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Measuring Benefits to Operation and Maintenance Expenditure in the Canal Irrigation System of Pakistan: A Simulation Analysis

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(Accepted 27 February 1989)

Abstract

Chaudhry, M.A. and Ali, M., 1989. Measuring benefits to operation and maintenance expenditure in the canal irrigation system of Pakistan: a simulation analysis. *Agric. Econ.*, 3: 199–212.

Estimates regarding benefits to O&M investments help rationalize financial allocation decisions. A distributed lag model is used to estimate the contribution to agricultural productivity of funds utilized for O&M of the canal system in Pakistani Punjab. Estimated parameters are used to simulate the effects of alternative O&M investment scenarios on agricultural output, farm prices and income. Marginal benefits to past and prospective O&M investments in the canal irrigation system were found to be fairly high, suggesting the need to allocate more funds for O&M of the canal system. Results indicate that O&M investments yield substantial gains to both producers and consumers, implying that funds required for O&M activities could be generated by taxing both these segments of society.

Introduction

Once an irrigation system is working, its operation and maintenance (O&M)¹ play a critical role in determining the growth of the agricultural sector. In agriculture, poor O&M will lead to below-capacity working and/or to erratic water supplies which will in turn reduce the area cultivated; it will depress yields; it will result in a shift to lower-value crops; it will lower investment in yield-

¹Operation and maintenance includes the management of water supplies and the upkeep of system facilities, from the water source to the farmer's fields. Operation means the allocations and delivery of water supplies, including the management of storage facilities, and 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).

enhancing variable inputs such a fertilizer; and it will reduce on-farm investments (Carruthers, 1981). In Pakistan, many of these negative consequences of inefficient O&M are already in evidence.

Pakistan has the largest contiguous irrigation system in the world. The Indus river and its major tributaries supply about 100 million acre-feet (MAF) or 123 350 million m³ of surface water through an irrigation network comprising three major reservoirs, 19 barrages/headworks, 12 link canals, and 43 canal commands. The Indus system also includes over 13 000 public tubewells and about 200 000 private tubewells, which pump about 34 MAF (42 000 m³) annually. The total length of the canal system which delivers surface water supplies to the farmers is about 40 000 miles or 64 000 km with watercourses, field channels, and field ditches running for another 1 million miles (1.6 million km).

The canal system is deteriorating rapidly because of continuously 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. In order to offset the negative impacts of deferred maintenance, the Government of Pakistan (GOP) and the donor agencies are providing US\$118 million to rehabilitate severely deteriorated portions of the system (Wolf, 1986).

Tight budgetary constraints and the very high opportunity cost of capital suggest that the state make rational decisions regarding inter-sectoral and intra-sectoral allocation of funds. Marginal returns to investment for sectors competing for a higher share of the available financial resources can serve as an economic criterion to make budgetary decisions. Since O&M of the canals is an expensive activity, and other components of the irrigation system such as dams, public tubewells, and drainage facilities actively compete with the canals for a large share of the total irrigation O&M budget, it is important to ascertain the social productivity of such investments. Research related to such policy choices would be useful to those making O&M allocation decisions at a government level, and the donor agencies providing financial and technical assistance to Pakistan for improving its irrigation system's performance.

An econometric model has been developed in this paper to estimate the contributions to agricultural productivity of recurring investments made for O&M of the canal irrigation system. The estimated parameters have been used to simulate the effects of various O&M investment scenarios on agricultural output, farm prices, and gross income. Social welfare impacts of alternative O&M investment level have been quantified. The study was undertaken for the Punjab province because of its dominance in Pakistan's agriculture. During the last 5 years, the Punjab's average share in Pakistan's total irrigated area and total O&M budget was 71 and 61%, respectively.

1. Analytical 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 (Lau and Yotopoulos, 1971). Also, problems of data and multicollinearity limit the usefulness of this approach (Binswanger, 1975). These problems can be avoided if indirect functions such as profit, cost, or supply functions are employed to estimate the contribution of various inputs to 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 fixed production inputs. Instead of including irrigated land as an input, we have treated canal infrastructure as a fixed input because our objective was to estimate returns to investment in O&M activities. Expressing fixed inputs in their flow values generally yield statistically superior results (Yotopoulos, 1967). The flow value of irrigation infrastructure is defined in terms of the amount spent for O&M on the canal system.

It is hypothesized that an increase in O&M spending would increase agricultural production through increases in both irrigated area and per-acre yield², raising the output and lowering the equilibrium prices. Consumers would definitely gain because of lower prices, while producers would gain only if an increase in output is greater than what is required to offset the impact of depressed prices. Society would be better off as long as the gains to consumers are greater than the loss to producers and taxpayers. It is assumed that funds for O&M activities would come from taxpayers (most likely farmers) to obtain gains from increased agricultural production.

1.1 Productivity model

The following model was used to estimate the contribution of various inputs to agricultural output:

$$\ln \text{PIND}_t = \ln A + \sum_{j=1}^{n+1} v_j \ln \text{OMC}_{t-j+1} + b_1 \ln \text{PR}_t + b_2 \text{TECH}_t + \ln U_t \quad (1)$$

where PIND_t is the agricultural productivity index in year t , with 1971 = 100, computed through Laspeyre's formula:

²Higher O&M spending would reduce the possibility of frequent canal breaches and improve the delivery efficiency of the system. This would result in larger and more timely availability of irrigation water.

$$[\text{sum } (Q_i P_0) / \text{sum } (Q_0 P_0)] \times 100$$

and OMC_{t-j+1} is operation and maintenance expenditure on canal system (million Rs.; US\$1 = Rs. 21); the expenditures are deflated by the GDP deflator, with 1971 = 100; TECH_t represents technology (captured through a trend variable); PR_t is the parity price ratio (prices paid/prices received); and U_t is the disturbance term. The subscript t refers to time period, and j represents the lag on OMC. A and b_i 's are parameters to be estimated.

The productivity index was constructed using production and prices of wheat, rice, cotton, maize, and sugarcane crops. These crops represent more than 80% of Punjab's total agricultural production. The crop production data were obtained from various issues of the Agricultural Statistics of Pakistan. The data with respect to output prices were the same as used by Tweeten (1985). The O&M costs data were taken from the provincial irrigation department (PID) files and various issues of the non-development budget (NDB) documents. We have used the input price index³ developed by Qureshi et al. (1985) on the basis of the market prices of six major inputs: seed, fertilizer, electricity, pesticides, water, and transportation.

1.2 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 are incorporated in the model. The aggregate supply and demand equations employed in the model are similar to those used by Tweeten and Quance (1972), Yeh (1976) and White and Havlicek (1982). 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:

$$\ln Q_d = \ln A_d + b_d \ln P_{dt} + (1 - r_d) \ln Q_{dt-1} + r_d \sum_{i=t_0}^{t-1} g_{di} + g_{dt} \quad (2)$$

$$\ln Q_s = \ln A_s + b_s \ln P_{st} + (1 - r_s) \ln Q_{st-1} + r_s \sum_{i=t_0}^{t-1} g_{si} + g_{st} \quad (3)$$

where Q_d and Q_s are quantities demanded and supplied, respectively; P_d and P_s are prices paid by consumers and received by producers, respectively (these are equilibrium prices and are net of inflation); g_d and g_s are rates of shift in

³Expenditure on each input relative to total expenditure on all inputs was used to assign a weight to each of the inputs to calculate the aggregate input price index.

demand and supply in the i th year; b_d and b_s are short-run price elasticities of demand and supply, respectively; r_d and r_s are coefficients of adjustments towards equilibrium in demand and supply, respectively; and A_d and A_s are constant terms in demand and supply equations, respectively.

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 10 years, population, per-capita income, and agricultural exports grew at an average annual rate of 3.13, 3.15 and 2.02%, respectively. On the other hand, agricultural imports are growing at an average annual rate of 4.7%, which are likely to offset some of the effects of parameters causing an outward shift in the demand curve. Since various economic parameters can cause a simultaneous shift (upward or downward) in the demand curve, three demand scenarios (low, moderate, high) were exogenously applied to the model. Low, moderate, and high-demand scenarios assume an upward annual shift of 1.5, 3.0 and 4.5% in the demand curve, respectively.

Similarly, a supply curve can shift due to a variety of reasons. However, O&M spending on the canal irrigation system is the only component of g_s considered in this study. Three scenarios of O&M spending considered in the simulation are: annual growth rates of 2, 4 and 6%. Annual growth rate in the productivity index between two time periods emerging from an increase in O&M spending on the canal irrigation system can be written as:

$$\ln(\text{PIND}_t/\text{PIND}_{t-1}) = \sum_{j=1}^{n+1} (v_j - v_{j-1}) \ln \text{OMC}_{t-j+1} \quad (4)$$

Replacing g_{st} in equation (3) by right-hand side of equation (4), and letting all constant terms be represented by $\ln C$, the following supply function is obtained:

$$\begin{aligned} \ln Q_{st} = & \ln C + b_s \ln P_{st} + (1 - r_s) \ln Q_{st-1} + r_s \sum_{i=t_0}^{t-1} \sum_{j=1}^{n+1} (v_j - v_{j-1}) \ln \text{OMC}_{i-j+1} \\ & + \sum_{j=1}^{n+1} (v_j - v_{j-1}) \ln \text{OMC}_{t-j+1} \end{aligned} \quad (5)$$

It is evident from equation (5) that supply shift is the cumulative effect of O&M spending on the canal 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.

2. Results and discussion

2.1 Estimation of productivity model

The model in equation (1) was fitted by OLS to provincial data for 1966–1986. The hypothesis of non-autocorrelated disturbances was rejected in favor

TABLE 1

Parameter estimates of distributed lag model indicating contribution of O&M spending on canal irrigation system to agricultural productivity in Punjab, 1966–86.

Explanatory variables	Regression coefficients
CONSTANT	3.093*** (0.943)
TECH	0.019** (0.009)
PR	−0.180** (0.078)
OMC _t	0.086
OMC _{t-1}	0.071
OMC _{t-2}	0.057
OMC _{t-3}	0.042
OMC _{t-4}	0.029
OMC _{t-5}	0.014
$\sum v_j, j=1, \dots, n+1$	0.299* (0.219)
R ²	0.94
Durbin–Watson Statistics.	1.89

Figures in parenthesis are standard errors.

*Coefficient is significant at 0.10 probability level.

**Coefficient is significant at 0.05 probability level.

***Coefficient is significant at 0.01 probability level.

of positive autocorrelation at the 0.05% level. Thus, autocorrelation was corrected by employing the Cochrane–Orcutt method. The correlations among independent variables were low and insignificant, except between TECH and PR where $r=0.93$.

While estimating (1), the number of lags on OMC was varied up to 10 under alternative assumptions of first, second and third-degree polynomial lag structure. We found that a 5-year lag period under the first-degree polynomial lag structure provided the results most consistent with theory and prior knowledge.

The coefficients of PR and TECH were significant at 5% probability level (Table 1). The coefficient of OMC was significant at 10% probability level. The coefficient of determination (R^2) was 0.94, indicating that the model explained the variation in agricultural productivity extremely well. Results with respect to O&M investment elasticities indicate that a 10% increase in O&M expenditures on canals in 1 year would increase agricultural productivity by 30% in 6 years. The productivity would be highest (8%) in the year the investment was made, followed by a declining trend, reaching a minimum of 1% in the 6th year.

2.2 Marginal returns to O&M investments

Following Knutson and Tweeten (1979), the marginal product (MP) of past investments made for O&M on the canal irrigation system is estimated using:

$$MP_j = v_j (PIND_t / O\&M_{t-j+1}) \quad (6)$$

where v_j is the elasticity of PIND with respect to O&M expenditure, and $(PIND_t / O\&M_{t-j+1})$ is the average productivity of O&M investment in period t . It is evident from (6) that MP_j is distributed over j lags in the same manner as the weights of the parameter on OMC_t are distributed. If PIND is expressed in terms of the value of output in (6), it would directly yield the marginal value product (MVP) of O&M investments made to run the canal irrigation system.

The marginal benefits to past O&M investments were significantly greater than unity and showed an increasing trend during the 1970's. Thereafter, MVP started declining in response to increased O&M spending, exhibiting the law of diminishing returns for additional investment. Summing equation (6) over the 5-year lag period yielded MVP of Rs. 19 in 1986. Since the returns are distributed over time, the present value of MVP discounted at 15 and 10% was estimated to be Rs. 14.60 and Rs. 12.95, respectively. The MVP figures seem plausible in view of the fact that the canal system's far-reaching network is responsible for producing more than 75% of the country's agricultural output and supplying 62% of the total irrigation water available at the farmgate. The value of O&M, in fact, is the maintenance of a very high percentage of the national product⁴ (McLoughlin, 1988).

Higher marginal benefits to O&M investments in canal system suggest the need to allocate greater financial outlay for O&M of this component of the irrigation system. This is particularly important since the financial allocation pattern in recent years has not favored O&M for canal irrigation. The data show that the share of total provincial irrigation O&M budget going to public tubewells has been consistently increasing as compared to that for canals⁵.

2.3 Parameters used in simulation

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 price elasticity of 0.18, as estimated by equation (1), is used. The long-run supply-

⁴In the absence of O&M, the system would become virtually inoperable which, in turn, would reduce the national economy markedly, increase its economic vulnerability and no doubt lead to social disorder (McLoughlin, 1988).

⁵This may not be interpreted to mean that more funds should be allocated for O&M of the canal system at the cost of public tubewells. We would like to emphasize that these systems are independent and have their own unique roles to play in increasing agricultural production.

price elasticity estimated by various studies and reported in Qureshi et al. (1985) and Tweeten (1985) ranges from 0.40 to 1.50. In the present study, a long-run supply elasticity of 0.51 and a lag parameter of 0.35 are used. On the demand side, price elasticity for major agricultural crops in Pakistan has been reported to range between -0.23 and -0.70 (Hamid et al., 1987). The present study assumes a short-run demand elasticity of -0.10 and a lag parameter of 0.25. Equations (2) and (5) were simultaneously solved to predict the equilibrium prices and quantities by using actual data for O&M activities from the period 1966–1986 under assumed demand conditions. Gross farm income is expressed in constant prices and is obtained by multiplying the equilibrium quantities by their 1986 prices.

2.4 Simulated economic outcomes

Reliability of the simulation model was tested by comparing the simulated values of selected variables for the past years with their observed values by using:

$$S = c + \beta A \quad (7)$$

where S represents simulated values, and A actual values. In the case of perfect fit, the model would result in $c=0$, $\beta=1$, and $R^2=1$. The hypothesis that $c=0$ and $\beta=1$ was not rejected at 70% and 90% confidence levels for output and gross income variables, respectively. In the case of prices, however, the margin of error was high as the hypothesis that $c=0$ and $\beta=1$ was not rejected at 15% and 1% probability level, respectively. R^2 was 0.95 for output, 0.74 for prices, and 0.93 for gross income. The high margin of error in the case of prices can be attributed to the fact that actual prices are set by the government, whereas predicted prices reflect the free-market situation. Some statistical discrepancies in data and random errors associated with the simulation might have resulted in a high margin of error as well.

The model's simulated economic outcomes are shown in Table 2. For a given demand scenario, increased O&M spending increases output (supply), which lowers prices. The price impact offsets part of the output impact, causing the gross farm income to decline. 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).

The maximum annual growth rates in output (10.72%) and gross income (3.45%) are observed when O&M outlays increase at an annual rate of 6% under the high-demand scenario. Under this situation, prices decline at a rate of 2.23% per annum. Maximum depression in prices received (3.44% yearly) would occur when O&M outlays are increased at an annual rate of 6% under the low-demand scenario.

Since there are three scenarios both for supply (O&M) and demand, there

TABLE 2

Annual growth rates of simulated economic outcomes under alternative demand and O&M investment scenarios in Punjab Province, 1990–2010.

Demand scenario	Annual growth in O&M investment (%)	Percent per year		
		Output	Prices	Gross income
Low	2	5.36	−3.05	−1.14
	4	5.88	−3.27	−1.42
	6	6.41	−3.44	−1.67
Moderate	2	7.16	−2.40	1.14
	4	7.77	−2.69	0.68
	6	8.39	−2.93	0.28
High	2	9.27	−1.49	4.85
	4	9.98	−1.89	4.12
	6	10.72	−2.23	3.45

are nine possible market solutions. Perhaps the most realistic scenario is an annual increase of 6% in financial outlay for O&M activities, subject to an annual shift of 3–4% in demand. This scenario seems plausible because assumed increases in financial outlays for the public irrigation system and population growth rate are consistent with the pattern observed in the recent past.

Under this scenario, the output index would increase from 132 in the year 1990 to 364 in the year 2010 (1986 = 100). During the same period, the price index would decline from 86 to 33, while the gross-income index would increase from 113 to 120. Marginal benefits to additional O&M investments in the canal system would go down from Rs. 16.33 in the year 1990 to Rs. 5.39 in the year 2010. Simulated estimates of marginal benefits indicate that it would be profitable to continue increasing O&M investments in the canal system during the simulation period. The profitability of additional O&M investments in the canal system not only suggests the need to allocate more funds to O&M activities, but also indicates that these funds could come from enhanced water charges.

3. Social welfare analysis

The welfare impacts of an increase in O&M investment are quantified by estimating the consumer and producer surpluses. An increase in O&M expenditures would shift the supply curve from S to S' in Fig. 1, causing the output to go up and price to decline. The consumers would gain from both increased supply and lower prices. In our simulation model, where supply and demand curves are assumed to shift simultaneously, gains to consumers would be the difference between the value of consumer surplus at two equilibrium solutions

PRICE

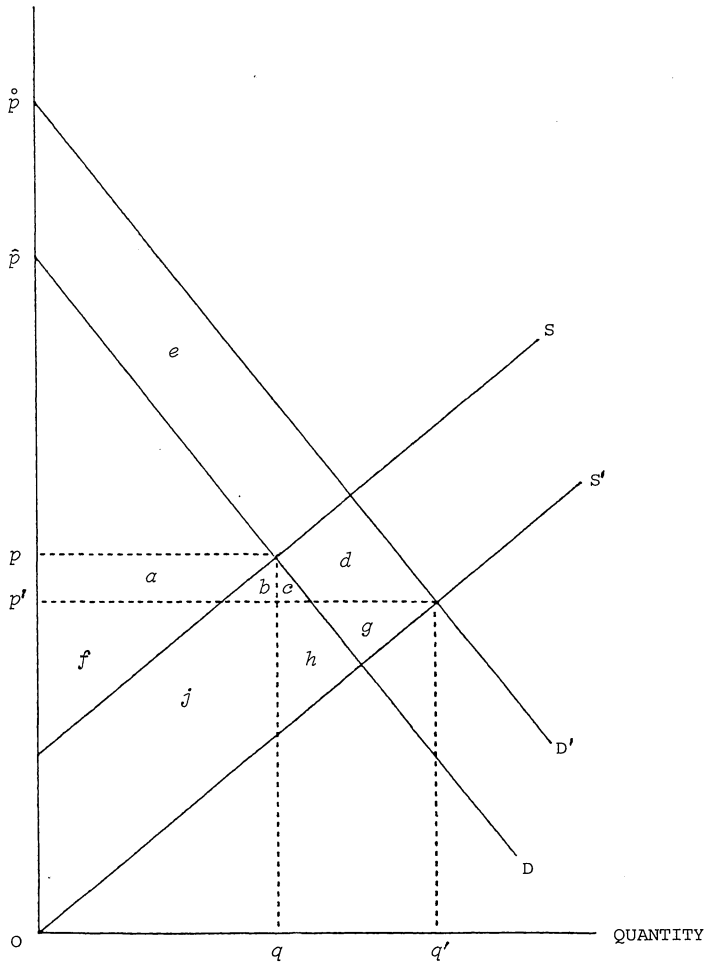


Fig. 1. Hypothetical impact of an increase in O&M spending on agricultural production.

corresponding to demand curves D and D' . This would be equal to area $[a+b+c+d+e]$ in Fig. 1, and is estimated by:

$$\int_{\bar{p}}^p [f(p) dp]_D - \int_{\bar{p}}^{p'} [f(p) dp]_{D'} \quad (8)$$

On the other hand, as a result of an expansion in output, producers may gain or lose depending upon whether the output or price impact is stronger, which is determined by the price elasticity. The gain or loss to producers would equal

the difference between producer surpluses at output q and q' . This would be equal to area $[a - (g + h + j)]$, which is measured by:

$$[pq - \int_0^q f(q) dq]_S - [pq' - \int_0^{q'} f(q) dq]_S \quad (9)$$

Losses to taxpayers (most likely farmers) would equal the O&M budget. Net gains to society would equal the difference between gain to consumers and loss to producers and taxpayers.

Since farmers (producers) represent about 39% of the population of Punjab province, they also gain as consumers. To account for this fact, equations (8) and (9) were adjusted accordingly⁶. It is estimated that under the moderate growth in demand and six percent annual increase in O&M spending (realistic scenario), net gains to society would increase from Rs. 2966 million in 1990 to Rs. 6315 million in the year 2010 (Table 3). This implies about 5.64% annual growth rate in net gains to society. Gains to consumers would increase from Rs. 1424 million in 1990 to Rs. 3936 million in the year 2010. During the same period, gain to producers would increase from Rs. 1595 million to Rs. 2550 million. The average annual growth rate in consumer and producer gains over the simulation period was estimated to be 8.8% and 3%, respectively.

Our analysis indicates substantial gains to both producers and consumers from increased financial outlays for O&M activities. This suggests that, in addition to producers who are the direct beneficiaries of improved O&M services, consumers should also be called upon to share part of O&M costs.

The price support programs should be tailored relatively more in favor of farmers; otherwise increases in output caused by higher levels of O&M investment would depress the prices to the extent that might worsen inter-sectoral terms of trade for agriculture. In the absence of such programs, the income distribution gap among the workers employed in agricultural and non-agricultural sectors would grow, leading to serious equity implications. Since a favorable price structure, in addition to an increase in O&M investment, causes the output to grow further, irrigated farmers could be taxed in the form of higher water charges⁷. Higher water charges would not only ensure recovery of a larger share of O&M costs, but would also reduce the income distribution gap between irrigated and non-irrigated farmers.

⁶Gains to producers = $(0.39) \times (8) + (9)$.

Gains to consumers = $(1 - 0.39) \times (8)$.

⁷Historically, water charges have not increased in the same proportion as output prices. This relationship, however, can be established by indexing the water charges with output prices. This mechanism would not only ensure automatic revision in water charges as output prices are revised/reviewed every year, but would minimize administrative costs and discourage political manipulation of the process.

TABLE 3

Social welfare impacts of increased O&M investments under alternative demand scenarios in Punjab-Province (figures in million Rs.)

Annual growth in O&M investment (%)	Year	Low demand				Moderate demand				High demand			
		Gain to consu- mers	Loss to produ- cers	O&M invest- ment	Net gain to society	Gain to consu- mers	Loss to produ- cers	O&M invest- ment	Net gain to society	Gain to consu- mers	Loss to produ- cers	O&M invest- ment	Net gain to Society
2	1990	1360	-1142	16	2486	949	-1772	16	2705	458	-2469	16	2911
	1995	1764	-650	18	2396	1499	-1467	18	2948	971	-2519	18	3472
	2000	1958	-707	19	2646	1921	-1643	19	3545	1438	-3044	19	4463
	2005	2171	-868	21	3018	2416	-1954	21	4349	2044	-3789	21	5812
	2010	2428	-1071	24	3475	3023	-2355	24	5354	2855	-4749	24	7580
4	1990	1576	-1064	34	2606	1193	-1681	34	2840	730	-2360	34	3056
	1995	1951	-654	41	2564	1751	-1440	41	3150	1307	-2455	41	3721
	2000	2155	-742	50	2847	2225	-1644	50	3819	1901	-2986	50	4837
	2005	2391	-937	61	3267	2790	-1991	61	4720	2682	-3741	61	6362
	2010	2683	-1179	74	3788	3490	-2439	74	5855	3726	-4725	74	8377
6	1990	1782	-993	53	2722	1424	-1595	53	2966	989	-2260	53	3196
	1995	2127	-661	71	2717	1988	-1422	71	3339	1623	-2403	71	3955
	2000	2342	-785	96	3031	2511	-1659	96	4074	2335	-2949	96	5188
	2005	2604	-1017	128	3493	3145	-2046	128	5063	3276	-3729	128	6877
	2010	2936	-1300	171	4065	3936	-2550	171	6315	4538	-4755	171	9122

Summary and conclusions

Efficient O&M of the canal irrigation system is one of the most important conditions for attaining required increases in agricultural production. Our results indicate that a 10% real increase in O&M expenditures on canal system in 1 year would increase agricultural productivity by 30% in 6 years. Estimates of marginal benefits to past and prospective O&M investments are significantly greater than unity, suggesting the need to allocate more funds to O&M on the canal system. However, since other components of the irrigation system such as dams, public tubewells, and drainage facilities compete with the canal system to have a share in the total provincial irrigation O&M budget, it is important to determine the economics of O&M in these components to make rational budgetary allocation decisions.

Increases in agricultural output can be realized by managing both supply and demand parameters. Under the most realistic demand and supply scenario, output and gross income would increase at an average annual rate of 8.39% and 0.28% respectively, over the simulated period. In contrast, prices would decline at a rate of 2.93% annually. As a result of these outcomes, net gains to society are estimated to increase at an average annual rate of 5.64%.

O&M investments yield substantial gains to producers and consumers as output is increased and prices are depressed, respectively. Therefore, in addition to producers who are the direct beneficiaries of O&M services, consumers should also be taxed to generate part of the funds required for O&M activities. The price support programs, targeted to favor producers, would provide an opportunity to finance O&M through enhanced water charges. Higher water charges would help bridge the income distribution gap between irrigated and non-irrigated farmers.

Acknowledgement

We acknowledge the useful suggestions made by Luther Tweeten and Robert A. Young on an earlier draft of this paper. The comments made by anonymous referees are also gratefully acknowledged.

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