non-agricultural wages. The results are reported in Table 12. The coefficients are reported in columns (i) and (ii). Although the coefficient for the agricultural sector is positive, it is not statistically significant. On the other

[28]Thick rounds have larger sample sizes compared to thin rounds that are conducted every year.

[29]CPI-AL is Consumer Price Index for Agricultural labor and CPI-IW is the index for Industrial Workers.

hand, the coefficient for the non-agricultural sector is negative but imprecisely estimated. [30]

### 8.2 Real Mean Per Capita Expenditure

We estimate the distributive effects of agricultural trade on real MPCE of farmers by land holding distribution. The results are reported in Table 13. Columns (ii) and (iv) control for demographic and economic variables including total population, percentage of working population, and percentage of literate population. In columns (iii) and (iv), we show the triple interaction results in over-exploited areas. Overall, the coefficients are positive for the farmers in the tails of the land distribution and negative in the middle. But these results are not statistically different than 0. In the over-exploited regions, the estimates for farmers with holdings larger than 2.06 hectares are negative but statistically indistinguishable from 0, whereas the coefficient for farmers with holdings smaller than 1 hectare are positive and imprecise. However, we find a large and negative effect on farmers with holdings between 1 to 2.06 hectare. This coefficient of -0.743 log points indicates that the MPCE for the farmers in the middle of the distribution fell by 74 percent over this period. This effect is economically large and is equivalent to 1.5 times a within standard deviation. These patterns are consistent with the fact that medium to large farmers typically sink a well in India as the fixed cost of well and pump ownership is very high. In Appendix figure A5, we use World Bank Survey of Living Conditions conducted in two agrarian states of Bihar and Uttar Pradesh in 1997 to show that the probability of well ownership is creasing in land holding. [31] Thus, if wells dry up, only such farmers would either have to expend significant resources to revive them or forgo lucrative farming practices that rely on assured irrigation from groundwater. Wealthier farmers can offset such costs but relatively smaller farmers may be worse off.

We conduct a falsification exercise repeating the above specifications for a period prior to the introduction of AEZs. We use two earlier rounds from 1987 and 1993 and examine if mpce by land holding exhibits the same patterns. If export driven fall in groundwater adversely effects the welfare of small farmers, we should not see any change prior to the treatment period. Consistently, in Table 14, we show that if anything the interaction coefficient for small farmers is positive but it is not distinguishable from 0. This also bolsters our confidence that pre-trends in the welfare by farm holding size are not driving this observed redistributive

[30]This may be on account of movement of labor within district into agricultural sector.

[31]These data come 1045 landowning farmers in 120 villages. The data include total of 2250 households.

effect.[32]

## 9 Cost of Depleted Groundwater

Finally, we use our estimates from Table 5 and monetize the social cost of lost groundwater. We used 2001 boundaries of Indian districts to calculate area of critical and overexploited treated districts. Then using our estimates of decline in depth and CGWB of India's recharge percentage in critical areas, we estimated the groundwater depletion in meter cubes under three scenarios: (i) 25 percent of the area has groundwater reserves under it, (ii) 50 percent of the area has groundwater reserves under it, (iii) 100 percent of the area has groundwater reserves under it.[33] Then, we determined how much will it cost to desalinize 1 cubic meter of sea water using reverse osmosis (RO) and multi-stage flash technologies. We used three million gallons per day (MGD) capacities (0.32, 1 and 5) for cost projections for the plants. The cost for desalinization in usd per meter cube for these capacities are calculated in Tare et al. 1991. We use their projections. The discussion is documented in Table 15. The lowest cost for a scenario with an RO technology and capacity 5 MGD assuming 25 percent of the area under treated overexploited and critical districts is over groundwater reserves gives a monetized cost of 1.1 billion dollars in 1991 dollar terms. The highest cost scenario is multi stage flash technology with capacity of 0.32 MGD assuming 100 percent of the area has groundwater under it. This estimate turns is as large as 9.4 billion dollars. These cost do not include energy costs required to pump water from the sea and distribution costs. Hence, these present lower bound scenarios.

## 10 Conclusion

Our paper investigates the effects of agricultural trade on groundwater depletion. Agricultural trade is often promoted as an important lever to boost productivity and improve standards of living in developing countries. Given the rapidly depleting groundwater resources around the world that present a threat to food security, understanding how promoting agricultural

[32]We do not use the periods prior to 1999 to control for pre-trends in Table 13 due to a change in the recall period in 1999 as doing so can introduce a bias in our panel estimates.

[33]Precise locations of groundwater reserves and their accurate thickness or extent is not known. Government of India has set up a task force to determine and map such reserves.

trade can affect groundwater stocks is vital.

We use the variation in trade introduced by the government of India's 2001 exim policy that set up agricultural trade promotion zones in various districts of India to promote the trade of export crops. We find that agricultural trade promotion exacerbates the depletion of water tables in India. Our findings show that using trade promotion as a lever to increase agricultural productivity can be counter productive in the long run if the institutional framework for groundwater extraction remains unchanged. Groundwater shortages can reduce agriculture production (Sekhri, 2013 b) and the rapid decline can have distributive effects lowering the standard of living for farmers farmers in the middle of the land distribution. The social cost of such depletion is economically significant. In a property rights regime that allows for unlimited access to groundwater conditional on landownership, such as exists in India, an increase in international agricultural trade provides incentives to extract more groundwater. Institutions that can promote resource management and conservation do not seem to be emerging .

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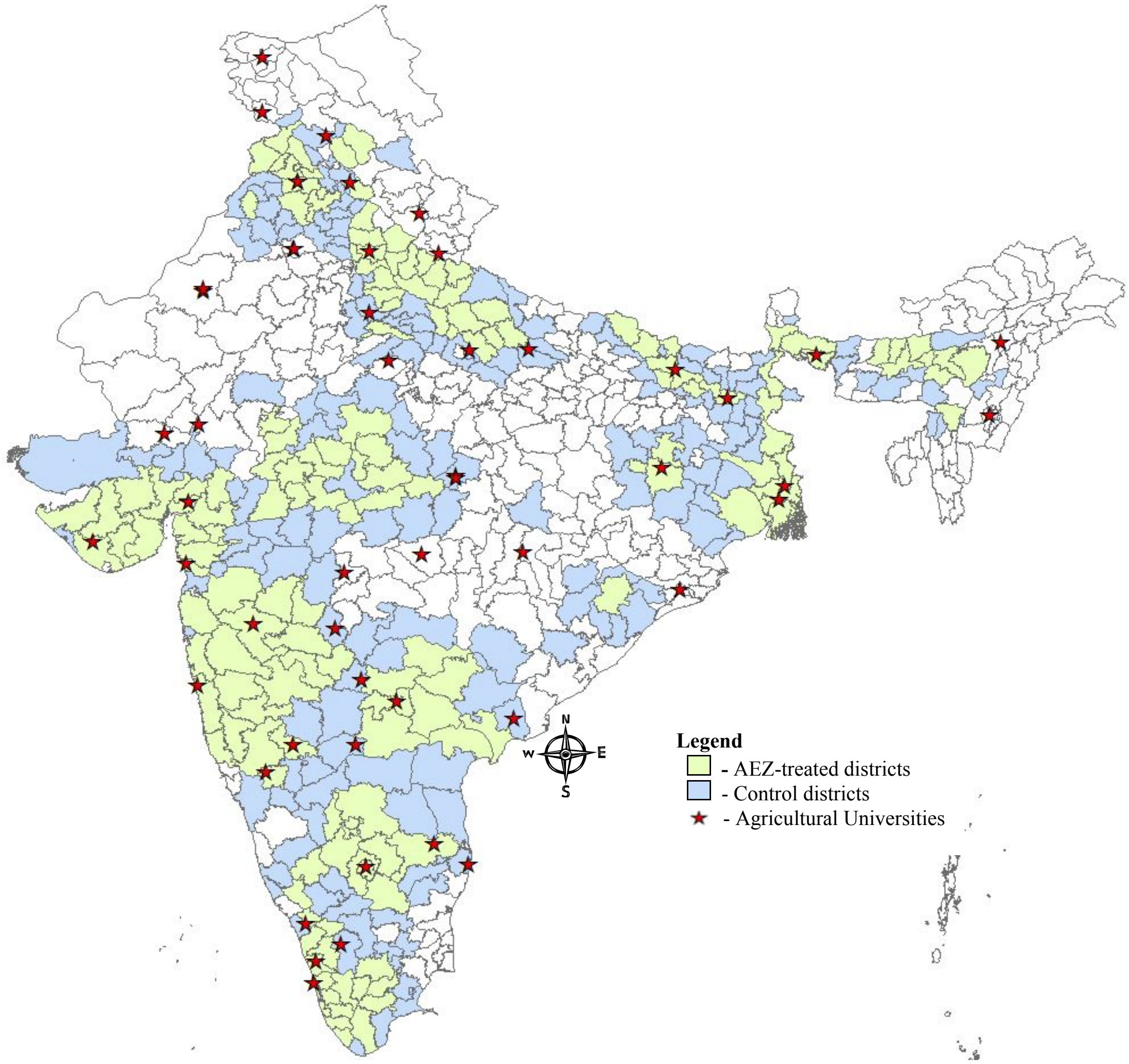
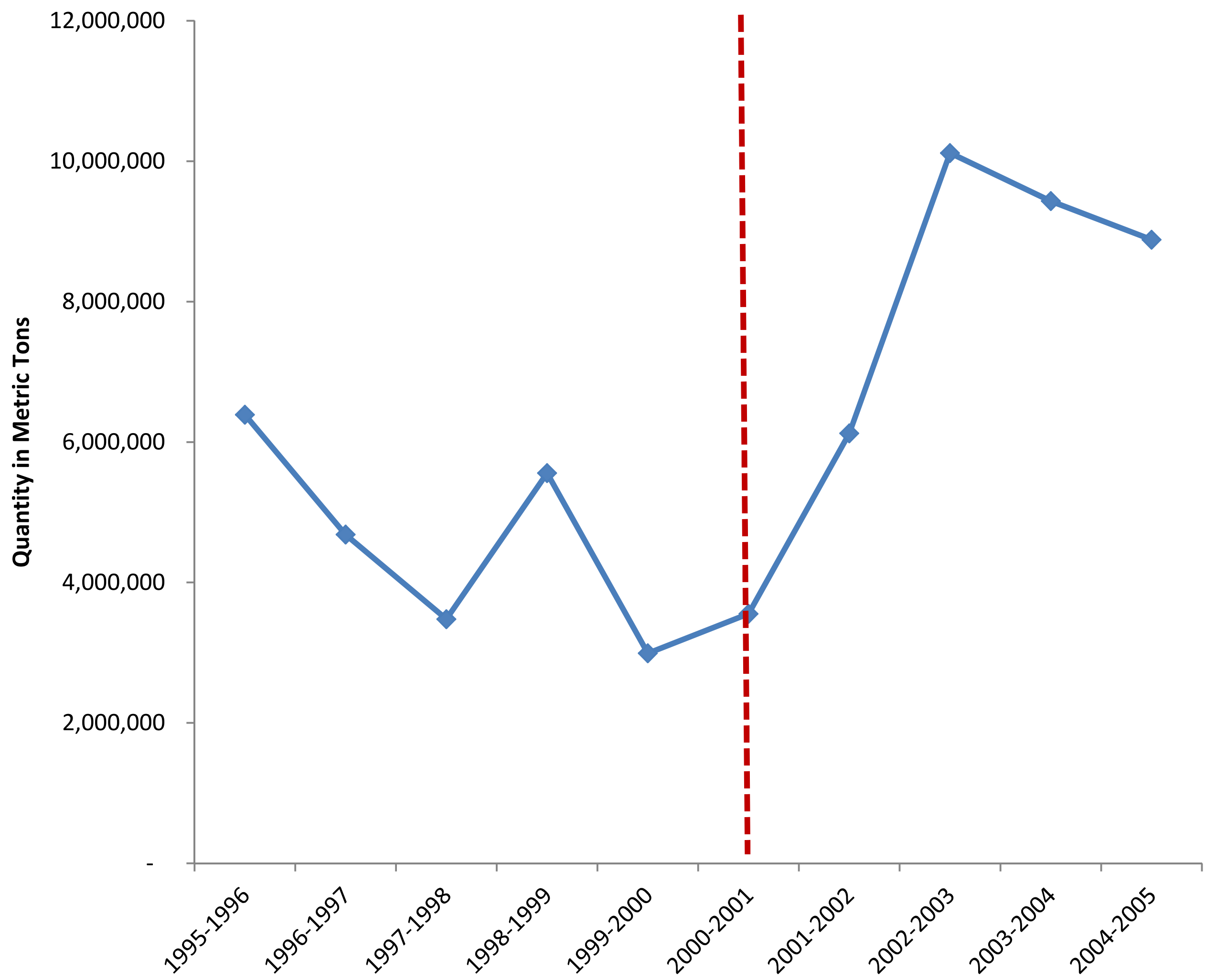



**Figure 1**: AEZ clusters – in-sample treated and control districts along with the location of Agricultural Universities

**Figure 2: Increase in Volume of Exports for APEDA Approved cash Crops**



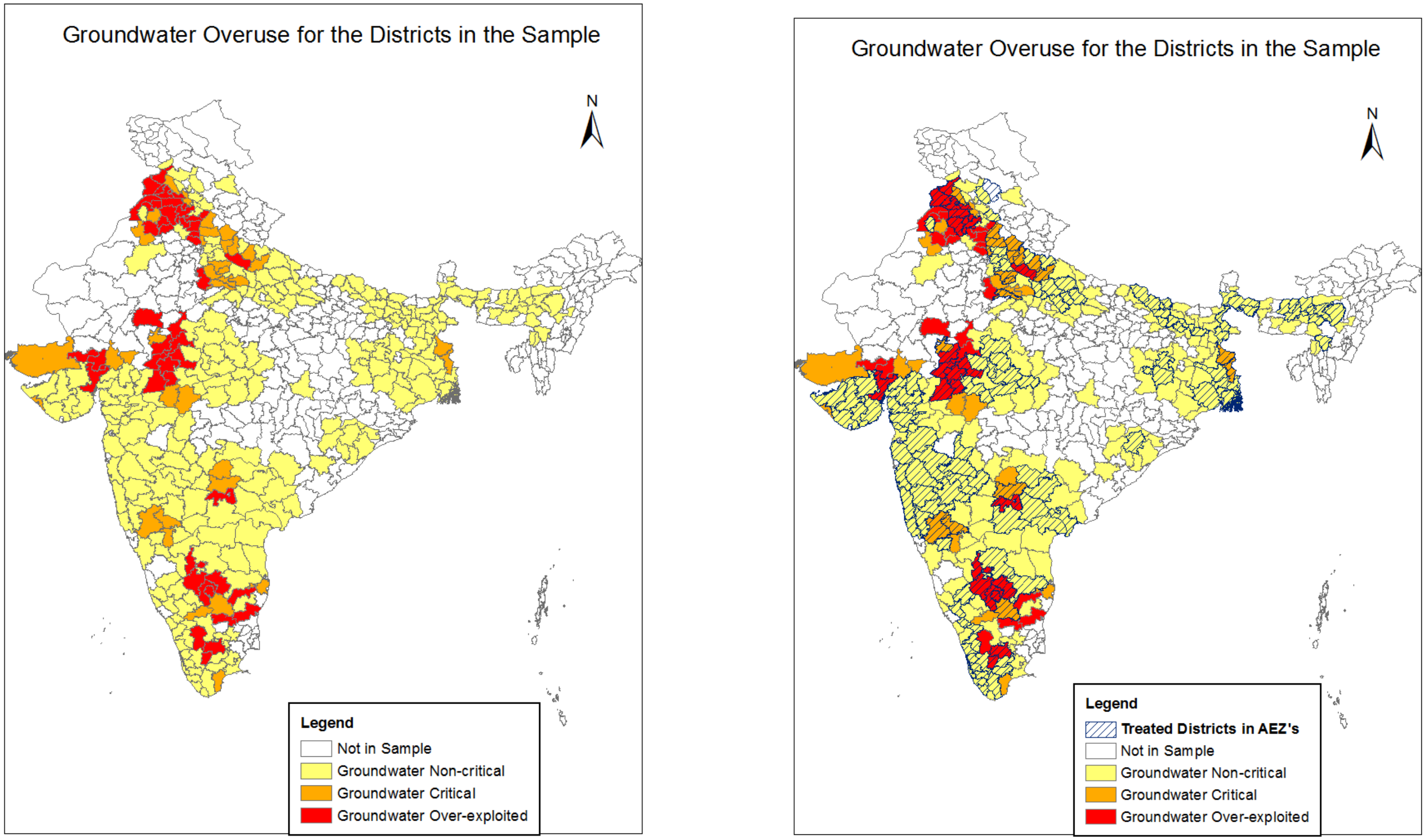



**Figure 3:** Panel in the left maps the over-exploited and critical districts and panel on the right indicates treatment status for these districts

**Table 1: Summary Statistics**

| | | All Districts | Treated Districts | Neighboring Districts |
|---|---|---|---|---|
| **Average Groundwater Level** | **Mean** | 7.2 | 6.8 | 7.6 |
| (meters from surface) | **Median** | 6.0 | 6.1 | 6.0 |
| | **Std dev** | 6.1 | 3.7 | 7.8 |
| **Average rainfall** | **Mean** | 34.4 | 37.0 | 31.6 |
| (meters/year) | **Median** | 15.9 | 17.5 | 14.6 |
| | **Std dev** | 46.5 | 49.6 | 42.8 |
| **Average Temperature** | **Mean** | 25.0 | 25.0 | 25.0 |
| (degrees celsius) | **Median** | 25.9 | 25.9 | 26.0 |
| | **Std dev** | 4.4 | 4.2 | 4.7 |
| **1991 Population** | **Mean** | 2,158 | 2,419 | 1,847 |
| (thousands) | **Median** | 2,000 | 2,213 | 1,710 |
| | **Std dev** | 1,224 | 1,401 | 883 |
| **1991 Fraction SC** | **Mean** | 0.16 | 0.16 | 0.16 |
| | **Median** | 0.16 | 0.15 | 0.17 |
| | **Std dev** | 0.08 | 0.08 | 0.07 |
| **1991 Fraction Literate** | **Mean** | 0.44 | 0.47 | 0.40 |
| | **Median** | 0.42 | 0.46 | 0.38 |
| | **Std dev** | 0.14 | 0.15 | 0.12 |
| **1991 Fraction Working** | **Mean** | 0.38 | 0.38 | 0.39 |
| | **Median** | 0.40 | 0.38 | 0.40 |
| | **Std dev** | 0.07 | 0.07 | 0.07 |
| **1991 Fraction Female** | **Mean** | 0.48 | 0.48 | 0.48 |
| | **Median** | 0.49 | 0.48 | 0.49 |
| | **Std dev** | 0.01 | 0.01 | 0.01 |
| **Number of Districts** | | 232 | 121 | 111 |

**Table 2: Summary Statistics by Year**

| | | Average Depth to Groundwater | | |
|---|---|---|---|---|
| | | **Overall** | **Treated** | **Neighbor** |
| **1996** | **Mean** | 6.9 | 6.4 | 7.6 |
| | **Median** | 5.8 | 5.8 | 5.7 |
| | **Std dev** | 7.3 | 3.2 | 10.0 |
| **1997** | **Mean** | 6.6 | 6.2 | 7.0 |
| | **Median** | 5.9 | 5.9 | 5.8 |
| | **Std dev** | 5.2 | 3.1 | 6.7 |
| **1998** | **Mean** | 6.2 | 5.8 | 6.6 |
| | **Median** | 5.3 | 5.4 | 5.2 |
| | **Std dev** | 5.0 | 2.8 | 6.5 |
| **1999** | **Mean** | 6.6 | 6.3 | 6.9 |
| | **Median** | 5.6 | 5.6 | 5.5 |
| | **Std dev** | 5.2 | 3.2 | 6.8 |
| **2000** | **Mean** | 7.0 | 6.6 | 7.4 |
| | **Median** | 5.9 | 6.1 | 5.8 |
| | **Std dev** | 6.0 | 3.5 | 8.0 |
| **2001** | **Mean** | 7.5 | 7.1 | 7.9 |
| | **Median** | 6.4 | 6.4 | 6.4 |
| | **Std dev** | 6.2 | 3.9 | 7.9 |
| **2002** | **Mean** | 7.9 | 7.5 | 8.2 |
| | **Median** | 6.7 | 6.9 | 6.6 |
| | **Std dev** | 6.1 | 4.0 | 7.7 |
| **2003** | **Mean** | 8.0 | 7.6 | 8.3 |
| | **Median** | 6.7 | 4.2 | 8.3 |
| | **Std dev** | 6.4 | 6.9 | 6.5 |
| **2004** | **Mean** | 7.9 | 7.6 | 8.3 |
| | **Median** | 6.8 | 6.8 | 6.8 |
| | **Std dev** | 6.4 | 4.1 | 8.2 |
| **2005** | **Mean** | 7.6 | 7.4 | 7.8 |
| | **Median** | 6.2 | 6.2 | 6.3 |
| | **Std dev** | 6.1 | 4.4 | 7.5 |

**Table 3: Characteristics Influencing Selection of Treated Districts**

| | Controls | Treated | Difference |
|---|---|---|---|
| **Demographics, Levels 1991** | | | |
| **Population** | 1847.30 | 2419.44 | 572.15* |
| **Percent SC** | 0.16 | 0.16 | 0.00 |
| **Percent Literate** | 0.40 | 0.47 | 0.06* |
| **Percent Working** | 0.39 | 0.38 | 0.00 |
| **Percent Female** | 0.48 | 0.48 | 0.00 |
| **Change in Demographics, 1991-2001** | | | |
| **Population** | 93.04 | 381.92 | 288.88* |
| **Percent SC** | 0.00 | 0.00 | 0.00 |
| **Percent Literate** | 0.13 | 0.11 | -0.01 |
| **Percent Working** | 0.02 | 0.02 | -0.00 |
| **Percent Female** | -0.01 | 0.00 | 0.00 |
| **Distance from Agricultural Universities** | 0.60 | 0.60 | 0.01 |
| **Distance from Pre-existing Agricultural Universities** | 0.71 | 0.61 | -0.10 |
| **Elevation** | 275.81 | 289.49 | 13.67 |
| **Rainfall (1996-2000)** | 33.30 | 39.50 | 6.19* |
| **Temperature (1996-2000)** | 24.97 | 24.98 | 0.01 |
| **Average Suitability for Certain Crops** | 5.48 | 5.74 | 0.26 |
| **Change In groundwater Level, '99-00** | 0.92 | 0.94 | 0.02 |
| **Average Groundwater Level (2000)** | 7.37 | 6.49 | -0.87 |
| **Number of Districts** | 121 | 111 | -- |

Notes: Average Crop suitability based on suitability measures for onion, rice, potato, banana, citrus, flower, vegetable, fruit and wheat. * indicates p<.05

**Table 4: Impact of Agricultural Trade Promotion on Groundwater**

| | Dependent Variable: Groundwater Level (m.b.g.l) | | | |
|---|---|---|---|---|
| | **(i)** | **(ii)** | **(iii)** | **(iv)** |
| **Post*AEZ Approval** | **0.398**** | **0.413**** | **0.408**** | **0.450**** |
| | [0.177] | [0.187] | [0.197] | [0.225] |
| **Linear Time Trend** | | -0.005 | -0.005 | -0.005 |
| | | [0.015] | [0.015] | [0.015] |
| **AEZ*Pre-trend** | | | 0.001 | 0.000 |
| | | | [0.015] | [0.015] |
| **AEZ*Post-trend** | | | | -0.006 |
| | | | | [0.033] |
| **Obs** | 13,084 | 13,084 | 13,084 | 13,084 |
| **R-Squared** | 0.844 | 0.844 | 0.844 | 0.844 |
| **Number of Districts** | 232 | 232 | 232 | 232 |

Notes: The control group consists of districts bordering a district receiving an AEZ who never receive an AEZ themselves. The treatment group excludes AEZs for which there was never any exports and AEZs that were not fully implemented. All regressions include district fixed effects, demographic and economic controls , average annual district rainfall and temperature. Post*Approval is a policy dummy equal to one for a district after the approval of an AEZ. Robust standard errors clustered at district level are in parentheses. *** indicates significance at 1 percent , ** at 5 percent, and * at 10 percent level.

**Table 5 : Impact of Agricultural Trade Promotion on Groundwater by Groundwater Overuse Status**

| | Dependent Variable: Groundwater Level (m.b.g.l) | | | |
|---|---|---|---|---|
| | | (2) | (3) | (4) |
| Post*AEZ Approval | **0.414**** | **0.449**** | 0.042 | 0.193 |
| | [0.197] | [0.225] | [0.220] | [0.288] |
| Post*AEZ Approval * Ground water critical | | | **0.748*** | **0.762*** |
| | | | [0.424] | [0.424] |
| Post*AEZ Approval * Ground water over-exploited | | | **2.497***** | **2.520***** |
| | | | [0.345] | [0.338] |
| AEZ*Post-trend | No | Yes | No | Yes |
| Observations | 13,008 | 13,008 | 13,008 | 13,008 |

Notes: The control group consists of districts bordering a district receiving an AEZ who never receive an AEZ themselves. The treatment group excludes AEZs for which there was never any exports or AEZs that were not fully implemented. All regressions include district fixed effects, demographic and economic controls , average annual district rainfall and temperature, linear trend and AEZ case specific pre-trend. Post*Approval for a district is a policy dummy equal to one after the approval of an AEZ. Standard errors clustered at district level are in parentheses. Columns(iii) and (iv) control for groundwater classification X treatment specific pretrends in groundwater depth.
*** indicates significance at 1 percent , ** at 5 percent, and * at 10 percent level.
As per GEC-97, Central groundwater board defines critical state as groundwater draft between 85-99 percent of recharge and overexploited as draft greater than 100 percent of recharge.

Are Investments Independently Driving the Results?

**Table 6: Falsification Test Using AEZs with no Exports**

**Dependent Variable: Groundwater Level (m.b.g.l)**

| | (i) | (ii) | (iii) |
|---|---|---|---|
| **Post*AEZ Approval** | -0.980*** | -1.014** | -0.687** |
| | [0.355] | [0.396] | [0.300] |
| **Obs** | 7,292 | 7,292 | 7,292 |
| **R-Squared** | 0.87 | 0.87 | 0.87 |
| **Number of Districts** | 53 | 53 | 53 |

Notes: The control group consists of districts bordering a district receiving an AEZ who never receive an AEZ themselves. The treatment group includes AEZs for which there was never any exports and AEZs which were not fully implemented. All regressions include district fixed effects, demographic and economic controls , average annual district rainfall and temperature. Post*Approval is a policy dummy equal to one for a district after the approval of an AEZ. Robust standard errors clustered at district level are in parentheses. Column (ii) controls for a linear time trend. Additionally, column (iii) ands an AEZ case specific pre-trend. *** indicates significance at 1 percent , ** at 5 percent, and * at 10 percent level.

**Table 7: Impact of Agricultural Trade Promotion on Groundwater along Cluster Boundaries**

| | Dependent Variable: Groundwater Level (m.b.g.l) | | | |
|---|---|---|---|---|
| | (1) | (2) | (3) | (4) |
| Post*AEZ Approval | **0.450**** | **0.453**** | **0.501**** | **0.689***** |
| | [0.198] | [0.206] | [0.225] | [0.181] |
| Observations | 11,713 | 11,713 | 11,713 | 11,713 |
| R-squared | 0.850 | 0.850 | 0.850 | 0.850 |
| Number of Districts | 205 | 205 | 205 | 205 |

Notes: The control group consists of immediate neighbors of districts receiving an AEZ which do not receive an AEZ themselves. The treatment group excludes AEZs for which there was never any exports and AEZs which were not fully implemented. All regressions include district fixed effects, demographic and economic controls , average annual district rainfall and temperature. Post*Approval is a policy dummy equal to one for a district after the approval of an AEZ. Robust standard errors clustered at district level are in parentheses. Column (ii) controls for a linear time trend. Additionally, column (iii) ands an AEZ case specific pre-trend and column (iv) adds both an AEZ case specific pre- and post trend. *** indicates significance at 1 percent , ** at 5 percent, and * at 10 percent level.

Are Investments Independently Driving the Results

**Table 8: Robustness Tests: Impact of Agricultural Trade Promotion on Groundwater**

| | Dependent Variable: Groundwater Level (m.b.g.l) | | | |
|---|---|---|---|---|
| | Sample- all treated districts | | Sample- treated districts along cluster boundaries | |
| | **(i)** | **(ii)** | **(iii)** | **(iv)** |
| **Post*AEZ Approval** | 0.448** | 0.405* | 0.689*** | 0.645*** |
| | [0.225] | [0.218] | [0.180] | [0.183] |
| **Investment * Trend** | Yes | No | Yes | No |
| **State * Trend** | No | Yes | No | Yes |
| **Controls - Immediate neighbors** | No | No | Yes | Yes |
| **Obs** | 13,084 | 13,084 | 11,713 | 11,713 |
| **R-Squared** | 0.844 | 0.844 | 0.850 | 0.859 |
| **Number of Districts** | 232 | 232 | 205 | 205 |

Notes: The control group consists of districts bordering a district receiving an AEZ who never receive an AEZ themselves. The treatment group excludes AEZs for which there was never any exports or AEZs which were not fully implemented. All regressions include district fixed effects, demographic and economic controls , average annual district rainfall and temperature, linear trend, ad AEZ case specific pre- and post trend. Post*Approval is a policy dummy equal to one for a district after the approval of an AEZ. Robust standard errors clustered at district level are in parentheses. *** indicates significance at 1 percent , ** at 5 percent, and * at 10 percent level.

**Table 9: Impact of Agricultural Trade Promotion on the Real Prices**

Dependent Variable: Average Real Price of Cereals and Cereal Substitutes

| | (i) | (ii) |
|---|---|---|
| AEZ * Post | 0.236 | 0.323 |
| | (0.223) | (0.248) |
| AEZ * Cereal * Post | **0.596*** | **0.704*** |
| | (0.345) | (0.383) |
| Observations | 61,357 | 53,063 |
| R-squared | 0.311 | 0.304 |

Notes:
*** indicates significance at 1 percent , ** at 5 percent, and * at 10 percent level.
Robust standard errors are clustered at district level and reported in parentheses.
Post is an indicator that equals to 1 for 2009 and 0 for 1999.
Each regression controls district fixed effects, and district specific annual rainfall and temperature . We also control for AEZ crop group interacted with post.
Weights specified by National Sample Survey Organization have been used.
Column (ii) also control for total population, employed population, and literacy rate interacted with post.

## Table 10: Impact of Agricultural Trade Promotion on Area Under Crops and Yields

**Panel A** Dependent variable: Area in hectare

| | Rice | | Pulses | |
|---|---|---|---|---|
| | (i) | (ii) | (iii) | (iv) |
| Post | 18,368 | 20,178 | 9,879** | 10,377** |
| | (11,534) | (12,842) | (4,407) | (4,645) |
| AEZ*Post | -16,905* | -15,816 | -13,996*** | -14,031** |
| | (8,741) | (9,991) | (4,479) | (5,687) |
| AEZ* Cereal * Post | **23,133**** | **24,269**** | -11,237 | -15,329 |
| | (10,015) | (11,067) | (12,393) | (12,075) |
| | 5,147 | 4,195 | 5,147 | 4,195 |

**Panel B** Dependent variable: Yield

| | Rice | | Pulses | |
|---|---|---|---|---|
| | (i) | (ii) | (iii) | (iv) |
| Post | 0.133** | 0.151** | 0.0115 | 0.0298 |
| | (0.0571) | (0.0633) | (0.0299) | (0.0314) |
| AEZ*Post | -0.140*** | -0.126** | 0.0538 | 0.0316 |
| | (0.0489) | (0.0540) | (0.0385) | (0.0420) |
| AEZ* Cereal * Post | **0.194**** | **0.154*** | **-0.123**** | **-0.124**** |
| | (0.0799) | (0.0851) | (0.0599) | (0.0627) |
| | 4,691 | 3,926 | 4,690 | 3,925 |

Notes:
*** indicates significance at 1 percent , ** at 5 percent, and * at 10 percent level.
Robust standard errors are clustered at district level and reported in parentheses.
Production data sample period is 1998 to 2010. Post is an indicator which takes value 1 after the approval of the AEZ. Each regression controls district fixed effects, year fixed effects, and district specific annual rainfall and temperature. We also control for AEZ crop group interacted with post. Second column for each crop additionally controls for total population, employed population, and literacy rate.

Robustness Test - Interaction with Hubs of Water Intensive Industries

**Table 11: Impact of Agricultural Trade Promotion on Groundwater**

| | Dependent Variable: Groundwater Level (m.b.g.l) | | | |
|---|---|---|---|---|
| | (i) | (ii) | (iii) | (iv) |
| **Post*AEZ Approval** | 0.432** | 0.444** | 0.441** | 0.485** |
| | [0.204] | [0.211] | [0.220] | [0.235] |
| **Post*AEZ Approval** | -0.111 | -0.103 | -0.103 | -0.105 |
| ***Water Intensive Industry hub** | [0.359] | [0.357] | [0.357] | [0.356] |
| **Linear Time Trend** | | -0.005 | -0.005 | -0.005 |
| | | [0.015] | [0.017] | [0.017] |
| **AEZ*Pre-trend** | | | 0.000 | 0.000 |
| | | | [0.015] | [0.015] |
| **AEZ*Post-trend** | | | | -0.006 |
| | | | | [0.033] |
| **Obs** | 13,084 | 13,084 | 13,084 | 13,084 |
| **R-Squared** | 0.844 | 0.844 | 0.844 | 0.844 |
| **Number of Districts** | 232 | 232 | 232 | 232 |

Notes: The control group consists of districts bordering a district receiving an AEZ who never receive an AEZ themselves. The treatment group excludes AEZs for which there was never any exports and AEZs that were not fully implemented. All regressions include district fixed effects, demographic and economic controls , average annual district rainfall and temperature. Post*Approval is a policy dummy equal to one for a district after the approval of an AEZ. Robust standard errors clustered at district level are in parentheses. *** indicates significance at 1 percent , ** at 5 percent, and * at 10 percent level.

**Table 12: Impact of Agricultural Trade Promotion on Rural Agricultural Wages**

**Dependent Variable: Real Wages**

| | **All Observations** | | **Agriculture** | | **Non-agriculture** | |
|---|---|---|---|---|---|---|
| | (i) | (ii) | (iii) | (iv) | (v) | (vi) |
| AEZ * Post | -15.31 | -37.48 | -5.501 | 5.030 | -44.41 | -69.42 |
| | (51.89) | (42.27) | (8.962) | (6.595) | (79.27) | (54.50) |
| District-level Demographic Controls | No | Yes | No | Yes | No | Yes |
| Observations | 229,270 | 204,124 | 68,748 | 62,141 | 160,522 | 141,983 |
| R-squared | 0.077 | 0.082 | 0.221 | 0.207 | 0.051 | 0.059 |

*** indicates significance at 1 percent , ** at 5 percent, and * at 10 percent level.
The outcome variable is the real wages of rural population. Robust standard errors are clustered at district level and reported in parentheses. Post is an indicator that equals to 1 for 2009 and 0 for 1999. Every regression controls for district fixed effects, post indicator, district level average rainfall and temperature. Demographic controls include total population of the district, percentage of working population, and percentage of literature population interacted with post. Weights specified by National Sample Survey Organization have been used.

**Welfare : Agricultural Landowners by Land Distribution**

**Table 13: Impact of Agricultural Trade Promotion on Per Capita Consumption**

| **Dependent Variable: log(Real Mean Monthly Per Capita Expenditure)** | | | | | |
|---|---|---|---|---|---|
| | Variable | (i) | (ii) | (iii) | (iv) |
| **0-25 percentile** (Land Holding 0.01 - 1 ha.) | Post*AEZ Approval | 0.000985<br>(0.0296) | 0.0334<br>(0.0425) | -0.00833<br>(0.0311) | 0.0244<br>(0.0442) |
| | Post*AEZ Approval *(Ground Water Overexploited) | | | 0.0901<br>(0.0941) | 0.109<br>(0.125) |
| **25-50 percentile** (Land Holding 1 - 2.06 ha.) | Post*AEZ Approval | -0.0880<br>(0.0643) | -0.0335<br>(0.0790) | -0.0717<br>(0.0618) | -0.0133<br>(0.0718) |
| | Post*AEZ Approval *(Ground Water overexploited) | | | **-0.739*****<br>**(0.149)** | **-0.743*****<br>**(0.169)** |
| **50-75 percentile** (Land Holding 2.06 - 2.2 ha.) | Post*AEZ Approval | -0.0158<br>(0.0884) | -0.0652<br>(0.122) | 0.0313<br>(0.0887) | 0.0236<br>(0.116) |
| | Post*AEZ Approval *(Ground Water overexploited) | | | -0.376<br>(0.301) | -0.275<br>(0.317) |
| **75 - 100 percentile** (Land Holding over 2.2 ha.) | Post*AEZ Approval | 0.0184<br>(0.0558) | 0.0234<br>(0.0708) | -0.00150<br>(0.0506) | -0.00456<br>(0.0625) |
| | Post*AEZ Approval *(Ground Water overexploited) | | | -0.114<br>(0.144) | -0.138<br>(0.143) |
| District-level Demographic Controls | | No | Yes | No | Yes |

**Falsification Test Using Pre-Treatment Periods**

**Table 14: The Impact of Agricultural Trade Promotion on Per Capita Consumption by Land Distribution**

**Dependent Variable: log(Real Mean Monthly Per Capita Expenditure)**

| | Variable | (i) | (ii) | (iii) | (iv) |
|---|---|---|---|---|---|
| **0-25 percentile** (Land Holding 0.01 - 1 ha.) | Post*AEZ Approval | 0.0698 | 0.0725 | 0.0762 | 0.0830 |
| | | (0.0431) | (0.0456) | (0.0463) | (0.0511) |
| | Post*AEZ Approval *(Ground Water Overexploited) | | | -0.0533 | -0.0775 |
| | | | | (0.0989) | (0.107) |
| **25-50 percentile** (Land Holding 1 - 2.06 ha.) | Post*AEZ Approval | -0.00221 | 0.0235 | -0.0513 | -0.0269 |
| | | (0.0509) | (0.0447) | (0.0477) | (0.0397) |
| | Post*AEZ Approval *(Ground Water overexploited) | | | 0.251* | 0.226 |
| | | | | (0.151) | (0.145) |
| **50-75 percentile** (Land Holding 2.06 - 2.2 ha.) | Post*AEZ Approval | 0.132 | 0.122 | 0.206 | 0.192 |
| | | (0.143) | (0.160) | (0.149) | (0.167) |
| | Post*AEZ Approval *(Ground Water overexploited) | | | -0.417 | -0.400 |
| | | | | (0.398) | (0.388) |
| **75 - 100 percentile** (Land Holding over 2.2 ha.) | Post*AEZ Approval | 0.0473 | 0.0506 | 0.103* | 0.111* |
| | | (0.0459) | (0.0492) | (0.0541) | (0.0586) |
| | Post*AEZ Approval *(Ground Water overexploited) | | | -0.173* | -0.186* |
| | | | | (0.0913) | (0.104) |
| District-level Demographic Controls | | No | Yes | No | Yes |

*** indicates significance at 1 percent , ** at 5 percent, and * at 10 percent level.
The outcome variable is the log of mean per capita expenditure within household. Robust standard errors are clustered at district level and reported in parentheses. Post is an indicator that equals to 1 for 1993 and 0 for 1987. Every regression controls for district fixed effects, post indicator, district level average rainfall and temperature. Demographic controls include total population of the district, percentage of working population, and percentage of literature population from Census 1981 interacted with post.
Weights specified by National Sample Survey Organization have been used.

## Table 15: Social Cost of Ground water Depletion in terms of Desalination

| | |
|---|---|
| Area under treated overexploited districts | 127962 squared kms |
| Area under treated semi to critical districts | 87807 squared kms |

| | **Scenarios** | Groundwater | **25 percent area with water** | **50 percent area with water** | **100 percent area with water** |
|---|---|---|---|---|---|
| | | km-cube | 922.6923 | 1845.3846 | 3690.7692 |
| | meter cube as per estimates | | 922692300 | 1845384600 | 3690769200 |
| | **capacity MGD** | **usd/mt-cube** | | **USD dollars 1991** | |
| **Reverse Osmosis** | 0.32 | 1.75 | 1614711525 | 3229423050 | 6458846100 |
| | 1 | 1.45 | 1337903835 | 2675807670 | 5351615340 |
| | 5 | 1.2 | **1107230760** | 2214461520 | 4428923040 |
| **Multi stage flash** | 0.32 | 2.55 | 2352865365 | 4705730730 | **9411461460** |
| | 1 | 2 | 1845384600 | 3690769200 | 7381538400 |
| | 5 | 1.35 | 1245634605 | 2491269210 | 4982538420 |

**Approximately ranging from 1.1 billion to 9.41 billion usd in 1991 dollar terms**

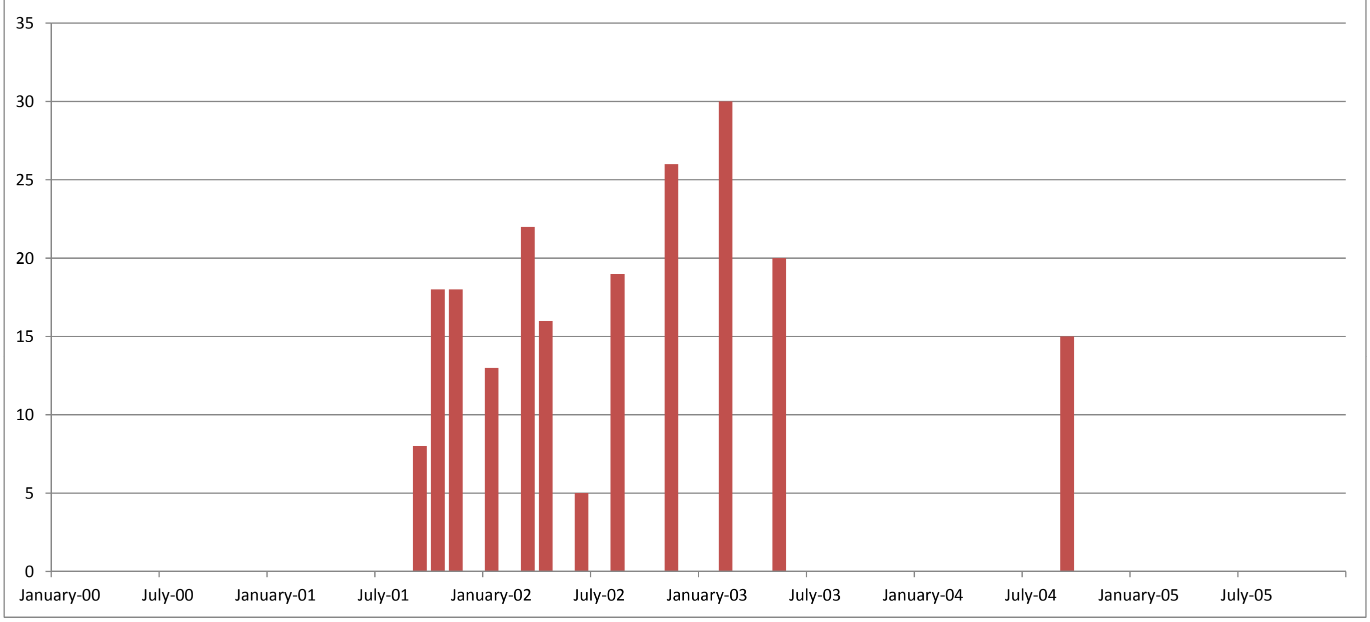
Note- Additional Cost of pumping seawater, collection, pumping from plant and distribution are not added

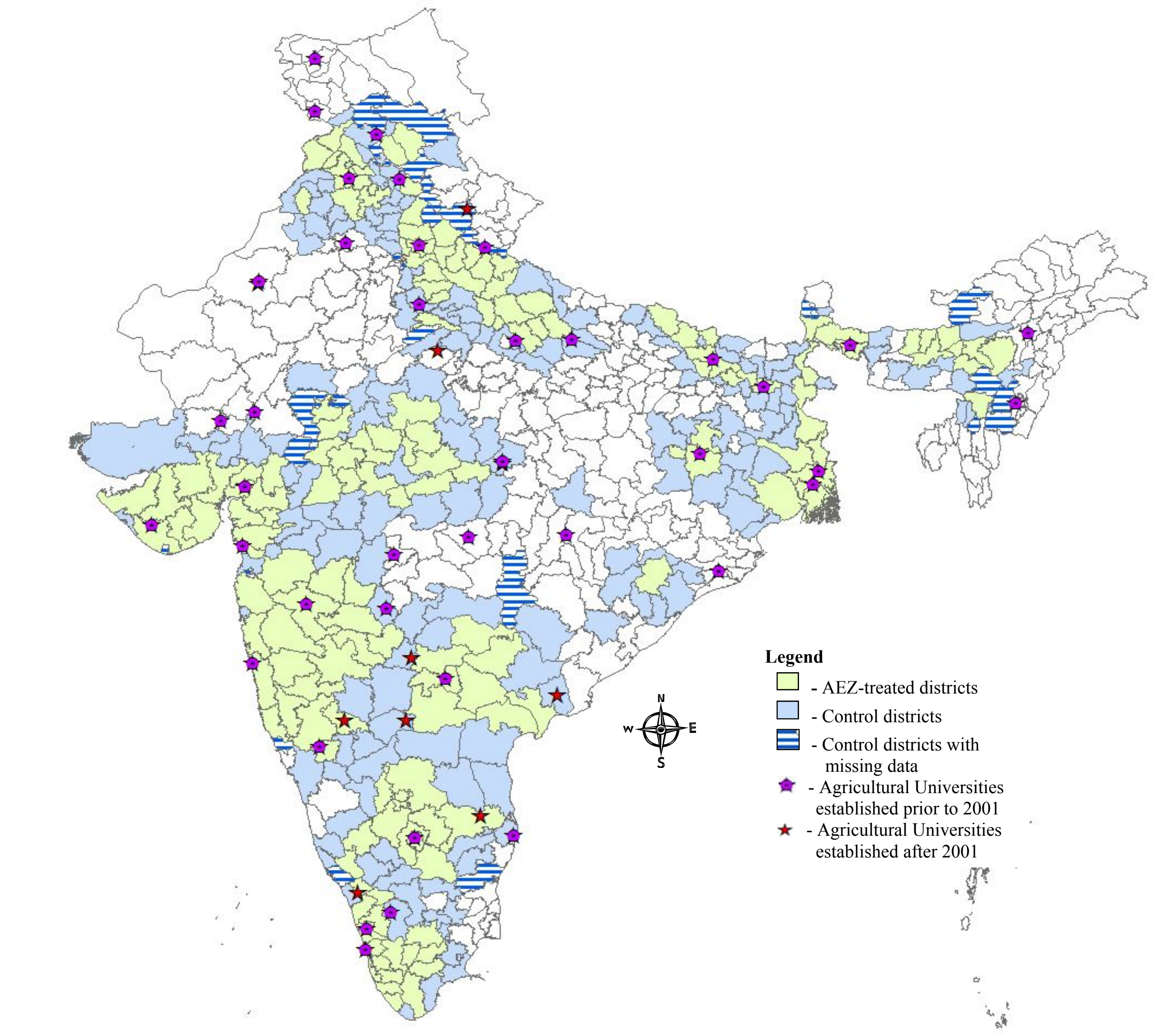
Energy is required for pumping and distribution

cost of capital is for 20 years at 15 percent interest

# Supplemental Material: Online Appendix

## Appendix Figure 1: Number of Districts Receiving AEZs by Month






**Appendix Figure 2**: AEZ clusters – in-sample treated and comparison districts along with the location of Agricultural Universities separated by year of establishment

**Figure A3 (a)**

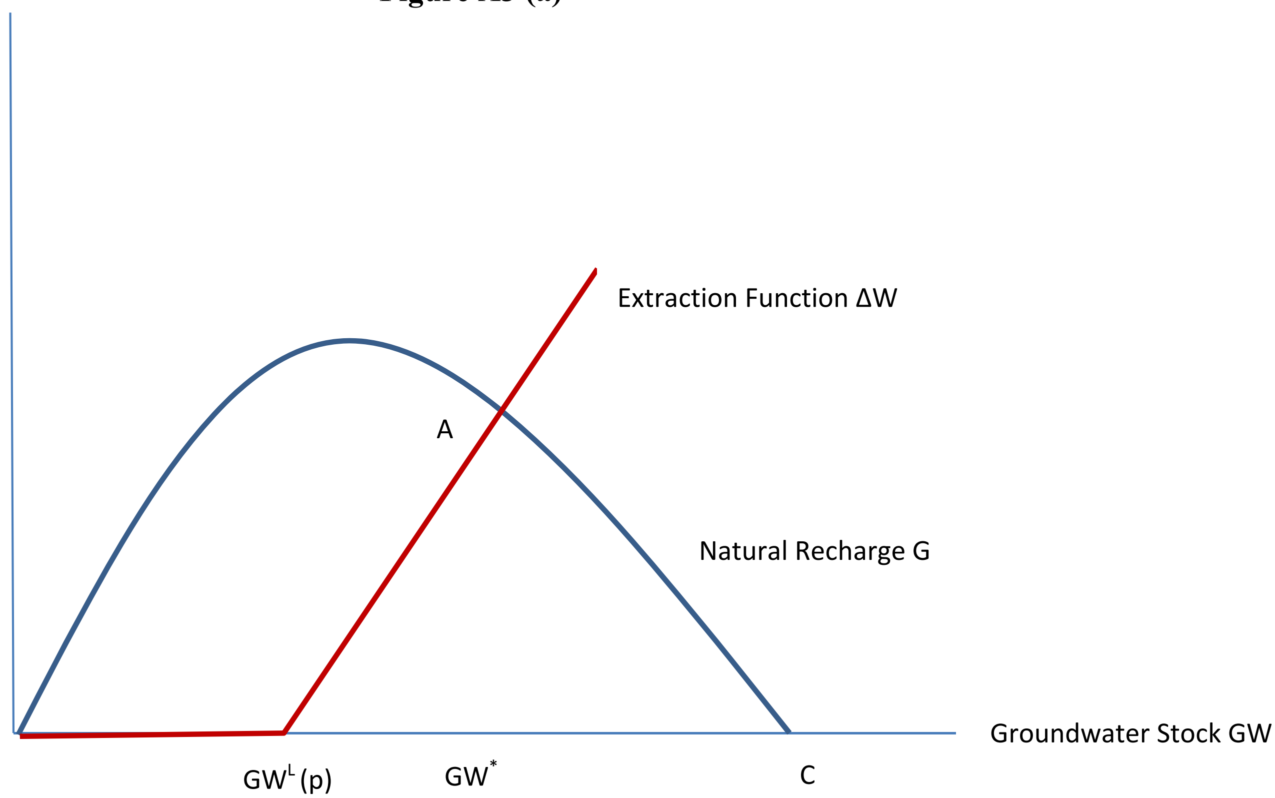
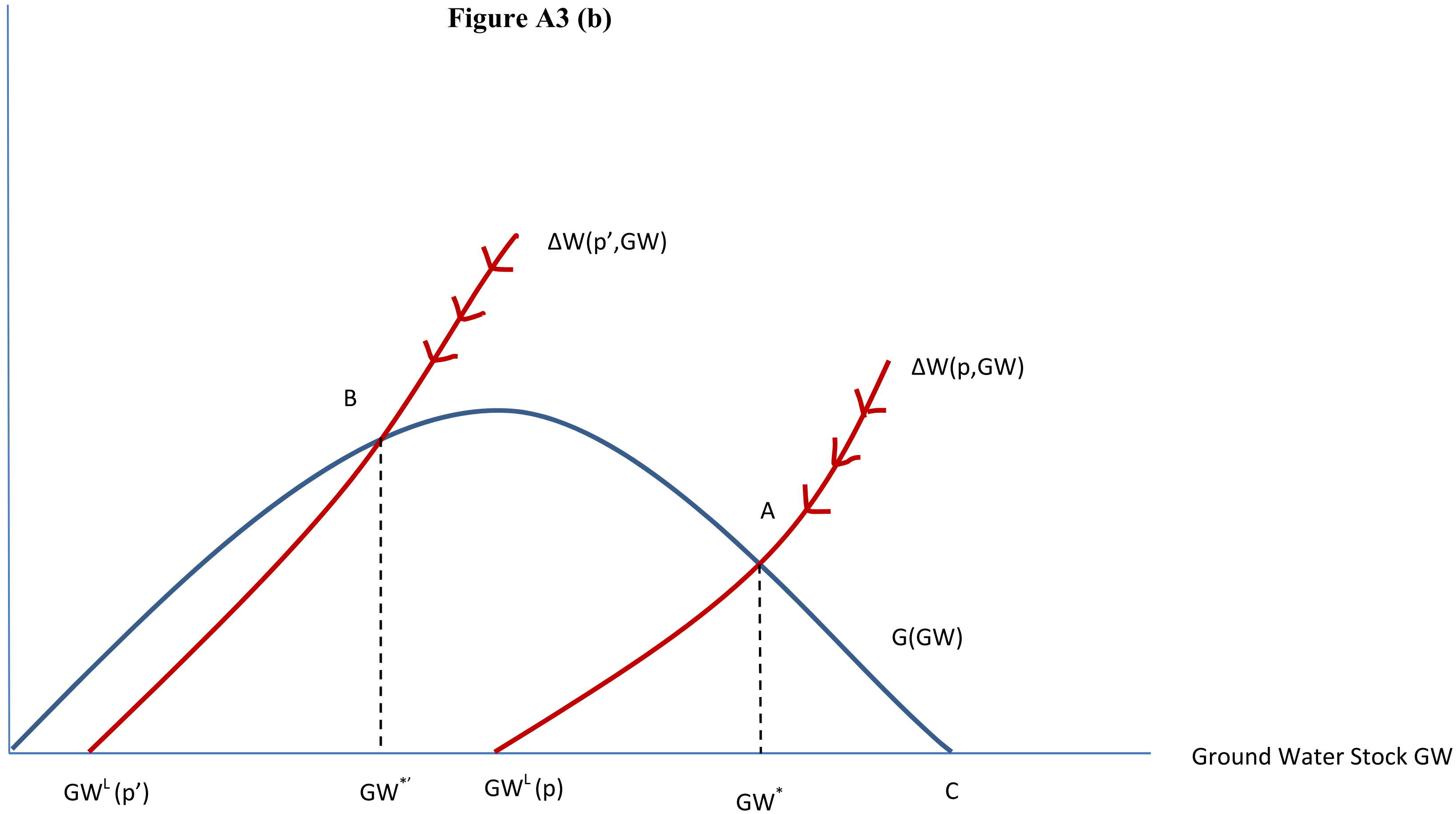
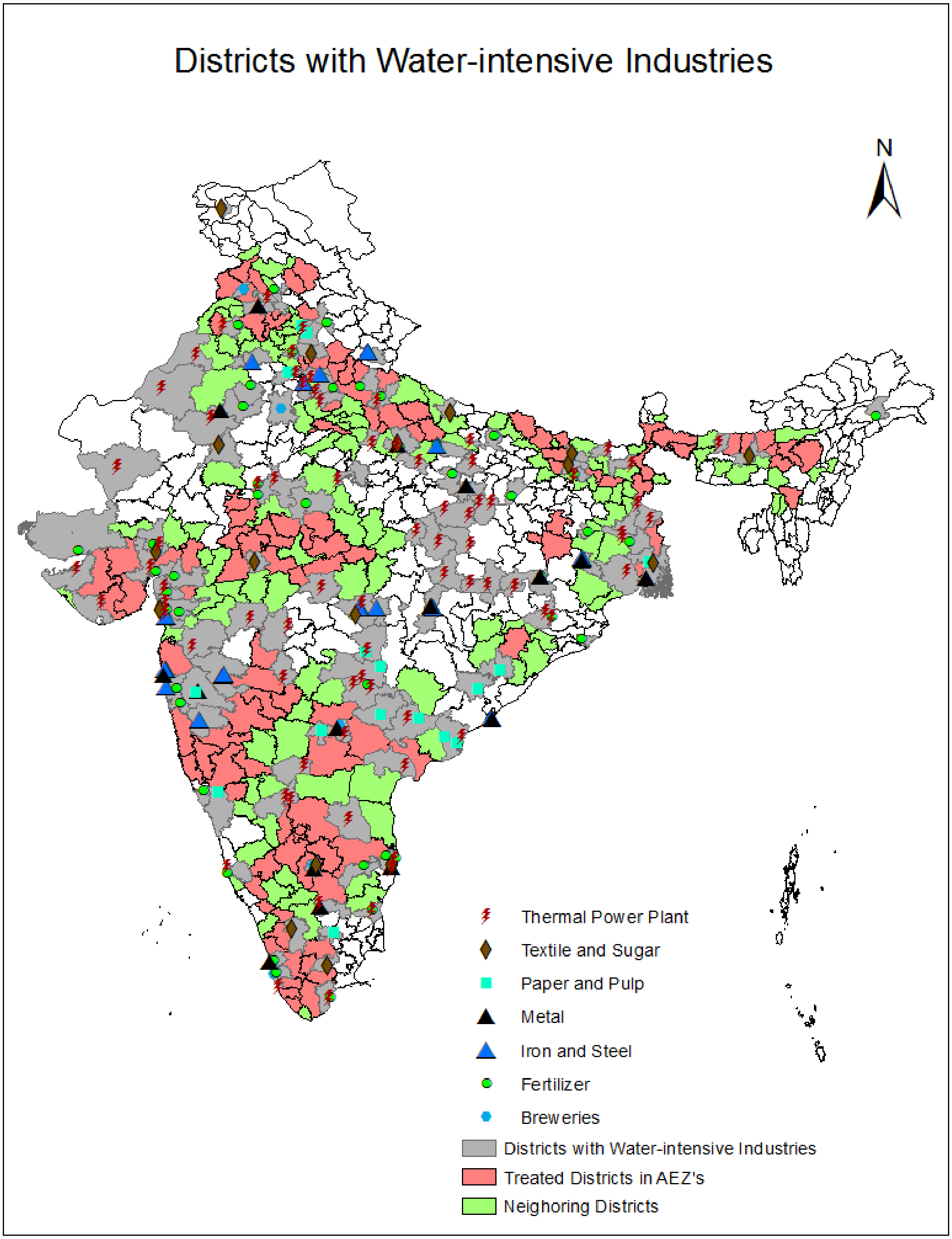
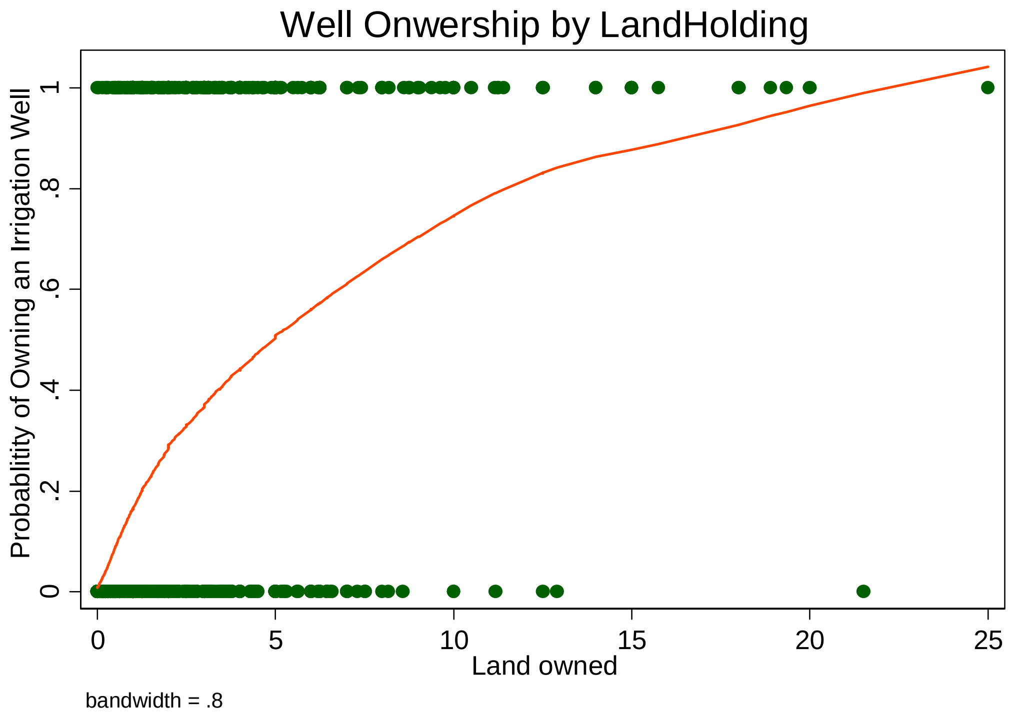

Extraction Function ΔW
A
Natural Recharge G
Groundwater Stock GW
GW^L (p)
GW*
C

**Figure A3 (b)**






**Appendix Figure 4**: Water Intensive Industry Hub Locations




**Appendix Figure 5:** Probability of Well-ownership increasing in Land Ownership

Source: World Bank Survey of Living Conditions 1997, Uttar Pradesh and Bihar India

Table A1: Catalog of Agri Export Zones and Associated Exports/Expenditures

| S. No | Product | State | District/Area | Date of Approval | Date of Notification | Date of Signing of MOU | Exports (Rs. Cr.) | Planned Percentage of Expenditures by Government |
|---|---|---|---|---|---|---|---|---|
| 1 | Pineapple | West Bengal | Darjeeling, Uttar Dinajpur, Cooch Behar and Jalpaiguri | 7-Sep-01 | 8-Oct-01 | 18-Sep-01 | 0.2 | 11.7 |
| 2 | Gherkins | Karnataka | Tumkur, Bangalore Urban, Bangalore Rural, Hassan, Kolar, Chtradurga, Dharwad and Bagalkot | 7-Sep-01 | 8-Oct-01 | 19-Sep-01 | 1237.05 | 29.2 |
| 3 | Lychee | Uttaranchal | Udhamsingh Nagar, Nainital and Dehradun | 7-Sep-01 | 8-Oct-01 | 22-Sep-01 | 2.45 | 60.5 |
| 4 | Vegetables | Punjab | Fatehgarh Sahib, Patiala, Sangrur, Ropar & Ludhiana | 11-Oct-01 | 8-Mar-02 | 29-Oct-01 | 0.03 | 44.2 |
| 5 | Potatoes | Uttar Pradesh | Agra, Hathras, Farrukhabad, Kannoj, Meerut, Aligarh and Bagpat | 11-Oct-01 | 8-Mar-02 | 7-Nov-01 | 7 | 88.1 |
| 6 | Mangoes and Vegetables | Uttar Pradesh | Lucknow, Unnao, Hardoi, Sitapur & Barabanki | 11-Oct-01 | 8-Mar-02 | 7-Nov-01 | 0.47 | 36.9 |
| 7 | Potatoes | Punjab | Singhpura, Zirakpur (Patiala), Rampura Phul, Muktsar, Ludhiana, Jallandhar | 27-Nov-01 | 8-Mar-02 | 20-Dec-01 | 2.8 | 78.7 |
| 8 | Mangoes | Uttar Pradesh | Sahranpur, Muzaffarnagar, Bijnaur, Meerut, Baghpat, Bulandshar and Jyotifulenagar | 27-Nov-01 | 8-Mar-02 | 21-Dec-01 | 12.49 | 52.4 |

Table A1 (cont)

| S. No | Product | State | District/Area | Date of Approval | Date of Notification | Date of Signing of MOU | Exports (Rs. Cr.) | Planned Percentage of Expenditures by Government |
|---|---|---|---|---|---|---|---|---|
| 9 | Grapes and Grape Wine | Maharashtra | Nasik, Sangli, Pune, Satara, Ahmednagar and Sholapur | 27-Nov-01 | 8-Feb-02 | 7-Jan-02 | 384.67 | 100.0 |
| 10 | Mango Pulp & Fresh Vegetables | Andhra Pradesh | Chittor District | 23-Jan-02 | 8-Mar-02 | 28-Jan-02 | 2736.03 | 43.8 |
| 11 | Pineapple | Tripura | Kumarghat, Manu, Melaghar, Matabari and Kakraban Blocks | 23-Jan-02 | 8-Mar-02 | 1-Feb-02 | 0 | 59.2 |
| 12 | Potatoes, Onion and Garlic | Madhya Pradesh | Malwa, Ujjain, Indore, Dewas, Dhar, Shajapur, Ratlam, Neemuch and Mandsaur | 23-Jan-02 | 8-Mar-02 | 11-Feb-02 | 15.99 | 41.9 |
| 13 | Mangoes | Maharashtra | Districts of Ratnagiri, Sindhudurg, Raigarh and Thane | 23-Jan-02 | 8-Mar-02 | 12-Feb-02 | 123 | 74.4 |
| 14 | Apples | Jammu & Kashmir | Districts of Srinagar, Baramula, Anantnag, Kupwara, Badgaum and Pulwama | 23-Jan-02 | 8-Mar-02 | 18-Mar-02 | 124.72 | 32.4 |
| 15 | Flowers | Tamil Nadu | Dharmapuri | 27-Nov-01 | 8-Feb-02 | 20-Mar-02 | 39.4 | 14.0 |
| 16 | Lychee | West Bengal | Districts of Murshidabad, Malda, 24 Pargana (N) and 24 Pargana (S) | 5-Mar-02 | 31-Mar-02 | 23-Mar-02 | 3.3 | 80.4 |

Table A1 (cont)

| S. No | Product | State | District/Area | Date of Approval | Date of Notification | Date of Signing of MOU | Exports (Rs. Cr.) | Planned Percentage of Expenditures by Government |
|---|---|---|---|---|---|---|---|---|
| 17 | Lychee | Bihar | Muzaffarpur, Samastipur, Hajipur, Vaishali, East and West Champaran, Bhagalpur, Begulsarai, Khagaria, Sitamarhi, Sarannd Gopalganj | 5-Mar-02 | 31-Mar-02 | 5-Apr-02 | 5.87 | 38.2 |
| 18 | Kesar Mango | Maharashtra | Districts of Aurangabad, Jalna, Beed, Latur, Ahmednagar and Nasik | 5-Mar-02 | 31-Mar-02 | 11-Apr-02 | 12.17 | 40.8 |
| 19 | Walnut | Jammu & Kashmir | Kashmir Region – Baramulla, Anantnag, Pulwama, Budgam, Kupwara and Srinagar / Jammu Region - Doda, Poonch, Udhampur, Rajouri and Kathua | 5-Mar-02 | 31-Mar-02 | 11-May-02 | 552.21 | 47.0 |
| 20 | Flowers | Uttranchal | Districts of Dehradun, Pantnagar | 23-Apr-02 | 5-Jun-02 | 30-May-02 | 0.04 | 21.7 |
| 21 | Mangoes & Vegetables | Gujarat | Districts of Ahmedabad, Khaida, Anand, Vadodra, Surat, Navsari, Valsad, Bharuch and Narmada | 23-Apr-02 | 5-Jun-02 | 30-May-02 | 1.65 | 45.6 |

Table A1 (cont)

| S. No | Product | State | District/Area | Date of Approval | Date of Notification | Date of Signing of MOU | Exports (Rs. Cr.) | Planned Percentage of Expenditures by Government |
|---|---|---|---|---|---|---|---|---|
| 22 | Flowers | Maharashtra | Pune, Nasik, Kolhapur and Sangli | 5-Mar-02 | 31-Mar-02 | 10-Jun-02 | 35.5 | 54.2 |
| 23 | Potatoes | West Bengal | Districts of Hoogly, Burdwan, Midnapore (W), Uday Narayanpur and Howrah | 23-Apr-02 | 5-Jun-02 | 18-Jun-02 | 3.72 | 22.0 |
| 24 | Rose Onion | Karnataka | Bangalore (Urban), Bangalore (Rural), Kolar | 13-Jun-02 | 1-Jul-02 | 1-Jul-02 | 276 | 40.7 |
| 25 | Flowers | Karnataka | Bangalore (Urban), Bangalore (Rural), Kolar, Tumkur, Kodagu and Belgaum | 13-Jun-02 | 1-Jul-02 | 1-Jul-02 | 31.74 | 65.2 |
| 26 | Mango & Grapes | Andhra Pradesh | Districts of Ranga Reddy, Medak & Parts of Mahaboobnagar Districts | 23-Apr-02 | 5-Jun-02 | 29-Jul-02 | 18.29 | 27.0 |
| 27 | Flowers (Orchids) & Cherry Pepper | Sikkim | East Sikkim | 13-Jun-02 | 1-Jul-02 | 26-Aug-02 | 0 | 32.5 |
| 28 | Ginger | Sikkim | North, East, South & West | 13-Jun-02 | 1-Jul-02 | 26-Aug-02 | 0 | 68.0 |
| 29 | Apples | Himachal Pradesh | Shimla, Sirmour, Kullu, Mandi, Chamba and Kinnaur | 28-Aug-02 | 13-Sep-02 | 17-Sep-02 | 0 | 48.3 |

Table A1 (cont)

| S. No | Product | State | District/Area | Date of Approval | Date of Notification | Date of Signing of MOU | Exports (Rs. Cr.) | Planned Percentage of Expenditures by Government |
|---|---|---|---|---|---|---|---|---|
| 30 | Basmati Rice | Punjab | Districts of Gurdaspur, Amritsar, Kapurthala, Jalandhar, Hoshiarpur and Nawanshahar | 28-Aug-02 | 13-Sep-02 | 17-Sep-02 | 1521 | 58.8 |
| 31 | Mangoes | Andhra Pradesh | Krishna District | 28-Aug-02 | 13-Sep-02 | 27-Sep-02 | 2.75 | 44.7 |
| 32 | Flowers | Tamilnadu | Nilgiri District | 28-Aug-02 | 13-Sep-02 | 6-Feb-03 | 44.56 | 45.5 |
| 33 | Onion | Maharashtra | Districts of Nasik, Ahmednagar, Pune, Satara and Solapur | 18-Nov-02 | 15-Jan-03 | 16-Jan-03 | 588 | 59.3 |
| 34 | Ginger and Turmeric | Orissa | Kandhamal District | 18-Nov-02 | 15-Jan-03 | 10-Jan-03 | 1.76 | 49.8 |
| 35 | Vegetables | Jharkhand | Ranchi, Hazaribagh and Lohardaga | 18-Nov-02 | 15-Jan-03 | 15-Feb-03 | 0 | 54.4 |
| 36 | Seed Spices | Madhya Pradesh | Guna, Mandsaur, Ujjain, Rajgarh, Ratlam, Shajapur and Neemuch | 18-Nov-02 | 15-Jan-03 | 28-Nov-02 | 38.43 | 51.6 |
| 37 | Basmati Rice | Uttaranchal | Udham Singh Nagar, Nainital, Dehradun and Haridwar | 18-Nov-02 | 15-Jan-03 | 24-Jan-03 | 0 | 48.5 |
| 38 | Mangoes | West Bengal | Malda and Murshidabad | 18-Nov-02 | 15-Jan-03 | 16-Dec-02 | 74 | 41.5 |
| 39 | Vegetables | West Bengal | Nadia, Murshidabad and North 24 Parganas | 18-Nov-02 | 15-Jan-03 | 16-Dec-02 | 4.43 | 25.2 |

Table A1 (cont)

| S. No | Product | State | District/Area | Date of Approval | Date of Notification | Date of Signing of MOU | Exports (Rs. Cr.) | Planned Percentage of Expenditures by Government |
|---|---|---|---|---|---|---|---|---|
| 40 | Mangoes | Tamil Nadu | Districts of Madurai, Theni, Dindigul, Virudhunagar and Tirunelveli | 18-Nov-02 | 15-Jan-03 | 6-Feb-03 | 0 | 43.4 |
| 41 | Wheat | Madhya Pradesh | Three distinct and contiguous zones:- Ujjain Zone comprising of Neemach, Ratlam, Mandsaur and Ujjain / Indore Zone comprising of Indore, Dhar, Shajapur and Dewas / Bhopal Division, comprising of Sehore, Vidisha, Raisen, Hoshangabad, Harda, Narsinghpur and Bhopal | 28-Aug-02 | 15-Jan-03 | 16-Jan-03 | 21 | 42.3 |
| 42 | Horticulture Products | Kerala | Districts of Thrissur, Ernakulam, Kottayaam, Alappuzha, Pathanumthitta, Kollam, Thiruvanthapuram, Idukki and Palakkod | 3-Feb-03 | 28-Feb-03 | 5-Mar-03 | 2277.79 | 60.3 |

Table A1 (cont)

| S. No | Product | State | District/Area | Date of Approval | Date of Notification | Date of Signing of MOU | Exports (Rs. Cr.) | Planned Percentage of Expenditures by Government |
|---|---|---|---|---|---|---|---|---|
| 43 | Fresh & Processed Ginger | Assam | Kamrup, Nalbari, Barpeta, Darrang, Nagaon, Morigaon, Karbi Anglong and North Cachar districts | 3-Feb-03 | 28-Feb-03 | 4-Apr-03 | 2.17 | 41.1 |
| 44 | Basmati Rice | Uttar Pradesh | Districts of Bareilly, Shahajahanpur, Pilibhit, Rampur, Badaun, Bijnor, Moradabad, J B Phulenagar, Saharanpur, Mujjafarnagar, Meerut, Bulandshahar, Ghaziabad | 3-Feb-03 | 28-Feb-03 | 11-Mar-03 | 0 | 50.9 |
| 45 | Medicinal & Aromatic Plants | Uttranchal | Districts of Uttarkashi, Chamoli, Pithoragarh, Dehradun and Nainital | 3-Feb-03 | 28-Feb-03 | 26-Mar-03 | 1 | 51.9 |
| 46 | Dehydrated Onion | Gujarat | Districts of Bhavnagar, Surendranagar, Amreli, Rajkot, Junagadh and Jamnagar. | 5-May-03 | 14-May-03 | 10-Jun-03 | 300.49 | 47.7 |
| 47 | Gherkins | Andhra Pradesh | Districts of Mahboobnagar, Rangareddy, Medak, Karinagar, Warangal, Ananthpur and Nalgonda | 5-May-03 | 14 May, 200 | 12 May, 2003 | 44.52 | 18.6 |

Table A1 (cont)

| S. No | Product | State | District/Area | Date of Approval | Date of Notification | Date of Signing of MOU | Exports (Rs. Cr.) | Planned Percentage of Expenditures by Government |
|---|---|---|---|---|---|---|---|---|
| 49 | Banana | Maharashtra | Jalgaon, Dhule, Nandurbar, Buldhana, Parbhani, Hindoli, Nanded and Wardha | 24-Sep-04 | 8-Nov-04 | - | 0.04 | 43.0 |
| 50 | Oranges | Maharashtra | Nagpur and Amraoti | 24-Sep-04 | 8-Nov-04 | - | 2.72 | 47.2 |
| 51 | Lentil and Grams | Madhya Pradesh | Shivpuri, Guna, Vidisha, Raisen, Narsinghpura, Chhindwara | 24-Sep-04 | 8-Nov-04 | - | 0 | 39.6 |
| 52 | Oranges | Madhya Pradesh | Chhindwara, Hoshangabad, Betul | 24-Sep-04 | 8-Nov-04 | - | 0 | 43.9 |
| 53 | Cashewnut | Tamil Nadu | Cuddalore, Thanjavur, Pudukottai and Sivaganga | 24-Sep-04 | 8-Nov-04 | - | 18.33 | 40.6 |
| 54 | Sesame Seeds | Gujarat | Amerali, Bhavnagar, Surendranagar, Rajkot, Jamnagar | 24-Sep-04 | 8-Nov-04 | 13-Jan-05 | 0 | 108.5 |
| 55 | Vanilla | Karnataka | Districts of Dakshin Kannada, Uttara Kannada, Udupi, Shimoga, Kodagu, Chickamagalur | 24-Sep-04 | 14-Jan-05 | - | 0 | 47.8 |
| 56 | Darjeeling Tea | West Bengal | Darjeeling | 24-Sep-04 | - | - | 0 | 26.4 |
| 57 | Coriander | Rajasthan | Kota, Bundi, Baran, Jhalawar & Chittoor | 24-Sep-04 | - | - | 23.4 | 47.5 |

Table A1 (cont)

| S. No | Product | State | District/Area | Date of Approval | Date of Notification | Date of Signing of MOU | Exports (Rs. Cr.) | Planned Percentage of Expenditures by Government |
|---|---|---|---|---|---|---|---|---|
| 58 | Cumin | Rajasthan | Nagaur, Barmer, Jalore, Pali and Jodhpur | 24-Sep-04 | - | - | 26.54 | 37.7 |
| 59 | Medicinal Plant | Kerala | Wayanad, Mallapuram, Palakkad, Thrissur, Ernakulam, Idukki, Kollam, Pathanamittha, Thiruvananthapuram | 24-Sep-04 | 14-Jan-05 | 1-Jan-05 | 0 | 67.6 |
| 60 | Chilli | Andhra Pradesh | Guntur | 24-Sep-04 | 14-Jan-05 | 29-Dec-05 | 51 | 37.8 |

Table A2: Agricultural Universities by Years of Establishment

| Name | District | State | Year of Establishment |
|---|---|---|---|
| Acharya NG Ranga Agricultural University | Hyderabad | Andra Pradesh | 1964 |
| Anand Agricultural University formerly Gujarat Agricultural University | Anand | Gujarat | 1972 |
| Assam Agricultural University | Jorhat | Assam | 1969 |
| Bidhan Chandra Krishi Viswavidyalaya | Nadia | West Bengal | 1974 |
| Bihar Agricultural University | Bhagalpur | Bihar | 2010 |
| Birsa Agricultural University | Ranchi | Jharkhand | 1981 |
| Central Agricultural University | Imphal | Manipur | 1992 |
| Chandra Shekar Azad University of Agriculture & Technology | Kanpur | Uttar Pradesh | 1975 |
| Chaudhary Charan Singh Haryana Agricultural University | Hisar | Haryana | 1970 |
| CSK Himachal Pradesh Krishi Vishvavidyalaya | Palampur | Himachal Pradesh | 1978 |
| Chhattisgarh Kamdhenu Vishwavidyalaya | Durg | Chattisgarh | 2012 |
| Dr Balasaheb Sawant Konkan Krishi Vidyapeeth | Ratnagiri | Maharashtra | 1972 |
| Dr Panjabrao Deshmukh Krishi Vidyapeeth | Akola | Maharashtra | 1969 |
| Dr Yashwant Singh Parmar Univ of Horticulture & Forestry | Solan | Himachal Pradesh | 1988 |
| Dr YSR Horticultural University | West Godavari | Andra Pradesh | 2007 |

| | | | |
|---|---|---|---|
| **Govind Ballabh Pant University of Agriculture & Technology** | Udham Singh Nagar | Uttranchal | 1960 |
| **Guru Angad Dev Veterinary and Animal Science University** | Ludhiana | Punjab | 2005 |
| **Indira Gandhi Krishi Vishwavidyalaya** | Rai Pur | Chattisgarh | 1987 |
| **Jawaharlal Nehru Krishi Viswavidyalaya** | Jabalpur | Madhya Pradesh | 1964 |
| **Junagadh Agricultural University** | Junagarh | Gujarat | 1972 |
| **Karnataka Veterinary, Animal and Fisheries Sciences University** | Bidar | Karnataka | 2005 |
| **Kerala Agricultural University** | Trichur | Kerala | 1971 |
| **Kerala University of Fisheries & Ocean Studies** | Kochi | Kerala | 1979 |
| **Kerala Veterinary and Animal Sciences University** | Thiruvananthapuram | Kerala | 2010 |
| **Lala Lajpat Rai University of Veterinary & Animal Sciences** | Hisar | Haryana | 2010 |
| **Nanaji Deshmukh Veterinary Science University** | Jabalpur | Madhya Pradesh | 2009 |
| **Maharana Pratap Univ. of Agriculture & Technology** | Udaipur | Rajasthan | 1999 |
| **Maharashtra Animal Science & Fishery University** | Nagpur | Maharashtra | 2000 |
| **Mahatma Phule Krishi Vidyapeeth** | Rahuri | Maharashtra | 1969 |
| **Manyavar Shri Kanshiram Ji University of Agriculture and Technology** | Banda | Uttar Pradesh | 2010 |
| **Marathwada Agricultural University** | Parbhani | Maharashtra | 1972 |
| **Narendra Deva University of Agriculture & Technology** | Faizabad | Uttar Pradesh | 1974 |

| | | | |
|---|---|---|---|
| **Navsari Agricultural University, formerly Gujarat Agriculture University** | Navsari | Gujarat | 1972 |
| **Orissa University of Agriculture & Technology** | Bhubaneshwar | Orrisa | 1962 |
| **Punjab Agricultural University** | Ludhiana | Punjab | 1962 |
| **Rajasthan University of Veterinary and Animal Sciences** | Bikaner | Rajasthan | 2010 |
| **Rajendra Agricultural University** | Samistipur | Bihar | 1970 |
| **Rajmata Vijayraje Sciendia Krishi Vishwa Vidyalaya** | Gwalior | Madhya Pradesh | 2008 |
| **Sardar Vallabhbhai Patel University of Agriculture and Technology** | Meerut | Uttar Pradesh | 2000 |
| **Sardarkrushinagar-Dantiwada Agricultural University** | Banaskantha | Gujarat | 1972 |
| **Sher-E-Kashmir Univ of Agricultural Sciences & Technology** | Jammu | Jammu and Kashmir | 1998 |
| **Sher-E-Kashmir Univ of Agricultural Sciences & Technology of Kashmir** | Srinagar | Jammu and Kashmir | 1992 |
| **Sri Venkateswara Veterinary University** | Tirupati | Andra Pradesh | 2005 |
| **Swami Keshwanand Rajasthan Agricultural University** | Bikaner | Rajasthan | 1987 |
| **Tamil Nadu Agricultural University** | Coimbatore | Tamil Nadu | 1971 |
| **Tamil Nadu Fisheries University** | Nagapattinam | Tamil Nadu | 2012 |
| **Tamil Nadu Veterinary & Animal Science University** | Chennai | Tamil Nadu | 1989 |
| **University of Agricultural Sciences, Bangalore** | Begaluru | Karnataka | 1963 |
| **University of Agricultural Sciences, Dharwad** | Dharwand | Karnataka | 1986 |

| | | | |
|---|---|---|---|
| University of Agricultural Sciences, Shimoga | Shimoga | Karnataka | 1963 |
| University of Horticultural Sciences | Bagalkot | Karnataka | 2008 |
| University of Agricultural Sciences | Raichur | Karnataka | 2009 |
| UP Pandit Deen Dayal Upadhaya Pashu Chikitsa Vigyan Vishwa Vidhyalaya evam Go Anusandhan Sansthan | Mathura | Uttar Pradesh | 2001 |
| Uttarakhand University of Horticulture and Forestry | Pauri Garhwal | Uttrakhand | 2011 |
| Uttar Banga Krishi Viswavidyalaya | Cooch Bihar | West Bengal | 2001 |
| West Bengal University of Animal & Fishery Sciences | Calcutta | West Bengal | 1995 |

**Table A3 : Impact of Agricultural Trade Promotion on Groundwater Allowing for Spatial Correlation**

| | Dependent Variable: Groundwater Level (m.b.g.l) | | | |
|---|---|---|---|---|
| | (1) | (2) | (3) | (4) |
| Cutoff | 0.25 degree | 0.5 degree | 1 degree | 1.5 degree |
| Post*AEZ Approval | **0.4496**** | **0.4496**** | **0.4496*** | **0.4496*** |
| | [0.2214] | [0.2225] | [0.2309] | [0.2501] |
| Observations | 13,084 | 13,084 | 13,084 | 13,084 |

Notes: The control group consists of districts bordering a district receiving an AEZ who never receive an AEZ themselves. The treatment group excludes AEZs for which there was never any exports or AEZs not fully implemented. All regressions include district fixed effects, demographic and economic controls , average annual district rainfall and temperature, linear trend, and AEZ case specific pre- and post trend. Post*Approval is a policy dummy equal to one for a district after the approval of an AEZ. Standard errors corrected for spatial dependence are in parentheses. *** indicates significance at 1 percent , ** at 5 percent, and * at 10 percent level.

**Table A4 : Impact of Agricultural Trade Promotion on Groundwater by Groundwater Overuse Status in Water Intensive Industries Hubs**

| | Dependent Variable: Groundwater Level (m.b.g.l) | | | |
|---|---|---|---|---|
| | (1) | (2) | (3) | (4) |
| | **Excluding Water Intensive Industries Hubs** | | **Restricting to Water Intensive Industries Hubs** | |
| Post*AEZ Approval | 1.111* | 1.116* | 0.189 | 0.227 |
| * Ground water critical | [0.575] | [0.575] | [0.512] | [0.511] |
| Post*AEZ Approval | 2.432*** | 2.442*** | 2.795*** | 2.843*** |
| * Ground water over-exploited | [0.403] | [0.391] | [0.683] | [0.696] |
| AEZ*Post-trend | No | Yes | No | Yes |
| Observations | 9068 | 9068 | 3,940 | 3,940 |

Notes: The control group consists of districts bordering a district receiving an AEZ who never receive an AEZ themselves. The treatment group excludes AEZs for which there was never any exports or AEZs that were not fully implemented. All regressions include district fixed effects, demographic and economic controls , average annual district rainfall and temperature, linear trend and AEZ case specific pre-trend. Post*Approval for a district is a policy dummy equal to one after the approval of an AEZ. Standard errors clustered at district level are in parentheses. All regressions control for groundwater classification X treatment specific pretrends in groundwater depth. *** indicates significance at 1 percent , ** at 5 percent, and * at 10 percent level.
As per GEC-97, Central groundwater board defines critical state as groundwater draft between 85-99 percent of recharge and overexploited as draft greater than 100 percent of recharge.

**Table A5: Characteristics for AEZ's with Positive and Zero Exports**

| | Non-zero Exports | Zero Exports | Difference |
|---|---|---|---|
| **Demographics, Levels 1991** | | | |
| **Population** | 2579.46 | 2065.97 | **513.49*** |
| **Percent SC** | 0.16 | 0.15 | 0.02 |
| **Percent Literate** | 0.45 | 0.49 | -0.03 |
| **Percent Working** | 0.38 | 0.36 | 0.02 |
| **Percent Female** | 0.48 | 0.48 | 0.00 |
| **Change in Demographics, 1991-2001** | | | |
| **Population** | 435.64 | 245.20 | **190.44*** |
| **Percent SC** | 0.00 | 0.00 | 0.00 |
| **Percent Literate** | 0.12 | 0.10 | **0.027*** |
| **Percent Working** | 0.02 | 0.01 | 0.01 |
| **Percent Female** | 0.00 | 0.00 | 0.00 |
| **Distance from Agricultural Universities** | 0.59 | 0.45 | 0.14 |
| **Distance from Pre-existing Agricultural Universities** | 0.62 | 0.50 | 0.13 |
| **Elevation** | 299.23 | 357.18 | -57.94 |
| **Rainfall** | 37.85 | 37.96 | -0.10 |
| **Temperature** | 25.02 | 24.35 | 0.67 |
| **Average Suitability for Certain Crops** | 5.71 | 5.86 | -0.15 |
| **Change in Groundwater Depth, '99-00** | 0.32 | 0.10 | 0.22 |
| **Average Groundwater Level** | 6.61 | 6.75 | -0.14 |
| **Number of Districts** | 136 | 36 | **--** |

Notes: Average Crop suitability based on suitability measures for onion, rice, potato, banana, citrus, flower, vegetable, fruit and wheat. * indicates p<.05