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Impact of Water Management on Agricultural Production

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ABSTRACT

This paper explores the impact of water management on output, labor, and capital growth for an agriculture-based developing economy like Pakistan. According to empirical findings, capital stock and labor force in the agriculture sector significantly affect output growth. Improvement of capital stock in the form of mechanization, improved seeds, fertilizers and pesticides on one hand, and labor force skills, techniques and management, on the other hand, will bring positive and significant impact on agricultural output. Any improvement in policy management by authorities will enhance agricultural production manifold. Water at farm gate, tube wells, and access to credit of farmers increase agricultural output by enhancing the productivity of capital and labor. Proper water management will result in efficient allocation of resources and has an indirect positive impact on growth of output. To increase overall efficiency, an irrigation technology that efficiently uses water for intensive crop production must be developed.

INTRODUCTION

Agriculture is an important sector of Pakistan's economy. It is almost wholly dependent on irrigation, as irrigated land supplies more than 90 percent of agricultural production. It also provides a living to 66 percent of the country's population. Agriculture absorbs 44 percent of the employed labor force. It accounts for 21 percent of GDP, and contributes 11 percent to export earnings. This sector supplies raw materials to the manufacturing sector and

provides market for manufactured products. The average annual growth of about 4 percent in the last four decades has been sustained by technological progress through the use of high-yielding varieties of grains, public investment in irrigation, agricultural research, and physical infrastructure (Ali 2004; Government of Pakistan 2008). While the transition to an urban and industrial economy should continue, agriculture will remain central to the well-being of people in Pakistan.

Agricultural growth is linked with availability of water resources. Pakistan is one of the world's most arid countries, having an average rainfall of less than 240 millimeters (mm) a year. The population and the economy depend on the annual influx of about 180 billion cubic meters of water into the Indus river system. The water comes from neighboring countries and the snow-melt of the Himalayas. Better water management is key to improving agricultural productivity, which results to lower levels of poverty due to improved rural employment and non-farm opportunities. Increased attention to efficient water management is also crucial to meeting the future demand for domestic and commercial agricultural products (World Bank 2004).

Globally, water is becoming a scarce commodity. In the next 25 years, more than a quarter of the developing world's population will face severe water scarcity. Equitable access to water of various sectors and utilization of this scarce resource will require improvements to achieve efficiency. In the agricultural sector, water-use efficiency is a potential criterion for improving yield under water stress. It evaluates the depth and method of water application and how it is absorbed by the crop. In this regard, to match water demands, water should be stored when amount river flow varies.

Compared with other arid countries, Pakistan has very little water storage capacity. Some developed countries, like the United States and Australia, have over 5,000 cubic meters of storage capacity per capita. Its neighboring country China, has 2,200 cubic meters, whereas Pakistan has only 150 cubic meters of storage capacity per capita¹.

According to studies, the increase in the supply of irrigation water is the most

important factor for the agricultural production breakthrough in Pakistan. Additional water supply is also available from the Mangla and Turbala dams which helped increase the area of winter crops. The output-augmenting effects of water from tube wells were observed which indicate that increase in irrigation water supply led to increased use and efficiency of traditional inputs like land, labor and livestock and the non-traditional inputs like chemical fertilizers and high-yielding crop varieties (Wizarat 1981; Nutly 1972).

In Pakistan, water-use management in agriculture is important because irrigation water resources and rainfall are limited. The future of the country's agriculture depends on its irrigation and drainage systems. However, they face major problems such as increasing water logging, salinity, overexploitation of fresh groundwater, low efficiency in delivery and use, inequitable distribution, unreliable delivery, and insufficient cost recovery. The future strategy for irrigation and drainage requires an efficient, self-sustaining, and improved water management system (Faruquee 1997).

In addition, increases in energy prices have an effect on water management, and will do even more in the future by pushing up the costs of pumping water, manufacturing fertilizers, and transporting products. These will have implications on access to water and irrigation, especially for the poor or marginal farmers. Agricultural water management is not only goal but is part of a process on resource management that provides key inputs to agricultural production and farmer incomes.

In Pakistan, the World Bank has been the largest source of assistance for agricultural and rural development. World Bank-funded projects

include a range of structural and nonstructural measures to harness, control, and manage surface and groundwater to improve agricultural production. These measures have involved varied combinations of irrigation, drainage and flood control, water conservation and storage, on-farm water management, and institutional support to improve sustainability. The On-Farm Water Management (OFWM) Program was initiated in 1976-77 to implement a water conservation strategy at farm level. With major financial assistance from the Bank, 15,128 watercourses have been improved and 3,711 irrigation schemes have been installed by the year 2008-09. The Water Management Research Centre was also created in 1991-92 to promote resource conservation technologies like watercourse improvement, precision land leveling, and high efficiency irrigation techniques.

This article has three main purposes: (1) to provide a quantitative analysis of the role of water management in agricultural growth, (2) to determine the empirical effects of water management on capital accumulation, and (3) analyze the quantity and quality channels of water management and how it can affect agricultural output growth. The quantity channel refers to the effect of water management on agricultural output growth rate through capital growth, while the quality channel refers to the effect of water management on agricultural output growth rate through labor force productivity. This is a significant contribution to literature because a better understanding about the magnitude of the effects of water management on growth through quantity and quality channels can influence agricultural policy.

This study also aims to develop a methodology that may aid managers in designing irrigation facilities and in determining the land area for crops by factoring in weather and climate uncertainties of the affected region. From this,

a decision tool can be developed for allocating limited available water among competing crops during the critical production period that will maximize the economic returns to the producer.

Water management and agriculture production are interrelated, but earlier studies focused only on one or the other, thus, the results 'under bound' their true value. Most of the empirical research on water management and agriculture growth predates the new generation of theoretical models, recent contributions gave limited attention to the measurement of water managements, and failed to address measurement issues. In this study, we have dealt with both aspects simultaneously, and have used subcategories of water management to be able to deduce clearer policy implications. The formulation used is an improvement over previous empirical studies on the influence of water management on agricultural growth.

The rest of the paper is presented as follows: the next section discusses the general framework of analysis; this is followed by an explanation of the data and methodology used in the study, and a presentation of the main empirical results. The final section sums up the discussion with concluding remarks and policy implications.

GENERAL FRAMEWORK OF ANALYSIS

The agricultural sector is affected by capital and labor force growth and development, and is measured by productivity. Furthermore, community support and participation, and measures to increase efficiency and sustainability of water resources, explain cross-country variations in agricultural growth. Effective irrigation and drainage systems contribute to increase in food production, rural employment generation, and increase in farmers' incomes. A sound agricultural water management system minimizes production risks, boosts output,

¹ To augment its water storage capacity, Pakistan had to invest in costly (and contentious) new large structures such as the Kalabagh dam.

and provides incentives for farmers to invest in other inputs and agronomic improvements which, in turn, help enhance labor and capital productivity. To observe the empirical effects of water management, a model is designed in accordance with the law of production.

One specific production function widely used in economic analysis is the Cobb-Douglas production function with constant return to scale (Chiang 1974).

$$Y_t = AK_t^\alpha L_t^{1-\alpha} \quad (1)$$

where A is a positive constant, and α is a positive fraction.

The logarithmic transformation of the production function provides a log-linear form, which is commonly used in econometric analysis by using linear regression techniques. The analysis employs a general form of the function that allows estimation of coefficient values and statistical testing of hypotheses on return to scale.

Taking the natural log of both sides of the above equation:

$$\ln Y = \ln A + \alpha \ln K + (1 - \alpha) \ln L \quad (2)$$

Observing that Y , A , K and L change over time, and to account for the growth process, we take the derivative of this log-linear form (with respect to time yields) and the following differential equation:

$$(1/Y)dY/dt = (1/A)dA/dt + \alpha(1/K)dk/dt + (1 - \alpha)(1/L)dl/dt \quad (3)$$

Or alternatively,

$$\dot{Y}/Y = \dot{A}/A + \alpha\dot{K}/K + (1 - \alpha)\dot{L}/L \quad (4)$$

where $\dot{}$ denotes the instantaneous rate of change over time; Y is output in the agriculture sector, K is a measure of flow of capital input, and L is the measure of the flow of labor input in period t . By imposing constant return to scale (CRS), it is only necessary to estimate α , effectively avoiding any potential problem of collinearity in estimation. The imposition of restriction of the CRS without testing it is econometrically unsatisfactory, so Wald test can be used to test the true value of the parameter based on the sample estimates.

Equation (4) indicates that the growth rate of aggregate output \dot{Y}/Y is equal to the weighted average of the growth rate in physical capital \dot{K}/K and growth rate of labor \dot{L}/L , plus the growth rate of technology (also known as total factor productivity). According to the objective of our study, we first analyze the impact of water management on each component of the above equation, and the impact of water management on output growth. In empirical analysis, we specify the following linear relationships:

$$\dot{L}/L = \alpha_0 + b^*W + c^*T + d^*E + e^*C + U \quad (5)$$

$$\dot{K}/K = \alpha_0 + \beta^*W + \gamma^*T + \delta^*E + \varepsilon^*C + V \quad (6)$$

Equation (5) estimates the impact of the following on the growth rate of labor force productivity: water at farm gate (W), number of tube wells (T), electricity (E), and credit (C) employed in agriculture, where:

α_0 measures the exogenous component of labor force productivity attributes to pure exogenous technological progress,

b measures the effect of water at farm gate growth,

c measures the effect of tube wells on labor force growth,

d indicates the effect of electricity used for water pumping on labor force growth, and

e measures the effect of credit on labor force growth.

Likewise, equation (6) estimates the impact of the same variables (b , c , d , and e) above on growth rate of capital productivity where:

α_0 indicates the exogenous growth in per worker capital that cannot be attributed to any of the variables in the equation, while

β , γ , δ and ε show the effect of water at farm gate, number of tube wells, electricity use, and credit on the growth rate of per worker capital, respectively.

U and V represent random productivity shocks in labor force growth and the random fluctuations in capital growth respectively.

Finally, the model of this study is represented by equations 1 to 6.

There are also public policy implications from the above formula. Thus, if public policy is being considered to stimulate the growth of real output, one needs to take these “exponents” into account in assessing the relative impacts of policies on the growth of input or productivity on the subsequent growth of real output.

DATA AND METHODOLOGY

To study the impact of water management on output, labor and capital growth on a developing and agriculture-based economy like Pakistan, the study chose a time-series data set of thirty years for Pakistan from 1977 to 2006. This is long enough to capture the long-run effect.

The study utilized different indicators to analyze the impact of water management on agricultural production. These are:

- growth rate of agricultural production at constant factor cost;
- capital stock in agriculture sector measured in millions of rupees;
- agriculture labor force measured in millions;
- total water availability at farm gate calculated in million acre feet;
- total number of public and private tube wells in agricultural production;
- supply of agricultural credit from formal institutions in millions of rupees; and
- consumption of electricity in agriculture sector measured in gigawatt hours.

These statistics were drawn from the annual issues of the Pakistan Economic Survey conducted by the Finance Division (Government of Pakistan 1980-2008), and the Agricultural Statistics of Pakistan conducted by the Ministry of Food, Agriculture and Livestock (Govt. of Pakistan 1980 to 2007).

Following Arellano and Bond (1991), Arellano and Bover (1995), Blundell and Bond (1997), the generalized method of moments (GMM), wherein the levels of instruments form the moment conditions for the equation, were used. The GMM is a generalization of the classical method of moments. A key in GMM is a set of population moment conditions derived from the assumptions of the econometric model. Given the data on the observable variables in this study, GMM finds values for the model parameters such that corresponding sample moment conditions are satisfied.

Specifically, if the causality problem between water management and output growth in agriculture are not settled, the random term

will be correlated with independent variables which create simultaneity biases. The proposed estimation procedures are: (1) the sector specific effect is eliminated in the equation with first difference; (2) for the equations in levels, we use appropriate the instrument to tackle this problem. We follow the second method using the software EViews 7 (Econometric Views), a statistical package for Windows for time series-oriented econometric analysis. In this method, lagged values are used as instrument in the regression analysis. The model (4-6), estimated by the GMM procedure, generated consistent and efficient coefficient estimates. The use of GMM is also called for in the light of simultaneity in these equations.

EMPIRICAL FINDINGS

Using the Cobb-Douglas specification, the study estimated the result by imposing restriction of CRS on production function. The regression result shows that R-squared is 0.84, indicating that 84 percent of the variations in total agricultural growth is explained by the growth rates of labor and capital. The empirical finding of the model in Table 1 indicates that capital stock and labor force used in agriculture sector affect output growth significantly.

The analysis also demonstrates that if capital stock (mechanization and improvement in seeds, fertilizers and pesticides) and labor input (skills, techniques and management) are improved with time, they bring a more positive impact on output.

In Table 2, the effect of water management on agricultural output growth via quantity and quality channels were analyzed. The quantity channel refers to the effect of water management on output growth rate through capital growth. R-square at 0.42 indicates that 42 percent of the variations in total capital is explained by the four independent variables. Water at farm gate, credit access of farmers, and presence of tube wells increase agricultural productivity by enhancing capital productivity.

On the other hand, electricity affects output growth negatively by decreasing capital productivity. Cost of electricity in Pakistan has been continuously rising, making it increasingly difficult for farmers to afford it.

The quality channel refers to the effect of water management on agricultural output growth rate through labor force employed in the sector (Table 2). It has a value of R-square 0.83, indicating that 83 percent of the variations in total labor force are explained by the independent variables.

Water availability at farm gate and tube wells increase agricultural output by enhancing productivity of the labor force. Note that credit availability seems to have a dominant impact compared with other variables in the model. Credit can enable the farmers to manipulate their expenditure patterns to maximize their output. The results also show that more use of electricity (at rising costs) affects output growth negatively, by decreasing labor productivity, although this variable shows a low coefficient value.

The imposition for restriction of the CRS without testing is econometrically unsatisfactory. To check if there is CRS or not, the study estimates without applying restrictions and applying the Wald test on the empirical findings. The result is to reject the null hypothesis that there is CRS (Tables 3 and 4). This means that output response is not proportional to change in inputs. Water at farm gate, tube wells, and credit positively affect capital and labor growth rates and outweigh the negative impact of electricity. Thus, the net effect of these variables shows an increasing return to scale.

From this analysis, it can be concluded that the future of Pakistan's agriculture depends on

the status of its irrigation and water management systems. Water supply, and agricultural growth can be expanded by improving the efficiency of the existing system because irrigated land accounts for 76 percent of total agricultural area and contributes more than 90 percent to the total value of agricultural production.

Water resources are becoming limited with little potential of increase in irrigated areas. The rigid system design and inadequate drainage, low delivery efficiency and inequitable distribution of water, water logging and salinity, and overexploitation of groundwater in fresh areas are major problems in Pakistan's irrigation system.

Improving the irrigation system to attain efficiency requires substantial improvement in water management, increased water supply, and demands better financial, managerial, and technical planning. With good water management, proper allocation of resources results to agricultural output growth.

Improved irrigation also alleviates poverty, benefiting the poor in several ways: (1) poor farmers benefit from production increase, enabling them to increase their own consumption

Table 1. The effect of growth in labor force and capital on agriculture growth

Variable	Parameter Estimate
Intercept	26.53 (16.91)*
Growth rate of labor	19.34 (16.47)*
Growth rate of capital	7.86 (03.22)*
R ²	0.84

Note: The t-values marked * are significant at 1 percent confidence level.

Table 2. Effect of water management on capital growth and labor force growth rates

Variable	Capital growth rate (Quantity channel)	Labor force growth rate (Quality channel)
Intercept	-26.83 (2.68)**	-2.645 (-3.72)*
Water at farm gate	41.70 (3.18)*	0.16 (18.20)*
Tube wells	0.033 (5.10)*	3.60 (5.82)*
Credit	0.039 (1.66)***	2.63 (1.45)***
Electricity	-4.13 (-4.11)*	-0.006 (-9.37)*
R ²	0.42	0.83

Note: The t-values are significant at the following confidence levels: *1 percent; ** 5 percent; *** 10 percent

Table 3. The effect of labor and capital growth rates on agricultural growth (with restriction of CRS)

Variable	Parameter estimate
Intercept	39.38 (3.63)**
Growth rate of capital	39.85 (10.65)*
R ²	0.43

Note: The t-values are significant at the following confidence levels: * 1 percent; ** 5 percent.

Table 4. The effect of water management on capital growth and labor force growth rates (with restriction of CRS)

Variable	Capital growth rate	Labor force growth rate
Intercept	-26.83 (2.40)**	-2.645 (-2.37)*
Water at farm gate	41.70 (2.79)**	0.16 (11.78)*
Tube well	0.033 (5.46)*	3.60 (8.78)*
Credit	0.039 (1.48)***	2.63 (1.57)***
Electricity	-4.13 (-3.89)*	-0.006 (-6.6)*
R ²	0.78	0.73

Note: The t-values are significant at the following confidence levels: * 1 percent; ** 5 percent; *** 10 percent

or to produce surplus of marketable products, thereby, increasing their farm income; (2) small farmers and landless laborers benefit from agricultural employment opportunities and higher wages; and (3) the rural and urban poor benefit from related growth in the rural and urban non-farm economy. High crop yields from irrigated areas lead to adequate and stable agricultural output, resulting in lower prices that benefit consumers, particularly the poor. Even so, it is the total package that matters for effective poverty alleviation and not just the supply of irrigation water. Investments in improved

irrigation system may not reduce poverty directly in any significant way unless accompanied by other complementary interventions.

Higher use and better mix of inputs like water, improved seeds, fertilizers, and the like also necessitate funds at the disposal of farmers. These funds can come from savings or credit. In less developed countries like Pakistan, savings are negligible among small farmers thus, agricultural credit and modern or appropriate technology are vitals input for higher productivity.

Agricultural credit also plays an important role in water management strategy to achieve

water efficiency. Most of the improved water management strategies increase the agricultural sector's output growth. Its impact is stronger than the others if its directly accessed by farmers. Only farmers' access to electricity affects production negatively. Most farmers are poor and can hardly afford this input that increases their cost of production.

No country has been successful against rural poverty without developing a progressive agriculture sector. Agricultural societies are mostly dependent on efficient water management, good drainage and, in some areas, flood protection to prevent crop damage. Such a sound water management strategy helps secure increased agricultural production, that results to a more stable economy.

CONCLUSION

The study analyzed the impact of water management on output, labor and capital growth for developing an agriculture-based economy like Pakistan. The analysis is based on government agricultural and economic data sets covering thirty years from 1977 to 2006, while the methodology is based on the GMM procedure.

The empirical findings show that capital and labor force affect output growth significantly. Capital stock, in the form of mechanization and improvement in seeds, fertilizers and pesticides; labor skills, techniques and management, if improved with time, will definitely bring positive and significant impact on agricultural output.

This paper also analyzed the effect of water management on agricultural output growth via quantity and quality channels. The quantity channel refers to the effect of water management

on agriculture output growth rate through capital growth, while the quality channel refers to the effect of water management on agricultural output growth rate through agricultural labor productivity. Water at farm gate, credit access, and adequate tube wells boost agricultural productivity by enhancing productivity of capital and labor. Use of electricity affects output growth negatively, by decreasing capital and labor productivity. Its ever increasing cost make it difficult for small farmers to continue using this input resource.

To increase overall efficiency, an irrigation technology that aims for water efficiency must be developed and promoted. In general, efficient use of water in agricultural production can be achieved by substantial public sector investments in controlling water logging and salinity, and in promoting optimal use of the existing water supply. The current policy on extending agricultural credit is a welcome development, especially for small farmers who do not usually have access to this vital input. To further ensure a sustainable irrigated agriculture, institutions like the On-Farm Water Management Programme and Water Management Research Center should be strengthened to formulate a comprehensive set of measures for the development and management of the country's limited water resources.

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