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ECONOMIC RETURNS TO OPERATION AND MAINTENANCE EXPENDITURE IN DIFFERENT COMPONENTS OF THE IRRIGATION SYSTEM IN PAKISTAN

Muhammad A Chaudhry and Mubarik Ali

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ECONOMIC RETURNS TO OPERATION AND MAINTENANCE EXPENDITURE IN DIFFERENT COMPONENTS OF THE IRRIGATION SYSTEM IN PAKISTAN

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1. INTRODUCTION

Pakistan's agricultural sector is presently confronted with a major challenge: how to increase production to the levels required to feed a population growing at an annual rate of more than 3 per cent. In general, agricultural production can be increased by either expanding the irrigated cropped area or by raising the crop yields. The possibilities of developing more land and new surface water supplies in the short run are remote as it would require huge capital investments and strong soil protection measures. Therefore, the most reliable way to increase irrigated cropped area and yield is to generate additional water supplies through groundwater development schemes, better management, and efficient operation and maintenance (O&M)[1] of various components of the existing irrigation system.

The national average yield of major crops is at present far below their production potential (Muhammad, 1982). Overall scarcity of water, non-availability of water at the right time, and inefficient utilisation of available water appear to be the leading factors restricting expansion in irrigated acreage and causing the gap between actual and potential yield levels.

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[1] Operation and maintenance includes the management of water supplies and upkeep of system facilities from the water source to the farmer's fields. Operation means the allocation and delivery of water supplies, including the management of any storage facilities, and the handling of drainage runoff. Maintenance is the upkeep of irrigation and drainage structures, embankments, dams, outlets and channels and the removal of silt and vegetation from canal and storage facilities (Easter, 1985).

The Government of Pakistan (GOP) has attempted to improve the performance of the irrigation system by implementing a series of irrigation development programmes. Consequently, the situation with respect to overall water availability has improved. However, the system is still confronted with the twin problems of low operational efficiencies and high distributional inequities (Chaudhry, 1986).

2. THE PROBLEM

Once an irrigation system is working, its O&M play a critical role in determining the growth of the agricultural sector. In agriculture, poor O&M will result in

- below capacity working and/or to erratic water supplies which in turn lower the area cultivated and depress yields
- a shift to lower value crops
- lower investment in yield enhancing variable inputs such as fertiliser
- reduced on-farm investments (Carruthers, 1981).

In Pakistan, many of these negative consequences of inefficient O&M are already in evidence. Therefore, substantial investments are being made to rehabilitate badly deteriorated segments of the irrigation system.

The public irrigation infrastructure is rapidly deteriorating because of continuous deferred maintenance. Inadequate maintenance of the canals results in frequent breaches and consequent interruptions in water supplies. The ability to carry out maintenance is inhibited, to a major degree, by financial constraints Financial constraints appear to be more binding because the revenues generated by the system have not kept pace with rising O&M costs; the latter have increased due to the positive relationship between system's deterioration rate and the age of the system (Chaudhry, 1986). Existing investments are therefore becoming

unproductive, and future investments are likely to suffer from the same set of problems. The constantly increasing demand for irrigation water, properly distributed in time and space, underscores the need to reform economic policies that tend to result in allocation of less funds for O&M activities.

Tight budgetary constraints and the very high opportunity cost of capital policy mean choices need to be made regarding the relative amounts to allocated for O&M of different components of the irrigation system. Investment in all components of the system may not be equally productive. Moreover, since O&M of a large irrigation system, as in the case of Pakistan, is an expensive activity, it is important to ascertain the social productivity of such investments. Research related to such policy choices would not only be useful to those making O&M allocation decisions at government level, but also to those international agencies providing financial and technical assistance to Pakistan in improving its irrigation system's performance.

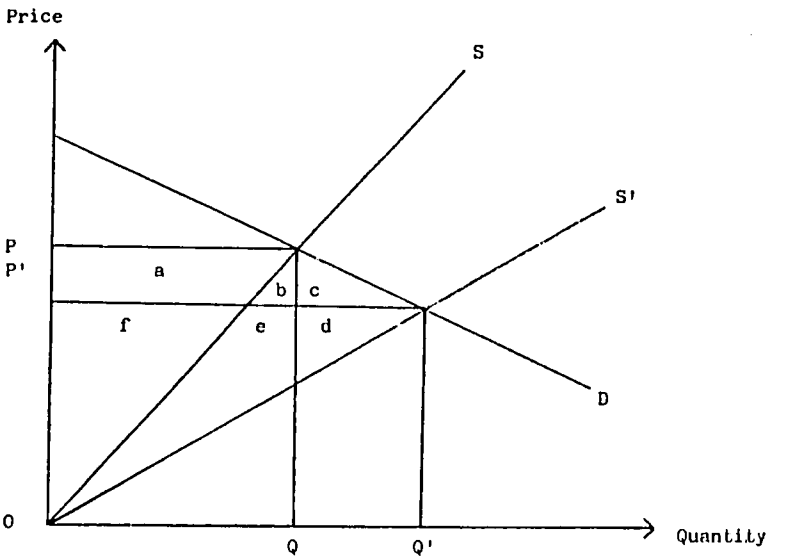
An econometric model has been developed in this paper to estimate the contributions of recurring investments, made for O&M of the irrigation system, to agricultural productivity. The estimated parameters have been used to simulate the effects of various O&M investment scenarios on agricultural output, farm prices, and gross income. The study is restricted to the irrigated areas of Punjab province because of its dominance in Pakistan's agriculture.

3. ANALYTICAL FRAMEWORK

3.1 Theoretical framework

The contribution of various conventional and non-conventional inputs to agricultural production can be measured by using the production function. However, the production function approach is confronted with a possible simultaneous equation bias problem (Hoch 1958; Lau and Yotopoulos, 1971). Also, problems of data and multicollinearity limits the usefulness of

Fig 1: Hypothetical impact of an increase in O&M spending on agricultural production



this approach (Binswanger, 1975; Braha and Tweeten, 1986). These problems can be avoided if indirect functions such as profit, cost, or supply are employed to estimate the contribution of various inputs in output.

The productivity model employed in this study is analogous to a supply function and is expressed as a function of the prices paid for variable inputs and received for agricultural output and the quantities of the fixed inputs of production. Instead of irrigated land, we have treated irrigation infrastructure as the fixed input because we were interested in estimating returns to investment in O&M activities. Expressing fixed inputs in their flow values generally yield statistically superior results (Yotopoulos, 1967). As such, the flow value of the irrigation infrastructure is defined in terms of the amount spent for O&M of the system.

It is hypothesised that an increase in O&M spending would increase the agricultural production through increases in both irrigated area and per acre yield. This would shift the supply curve rom S to S' in Figure 1, lowering the equilibrium prices from P to P' and raising output from Q to

Q'. Net social benefits of this shift in the supply curve can be estimated as follows:

gain to consumers would equal the difference between consumer surpluses at prices P and P': (a+b+c)

losses to producers would equal the difference between producer surpluses at prices P and P': a-(d+e)

losses to taxpayers (farmers) would equal: O&M budget

net gains to society would equal the difference between gain to consumers and loss to producers and taxpayers: (b+c+d+e)-(O&M).

It is assumed that funds for O&M activities would come mainly from farmers in the form of water charges. The producers will be better off as long as the cost savings from productivity gains, measured by area (d+e), exceed losses in total receipts which would be equivalent to area (a) in Figure 1.

3.2 The productivity model

The following model was used to estimate the contribution of various inputs to total agricultural production.

1. $\ln PIND_t = \ln A + b_1 \ln OMC_t + b_2 \ln OMGTW_t + b_3 \ln OMPTW_t + b_4 \ln PR_t + \ln U_t$

where

$PIND_t$ = Agricultural index in year t with 1971=100. This is computed through Laspeyre's formula: (sum $(q_t * p)$/sum $(q_0 * p_0)$)*100;

OMC_t = Operation and maintenance expenditure on canal system (million rupees). The expenditures are deflated by GDP deflator, with 1971=100;

$OMGTW_t$ = Operation and maintenance expenditure on government tubewells (million rupees). The expenditures are deflated by GDP deflator, with 1971=100;

$OMPTW_t$ = Operation and maintenance expenditure on private tubewells (million rupees), expressed in 1971 prices;

PR_t = Parity price ratio (prices paid/prices received);

ln = natural logarithm;

U_t = Disturbance term.

The subscript t refers to time period, while A (conglomeration of shifters) and b_i's are parameters to be estimated.

The data with respect to operation and maintenance costs of the canal system and government tubewells in Punjab Province were obtained from the provincial irrigation department (PID) files and various issues of the non-development budget (NDB) documents. O&M cost of private tubewells for each year were calculated by multiplying the total number of tubewells in that year with the average O&M cost of a tubewell in the year 1971. In order to account for O&M cost variations in electric and diesel tubewells, proper weights were assigned while calculating average O&M cost for the year 1971. Data regarding prices paid and received by the farmers for inputs and outputs, respectively, were taken from Tweeten (1985) and Qureshi et al, (1985).

3.3 The simulation model

A simulation model is employed to trace the effects of an exogenous increase in O&M spending on agricultural output, farm prices, and gross income. In order to portray market equilibrium conditions, both supply and demand functions have been incorporated in the model. Similar models with varying assumptions have been used by Tweeten and Quance (1972), Yeh (1976), White and Havelicek (1982) to evaluate the impact of public expenditure in different non-conventional inputs on agricultural productivity. Economic outcomes are simulated in response to changes

both in demand and supply parameters to reflect different possible market conditions.

The reduced form of the demand and supply equations can be written in double log form as follows:

$$[2] \quad \ln Qd_t = \ln Ad + bd \ln PPt + (1 - rd) \ln Qd_{t-1} + rd_i \sum_{i=to}^{t} gd_i$$

$$[3] \quad \ln Qs = \ln As + bs \ln PR_t + (1 - rs) \ln Qs_{t-1} + rs_i \sum_{i=to}^{t} gs_i$$

where:

Qd, Qs = Quantities demanded and supplied, respectively;

PP, PR = Prices paid by customers and received by producers, respectively; these are equilibrium prices and are net of inflation;

gd, gs = Rates of shift of demand and supply in the ith year;

bd, bs = Short-run price elasticities of demand and supply, respectively;

rd, rs = Co-efficients of adjustments towards equilibrium in demand and supply, respectively;

Ad, As = Constant terms in Ordinary Least Squares demand and supply equations, respectively.

A number of economic parameters can cause a shift in demand and supply curves. The demand curve can shift due to an increase in population growth rate, per capita income, export demand and similar other parameters, During the last ten years, population, per capita income, and agricultural exports grew at an average annual rate of 3.13, 3.15, and 2.02 per cent, respectively. On the other hand, agricultural imports

also grew at an average annual rate of 4.7 per cent during the same period. If this trend persisted, it would offset some of the effects of parameters causing an outward shift in demand curve. Moreover, increased emphasis on education is also expected to slow down population growth a bit. Since various economic parameters can cause a simultaneous shift (upward or down ward) in the demand curve, three demand scenarios (low, moderate or high) were exogenously applied to the model. Low, moderate and high demand scenarios assumes an annual shift of 1.5, 3.0 and 4.5 per cent in the demand curve, respectively.

Similarly, a supply curve can shift due to a variety of reasons. However, O&M spending on the irrigation system is the only component of gs considered in this study. Three scenarios of O&M spending considered in the simulation are: annual growth rates of 5 per cent, 10 per cent, and 15 per cent. However, it is assumed that O&M spending would increase simultaneously on all components of the irrigation system. Annual growth rate in the productivity index between two time periods emerging from an increase in O&M spending on different components of the irrigation system can be written as:

$$[4] \quad \ln (PIND_t/PIND_{t-1}) = B_t \ln(O\&M_t/O\&M_{t-1})$$

Replacing gs_t in equation [3] by RHS of equation [4], the following supply function is obtained:

$$[5] \quad \ln Qs_t = \ln As + bs \ln Ps_t + (1-rs) \ln Qs_{t-1} + rs \sum_{t=t_0}^{t} bi \ln(O\&M_t/O\&M_{t-1})$$

It is evident from equation [5] that supply shift is the cumulative effect of O&M spending on different components of the irrigation system over time. Equations [2] and [5] are used to simulate equilibrium output, farm prices, and gross income under alternative demand and supply scenarios.

4. RESULTS AND DISCUSSION

The model in equation [1] was used to measure the contributions of funds spent for operation and maintenance of different components of the irrigation system to agricultural productivity. The model was fitted by OLS to data for 1966-1986. The Durbin-Watson statistics of 1.94 suggests no serial correlation in the model. The correlations between independent variables were low and insignificant, except between OMGTW and OMPTW where r = 0.93. According to Hu (1973) "if economic theory suggests that a variable should be included in the function, then one may have to leave the variable in the equation, although it contributes to multicollinearity problem.."

Results of the model are reported in Table 1. The constant term and co-efficient of OMPTW were significant at 1 per cent probability level; whereas co-efficients of OMC and PRATIO were significant at 5 per cent probability level. The co-efficient of determination (R^2) was 0.91; indicating that the model explained the variation in agricultural productivity extremely well.

Table 1: Regression results indicating contribution of O&M spending in different components of the irrigation system to agricultural productivity in Punjab province

lnA	lnOMC	lnOMGTW	lnOMPTW	lnPRATIO	R^2	D.W
.671*	0.308**	0.004	0.358*	-0.40**	0.91	1.94
(0.609)	(0.19)	(0.084)	(0.10)	(0.157)		

Figures in parentheses are standard errors.

* Co-efficient is significant at 0.01 probability level.

** Co-efficient is significant at 0.05 probability level.

The results with respect to O&M investment elasticities indicate that a 10 per cent increase in O&M expenditures on canals, public tubewells, and private tubewells would increase agricultural productivity by 3.08 per cent, 0.04 per cent and 3.58 per cent, respectively. The elasticity of PIND with respect to PRATIO was -0.40.

In order to assess the relative profitability of increased O&M investments in different components of the irrigation system, marginal products (MP) of past O&M investments are estimated by using the following equation.

[6] $$MPi_t = bi(PIND/O\&Mi)_t$$

where bi is the elasticity of PIND with respect to O&M investments, and $(PIND/O\&Mi)_t$ is the average productivity of O&M investments in period t for ith component of the irrigation system. If PIND is expressed in terms of the value of output in equation [6], it would directly yield the value of marginal product (VMP), or the marginal benefit of O&M investments made in different components of the irrigation system.

Historical estimates of marginal benefits to O&M investments in canals, public tubewells and private tubewells are given in Table 2. Marginal benefits to past O&M investments in canal system were highest and were followed by those in private and public tubewells, respectively. In the case of canal system, marginal benefits to past O&M investments were significantly greater than unity, and showed an increasing trend, suggesting the need to allocate more funds for O&M of the canal system.

However, marginal benefits to past O&M investments in public and private tubewells were found to be declining over time; exhibiting the law of diminishing returns from O&M investments[2]. The MVP figures estimated above are high but seem plausible in view of the fact that the irrigation infrastructure is assumed as given, which means that the capital costs are not accounted for.

Higher marginal benefits to past O&M investments in canal system suggest that agricultural production can be increased at a relatively faster rate by increasing O&M investments in this component of the irrigation system.

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[2] Marginal benefits from past investments in different components of the irrigation system were regressed against the time variable to see their trend over time. The co-efficients for canal, public tubewells, and private tubewells were 0.0179, -0.0437 and -0.0644, respectively. All co-efficient were significant at 1 per cent probability level.

Table 2: Historical estimates of marginal benefits to O&M investments in different components of the irrigation system in Punjab province, 1966-86

Year	Marginal benefits per Rupee of O&M investment to		
	Canals	Public tubewells	Private tubewells
1966	11.58	0.59	15.15
1967	14.90	0.76	13.60
1968	15.19	1.15	13.10
1969	16.42	0.84	12.42
1970	20.39	0.69	11.92
1971	17.93	0.40	9.71
1972	18.70	0.57	9.53
1973	19.08	0.43	8.76
1974	22.60	0.40	8.00
1975	18.81	0.44	6.60
1976	20.24	0.36	6.84
1977	20.99	0.41	6.43
1978	21.02	0.47	6.51
1979	23.54	0.35	6.63
1980	24.36	0.29	7.03
1981	26.94	0.27	7.01
1982	20.06	0.27	6.87
1983	21.38	0.28	7.20
1984	15.72	0.19	5.06
1985	19.29	0.26	6.37
1986	20.66	0.29	6.81

(Figures expressed in 1971 Rupees)

Marginal benefits to past O&M investments in private tubewells, although showing a decreasing trend, are significantly greater than unity, indicating that it is still profitable to increase O&M investments in private tubewells. This can be done by increasing the total number of tubewells or enhancing the utilisation rate of existing tubewells. However, benefits of increased O&M spending on private tubewells would be

reaped mainly be tubewell owners who are few relative to the size of the whole farming community. Contrarily, increased O&M investments in canal system would yield benefits not only for large number of farmers, but these benefits would be distributed equitably as well. This, however, should not be interpreted as increased O&M investments being directed towards the canal system at the cost of private tubewells. Both systems are independent and have their own unique roles to play in increasing agricultural production.

Marginal benefits to past O&M investments in governments tubewells are very low. One possible explanation for insignificant relationship between agricultural productivity and O&M investments in public tubewells might have been the fact that the dependent variable was developed for the whole province; whereas the benefits of public tubewells are reaped only in certain geographic pockets. In view of the tight budgetary constraints, and continuously increasing O&M requirements for the public tubewells, the government has decided to divest these tubewells to private sector in fresh groundwater zone. The ongoing transition programme should be pursued cautiously - the public tubewells should be shut down only as they are replaced by alternative pumping facilities. Otherwise, waterlogging problems may become more serious.

5. PROJECTED ECONOMIC OUTCOMES

Economic outcomes of alternative shifts in the agricultural supply curve due to assumed annual growth in O&M investments are simulated under low, moderate, and high demand scenarios. In the supply equation [5], a short run elasticity of 0.40, as estimated by equation [1], is used. The long run price elasticity estimated by various studies and reported in Qureshi et al (1985) and Tweeten (1985) has been argued to range from 0.40 to 1.50. In the present study, a long run elasticity of 1.0 and lag parameter of 0.40 are used. On the demand side, price elasticity for major agricultural crops in Pakistan has been reported to range between -0.3 to -0.70 (Hamid et al, 1987). The present study assumes a short run elasticity of -0.29 and lag parameter of -0.20.

The model's projected economic effects follow the outcomes hypothesised in Figure 1: for a given demand scenario, increased O&M spending increases output (supply), which lowers prices. However, the combined effect of lower prices and higher output is higher farm income. Contrarily, when annual growth in O&M investments is held constant, and demand for agricultural output is increased, all of the selected variables tend to move in the same direction (upward).

Simulated economic outcomes under assumed demand and supply conditions are shown in Table 3. The maximum annual growth rates in output (14.10 per cent) and gross income (10.10 per cent) are registered when O&M outlays increases at the rate of 15 per cent annually under high demand

Table 3: Annual growth rates of simulated economic outcomes under alternative demand and O&M investment scenarios in Punjab province, 1988-2000

Demand scenario*	Annual growth in O&M investment**	Variables (% per year)		
		Output	Prices	Gross income
Low	5%	4.87	-0.12	4.66
	10%	7.82	-1.24	5.22
	15%	11.32	-2.14	5.79
Moderate	5%	5.74	0.42	6.49
	10%	8.91	-0.78	7.14
	15%	12.66	-1.75	7.79
High	5%	6.68	1.01	8.6
	10%	10.07	-0.28	9.35
	15%	14.10	-1.33	10.10

* Annual growth rate under low, moderate and high demand scenarios is assumed to be 1.5, 3.0, and 4.5%, respectively.

** Assume annual growth in O&M investment in canals, public tubewells, and private tubewells at the same time.

Table 4: Marginal benefits to increased O&M investments in different components of the irrigation systems under alternative demand scenarios in Punjab province, 1988-2000

Annual growth in O&M investment	Year	Canal system			Government tubewells			Private tubewells		
		Low demand	Moderate demand	High demand	Low demand	Moderate demand	High demand	Low demand	Moderate demand	High demand
5%	1988	20.09	20.38	20.66	0.29	0.29	0.29	3.94	3.99	4.05
	1992	20.50	21.65	22.87	0.29	0.31	0.32	4.02	4.24	4.48
	1996	18.83	20.84	23.07	0.27	0.30	0.33	3.69	4.09	4.52
	2000	16.83	19.55	22.72	0.24	0.28	0.32	3.30	3.83	4.45
10%	1988	17.81	18.06	18.31	0.25	0.26	0.26	3.49	3.54	3.59
	1992	15.20	16.05	16.96	0.22	0.23	0.24	2.98	3.15	3.32
	1996	11.81	13.08	14.47	0.17	0.19	0.21	2.32	2.56	2.84
	2000	8.96	10.41	12.09	0.13	0.15	0.17	1.76	2.04	2.37
15%	1988	15.86	16.08	16.31	0.23	0.23	0.23	3.11	3.15	3.20
	1992	11.42	12.06	12.74	0.16	0.17	0.18	4.24	2.36	2.50
	1996	7.57	8.38	9.27	0.11	0.12	0.13	1.48	1.64	1.82
	2000	4.91	5.70	6.62	0.07	0.08	0.09	0.96	1.12	1.30

* Annual growth rate under low, moderate and high demand scenarios is assumed to be 1.5, 3.0 and 4.5%, respectively.

scenario. Under this situation, prices decline at an annual rate of 1.33 per cent. Maximum depression in prices received (2.14 per cent yearly) would occur when O&M outlays are increased at an annual rate of 15 per cent under the low demand scenario. Our results indicate two ways of meeting increased demand for agricultural output: increased O&M outlays, or let farm prices rise. In the former case, increased O&M would cause the agricultural output to increase through ensured and timely availability of water; whereas in the latter case, agricultural output would increase as a result of a more efficient allocation of available resources by the farmers.

Since there are three scenarios both for demand and supply, there are nine possible market combinations. Perhaps the more realistic scenario is - annual increase of 5 per cent in financial outlays for O&M activities subject to an annual shift of 3 to 4 per cent in demand. This scenario seems plausible because financial outlays for the public irrigation system have increased at an annual rate of about 5 per cent in real terms during the last five years; whereas on the demand side, population and per capita income have grown at an average rate of 3.1 and 3.15 per cent, respectively, during the last ten years. Under this scenario, output, prices and gross income would grow at an annual rate of 5.74, 0.4 and 6.49 per cent, respectively.

During the projected period, marginal benefits to additional O&M investments are highest in the canal system, and are followed by those in private and public tubewells, respectively (Table 4). For a given O&M investment level, marginal benefits exhibit a positive relationship with the demand level because higher demand causes the prices to go up. Contrarily, when the demand is constant, marginal benefits from additional investment show a declining pattern because increased output lowers the prices. Under the most realistic scenario, marginal benefits to O&M investment in canal system would go down from Rs 20.38 in the year 1988 to Rs 19.55 in the year 2000. Projected estimates of marginal benefits indicate that it would be profitable to continue making increased O&M investments in canal system and private tubewells during the projected period. The profitability of additional O&M investments in the canal system not only suggests the need to allocate more funds for O&M activities, but to generate these funds by raising water charges too.

6. CONCLUDING REMARKS

Increases in agricultural production can be realised by increasing O&M investments in the canal system and private tubewells. Increased O&M spending in canals would result in less frequent canal breaches and also savings of water losses occurring as a result of continuous deferred maintenance. The end result, however, will be availability of higher and more reliable water supplies. Increased O&M investments in private tubewells can be made either by increasing the total number of tubewells or enhancing the utilisation rate of existing tubewells - both options eventually translate into increased water availability.

The estimates of marginal benefits to past and prospective O&M investments in canals and private tubewells are significantly greater than unity; suggesting the need to allocated more funds for O&M of these components of the irrigation system. High returns to O&M investments as reflected in increased agricultural production provides a sound basis to the state to enhance water charges, thereby making O&M a self financing activity.

In practice, it is always difficult for the government to enhance water charges on a yearly basis. This underscores the need to develop an automatic mechanism that would minimise administrative costs and discourage political manipulation of the process. Since output prices are reviewed by the government every year and inflation rates are not too high as well, the possibility of indexing the water charges with output prices may be considered.

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