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DG-0014-11

White Paper 2
October, 2013

The Shadow Value of Groundwater in Punjab, India:
An analysis in an Economy-Wide Context

University of Minnesota
Institute on the Environment
National Center for Earth-surface Dynamics
Center for International Food and Agricultural Policy

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Harumi Nelson
Terry Roe
Rodney Smith
Diego Ponce de León Baridó
Efi Foufoula-Georgiou

Through the University of Minnesota, Institute on the Environment Discovery Grants, researchers from the National Center for Earth-surface Dynamics, Center for International Food and Agricultural Policy, University of Minnesota the Indian Institute of Technology, Hyderabad, and the International Water Management Institute, Delhi are able to work in the development of academic and institutional partnerships to answer some of the most pressing questions related to the sustainability of our planet.

We would like to thank Institute on the Environment, University of Minnesota for the funding and the unique research opportunity.

(Cover page) Punjab photo credit. Diego Ponce de León Baridó

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Executive Summary

The deep alluvial aquifer of the Punjab region of India has made the region one of the most agriculturally productive regions in the world and a leading supplier of food grains (rice and wheat) to the country. The provision of essentially free electricity made groundwater extraction for agriculture relatively inexpensive, and facilitated Punjab's rise to productive prominence. This prominence, however, is now threatened, because groundwater tables have dropped to the point where concerns with water salinity are being raised, and because political pressures are mounting for the government to eliminate, or at least lower the subsidy rates. The energy subsidies are particularly deleterious for two major reasons. First, they have encouraged farmers to withdraw groundwater at – what most would consider – unsustainable rates. The rapid rates of groundwater extraction lowers groundwater tables, which in turn requires more energy to pump water to the surface: this process creates a trap in which eliminating or lowering the subsidy leads to groundwater extraction costs that would make agricultural production unprofitable for many farmers. Second, the excessive use of electricity in water extraction makes electricity more expensive for the non-farm economy, inhibiting thus the non-farm economy's ability to absorb labor from the farm economy, and hence, serves as a drag on the county's economic growth potential.

We examine the economics of electricity subsidies by introducing groundwater dynamics into a dynamic macroeconomic framework and evaluate the economic impact of groundwater depletion on the agricultural and non-agricultural sectors of Punjab and the rest of India. Our findings suggest that eliminating electricity subsidies for irrigation could lead to less groundwater consumption and lower agricultural production levels and agricultural income, while increasing the productivity and income of the non-farm sectors (via decreased energy prices). When cutting the electricity subsidy, our results suggest that farmers could decrease water use by 30 percent, while minimally hurting the Punjabi agricultural value-added economy (a decrease of approximately 5 percent of income in 2007 dollars) and, while surprisingly, increasing the gross state domestic product for Punjab manufacturing by approximately 70%. Although these figures have considerable uncertainty, they demonstrate that serious consideration must be given to trade-offs between rapid economic growth in one sector and long-term sustainability of water resources and overall economic growth.

We also examine the likely effects of increased precipitation variability on Punjabi agricultural production, exemplified by an increased intensity and frequency of wet extreme events, and more prolonged dry periods. Here, we investigate the economic impacts of an extended drought on the Punjab and the rest of the economy. Assuming electricity is fully subsidized, the results suggest an extended drought could speed up the rate of aquifer depletion, with the subsidy shielding farmers from the impact of increased water extraction energy costs. The rest of the economy, however, is likely to bear the burden of this protection by paying higher electricity costs and experiencing lower productivity (compared to a world without electricity subsidies) and slightly slower economic growth.

1. Introduction

Freshwater availability is closely linked to the fundamental well being of people and the socio-economic environment. This link is particularly important for countries like India where agriculture consumes over 70 % of total disposable water supplies and a sizable proportion of the population depends on agriculture as their main source of sustenance. Integrating groundwater into the process of economic and policy decision-making is now becoming a necessity and a vehicle by which countries can be encouraged to incorporate sustainability issues into their development planning, helping thus preserve natural resources for future generations.

Punjab, located on the Indo-Gangetic planes, has been a leading producer of rice and wheat since the Green Revolution in the 1960s. Gifted by water-rich alluvial aquifers, Punjabi farmers grow the water intensive rice and wheat – crops that would not have been their first choice had they remained rain dependent farmers. In recent decades, however, Punjab’s water table has been dropping at an alarming rate, with irrigated groundwater exploitation being the major cause. The current status of groundwater development in Punjab is the most critical in the nation, as 80% of monitored wells are considered overexploited (CGWB, 2012).

Introducing groundwater dynamics into a dynamic macroeconomic framework, the present study evaluates the economic impact of groundwater depletion on the agricultural and non-agricultural sectors of the Punjab and the rest of India. Despite the importance of the subject, relatively few studies have focused on water as an economy-wide resource in the context of economic growth and the transition of an economy over time. Moreover, no economy-wide studies to the best of our knowledge have incorporated groundwater dynamics, and linked those dynamics with government policy and climate variability. In the Punjab, food grain producers benefit from a number of policy instruments that are aggressively implemented by both national and state governments. Particularly important is the provision of free electricity to pump groundwater for irrigation. The administrative priority of subsidizing electricity for irrigation imposes economic burdens on the non-agricultural sectors of the economy: as the subsidy costs must be financed by tax revenues from either households or non-agricultural firms. This project evaluates the economic consequences of Punjabi electricity policy on groundwater dynamics, resource allocation, and economic growth.

The results from our model suggest that eliminating the ‘electricity for irrigation’ subsidy potentially leads to double gains: a gain from water conservation and a gain from other resource reallocation. Removal of the subsidy tends to discourage farmers from producing crops of high water intensity, thus slowing overexploitation of groundwater. Removing the subsidy could also make electricity less expensive for competing sectors, which in turn increase electricity demand, as well as increase the demand for labor and capital. This reallocation of resources to a broader spectrum of sectors in the economy can lead to an increase in Punjabi gross state domestic product (GSDP), as compared to the case where electricity is subsidized.

We also investigate the likely effects of a negative weather related shock – here, a prolonged dry periodicity (an extended drought). The results of our model suggest that under free electricity for pumping regime, a drought speeds up the depletion of aquifers while protecting farmers from what would otherwise be, soaring energy costs. Future dry periodicities could continue raising the cost of energy subsidies imposing additional long-term stress on other sectors of the economy. Predicted GSDP in this case is likely to fall leaving resources in the hand of less productive agricultural sectors. Along with the majority of states in India, the Punjab experiences a large degree of inter- and intra-seasonal rainfall differences. Thus, Punjabi reliance on groundwater as buffer storage – especially during the periods of drought – is much anticipated. In addition, as found in the progress report (Ponce de León *et al.*, 2012), the increasing variability of monsoonal rain and extreme climate events in the recent decades imposes uncertainty on water availability and makes groundwater an even more reliable source of water supply. Thus, farmers' over-dependence initiated by policy arrangements accompanied by increased hydrological variability extends its adverse effects to the fundamental economic activities of the region and country leaving an unsustainable rate of depletion of ground water supplies. Recognizing these concerns for present and future generations, the current study provides an attempt for answering some of the questions raised for water management options that are currently imposed.

The report proceeds as follows. The next section highlights key aspects of the economy pertinent to groundwater management, and the current economic and policy environment that Punjabi farmers face. The conceptual structure of the dynamic general equilibrium model is presented next with emphasis placed on its implications for studying the sustainability of aquifers within the context of the Punjabi economy. We then present our methodology and data, with its benefits and limitations, and our procedures for estimating the model's parameters. The result of this process is a "baseline" model. The model is solved numerically to provide time-dependent forecasts of the Punjab economy and the broader Indian economy. The results from the base model are then compared to those from two modeled scenarios: (i) removing the energy subsidy for irrigation, and (ii) an extended drought. We conclude by summarizing the economics of groundwater exploitation and resource allocation – with and without the electricity subsidy, and then, in the presence of a long term drought (with an electricity subsidy). Directions for future research are also discussed.

2. Background

Punjab, a northwest state of India (Figure 1), is an agriculturally intensive region that relies heavily on groundwater, the extraction of which is causing a steady decline in the region's water table. According to Critical Economic Indicator in Punjab (CEIP) (2011), the share of agriculture and allied sectors in the total gross state domestic product in 2007-2008 was 30% for the Punjab, and 16% for all of India. In particular, the production of food grains in Punjab expanded rapidly in past decades and quadrupled the level relative to the late 1960s. In Punjab, the vast majority of crop farmers grow rice in the summer monsoon season and wheat in the winter season. About 77% of total cropped area was devoted to growing rice and wheat. Between 1970 and 2002, rice area almost increased by a factor of 6.4 to 2.48 million *ha* while wheat area increased by a factor of 1.5 to 3.42 million *ha* (Humphreys *et al.*, 2010). As a grain surplus

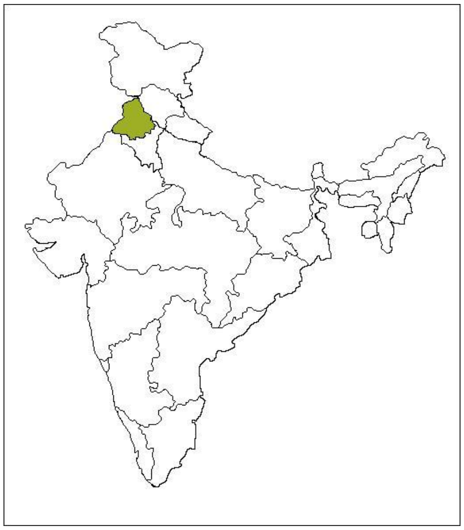

Figure 1: Punjab in northwest India, a major contributing state for the nation's food security. Punjab's area (50,326 km^2) is 2% of India and 2% of the total population lives in the state. Source: Critical Economic Indicators-Punjab (2011), Ponce de León *et al*. (2012), Bing (map).

state, Punjab contributed to 61% of wheat and 28% of rice of the central pool of food grains in 2007-2008 (CEIP, 2011). However, the region's success as a leading producer of rice and wheat is dependent upon its water rich alluvial deep aquifers as an irrigation source. In fact, Punjab's normal precipitation is inadequate for its rice-wheat growing cycle (Perveen, 2011). Currently, almost all cropped area in Punjab is irrigated. The gross irrigated area was 98 percent of gross cropped area for Punjab while 45% for all India in 2007-2008 (CEIP, 2011). Groundwater as a source of irrigation accounted for 72% of total area irrigation in Punjab for the same period. Supporting this impressive expansion of irrigation from groundwater, are various types of economic incentives set up by the government to promote the rice-wheat growing cycle. One of the policy instruments that we focus is an energy subsidy for farmers. Since 1997, free electricity is provided for famers to pump groundwater for irrigation.[1] The share of consumption of electric power for agriculture use is 32 percent for Punjab for the period 2007-2008 (CEIP, 2011). Between 1990 and 2008, the number of tube-wells operated by electric pumps almost doubled to slightly over 1 million (Economic Adviser to Government of Punjab, 2009). In fact, since 1960, the number of tube wells grew by a factor of 12 (Humphreys *et al*., 2010) and continue to increase.

The expansion of food grain production, assisted by the government's agricultural policies, contributes greatly to aquifer water depletion in Punjab. According to a state-wise analysis of the depth to groundwater level, the depletion of groundwater resources in the northwest region including Punjab is alarming (Figure 2). The depth to water table ranged widely from the minimum depth, 0.67 meters below ground (*mbg*) to the maximum depth, 33 *mbg* among 193 wells analyzed. Among these wells monitored, 36.27% were in the depth range of 10 *m* to 20 *m*, and 15.54% were in the depth range between 20 *m* and 40 *m* (CGWB, 2012). The remaining approximately 50% of wells were at shallow depths (27.46% were in the depth range of 5 *m* to 10 *m* while 16.58% were in depth range of 2 *m* and 5 *m*). Figure 3 shows that even during the monsoon season which typically dumps the majority of rainfall in July and August, parts of Punjab experience a decline in the water table while most parts of India show rising water tables. This decline suggests the pressure on this resource relative to the rest of India, and possible overexploitation of aquifers in the Punjab region. Comparing the depth to water table in Punjab during pre-monsoon 2010

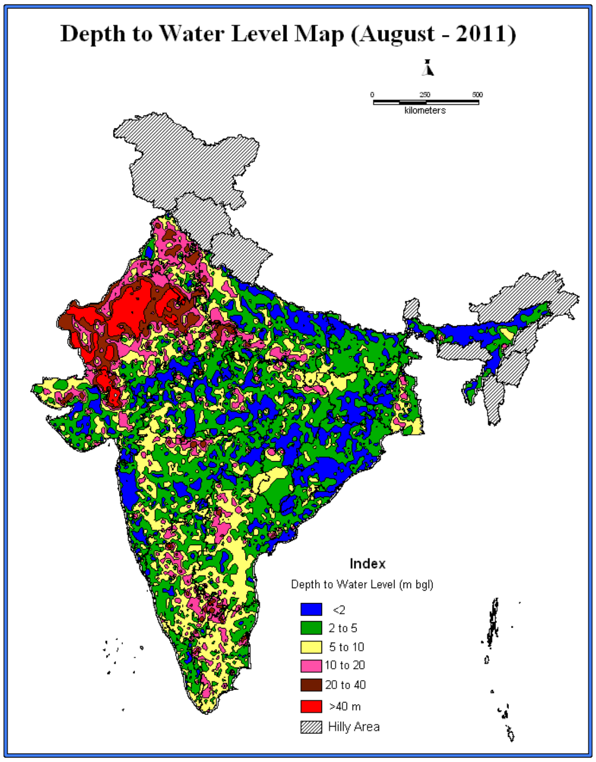

Figure 2: Depth to water level map (August, 2011). The northwest region including Punjab is the most critical area in the nation. The depleted aquifers in the region are shown by pink, brown and red. Source: Central Groundwater Board (CGWB, 2012).

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[1] In Punjab, electricity for pumping was free from 1997 to 2002 and after 2005 (Perveen *et al*., 2011).

with pre-monsoon 2011, Groundwater Year Book (2012) shows an overall decline in the water level. 39.86% of wells experienced a decline in the water level in the range between 0 *m* and 2 *m*.[2] In particular, over the last 20 years, the water table has declined between 5 *m* and 15 *m* in 11 districts across Punjab and Haryana. The average depth to the water table in districts of central Punjab was between 15 *m* and 28 *m* in 2006 (Humphreys *et al*., 2010). The study predicted that 75% of Punjab wells will experience a decline in water table by an additional 10 *m* by 2020, and that 30% of wells are likely to experience water tables deeper than 30 *m* by 2025. These depths make impossible the use of hand pumps or an array of small submersible pumps (Humphreys *et al*., 2010).

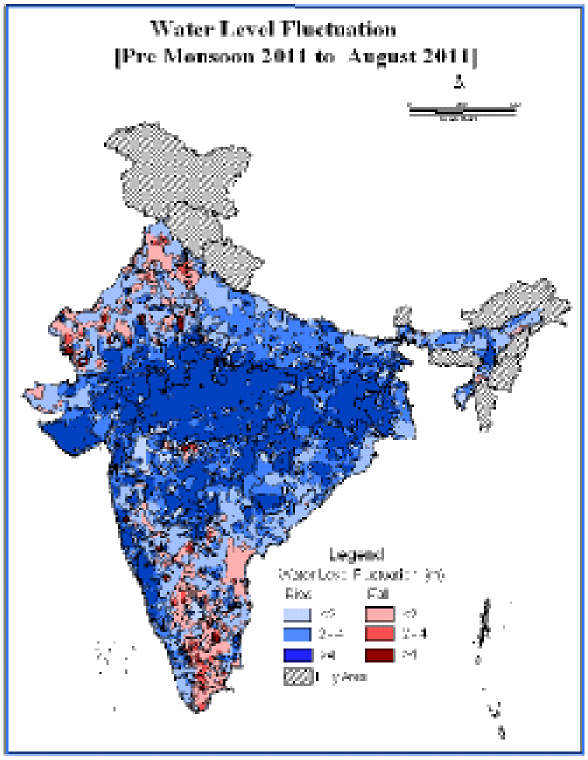

Figure 3: Seasonal water level fluctuation (Pre-Monsoon 2010 to August 2011). The monsoonal rainfall moistened most parts of the nation, indicated by rising water tables (blue). However, the Punjab's water tables declined (pink). Source: CGWB (2012).

As the depth to water table continues to increase, farmers face rising pumping costs due to expenditure on larger pumps, and the need to deepen their wells while the rest of society faces higher costs for electricity subsidies. According to a survey conducted by Columbia Water Center, Punjab farmers are extremely dissatisfied with unreliable electricity supply, the voltage of which fluctuates with potential damage pumps (Perveen *et al*., 2011). In addition, farmers are allowed to access only limited hours of electricity per day, about 6 to 7 hours (Fishman, 2011). Furthermore, financing the increasing costs of electricity for irrigation pumping puts pressure on the electrical grid and leads to the unstable supply of power for other sectors in the economy. From the 1990s to 2002, the electricity subsidy to agriculture increased by a factor of 3.4. Consequently, over 40% of the state's budget deficit is accounted for subsiding electricity (Singh *et al*., 2004). Thus, the administrative priority of water allocation to the farmers imposes an extensive economic stress on other parts of the economy and consequently, the process of the industrial growth and economic development is adversely affected.

The summer monsoon comprises over 80% of the total annual rainfall in the Punjab region. The presence of water-rich aquifers has helped Punjab farmers grow water intensive crops that would not be their first choice if they were to only rely on rain-fed water supplies. Thus, Punjab may not appear as vulnerable as some other states such as Andhra Pradesh against hydrological variability and anthropogenic induced change. However, if there is a steady pattern of increased hydrological variability and continued groundwater exploitation, the region could severely threaten groundwater potential and food security. According to Ponce de León *et al*., (2012), intensified and more frequent extreme precipitation events and prolonged dry periodicities have been detected in the predominant areas in Punjab in recent decades.

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[2] During the same period, the data indicate that 46.15% of wells showed rising water level in the range between 0 *m* and 2 *m* (CGWB, 2012).

Many parts of the region have also experienced more variable daily monsoonal precipitation. For our economic modeling, rainfall plays two key roles: A substitute for irrigated groundwater for producing crops, especially rice, and the most important recharging source for the aquifer system. A prolonged drought pattern leads to depleting aquifers through both the over-dependence on groundwater for irrigating crops and a lower recharge into the aquifer system. *The serious consequence of depleting groundwater, further exacerbated by electricity subsidies, is clearly an economy-wide concern. Withdrawing groundwater at rates that threaten to deplete aquifers in the Punjab region affects not just the livelihood of farmers and the regional economy but also the broader economy through the significant loss of food staples currently produced in the region. As the depth of the water table increases, future generations could face higher costs for water withdrawal which could force structural changes on the Punjab economy and lower the region's contribution to food security.*

Some studies have focused on water as an economy-wide resource and extend the resource management of water to a general equilibrium setup. Both Diao *et al*. (2008) and Hassan *et al*. (2008) analyze impacts of groundwater on the agricultural and non-agricultural sectors using a detailed general equilibrium, but static framework. They show that allowing markets to play a more significant role in the allocation of water to its most productive alternatives leads to an increase in gross domestic product of 3 to 4% in the case of Morocco and South Africa. This efficiency gain at the national level is large when irrigated agriculture only accounts for 5 to 10% of the economy. Although their quantitative simulations have an important implication of water regulation in the macroeconomic perspective, the analysis focuses on a static approach so that questions regarding the effects of economic growth and sustainability of water supplies are not addressed. No studies to our knowledge have focused on water as an economy-wide resource in the context of economic growth and the transition of an economy over time. Moreover, as we note below, no studies of an economy-wide nature have incorporated into the analysis the water cycle dynamics, linking the key features of hydrology to water extraction and hydrological variability.

As shown in Tsur *et al*. (2004), the economic literature on groundwater resource is predominantly a partial equilibrium type. For instance, while Balali *et al*. (2011) recognize the important relationship between the groundwater dynamics and the government subsidies, their analyses are limited to the agricultural sector. Consequently, the indirect economic interaction among sectors and the rest of the economy is overlooked. Knapp *et al*. (2003) evaluate the efficiency/inefficiency of different types of water resource management, recognizing an important effect of groundwater dynamics on the value of water. In their model structure, the demand for irrigated water is determined by the price of water resources whereas other elements including the prices of energy and factor prices of water production are exogenously given. Although their implication of efficiency gains from establishing water markets is a shared view with our approach as well as many others, their partial equilibrium analysis may lead to an incorrect conclusion when the total effects of groundwater-related policies are evaluated. With a similar approach, Krulce *et al*. (1997) model groundwater dynamics that link to the cost of desalination of water. Increased salinity of groundwater has become a serious issue in many parts of our study region and thus, the deterioration of groundwater quality should be addressed when the critical depth of water tables is considered.

There are also studies that focus on India's regional models in order to examine the specific issues in the context of local and microeconomic aspects such as Diwakara *et al*. (2007) and Reddy (2005). Both studies evaluate the costs of alternative recharge mechanisms such as watershed development programs and irrigation and percolation tanks in order to reduce the external environmental costs caused by the exploitation of groundwater. Overall, these studies provide important insights into the effects of water scarcity on individual farmers, the choice of crops and production techniques, but they provide no insight into the broader regional and economy wide effects mentioned above. Thus, they tend to grossly underestimate the consequences of policies to sustain/deplete ground water supplies. Moreover, the effects of water policy on the regional and national economy feedback to farmers in terms of changes in wage of labor, capital costs and food prices. These indirect effects can exceed the direct effects measured by partial equilibrium analysis examined in the studies mentioned above. The study by Bhatia *et al.* (2006) analyzes both direct and indirect effects of the policy changes on the state of Tamil Nadu economy. Using an optimization approach, they suggest if the state shifts from fixed sectoral allocation to a flexible water allocation system, then the change brings 15% less overall water used and 24% less water pumped from aquifers in 20 years. With exogenously projected output level, however, the role of input prices including the shadow prices of water in the resource allocations is not clearly analyzed in the study.

It is interesting to see the past literature about Punjab and learn how the general view of the economy has shifted from a successful agricultural state to one that faces challenges with an unsustainable economy over time. Comparing two input-output tables, one for 1969-1970 and the other for 1979-1980, Bhalla *et al*. (1990) find that the rapid growth and structural transformation of the Punjab economy during this time period has taken place primarily as a result of technological breakthroughs in agriculture. Industry was dominated by an agriculture based sector. Thus, the transition to a more diversified economy was rather slow. As an agricultural surplus state, Punjab enjoyed its comparative advantage specializing in producing food grains. Labor emigrated from the neighboring states to Punjab and capital was imported mostly for agricultural purposes. In the study of Bhalla *et al.* (1990), there was no concern about the sustainability of groundwater resource. The heavy subsidy on agricultural sectors was accounted as a necessary public spending and considered even as an engine to the economic growth. Unfortunately, water input was not included in this analysis due to the unavailability of data and lack of economic focus.

Observing the time series data between the 1960s and 1980, McGuirk *et al*. (1990) characterize the Punjab economy in a similar way as Bhalla *et al*. (1990). That is, the economic growth in Punjab during this period was generated by agriculture-based growth. Emphasizing modern higher yielding varieties for wheat and rice, they conclude that agriculture continues to prosper as long as irrigation technology and fertilizers expand and more productive agricultural techniques are adopted. It appears that the authors' concerns for the continuous economic growth are more toward the availability of new varieties of crops than the constraints of resources including groundwater. Several years later, Bhalla (1995) acknowledged that the expansion of irrigation from groundwater was the key to agricultural growth in the region. The study also makes a remark about the demand for power that exceeds the supply due to the power subsidy. However, according to his analysis, the increase in electricity demand was caused not just by pumping groundwater but also by electrification of the rural areas of Punjab. The threat of scarce water was not yet a serious concern to the Punjab economy at this point in time.

Comparing the past to the 1990's economic behavior, Gulati (2002, 2007) points out a sluggish agricultural growth in the 1990s and the resulting slow overall growth in the agriculture-dependent economy. According to his view, Punjab has enjoyed being a surplus state of rice and wheat which were absorbed by the deficit states of these food grains in the past. However, the grain deficit states have caught up Punjab's agricultural technology so the demand for Punjab grains declined in the recent decade. In addition, studies acknowledge that the increase in capital cost put pressure on the agricultural sector and subsidies for farmers crowd out other investment projects. Free electricity was blamed for excess mining of groundwater and the annual rate of declining water table was estimated 15 *cm* which was slower than the estimate of recent studies. It appears that the government finally shifted their focus to the over-subsidized agricultural sector and the adverse effects subsidies have on the economy. Shreedhar *et al*. (2012) blame policy makers for helping Punjab fall into this crisis of stagnant economic growth and unsustainable groundwater withdrawals. In terms of water governance, they suggest the revitalization of canal irrigation systems because the conjunctive use of canals and groundwater is more environmentally beneficial. Although it is difficult to remove the power subsidy completely and immediately, they suggest the subsidy to be gradually phased out and converted into investments in rural infrastructure and research. Furthermore, promoting community management of groundwater resource, water policy should help clear uncertainties over the establishment of water rights in the region.

3. Modeled Economy

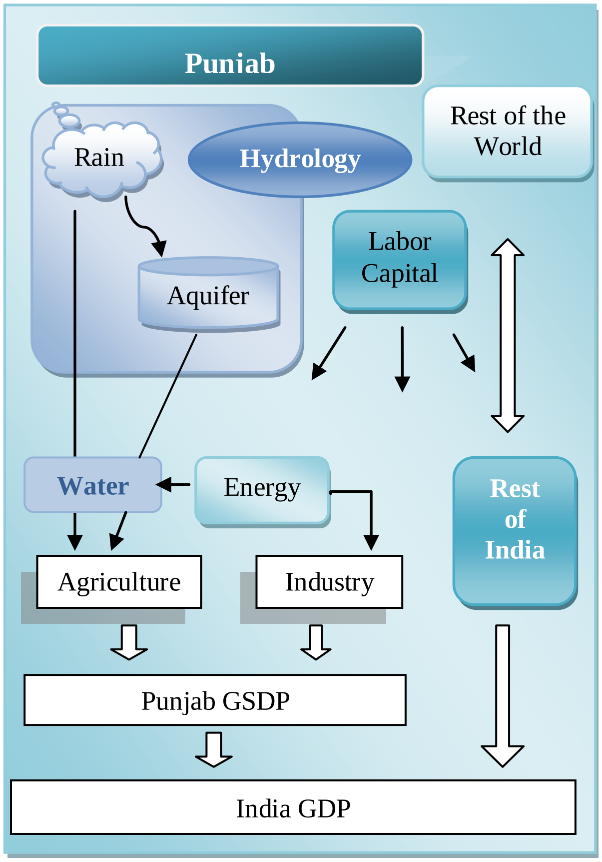

Figure 4: Modeling Punjab. Groundwater dynamics are incorporated into the general equilibrium economic model. Agricultural sectors compete for water. Agriculture competes energy with industry. Labor and capital are free to move between sectors and regions. Punjab and the rest of India contribute to the total output for India which trades with the rest of the world.

Our main conceptual contribution is to integrate the dynamic behavior of a renewable natural resource (groundwater in this case) with economic fundamentals of the dynamic general equilibrium framework. Thus, our modeling approach begins with the basic structure of the general economic environment and the primary ingredients that characterize the Punjab economy. Each piece of economic fundamentals is assembled together within a widely accepted growth economic theory that we propose to use, albeit some of its inherent limitations.[3] The model is extended to incorporate the dynamics of groundwater and examines the effects of water policy on both economic and water sustainability into the long run. Figure 4 shows a simple illustration of the basic model structure sketching out the key features of the regional economy and interrelation to the broader economy of India. The model represents a two-region economy: Punjab and the rest of India. India is an open economy which trades goods and services with the rest of the world. Punjab is linked to the rest of India largely through commonly used resources for production processes. The agricultural and industrial sectors are the major player of the commodity producing sectors in which labor force, the stock of capital (machinery) and land are the

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[3] See the dynamic multi-sector general equilibrium model in Roe *et al*. (2010) for more detail.

primary factors of production.[4] Labor and capital are allowed to move freely among sectors across regions in response to better economic opportunities while land is unmovable and specific to a particular sector such as hectares of cropped land for farming sectors. Households are the ultimate recipient of resource income; they earn wages from supplying their labor services to firms, as well as interest on capital assets and rents to fixed resources such as land. In turn, households' income is spent on products and services produced and sold in the region and the broader economy. The residual of income less spending is saved. Saving is allocated by financial markets which typically results in an increase in the country's stock of capital. All sectors in Punjab and the rest of India together contribute to the economy's aggregated output, measured by Punjab's gross state domestic product (GSDP).

3. 1 General Equilibrium Framework

A general economic framework is based on the generally accepted principles of economic equilibrium: Constrained optimization and market clearing (demand equals supply). Optimization indicates that agents make the best choice from their feasible set of possible choices while market clearing conditions imply that prices adjust so that demand equals supply for a particular commodity including resources for production activities. We use widely accepted mathematical methods of dynamic optimization for each agent of the economy.[5] Specifically, firms' goal is to maximize their profits for a given technology as well as given prices of output and input. Farmers behave likewise, subject to their technology for producing rice, wheat and other crops in both the Punjab region and in the rest of India. In Punjab only, we account for the withdrawal of groundwater and the depth which requires more energy resources when water withdrawal exceeds water recharge. At the same time, households optimize the discounted present value of their inter-temporal preferences given their flow budget constraint. The household and firm behavior culminates in demand and supply over time, of consumption and production goods, and investment. The agents' behavior causes markets to clear, given government subsidies to electricity in the Punjab region, determining wages, capital rental rates, prices of home goods (which we refer to as service goods) and investment. Our modeled economy is thus an abstraction of the true economy. Moreover, we disregard the population growth and growth in factor productivity, i.e., technological change, in the current study because our attempt is to begin with the analysis of the economic fundamentals without being encumbered by other exogenous forces of the economy. Therefore, model results must be interpreted with caution. That is, more confidence can be placed on the prediction of the direction of change (increase or decrease) and relative magnitude of changes in crop production and water supplies, for example, than on the numerical magnitude of those changes.

In the process of solving the model, there is a system of equations, some of which describe the behavior of the economy for a single year and others depict how the economy changes over time. Combining all relevant equations, the economy is typically summarized by a system of differential equations. *In the current study, there is a system of four differential equations: Economy-wide capital stock, the depth to water table, the price of service goods as home goods that are only traded within the economy, and the shadow value of water. We are interested in the transitional dynamics that show how an economy*

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[4] Although in the real world, a large number of varieties of output are produced from a number of different types of inputs, it is a common practice to summarize all of inputs into physical capital, labor, land and technology in order to produce a few types of aggregated output. Physical capital represents durable goods such tractors, machine, equipment and buildings.

[5] For an introductory discussion of our approach and terminology that is commonly used in the macroeconomics of economic growth, see Barro and Sala-i-Martin (2004).

converges toward a steady state or the long run equilibrium. Solving forward in time, we seek to explain the impact that both economic policy and hydrological shocks can have on water availability and aquifer sustainability through the channels of economic activities. See Chapter 9 in Roe *et al*. (2010) for solution methods in transition dynamics.

3. 2 Groundwater Dynamics

On the basis of primary economic forces in the general equilibrium environment, we introduce model specific elements of a renewable resource. This augmentation provides a unique opportunity to study sustainability issues of natural resources, in this case, groundwater. To prepare our analysis of direct and indirect effects of hydrological features to Punjab economy, the agriculture sector is disaggregated into paddy rice, as the most water consuming crop, and other resource-competing crop, wheat. All other agricultural related sectors are grouped as the rest of agricultural sector that is treated as an insignificant water user. Thus, we lay out the agricultural environment in which farmers are interlinked with groundwater and electricity as complementary input into pumping (or harvesting) the natural resource in addition to primary factors of production. For relatively fixed supply of electricity in the economy, increasing electricity for irrigation purpose directly impacts on other electricity users of the economy. Therefore, as a representative competitor of energy with irrigation farmers, the manufacturing/industrial sector is incorporated in the model. Finally, the energy subsidy for irrigation purpose is introduced in the model through the channel of pricing the value of groundwater extraction. Especially interesting is investigating the hypothesis that ponders whether removing the subsidy on agriculture has an impact on other sectors of the economy.

The hydrology component of the model captures the economic incentives that lead to the extraction of groundwater causing the depth of the water table to deepen in the Punjab region. As the water table deepens, all else constant, the cost of irrigated crop production rises as more electricity, and some labor and depreciation of pumping equipment rises. Farmers are thus, placed at an increasing disadvantage relative to the rest of the economy, and the availability of ground water for future generations becomes costlier. The economic effects become more complicated, of course because, over time, “all else” is not constant. In the current study, a simple aquifer model is adopted to illustrate inflow and outflow of groundwater in aquifers. The main source of recharge of aquifers is rainfall while the main source of outflow is agricultural irrigation as the data show. Rainfall is also a part of input for water consuming crops substituting for irrigated water from aquifers. For a given level of recharge by rainfall, more energy is required to extract the amount of groundwater as the depth to water table deepens. We adopt a basic equation for hydraulic power to capture the behavior of increasing electricity consumption for pumping per unit of irrigated water as the depth to water table increases. The natural resource environment is affected by economic behavior through groundwater extraction which in turn is determined by various variables such as values of energy and water as well as the condition of aquifers.

4. Methodology and Data

The conceptual model provides definitive guidelines to data requirements, and methods for estimating model parameters. Among the model’s general structure, water and energy are the key elements causing the framework developed here to depart from the explanation of economic activity given by the typical dynamic general equilibrium structure. We thus place relative emphasis on this aspect of the analysis. Since economic data for the water and many other model parameters are limited, parameter estimation based on relevant existing data deserves close attention. We introduce hydrology and hydraulics in order to link the behavior of the natural resources to economic fundamentals in theory and applications.

4. 1 Social Accounting Matrix (SAM)

The first step of application involves organizing the economic data on resource allocation to various crop production and non-farm production activities within the regional and national economy, as well as goods consumed, level of savings and other features of the economy. The data are cast into a social accounting matrix or SAM.[6] This is the typical method used by economists engaged in applied general equilibrium analyses. The SAM is a double-entry accounting system that shows the major economic transactions among agents of an economy over a given period of time, usually one year. It organizes the data based on economic identities such that flows of payments to remunerate resource balances with the value of the goods and services produced in an economy. Returns to resource are distributed to households, governments and foreigners in terms of international trade flows. The SAM thus produces a one-period snap shot of an economy. The economy is presumed to be in "transitional" equilibrium.

Issues related to the SAM

A principle purpose of a SAM is to provide a guide to the estimates of the parameters for production technologies and household preferences for the simulation analysis.[7] Optimization is then imposed on these economic functions which consist of options for agents to make a choice subject to the constraints that they face. However, it is not uncommon that reported data are insufficient to construct a SAM conditional to the theoretical setup. This applies to the current case of Punjab. In particular, there are two types of information that cannot be quoted directly when we estimate the parameters related to production behavior. The first one is the cost associated with water input in the production of agricultural products. Farmers are not charged (or required to remunerate some other firm) for groundwater extracted since there is no centrally managed market for water. Thus, the true cost of water for agriculture is not often reported in the official data.[8] However, extracting groundwater is clearly accompanied by the cost such as the use of pumps and electricity for farmers. It is logical to consider that the cost of water is embodied in farm profits after priced farm inputs are paid including costs for labor and capital which are typically reported in the data. Thus, we are required to figure out what proportion of remaining farmers' profits after subtracting all other inputs accounts for the cost related to the water resource.

The second input data that deserve close reassessment is the cost associated with energy use for the purpose of agricultural irrigation. As mentioned in the previous sections, Punjab farmers are currently

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[6] See Chapter 8 in Roe *et al.* (2010), for examples and a step-by-step instruction for how to interpret a SAM.

[7] Often used in economic studies is Cobb-Douglass functions which relate the parameters to the shares of total cost. A typical functional form is given by $y=L^a K^b T^c$, where y is output, L, K, and T are input, a, b and c are parameters that are attached to each input. For example, parameter, a is estimated by the cost share of input L. Similarly, b and c are estimated by the cost share of input K and T. This is very convenient because a constant proportion of input cost is result and makes models simple and tractable.

There are model parameters that are not directly related with a SAM and are needed for simulation. We follow the parameter values that are used in Roe *et al.* (2010).

[8] The original data include the cost of water in the agricultural sector. However, the values are significantly small and could be the charge for some municipal water use.

subsidized by the government for their electricity use for pumping groundwater. Consequently, the reported data for energy cost for each agricultural sector does not reflect the true economic cost that farmers should be charged as a tariff if they pay the full amount of energy use. This implies that the energy subsidy is likely to have shifted up their profits by the amount of the tariff that they should pay (tariff-equivalent subsidy). Therefore, we need to find the portion of tariff-equivalent subsidy that is very probable to be included in the current value of profits. In other words, our strategy is to construct a SAM that is absent of distortions in water and energy and then to impose a policy instrument, free electricity in the current case attempting to reproduce the current Punjab economy. In order to accomplish "materializing" the costs hidden in farms' profits, we decompose farm profits into two steps: First, divide profits into the value of groundwater that is used for growing crops and the remaining profits that are essentially attached to rental value of land; Second, take the value of water obtained from the first step, and then disaggregate it into tariff-equivalent subsidy as energy cost and other relevant costs such as the cost of pumps. We implement this practice for each applicable sector which uses the resources of water and energy in its production process.

To Build a SAM that Tailors to the Modeling

Keeping the primary strategy above for constructing the SAM in mind, we start with a sub-categorized original input-output data (Saluja, 2012) and aggregate the value of each primary input over relevant sectors according to our modeling structure.[9] For instance, rice and wheat are two major sectors that are kept from the original data as an independent sector while the other agriculture sector (rest of agriculture) is the result of summing all other agricultural and allied sectors. The sum includes subsectors of other crops, livestock, forestry and logging, and fishing. The industrial sector and service sector are also aggregated from the original data based on the structure of the model (Roe *et al.*, 2010).[10] The aggregated SAM is shown in Appendix (Table A1). The entries in the SAM in the current study show major economic transaction in terms of 2007-US million dollars. The SAM is "corrected" based on the economic assumptions explained above. One of our challenges is to attach a value to water used by farmers. As explained above, farm profit after the services provided by labor and capital are paid is likely to be overestimated because it includes the cost of water in addition to land holdings. Therefore, in order to separate the share of the value of water in total farm profits from the share of the value of land in profits, we use the estimated values from a study in which the value added of rice is regressed on a number of primary inputs, conducted for Tamil Nadu, a southern state of India (Smith, 2013). Tamil Nadu is an intensive rice producing state and its cost structure for producing rice is deemed comparable to Punjab. The state has also similar values of gross value added as well as yield per hectare for rice production (Agricultural Research Data Book, 2011).[11] As seen in the SAM, the value of water and land in the activity column under Punjab rice production are computed based on the estimated coefficient in the Tamil Nadu study.

As the next step, we determine how much rainfall contributes to the total water use in rice production. We assign 70% of total water use in rice production for irrigated water and the rest of water for rainfall. Data also suggest that rice production consumes approximately 70% of total irrigated water pumped from the aquifer with the remaining 30% allocated to wheat production (Palanisami, 2013). For simplicity, we

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[9] If data are missing, the data from the 2007 Global Trade Analysis Project (GTAP 8) data base are used as a guide.
[10] See Appendix (8.7) of Chapter 8 for sector definitions and aggregation methodology.
[11] See Table 5.18 Cost of cultivation of principal crops (2006-2007).

assume in the model that rice and wheat are the major water users for production. Another difficulty we faced due to lack of data was the energy cost associated with irrigation. Since Punjab farmers are not currently charged for the full amount of electricity, the true cost is not found in reported data. Therefore, taking the value of electricity supplied in the state from the original data, we disaggregate the value of supply based on electricity consumption data for irrigation use and industry use.[12]

4.2 Groundwater Dynamics

The challenge is to capture and integrate the fundamental physical features of ground water dynamics, with the economic behavior of farmers seeking to optimize returns to resources given these dynamics. Since irrigation activities are strongly influenced by the cost of withdrawing groundwater, the sustainability of this natural resource depends directly on economic costs and the incentives to producers that are imparted by policy instruments.

Evolution of the Depth to Water table

Punjab's water tables have been deepening because the extraction of groundwater from aquifers exceeds the inflow of new supply of water into the aquifers (recharge). In this study, we adopt a simple, single cell bathtub-like aquifer model in order to describe groundwater dynamics in a tractable way within a general equilibrium framework. As previously discussed, the depth to water table of monitored wells in Punjab widely ranges from less than 1 *m* below ground (*mbg*) to over 30 *mbg* throughout the state. As analogous to the spatial difference in the depth level of the water table, the rate of deepening (or rising for some cases) varies across the state. Thus, the depth to water table and its rate of change in the analysis are treated as the behavior of an average water table across the districts in Punjab. In general, the major sources of inflow into aquifers are precipitation in addition to other sources of recharge including that from irrigation recharge. On the other hand, the main sources of flow out of aquifers are water extraction for agricultural irrigation, and other industrial and residential purposes as well as natural discharge.[13] Groundwater response to precipitation recharge depends on a number of factors including soil properties and precipitation characteristics. Recommended rainfall infiltration factor for Indo-Gangetic plains in which Punjab is located is 0.2 (22% of rainfall is infiltrated) according to Central Ground Water Board (CGWB) (2009).[14] The aquifers underlying Punjab are characterized by alluvial deep systems which lead to higher specific yield relative to shallow hard-rock formations in other parts of India. The value for the specific yield used in the current study is 0.1 which measures water availability to wells relative to the volume of aquifer and is recommended by CGWB (2009).[15] As the depth to water table deepens, the

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[12] According to Critical Economic Indicator-Punjab (2011), electricity for irrigation use was 10,022 *Gwh* while that for industry use was11,354 *Gwh* in the period of 2007-2008.

[13] According to Ground Water Year Book (2012), total annual groundwater replenished in Punjab in 2009 was 22.56 billion m^3 in which the recharge from monsoon rainfall was 10.57 billion m^3 while recharge from non-monsoon rainfall was 1.34 billion m^3. The difference between the total replenished amount and recharge from annual rainfall was recharge from other sources. Subtracting natural discharge from total annual replenished groundwater, the net annual groundwater availability was 20.35 billion m^3. On the other hand, total annual groundwater draft was 34.66 billion m^3 among which 33.97 billion m^3 was used for irrigation purpose and 0.69 billion m^3 was used for domestic and industrial uses.

[14] The data were provided by Dr. Shashidhar Thathikonda, Indian Institute of Technology, Hyderabad, India in June 2012.

[15] The differential equation for the depth to water table for this study is given by

$$\dot{D}(t) = \frac{c_1 y(t) - c_2 R}{z},$$

amount of energy that is required to pump a unit of groundwater is likely to increase. In order to capture the linkage between the increasing energy consumption and deepening water table, we adopt a simple hydraulic energy equation in which energy requirement per unit of water lifted is linear in the depth to water table.[16]

5. Simulation Results

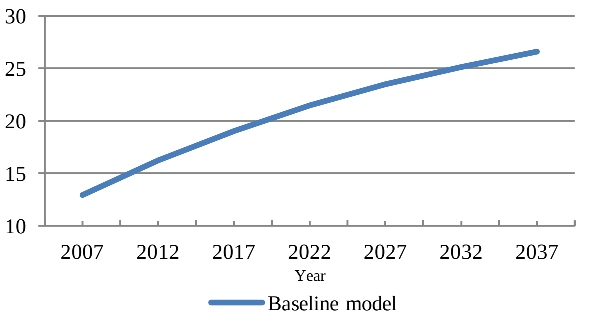
This section investigates the implication of our model highlighting the impact of sustainable aquifers on resource allocation and production. The linkage between the policy instrument - here free electricity for pumping groundwater- and supplies of agricultural and other outputs through irrigation is particularly important for the analysis. After the extensive discussion of the baseline model, two types of simulations are conducted. A policy shock evaluates the effect of removing the electricity subsidies on crop production and water supply. The second simulation studies the effect of a natural shock by imposing a prolonged drought condition. Each shock has a different implication in the applied perspective and provides a basis for evaluating water policy instruments. As we mentioned in the subsection of general equilibrium framework we present the model focusing on the economic fundamentals that are influenced by the groundwater dynamics without being encumbered by the economic effects of technological progress and labor force growth. Therefore, the model predictions of change in the endogenous variables should be interpreted in terms that are relative to their corresponding magnitude in the base solution.

5. 1 Baseline Model

The baseline model demonstrates how subsidized electricity for pumping could impact the farmers' irrigation behavior and the dynamics of the natural resource environment. The channels that interlink the aquifers depletion to the behavior of the fundamental economic forces are analyzed extensively. For the base analysis, rainfall is assumed to be constant at the average amount of rainfall.

5.1.1 Evolution of Depth to Water Table

Figure 5: Depth to water table (m)



As shown in Figure 5, the depth to water table in the initial or "start period" is approximately 13 *m* below ground (*mbg*) which is nearly the average value computed over the region.[17] Since the depth widely varies over the state as shown in the data, the value of the depth in the present study is considered as the average behavior of water table across the state. The depth to water table tends to deepen faster in

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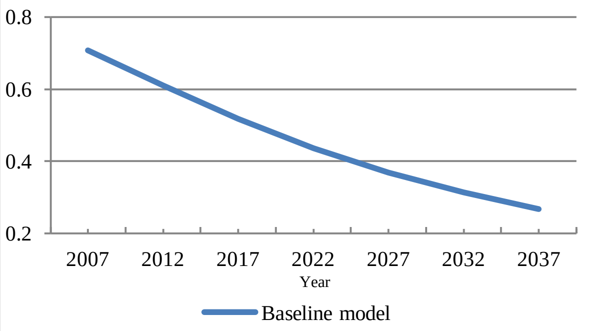
where $\dot{D}$ is time derivative of the depth to water table (m), y is the amount of groundwater extracted (m^3), R is the amount of rainfall (m^3), c_1 and c_2 are coefficients and z is a conversion factor. The conversion factor in the present study is assumed as a constant that accounts for the area of aquifers and specific yield (Roumasset *et al.*, 2012).

[16] The equation is given by $v = \frac{yD}{367e}$, where v is hydraulic energy consumption (gigawatt hours or GWh), y is the amount of groundwater lifted (million m^3) and D is the depth to water table (m). The denominator is a physical constant multiplied by pumping efficiency e ($0 \leq e \leq 1$) (FAO, 2012 and Coker, 2007).

[17] The average value is based on the distribution data (CGWB, 2012), taking the midpoint of each range, multiplying it by the corresponding percentage and then, summing them up to obtain the result.

Figure 6: Rate of change:Depth to water table (*m*)



the early periods and could reach 19 *mbg* in the first 10 years. *By year 2032, the base model predicts that the depth to water table possibly passes the half-way point to the steady state (i.e., long-run) depth level of 37 mbg (simulation result). The level of the water table could be twice as deep as the beginning level in 30 years.* According to Figure 6, the annual rate of water table deepening is approximately 0.7 *m* at the beginning in the base model. This value is consistent with values in other studies such as the range between 0.4 *m* and 0.5 *m* by NASA (Rodell *et al*., 2009),[18] 0.75 *m* in the central Punjab between 2002 and 2006 studied by Singh (2006) and 1 *m* for more recent observation by Palanisami (2013). As analogous to the spatial difference in the depth of the water table, the rate of deepening is varied across the state. Thus, the model prediction is considered as an average annual increment over the state. The annual rate of deepening in the base model could decline to 0.267 *m* in 2017 (Table 1). By year 2037, the rate possibly declines to 38% of the 2007-level. The annual rate of change in the depth is likely to continue declining until it reaches the steady state (37 *mbg*). At the steady state, the groundwater withdrawal equals the recharge by rainfall. As the water table changes from 13 *mbg* to 37 *mbg* in the long run, the decline in groundwater use and effects on resource allocation are discussed in the following section.

5.1.2 Impact on Economic Variables

Our main focus is to understand the linkages between the aquifer sustainability and economic variables through irrigated water demanded by agriculture sectors, especially rice and wheat farmers. The behavior of groundwater extraction is determined directly by the "shadow" value of water, the depth to water table, the price of farm inputs including the price of electricity for pumping and the cost of labor and capital employed. We highlight economic adjustments that take place in the regional and the broader economies as the water table depletes over time.

Table 1: Baseline Model

	Depth to Water Table		Value of	Price of	Irrigated Water			Energy for	Supply of Output				Punjab
Year	Level	Rate	Water	Energy	Total	Rice	Wheat	Irrigation	Rice	Wheat	Other Agri	Manufacture	GSDP
	(m)	(m)	2007=1	2007=1		(million m^3)		(Gwh)					
2007	12.961	0.708	1.000	1.000	40,622	29,979	10,643	13,472	2,685	3,526	6,023	4,381	16,921
2012	16.253	0.609	1.233	1.295	37,785	27,345	10,440	15,714	2,510	3,458	5,188	3,138	14,639
2017	19.064	0.517	1.474	1.538	35,151	24,906	10,245	17,148	2,348	3,394	4,490	2,344	13,001
2022	21.444	0.437	1.692	1.719	32,849	22,782	10,067	18,025	2,207	3,335	3,926	1,857	11,856
2027	23.453	0.369	1.874	1.839	30,912	21,002	9,910	18,551	2,088	3,283	3,476	1,566	11,059
2032	25.154	0.313	2.016	1.911	29,310	19,537	9,773	18,866	1,991	3,238	3,119	1,391	10,501
2037	26.600	0.267	2.123	1.949	27,993	18,337	9,655	19,054	1,911	3,199	2,833	1,287	10,105

Sourse: Simulation result; Unit in 2007 US million dollars, otherwise stated. Other Agri means other agriculture.

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[18] The NASA's satellite-based estimates of groundwater depletion show that the groundwater in three states of northwestern India including Punjab is being depleted at a mean rate of 4*cm* per year between August 2002 and October 2008. This is equivalent to annual rate of 0.4 *m* if we assume a specific yield of 0.1.

Increase in Values of Water and Energy

Table 1 shows the values of water and electricity as well as the quantities produced of each output in the Punjab economy in the baseline model. The shadow value of water is normalized to 2007-level of unity. The shadow value of groundwater tells the maximum amount the farmers would be willing to pay to acquire another unit of groundwater in order to produce output, rice and wheat in the present case. The value also implies the increasing economic cost of extracting groundwater that is applied to grow another unit of the Punjab's major grains. The shadow value of water could rise by 47% in 10 years and possibly approaches the level that is more than double the initial level by year 2032. In 2037, the value of water could increase by as large as a factor of 2.12. The price of energy also is normalized to the 2007-level of unity and increases over time. The energy price could increase by 54% from the 2007-level and become almost double the 2007-level in 30 years. This increase in value signals the need to ration this scarce resource, relative to past use, and discourages the over exploitation of the aquifer, thus preserving this water resource for future generations.

Decline in the Availability of Groundwater

Figure 7: Irrigated water supply (million m^3)

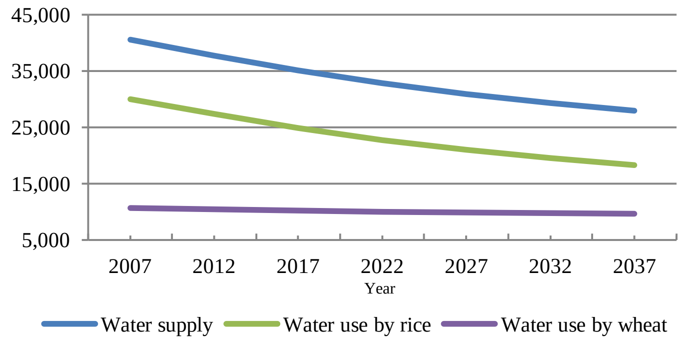

Figure 7 shows that availability of groundwater for irrigated crops declines over time, in spite of the electricity subsidy. The supply of irrigated water starts at approximately 40,000 m^3 in 2007 and could decrease by 14% in 2017 (Table 1). It continues declining to possibly 76% of 2007-level in 20 years and could reach the value below 28,000 million m^3 which is 69% of 2007-level in 2037. Approximately 30,000 million m^3 that is slightly over 70% of total irrigated water is applied to growing rice in 2007 and the rest of groundwater withdrawn is applied to growing wheat.[19] The level of irrigated water demanded by both rice and wheat decreases over time. However, due to the different level of water consumption by crops, the groundwater demanded by rice tends to decrease at a faster rate than water demanded by wheat. In 2017, the irrigated water use for growing rice could decrease by 17% relative to 2007-level while that for growing wheat could decrease by 4%. In 2037, the irrigation demand by rice farmers decreases possibly by close to 40% relative to 2007-level while the demand by wheat farmers decreases only by 10% compared to 2007-level. Consequently, the share of irrigated water use by wheat production increases from 26% in 2007 to 34% in 2037 though rice remains as the most water-consuming crop.

Decline in Agricultural Production

Punjab's agricultural production diminishes over time to a different degree in the baseline model. As shown in Table 1, rice production could decline by 13%, 22% and 30% in 2017, 2027 and 2037,

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[19] Recall that irrigation applies to rice and wheat, not to the rest of agriculture in the current setup.

respectively relative to 2007-level while wheat production could fall by 4%, 7% and 9% in the same respective time periods as rice, relative to 2007-level. The manufacturing sector is likely to experience a greater proportional decline in its production than agriculture; it could shrink to a half of the initial level of production in 20 years and approach possibly 30% of 2007-level of output in 30 years. The agricultural sector excluding rice and wheat also tends to reduce its production significantly and approaches in 30 years the level that is possibly less than a half of the 2007-level output produced. As a result of depressed output production in all sectors over time, Punjab gross state domestic production (GSDP) as the total output measure could decline by 23% in the first 10 years and by 35% in the additional 10 years from the initial level of GSDP. The total output continues to fall and could reach 40 % of 2007-level of GSDP in 30 years. We next focus on the cause of these results.

5.1.3 Discussion

The baseline model summarizes Punjab as a weakening economy in the long run if the current electricity subsidy for extracting groundwater continues, showing that the aquifers are likely to deplete the supply of water, the cost of electricity outside of Punjab agriculture tends to increase and the extraction costs of water increases while all production sectors, and especially so for the manufacturing sector, shrink compared to the initial values of 2007. As a result, Punjab's GSDP is likely to diminish significantly over time. This decline in GSDP is associated with the flight of labor and capital to other sectors in the "rest" of the Indian economy, and a decline in returns to the Punjab's sector specific resources, such as land. Effectively, the Punjab economy is "losing" its comparative advantage with the rest of the Indian economy in competing for economy-wide resources. Consequently, Punjab's net exports of agricultural products including rice and wheat fall and thus, the grain surplus region becomes less self sufficient and food security issue would be extended to the rest of India. Consequently, other areas of India that are more suitable for rice and wheat production could increase their crop production using more economy-wide resources that potentially flow into the areas.

Increasing Extraction Costs

Figure 8 sketches out a flowchart of inter-linkages between groundwater depletion and Punjab economy as well as the broader economy. As long as the groundwater consumption exceeds the groundwater recharge during a period of time, the rate of water withdrawal is not sustainable and the stock of water in aquifers for future generations is diminished. This is the case that Punjab has experienced in the past decades and the authority confirms that Punjab's rate of water extraction overexploits the aquifer.[20] As the depth to water table deepens, water withdrawal requires more electricity per unit of water extracted. Consequently, this increase in electricity demand for pumping puts upward pressure on the price of energy for relatively fixed total electricity supplied. As a result of the increase in the energy price (or shadow value for the case where the government fixes electricity prices), profits are likely to diminish over time for energy users, farmers of irrigated crops as well as firms in the manufacturing sector. Since farmers are subsidized for electricity use for pumping, their profits are unlikely to decline as much as it would in the case which farmers pay the full energy cost. However, electricity is not completely free for the farmers because the true economic cost of energy use is extended to capture any implicit costs that

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[20] The status of groundwater exploitation in Punjab is one of the most serious cases in India because among Punjab's 138 assessed units of blocks, 80% was considered to be overexploited (CGWB, 2012). Furthermore, the authority confirmed that the state's annual groundwater consumption exceeds that annual groundwater recharge.

potentially undermine the agricultural activity. These include unreliable electricity supply and pump damage caused by voltage fluctuation due to extremely stressed Punjab economy's grid system. As a result, subsidized irrigation imposes the indirect cost on farmers and discourages water extraction and thus, groundwater available to irrigated crops is reduced. Further, the electricity subsidy becomes a "trap." Not only is the depth of the aquifer increased, which if continued lessens the profitable amount of water to be withdrawn in the future, removal of the subsidy will tend to cause a drastic decline in the profitability of water withdrawal. Removing the subsidy could precipitate a substantial decline in rice and wheat production that could last a period of time required to replenish the aquifer. In the manufacturing sector, on the other hand, rising energy price lowers firms' profits directly by a substantial amount so that its production quickly recedes. Therefore, the contraction of all production sectors results in the diminishing Punjab economy, measured by GSDP over time.

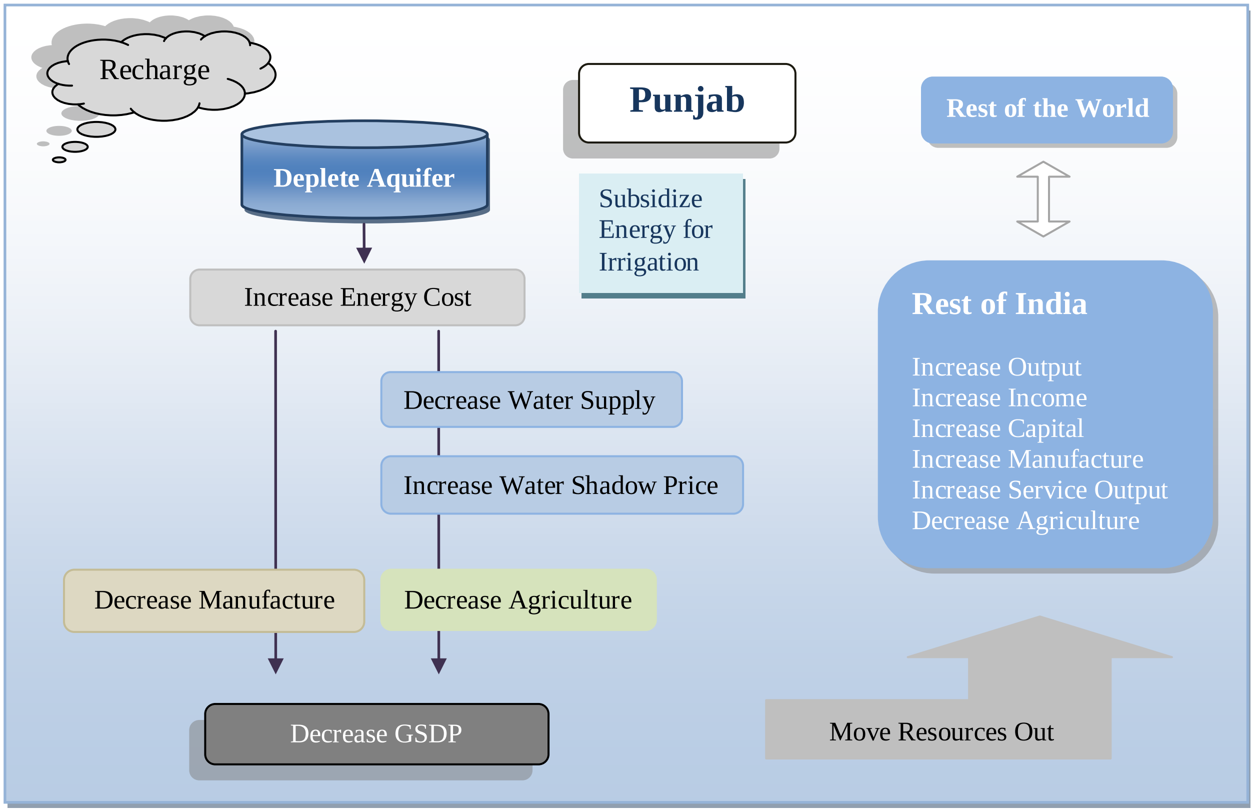

Figure 8: Flow chart of the major effects of groundwater depletion in the baseline model. As the withdrawal of groundwater exceeds recharge, water tables deepen leading to the increase in energy cost which is subsidized for irrigation use. The high Energy cost discourages manufacturing directly. Depletion of aquifers also decreases water supply and increases the shadow value of water and thus, lowers irrigated agricultural productions. As a result, Punjab gross state domestic product (GSDP) decreases. The resources of production including labor and capital leave Punjab and move into the rest of India.

Economic Fundamentals

While the scarcity of irrigated water supplied tends to put upward pressure on the shadow value of water, there is also the downward pressure on the demand for irrigated water stemmed from the economic fundamentals. In the current setup of the general equilibrium model, both labor and capital are assumed to be homogeneous and free to move between regions. Since the size of labor force as well as capital stock employed by the production sectors in Punjab is small compared to the rest of India, the rest of India's economy dominates the national wage and rental rate of capital. As India's economy grows, the economy-wide stock of capital increases and the cost of using capital measured by the rental rate of capital declines while the cost of labor measured by wage payment increases over time. This is the typical pattern observed for countries that are experiencing an increase in the employment of capital per worker over time.

The rise in wages and decline in the cost of capital over time have differential effects on sectors of the economy. Those sectors that employ a lot of capital to labor per unit of output (i.e., a high capital to labor ratio) tend to experience a decline in cost when the cost of capital declines and wages rise. As the capital to labor ratio per unit of output falls, the wage effect tends to dominate the decline in capital cost, causing the sector to decrease its level of production. Without going into the detail of theoretical concepts, the intensity of input is indicated by the cost share of input in total cost (Table A2 in Appendix). Thus, it is clear that manufacturing is the most capital intensive (i.e., high capital to labor ratio) sector in Punjab because the sector's cost share of capital is 62% while the cost share of labor is 27%. This indicates that capital cost is 2.3 times more than the labor cost in the manufacturing sector and this capital to labor ratio is the highest among sectors in Punjab. By the same reason, the rest of agriculture is the most labor intensive sector because labor cost is 2.5 times more than capital cost in the sector.

Resource Reallocations

With the above background, we can now explain the economic forces inside and outside of Punjab that impact the evolution of the state economy. First, Punjab's rest of agricultural sector which is the most labor intensive sector (i.e., a low capital to labor ratio) is affected by the increase in labor cost. Consequently, the rise in wages, (which as noted, stems largely from labor productivity in the rest of the Indian economy) causes the supply of the rest of agricultural goods in Punjab to decline sharply, such that the sector's production is surpassed by the wheat sector which is relatively capital intensive (Table 1). In addition to the force of economic fundamentals, Punjab is influenced significantly by the natural resource availability and complementary energy resource. Furthermore, farmers are not charged for the use of electricity in the base model. All of these elements complicate greatly the resource reallocation in Punjab over time. In particular, the primary input of labor and capital migrates from Punjab to the rest of India.

Table 2 indicates that capital stock in Punjab declines to possibly 58% of 2007-level in 30 years while total wages paid to Punjab labor could fall to a half of the initial level of wage income in 2037. Within

Table 2: Baseline Model-Resource Allocation

Year	Capital Stock	Capital Share				Labor Income	Labor Share			
		Rice	Wheat	Other Agri	Manufacturing		Rice	Wheat	Other Agri	Manufacturing
2007	36,092	0.1172	0.1310	0.2168	0.4959	4,868	0.1306	0.1032	0.5510	0.2128
2012	30,440	0.1343	0.1598	0.2331	0.4277	4,111	0.1419	0.1195	0.5621	0.1741
2017	26,642	0.1480	0.1877	0.2423	0.3719	3,542	0.1510	0.1356	0.5645	0.1463
2022	24,190	0.1576	0.2121	0.2444	0.3321	3,122	0.1582	0.1506	0.5600	0.1285
2027	22,642	0.1636	0.2320	0.2412	0.3070	2,810	0.1637	0.1643	0.5509	0.1184
2032	21,677	0.1671	0.2476	0.2346	0.2930	2,577	0.1682	0.1763	0.5390	0.1136
2037	21,085	0.1690	0.2596	0.2265	0.2866	2,398	0.1719	0.1869	0.5261	0.1124

Source: Simulation result. Capital stock and labor income are in 2007 US dollars. All others are in the sectoral proportion of Punjab's production factor. For example, 0.1172 in rice, 2007 under capital share indicates 11.72% of Punjab capital was used in rice sector in 2007.

the state of Punjab, resources are reallocated in a significant fashion. The share of Punjab capital in all agricultural sectors tends to increase in particular, in wheat production. Wheat farmers used 13% of Punjab's total capital in 2007 and could double the share in 30 years while rice farmers used 12% of Punjab capital and increase it to 17% in 2037. This trend reflects a major substitution in production of cheaper capital for more expensive labor. On the other hand, the manufacturing sector which employs a half of Punjab's capital in 2007 could reduce the share to 29% of Punjab capital in 2037. There is a similar downward movement of the share of labor within Punjab except for a slight decrease in labor share in the rest of agricultural sector. The share of Punjab labor employed by manufacturing falls from 21% in 2007 to possibly 11% in 30 years while the share of labor by rice and wheat sectors is likely to increase from 13% to 17% and from 10% to 19%, respectively in 30 years. In short, in spite of the employment of more capital per unit of labor per unit of output, both capital and labor tend to emigrate from Punjab to the rest of India. Comparing sectors within Punjab, both capital and labor tend to leave the manufacturing sector and immigrate into agricultural sectors, especially rice and wheat. In principle, as the economy grows, the capital intensive manufacturing sector is expected to gain most from falling economy-wide capital cost and expand its production while labor intensive agriculture sectors, accompanied by the use of scarce natural resource, diminish the production. On the contrary, Punjab manufacturing reduces the production and all resources are reallocated away from the sector. This is clearly the consequence of the electricity subsidy that adversely affects the cost of manufacturing in Punjab, causing the sector to release resources to other sectors of the economy.

Rest of the Economy

The result of the rest of India presents the principle property of economic fundamentals. The manufacturing sector is the most capital intensive sector in the rest of India because the cost share of capital is 74% (Table A3 in Appendix). While all agricultural sectors in the rest of India are relatively labor intensive, the most labor intensive sector is wheat, followed by rice and the rest of agriculture. Table A4 in Appendix supports expected results based on the characteristics of input intensities in the rest of India. As the capital rental rate decreases over time, capital stock for the rest of economy could expand by a factor of 3.76 in 30 years while the wage could exceed the double of the 2007 level. In the same time period, the quantities supplied by farmers of rice, wheat and the rest of agriculture contract to possibly 25 %, 17 % and 25 %, respectively, relative to 2007 while the supply of manufacturing increases by a factor as large as 3.59. In other words, India's agricultural sectors employing more labor than machines suffer from the increase in labor cost though the effect of wage increase is partially offset by the fall in rental rate of capital and thus, reduce their production. On the other hand, the capital intensive manufacturing sector benefits more from declining rental costs of capital than increasing labor cost.[21] These results are mostly explained by the economic fundamental forces created by different factor intensities among sectors in the presence of economic growth induced, in part, by capital increase. Consequently, the total output produced in the rest of India measured by GDP could grow by a factor of 2.36 in 30 years.

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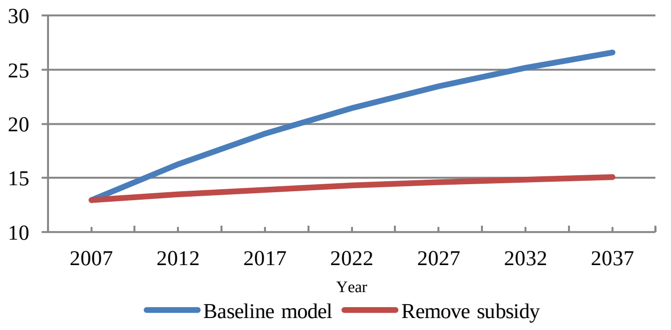
[21] In the model, there is a service sector which produces goods consumed entirely by the people. The sector is labor intensive and increases its supply through the wage hikes leading to production cost increases because of higher price of service goods encouraging the sector to increase production.

5.2 Removal of Electricity Subsidy

By removing the electricity subsidy for irrigation, both water preservation and economic gains are expected. In other words, this model simulation highlights the interaction between economic fundamentals and water dynamics in the absence of governmental intervention. The complete cancelation of this farm aid may not seem realistic at least in the short run. Furthermore, once and for all policy changes are socially disruptive and can lead to policy reversals. Therefore, this simulation is considered as a first step to "phased in" policy options that are likely to curtail groundwater extraction and increase the longevity of the aquifer for future generations.

5.2.1 Effects on Groundwater Dynamics

Figure 9: Depth to water table (*m*)



The basic economic forces discussed above remain present, only their magnitudes are modified. As shown in Figure 9, the water table continues to deepen over time when the energy subsidy is removed. The depth to water table in the initial period is identical to the initial level of the base solution. However, without the energy subsidy, the rate of water withdrawal per unit of time is greatly reduced. If the subsidy program is terminated at the beginning and continues to be lifted for the following years, the depth to water table could be approximately 14 *m* below ground (*mbg*) in 10 years and reach 15*mbg* in 30 years. These values are significantly lower than the corresponding base value. The depth to the water table in this policy simulation possibly increases by 7% and 12% relative to the initial period in 2017 and 2027 years, respectively. While the depth in the baseline model in 2037 could be twice as deep relative to the initial depth, the corresponding depth in the simulation is likely to increase only by 16% relative to the initial depth. The annual rate of depletion could be also significantly lower as shown by the slope of the evolution of the depth to water table (Figure 9). Table 3 shows that the rate of depleting the aquifers could be nearly 76% lower than the baseline values for all periods. Therefore, the simulation result suggests that the removal of subsidy, given the same initial conditions as the case with the subsidy, makes farmers tend to have less incentive to over-exploit the aquifer, thus extending the stock of the aquifer's water for future use.

Table 3: Simulation 1 (Subsidy Removal) Relative to the Baseline Model (See Table 1)

Depth to Water Table			Value of	Price of	Irrigated Water			Energy for	Supply of Output				Punjab
Year	Level	Rate	Water	Energy	Total	Rice	Wheat	Irrigation	Rice	Wheat	Other Agri	Manufacture	GSDP
2007	0.0000	-0.7587	4.9529	-0.1206	-0.3786	-0.5000	-0.0366	-0.0674	-0.3713	-0.0366	0.0003	0.1148	-0.0714
2012	-0.1707	-0.7679	3.6729	-0.3678	-0.3543	-0.4768	-0.0335	-0.1964	-0.3454	-0.0335	0.0002	0.5449	0.0137
2017	-0.2704	-0.7703	2.7451	-0.5067	-0.3244	-0.4454	-0.0300	-0.2601	-0.3142	-0.0300	0.0002	1.0547	0.0889
2022	-0.3343	-0.7687	2.1056	-0.5911	-0.2925	-0.4100	-0.0265	-0.2931	-0.2815	-0.0265	0.0001	1.5765	0.1505
2027	-0.3780	-0.7650	1.6648	-0.6457	-0.2614	-0.3738	-0.0232	-0.3105	-0.2500	-0.0232	0.0000	2.0390	0.1986
2032	-0.4094	-0.7605	1.3533	-0.6830	-0.2325	-0.3386	-0.0203	-0.3197	-0.2210	-0.0203	0.0000	2.4021	0.2353
2037	-0.4328	-0.7559	1.1252	-0.7099	-0.2064	-0.3057	-0.0178	-0.3243	-0.1951	-0.0178	0.0000	2.6608	0.2632

Sourse: Simulation result. Other Agri means other agriculture.

Each value is computed by (Value in Simulation/Value in Baseline Model) - 1. For example, -0.1707 (depth to water table level in 2012) is computed by (13.479/16.253) - 1, where 13.479 is the water table level in 2012 in the simulation and 16.253 is the corresponding value in the baseline model (in Table 1).

5.2.2 Economic Gains

Without an electricity subsidy, farmers are now obliged to pay the full cost of energy use for irrigation. Consequently, farmers who face soaring energy cost are incentivized to reduce their energy demand for irrigation purposes. According to Table 3, Punjab farmers reduce their energy use for extracting groundwater potentially by 7%, 26% and 32% in 2007, 2017 and 2027, respectively from the corresponding value in the baseline model. For a limited supply of electricity in the state, less electricity demand by farmers is counteracted by the increase in energy use by the manufacturing sector. However, the predicted fall in energy demand by farmers is so significant that the price of energy is not just lower than the base model but it tends to decrease over time in this policy simulation. The energy price in 2007 is about 12% less than the corresponding base solution value in 2007. Over time, the energy price in this simulation relative to the base discussed above tends to continue declining, in contrast to the base solution. The initial shock of this policy change also reduces water use by irrigated crops dramatically. Because water use is decreased possibly by one half at the beginning due to the cost of energy, rice farmers are forced to contract their production of rice. On the other hand, wheat farmers are likely to reduce their water use by only 3.6% at the beginning base solution quantity and possibly by 1.8% in 30 years relative to the corresponding value in the base model. Thus, the effect of policy change on wheat production is not as detrimental as the effect on rice production.

This changing behavior of irrigated water use by sectors of rice and wheat is directly translated to the reduction of output supply of each crop. In contrast, the manufacturing sector benefits from the lower energy price, causing it to increase production. The sector which produces 11% more manufacturing output than the base value in 2007 expands its production possibly by a factor of 2.7 in 2037 relative to the corresponding value in the base model. Consequently, Punjab economy measured by GSDP in the case of terminating the energy subsidy could be 9% greater than the base model in 2017 and 26% greater than the corresponding base value in 2037. Labor tends to depart agriculture for employment in Punjab manufacturing. However, the negative consequence of the policy shock on agriculture is completely offset by the manufacturing sector's expansion.

Table 4: Simulation 1 (Subsidy removal)-Resource Allocation

Year	Capital	Capital Share				Labor	Labor Share			
	Stock	Rice	Wheat	Other Agri	Manufacturing	Income	Rice	Wheat	Other Agri	Manufacturing
2007	-0.0292	0.0463	0.1204	0.2234	0.5778	-0.0645	0.0535	0.0985	0.5892	0.2573
2012	0.1701	0.0478	0.1231	0.1993	0.5984	0.0155	0.0582	0.1060	0.5536	0.2806
2017	0.3644	0.0498	0.1254	0.1776	0.6165	0.0900	0.0636	0.1133	0.5180	0.3035
2022	0.5364	0.0518	0.1272	0.1591	0.6319	0.1561	0.0691	0.1201	0.4844	0.3248
2027	0.6787	0.0538	0.1287	0.1437	0.6445	0.2134	0.0745	0.1260	0.4540	0.3438
2032	0.7920	0.0557	0.1298	0.1309	0.6549	0.2623	0.0796	0.1312	0.4270	0.3606
2037	0.8805	0.0574	0.1307	0.1204	0.6634	0.3041	0.0842	0.1357	0.4034	0.3751

Source: Simulation result. Capital stock and labor income are relative to the baseline model (See Table 2).
All others are in the sectoral proportion of Punjab's production factor in the simulation.

5.2.3 Resource Reallocation

Accompanied by manufacturing expansion, both capital and labor used in Punjab production sectors likely to increase significantly, especially capital, relative to the base model. As shown in Table 4, the level of Punjab capital could be 36% greater in 2017 and 68% greater in 2027 relative to the base value in the corresponding year. In 30 years, the Punjab's capital stock employed in all sectors is possibly 88% higher than the base value of the same period. On the other hand, labor could be 21% and 30% higher in 20 years and in 30 years, respectively compared to the corresponding base value. The greater proportional increase in capital than labor in the simulation relative to the base model is attributed to the boom of capital intensive manufacturing sector in Punjab. Among Punjab production sectors, rice farmers who receive the most benefit from the subsidy are almost certain to reduce their use of resources if the governmental aid is cancelled. This is indicated by the fall in the share of both capital and labor used by rice production. The capital share for rice could fall to 5% of total Punjab capital available in the initial period and stays at the lower level. This is significantly lower than the base model where the capital share for rice is 12% initially and rises possibly close to 17% in 30 years. The share of Punjab labor that is employed in rice production is also lower after the policy change than the base model. The labor share for rice in the initial period is 5% of Punjab labor and could increase to 8% in 30 years in the simulation while 13% of Punjab labor works for rice initially and increases to 17% in 30 years in the base model.

Farmers in wheat and the rest of agriculture also are likely to experience the reduction of capital and labor shares. However, each has a different reason for releasing resources. The rest of the agricultural sector is little affected by the policy change directly so the amount of input use for this sector is virtually unchanged. However, since there is more capital and labor available for Punjab sectors in the simulation than in the base model, the rest of agriculture's share of these inputs declines. The resource allocation for the wheat sector is also affected, but not to the extent of the change in rice production. The predicted share of total Punjab capital employed in the production of wheat in the base model is 13% initially and could approach 26% in 30 years. The policy simulation predicts that 12% of Punjab capital is employed in the wheat production and increases slightly to 13% in 30 years. The labor share for wheat production in the simulation is also likely to be lower than the base model. In the subsidy case, nearly 10% of Punjab labor is employed in the production of wheat in initial periods, and possibly rises to 14% in 30 years; the corresponding comparison for the case of no subsidy is 13% initially, with the proportion potentially increasing to 19% in 30 years. The elimination of the subsidy tends to discourage farmers from pumping water at historic levels, thus reducing crop production, and pushing some resources out of these crops. The purchasing power of farm households due to returns to land alone falls. In spite of these adverse effects of eliminating the subsidy on irrigated crop farmers, the potential gains that are generated by more efficient use of groundwater is expected to be significant in the long run. Thus, to preserve the groundwater for the future generations, an immediate task for the policy maker is to create and implement the system in which farmers are willing to allocate more water to crops that are economically efficient and use it more efficiently for the crops they select.

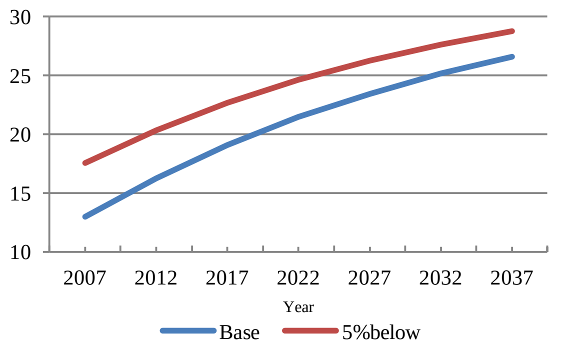
5.3 Introducing Hydrological Variability

A natural shock is implemented by imposing a different level of precipitation projection on the baseline model. The change in the amount of rainfall directly affects the depth to water table for a given irrigation activity. It also affects farmer's decision-making with respect to water. If the monsoon and daily precipitation were a reliable source of water, a farmer would not have to overdraft groundwater. However, with increasing hydrological variability the deep aquifers of Punjab provide farmers a buffer system that has been increasingly abused over time. Variability can also affect the farmers' profit through altering the profitable amount of water to withdraw because rainfall is a substitute for groundwater. In particular, rice farmers who “consume” rainfall as water input in production are likely to make an adjustment in the irrigation activity to weather shocks. In order to investigate the effects of rainfall on the economy for relatively long run rather than the effects of short term fluctuations,[22] we compare the baseline model with the case of once and for all changes in trend precipitation levels. That is, a weather shock is given at the beginning period and remains unchanged over time. Cases of above and below normal precipitation in different degrees are tested. Although different levels of precipitation lead to various responses by the economy in some degree, the basic mechanism of economic reaction to the precipitation shocks continues to hold for all cases.

5.3.1 Effects on Groundwater Dynamics

As seen in Figure 10, the depth to water table tends to be deeper in the case of 5% decline in the trend rate of precipitation compared to the baseline model for the entire time period. This result is mostly due to the profitability of increasing water withdrawal for mostly rice, and secondarily, wheat production, as well as a lower rate of aquifer recharge. The initial shock of a low amount of rainfall leads to 17*mbg* as the depth to water table in 2007. As shown in Table 5, the depth could be 36% deeper than the corresponding base value at the beginning. In 2017, the aquifers are depleted at a slower rate than the beginning, shown possibly by 23 *mbg* which is 19% deeper than the base value. As indicated in the dynamics of groundwater, the withdrawal of groundwater approaches the rate of recharge by rainfall in the long run. The drought simulation model predicts that the depth to water table could pass the half-way point to the steady state depth level of 35 *mbg* in 20 years which is slightly earlier than the base model. Since the case of 5% below normal rainfall is likely to bring a large shock to irrigation activity initially, the amount of extracting groundwater tapers off as the economic adjustment takes place over time. As shown in Table 5, the annual rate of depleting groundwater is lower than the baseline model by the range between 14% and 19%. The rate of depleting groundwater possibly decreases to a half of the initial level after about 20 years in both the base model and drought simulation. In other words, drought causes farmers to exploit the aquifer to a greater degree in the short run than under normal weather conditions. But, in the long run, the depth to the aquifer’s water table remains relatively unchanged. If rice and wheat prices were to rise due to the drought (a situation that does not arise in this study because of access to world markets) then farmers would have an incentive to increase water withdrawals in the long run relative to the base case.

Figure 10: Depth to water table (*m*)



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[22] An aquifer also serves as a self insurance like resource which allows farmers to adapt to departures from normal precipitation patterns. If the depth to the water table is exacerbated by excess water withdrawals due to electricity subsidies, then this form of insurance becomes relatively more costly to utilize under drought conditions. This analysis is left for future study.

Table 5: Simulation 2 (Drought) Relative to the Baseline Model (See Table 1)

Year	Depth to Water Table		Value of	Price of	Irrigated Water			Energy for	Supply of Output				Punjab
	Level	Rate	Water	Energy	Total	Rice	Wheat	Irrigation	Rice	Wheat	Other Agri	Manufacture	GSDP
2007	0.3551	-0.1444	0.5566	0.7484	-0.0417	-0.0551	-0.0040	0.2985	-0.0394	-0.0040	0.0003	-0.5089	-0.1540
2012	0.2518	-0.1651	0.5295	0.5890	-0.0488	-0.0656	-0.0047	0.1907	-0.0470	-0.0047	0.0003	-0.5293	-0.1352
2017	0.1891	-0.1803	0.4654	0.4679	-0.0514	-0.0705	-0.0050	0.1280	-0.0502	-0.0050	0.0003	-0.5192	-0.1156
2022	0.1476	-0.1888	0.3936	0.3733	-0.0499	-0.0698	-0.0049	0.0903	-0.0493	-0.0049	0.0002	-0.4860	-0.0989
2027	0.1186	-0.1920	0.3296	0.3019	-0.0460	-0.0655	-0.0045	0.0672	-0.0461	-0.0045	0.0002	-0.4413	-0.0858
2032	0.0976	-0.1919	0.2778	0.2492	-0.0411	-0.0596	-0.0041	0.0525	-0.0419	-0.0041	0.0002	-0.3945	-0.0760
2037	0.0819	-0.1901	0.2373	0.2104	-0.0362	-0.0533	-0.0037	0.0428	-0.0377	-0.0037	0.0002	-0.3508	-0.0686

Sourse: Simulation result. Other Agri means other agriculture.

Each value is computed by (Value in Simulation/Value in Baseline Model) - 1. See Table 3 for an example.

5.3.2 Economic Adjustments

Since for given conditions of the base model, the lower level of precipitation implies less recharge into aquifers, more energy is required to withdraw the same amount of groundwater as the case of average rainfall in the baseline model. This leads to an upward pressure on the demand for energy and resulting energy demand for irrigation is potentially 30%, 13% and 7% higher than the corresponding baseline value in 2007, 2017 and 2027, respectively. As the price of energy rises over time, the energy demand tends to reduce its rate of increasing and approaches in 30 years to the level which could be 4% higher than the baseline model. The higher energy demand by irrigation use is accompanied initially by 75% higher energy price than the baseline value. The energy price could be still 33% higher than the base value in 20 years. Energy price changes relative to the base analysis is the way in which a drought directly affects the rest of the economy. The indirect effects are through changes in the employment of labor and capital in agriculture that spills over to other sectors as these factor markets re-equilibrate. The energy price hike, thus directly hurts the manufacturing production and hence, the production of manufacturing could drop to almost a half of the base value in the initial period. Comparing to the baseline model, the manufacturing production could stay significantly lower than baseline model by 52%, 44% and 35% in 2017, 2027 and 2037, respectively.

In contrast, the agricultural sectors may not be damaged as badly as manufacturing because of the electricity subsidy that protects farmers from the soaring energy cost in the base model. Of course, the subsidy is a tax upon the rest of the economy's households which affects negatively their level of expenditure and saving. Irrigated water that is applied to rice production is possibly 5% to 7% lower than the base value throughout the period while irrigated water use by wheat farmers is almost unchanged from the base value for the entire study period. Therefore, a prolonged drought tends to impose additional stress on manufacturing which is not protected from the rise in energy prices. In other words, a weather shock accompanied by the policy advantage to agriculture is likely to impair nonagricultural sectors which are not directly affected by weather changes. Over time, the energy price decelerates as energy demanded by irrigation decreases though it could be still 21% higher than the base value in 2037. Thus, a continuous drought condition has an adverse effect on the economy as whole. In the current case, Punjab GSDP could be 13% lower than the initial value in the base model and could approach to the level 7% lower than the base value in 30 years.

Table 6: Simulation 2 (Drought)-Resource Allocation

Year	Capital	Capital Share				Labor	Labor Share			
	Stock	Rice	Wheat	Other Agri	Manufacturing	Income	Rice	Wheat	Other Agri	Manufacturing
2007	-0.2862	0.1511	0.1813	0.3038	0.3103	-0.1294	0.1380	0.1171	0.6331	0.1092
2012	-0.2618	0.1647	0.2134	0.3159	0.2466	-0.1151	0.1451	0.1331	0.6354	0.0838
2017	-0.2289	0.1725	0.2397	0.3143	0.2103	-0.0998	0.1508	0.1483	0.6273	0.0708
2022	-0.1960	0.1765	0.2599	0.3041	0.1943	-0.0860	0.1559	0.1624	0.6129	0.0661
2027	-0.1679	0.1784	0.2750	0.2899	0.1907	-0.0747	0.1605	0.1751	0.5954	0.0661
2032	-0.1454	0.1790	0.2861	0.2746	0.1942	-0.0657	0.1648	0.1864	0.5771	0.0689
2037	-0.1278	0.1789	0.2942	0.2597	0.2014	-0.0588	0.1687	0.1963	0.5590	0.0732

Source: Simulation result. Capital stock and labor income are relative to the baseline model (See Table 2).
All others are in the sectoral proportion of Punjab's production factor in the simulation.

5.3.3 Resource Reallocation

A drought induces further economic adjustments in the resource allocation process. The total capital employed in Punjab production sectors likely to decrease significantly. Table 6 indicates that Punjab capital is lower than the base value in the initial period. It remains below base solution levels possibly by 23%, 17% and 13% for the years 2017, 2027 and 2037, respectively. This suggests that capital tends to pour out of Punjab into the rest of India over the entire period. Some farm equipment, such as tractors and vehicles, can be employed, at least part time, in non-farm activities. While the level of each sector's capital use is lower than the base model, the fall in manufacturing capital is most significant. In the baseline model, almost a half of the Punjab's total stock of capital is employed in manufacturing in the initial period. In the base line model, the share of total capital employed in manufacturing could be larger than all other sectors in Punjab. However, in the drought simulation, the share of capital accounted for manufacturing could drop to about 30% of total Punjab capital stock initially, and relative to the base-line analysis manufacturing's share of capital continues to decline over time. In 2037, its share only amounts to 20% of Punjab capital being employed in manufacturing.

This decline in manufacturing capacity tends to be greater than the decline in resources employed in agriculture. The share of total Punjab capital stock in wheat and other agricultural production exceeds, in contrast to the base analysis, the share of capital employed in manufacturing. Punjab labor force also tends to move out of the manufacturing sector. The labor share in manufacturing is 21% of Punjab labor initially in the base analysis and could fall to 11% of Punjab labor in the simulation while labor share in the production of rice and wheat is slightly higher than the baseline value. Therefore, while a drought could cause a downturn in the Punjab economy, we find that agriculture counters the effect of a drought by consuming more electricity to help sustain crop yields, although they decline somewhat, and mostly for rice. However, the consumption of limited electricity supplies makes electricity less available to the manufacturing sector, which surprisingly, bears the brunt of the drought effects. The drought also causes an increase in the exploitation of the aquifer, lessening the time when it is only profitable to withdraw water at the rate of recharge. This rate is sped up by the electricity subsidy.

6. Conclusion

This study develops a methodology for evaluating the impact of economic activity and policy (here, electricity subsidies) on natural resource dynamics, by integrating ecosystem services (groundwater in the current case) into the process of economic and policy decision making. Our results suggest that groundwater dynamics in the Punjab region of India have economy-wide implications. We construct, and fit to data, a dynamic general equilibrium model in which aquifer hydrology dynamics in the Punjab region and capital accumulation across India are endogenous. Within this context, the relative magnitude of groundwater use is carefully evaluated in order to understand the effects, over time, of groundwater resources on Punjab and the broader Indian Economy. The model predicts Punjabi aquifer depletion – defined as a point where water withdrawal cannot profitably exceed recharge – will trigger economic adjustments in both the regional and national economy. From the Punjab perspective, the unsustainable extraction of groundwater encourages the employment of agricultural labor and other farm inputs at levels in excess of those that would be employed if groundwater was extracted at rates that sustain the capacity of the aquifer. Thus, it is almost certain that aquifer depletion would lead to an eventual decline in farm employment and a sharp fall in returns to land that serves as a main source of Punjabi farm profits.

Beyond the farm, the production of food staples at unsustainable levels tends to maintain a regional economy of food marketing, food processing and ancillary economic activities, all of which are likely to face large contractions with employment declines (and possible out-migration of workers from the region) when groundwater is depleted. In recent years, India has been an exporter of wheat and rice, the foreign exchange earnings of which have been used to pay for the imports of machinery and other industrial goods. These goods help the economy to increase the productivity of labor and foster growth in per capita income. The decline in wheat and rice production as the aquifers in the Punjab region are depleted will cause the country to risk the loss of this source of foreign exchange earnings. Moreover, the loss of this production of staple crops will likely force the economy to allocate more resources toward staple food production in other regions of the country and, possibly, away from other sectors of the economy. While the projected decline in irrigated crop production in Punjab alone appears not to be significant enough to jeopardize the national economy, a number of other Indian states also appears to be over-exploiting their aquifers. They are likely to experience the rise in the cost of irrigation as in Punjab. Therefore, with "business as usual," the resource reallocation attributable to unsustainable aquifers will almost surely increase, and affect economic growth at the national level.

Our analysis suggests the fundamental economic issues of groundwater use require developing a deep understanding of the direct and indirect economic impacts of resource (e.g., water and electricity) linking the irrigated to other sectors of the economy since they compete for economy-wide resources (e.g., labor and capital) and benefit from intermediate resource linkages. Given the current policy of subsidizing electricity to farmers, the analysis focuses on economic and natural resource (ecosystem service) consequences assuming the policy continues and then, examines the potential gains and distribution of those gains if the policy were terminated. The results suggest a once and for all elimination of the subsidy would have undesirable impacts on Punjabi agriculture in that higher electricity costs would likely make energy costs too high for many farmers, driving them out of grain production.

We also investigate the likely effects of an extended drought on Punjab agriculture and the rest of the economy. Assuming electricity is fully subsidized, our result suggests that the drought speeds up the depletion of aquifers while protecting farmers from otherwise soaring energy costs. The rest of the economy, however, bears the burden of this protection by paying higher electricity costs and experiencing lower productivity. Thus, the measured gross state domestic product in this case is likely to fall leaving resources in the hand of less productive agricultural sectors. Without future positive climate shocks wet hydrological periodicities that can offset the effects of drought, the depth to aquifers is forever deeper thus raising the cost of energy subsidies into the future generations.

Our next step is to examine the economic impact of other policies likely to decrease groundwater extraction to rates that lead to an acceptable level of aquifer sustainability, and at what rate should these policies be phased in over time. We could also evaluate the effects of farmers adopting more efficient water allocation technologies, or their effects of producing less water consuming crops. A water user right contract that is provided to each farmer is an instrument that facilitates the purpose of efficient water allocation. The contract endows the farmer with the right to withdraw a given amount of groundwater. This amount would likely be less than the amount of water the farmer has historically withdrawn. This limitation would be required to sustain the aquifer. However, the farmer could "rent out" all or part of his contract to other farmers. That is, those farmers who are more efficient are willing to pay the price to rent the contract. In this way, water is allocated to its highest marginal product, and the less efficient farmer is appropriately compensated, thus lessening resistance to a policy that seeks to sustain open access to the aquifer. Malik *et al*. (2008) show that with shared groundwater irrigation systems which are operationally equivalent to the informal arrangement of water rights in a small area in Punjab, farmers are willing to allocate more water to crops that are economically efficient and use it more efficiently for the chosen crops than individual owners of wells. The amount of water which the farmers in shared systems can access through the well is rationed by restricted power supply. Extending enforcement of tradable property rights in groundwater to other regions helps greatly reduce over-drafting of groundwater. Recognizing water resource concerns for present and future generations, the current study provides a sound basis to evaluate the human activities within sustainability constraints of natural resource and economic systems and to formulate more efficient water management options.

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8. Appendix

Figure A1: Depth to water table (*m*)

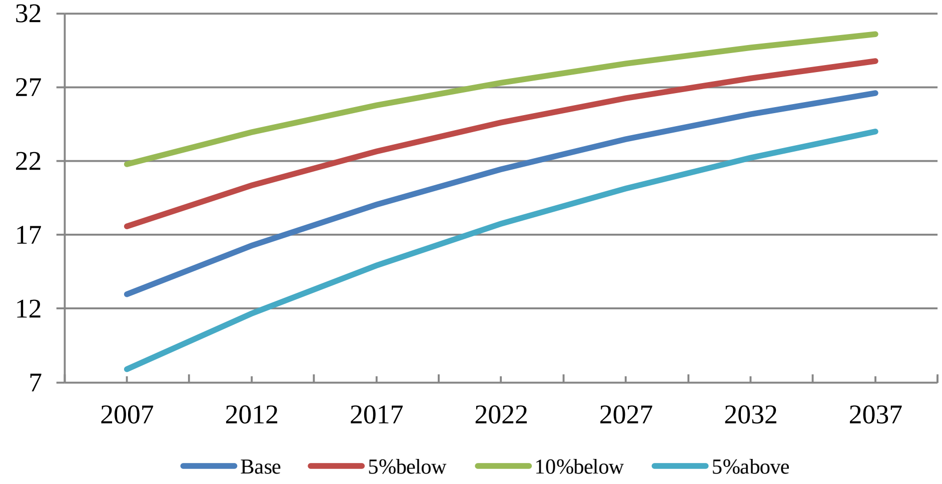

Table A1: Social Accounting Matrix (SAM) for Punjab & Rest of India (ROI)

			Activity											Commodity							Factors							Agents (AG)		Accumulation		Trade	
			Punjab						Rest of India (ROI)												Labor (L)		Cajpital (K)		Land (T)		Rain	Household (HH)		(AC)			
			Rice	Wheat	ROA	Manuf	Energy	Water	Rice	Wheat	ROA	Manuf	Service	Rice	Wheat	ROA	Manuf	Energy	Water	Service	Punjab	ROI	Punjab	ROI	Punjab	ROI		Punjab	ROI	Punjab	ROI		Total Receipt
	p	Rice												16																		2,289	2,305
A	u	Wheat													6																	3,438	3,445
c	n	ROA														624																4,801	5,426
t	j	Manuf															6,293																6,293
i	a	Energy																691															691
v	b	Water																	546														546
i		Rice												1,046																		19,605	20,651
t	R	Wheat													415																	13,793	14,208
y	O	ROA														40,040																124,614	164,654
	I	Manuf															203,431																203,431
		Service																		717,527													717,527
C		Rice																										16	1,046				1,062
O		Wheat																										6	415				421
M		Roa																										624	40,040				40,664
M		Manuf																										2,313	148,364	3,494	224,094		378,265
O		Energy				367		324																									691
D	T	Water	420	126																													546
I	Y	Service																										11,015	706,513				717,527
F	L	Punjab	481	480	2,416	1,571	598	10																									5,555
A		ROI							12,172	9,315	92,373	52,721	418,385																				584,965
C	K	Punjab	432	609	950	3,658	93	77																									5,818
T		ROI							2,424	1,112	27,591	150,711	299,143																				480,981
O	T	Punjab	972	2,230	2,059	697		10																									5,969
R		ROI							6,055	3,781	44,690																						54,526
S		Rain						126																									126
A	H	Punjab																			5,555		5,818		5,969		126						17,469
G	H	ROI																				584,965		480,981		54,526							1,120,471
	A	Punjab																										3,494					3,494
	C	ROI																											224,094				224,094
Trade																	168,540																168,540
TotalExpenditure			2,305	3,445	5,426	6,293	691	546	20,651	14,208	164,654	203,431	717,527	1,062	421	40,664	378,265	691	546	717,527	5,555	584,965	5,818	480,981	5,969	54,526	126	17,469	1,120,471	3,494	224,094	168,540	4,950,361

ROA = Rest of Agriculture; Manuf = Manufacturing

Table A2: Sectoral Cost Share of Input - Punjab

	Sector			
	Rice	**Wheat**	**Other Agri**	**Manufactruing**
Labor	0.255	0.145	0.445	0.265
Capital	0.229	0.183	0.175	0.617
Land	0.516	0.672	0.380	0.118

Table A3: Sectoral Cost Share of Input - Rest of India

	Sector			
	Rice	**Wheat**	**Other Agri**	**Manufactruing**
Labor	0.589	0.656	0.561	0.259
Capital	0.117	0.078	0.168	0.741
Land	0.294	0.266	0.271	

Table A4: Baseline Model - Rest of India

Year	GDP	Capital	Wage	Supply of Output				
				Rice	Wheat	Other Agri	Manufacture	Service
2007	1,093,309	3,708,515	527,220	25,046	18,127	199,305	331,400	543,403
2012	1,338,381	5,279,058	612,475	19,012	12,800	151,718	511,286	631,246
2017	1,591,668	6,944,897	707,689	14,556	9,137	116,478	674,775	715,738
2022	1,847,136	8,673,607	809,040	11,357	6,679	91,110	822,865	795,735
2027	2,099,774	10,433,561	913,067	9,071	5,029	72,938	957,308	870,752
2032	2,345,730	12,195,778	1,017,029	7,422	3,904	59,801	1,079,713	940,633
2037	2,582,210	13,935,125	1,118,903	6,213	3,119	50,151	1,191,355	1,005,398

Sourse: Simulation result; Unit in 2007 US million dollars. Other Agri means other agriculture.