Go Back

Contributing Paper

Best Practice Methods for Valuing Irrigation Benefits

Douglas Southgate
Department of Agricultural Economics, Ohio State University, USA

Prepared for Thematic Review III.1:
Economic, financial and distributional analysis

For further information see http://www.dams.org/

Go Back

22 March 2000

ESTIMATING IRRIGATION BENEFITS:
A Methodological Overview

Douglas Southgate
Department of Agricultural Economics
Ohio State University

Like economic valuation in other contexts and settings, assigning a monetary value to the agricultural output resulting from improved water availability involves what practitioners of cost-benefit analysis (CBA) term a with-versus-without comparison (Gittinger, 1982). That is, a measure of value – income or land prices, for example – is estimated for two scenarios, one being that an irrigation system has been brought on line and the other being the without-project case. If the additional value captured because of project implementation exceeds discounted expenditures on constructing, operating, and maintaining irrigation infrastructure and if environmental costs have been taken into account, then the project satisfies standard efficiency criteria. One such criterion is the benefit-cost ratio, which should equal or exceed 1.00.

Although with-versus-without comparisons may be conceptually straightforward, difficulties and ambiguities almost always arise. Take prices, for example. Governmental interference with market forces – a food subsidy here, a minimum wage there – distorts price signals, thereby complicating the task of determining irrigation's true benefits. Since CBA is supposed to indicate whether or not society as-a-whole gains from project implementation, shadow-pricing is called for to correct for policy-induced market distortions. By the same token, environmental goods and services are often shadow-priced since market values for many of them are entirely absent.

Other challenges facing CBA practitioners are of a practical nature, relating to limited information. It is rare for all the data needed for definitive assessment of a project to be readily available. The conscientious analyst is explicit about what is known and what is not as well as the assumptions that underlie important findings. Furthermore, he or she undertakes sensitivity analysis (i.e., calculating efficiency measures under alternative assumptions) to see whether or not conclusions about a project's net benefits are rendered invalid if circumstances turn out to be different from those expected.

The Conventional Approach to *Ex Ante* Analysis

More often than not, evaluation of a proposed irrigation project is based on residual imputation of water values. This means that the combined economic worth of factors of production other than water is subtracted from commodity sales revenues, the difference between the two being assigned to water.

Young (1996) points out that residual imputation is valid if two conditions are satisfied. First, all inputs and outputs must be exchanged in markets that are both competitive and unregulated. On the factor side, this means that the price of each and every input is equal to its marginal value product (i.e., output price multiplied by the additional output associated with a marginal increase in employment of the factor). Second, the production function should be 'well-behaved,' in the sense that an X-fold increase in each and every input leads exactly to an X-fold increase in output. For the case where just one commodity is being produced, these two conditions imply that sales revenues are exactly equal to the sum of input employment levels multiplied by their respective prices:

$$P\,Q \;=\; \Sigma\, W_i\, N_i \;+\; \text{residual water value}\,, \tag{1}$$

where P is the competitively determined commodity price, Q represents commodity production, W_i is the competitively determined price (equal to marginal value product) of non-water factor i, and N_i stands for employment of the same factor.

If all inputs, including water, were exchanged in competitive markets and employed in production processes featuring the desirable (and normal) mathematical property described in the preceding paragraph, then equation (1) would be simpler. Water value – its (efficient) price multiplied by the volume used – would be included in the summation along with other input payments. But because water markets function poorly or not at all, this integration is not possible. Instead, the value of water is defined by rearranging terms in equation (1):

$$\text{residual water value} \;=\; P\,Q \;-\; \Sigma\, W_i\, N_i\,. \tag{1A}$$

From this definition, one moves directly to the conventional approach to *ex ante* evaluation of irrigation projects, which is to estimate changes in farm income. Suppose, for example, that all output from the project area is sold in larger competitive markets where prices are not affected by project implementation. Assume as well that competitively determined prices of labor, capital, and other non-water inputs are unaffected by factor employment in the project area. Under these circumstances, irrigation benefits during any year when canals and other infrastructure are in operation result exclusively from changes in production (from Q to Q' for each output category, j) and input levels (from N_i to N_i' for all input categories) and are expressed exclusively as an increase in residual water values:

$$\text{irrigation benefits} \;=\; [\Sigma P_j Q_j' - \Sigma W_i N_i'] \;-\; [\Sigma P_j Q_j - \Sigma W_i N_i]\,, \tag{2}$$

where P_j is the price of commodity j and Q_j stands for the corresponding output level.

The preceding expression describes in a general way the many calculations, now routinely carried out on computer spreadsheets, required for *ex ante* estimation of irrigation's annual benefits. Of course, the same set of calculations would have to be made during each and every year of the project's lifetime (defined as T years) in order to obtain a full time series of annual benefits: $B_1, B_2, \ldots, B_T$. All of these must be discounted, using the real interest rate (r) or some alternative measure, in order to arrive at the combined present value of current and future benefits:

$$B_1)(1+r)^1 + B_2)(1+r)^2 + . . + B_T)(1+r)^T = \Sigma B_t)(1+r)^t . \quad (3)$$

To estimate any particular year's benefits, B_t, the CBA practitioner typically begins by determining how irrigation affects production. There are three broad possibilities. First, a switch might be made from lower- to higher-valued crops. Second, intensification can occur, either due to higher yields or to the harvesting of a second or third crop each year where one or two have formerly been raised. Third, extensification, meaning that new land is brought into production, is also a possibility. Each of these requires the application of additional non-water inputs: labor, fertilizer, machinery time, and so forth. If local crop budgets are unavailable from an experiment station or extension service, then surveying of some sort is required to estimate increases in output and factor employment. Once this task is completed and price data have been collected, the change-in-net-income method can be applied.

Utilization of Mathematical Programming Models

Additional insights are gained into the benefits of an irrigation project by using a mathematical programming model of farming operations. Such a model features an objective function – agricultural income, for example, defined as the difference between commodity sales revenues less expenditures on commercial inputs – as well as a series of constraints (Hazell and Norton, 1986). One such constraint may relate to land availability, since the supply of land that lends itself well to crop production is far from infinite. Likewise, labor is scarce, not entirely mobile, or both in many rural settings. Where there are shortages during planting or harvesting seasons, restrictions on labor supply should be included. Another model constraint, of course, has to do with water availability.

Any run of a mathematical programming model indicates the shadow price of each and every resource constraint. For example, the additional net earnings associated with increasing water supplies by a single cubic meter (the definition of marginal change in a programming context) are reported. More substantial relaxation of the water constraint, caused by the opening of an irrigation system, can easily lead to changes in the mix of inputs and outputs, which alters resource shadow prices. To estimate income impacts, one must conduct a with-versus-without exercise. The mathematical programming model is run first with the original level of water supplies, thereby obtaining an estimate of without-project income. Next, net earnings with the project are estimated by running the model with the higher level of water supplies.

Among the examples of economic analysis of irrigation issues using a mathematical programming approach is a study by Bernardo *et al*. (1987), in which a programming model was developed and applied to assess irrigation management decisions in the northwestern United States. The researchers identified various responses to growing water scarcity and rising energy costs, including more careful irrigation scheduling, crop substitution, the adoption of irrigation labor practices, and the idling of land.

To be sure, benefit estimates obtained with a mathematical programming model are no less subject to the biases associated with distorted policies than estimates obtained using budget-based spreadsheets are. In the Dominican Republic, for example, tariffs and import quotas have been applied to maintain rice prices above international levels. If domestic prices were used to evaluate the additional rice output made possible by an investment in water delivery systems, then there would be a corresponding exaggeration of the benefits of irrigation. To avoid this sort of error, rice would have to be shadow-priced. In practical terms, this would involve using border values – which reflect international prices as well as the expense of delivering rice to the importing nation – to evaluate production changes.

An advantage of using a mathematical programming model in this context is that farmers' switch from one crop to another can be investigated. In particular, bringing rice prices down to efficient levels would probably cause land formerly planted to that crop to be used instead for the production of other things – fruits and vegetables, for instance. It would be important to consider this response in an evaluation of irrigation development in a place like the Dominican Republic.

Finally, mathematical programming requires at least as much data as a spreadsheet-based study does. Where assumptions have to be made because information about prices, output yields, input requirements, or resource constraints is limited, sensitivity analysis is a good idea. For example, irrigation benefit estimates should be obtained under alternative assumptions regarding future prices, yields, and other variables that are not known with certainty.

Accounting for Variation in Water Quality

Water resource development is not driven exclusively by quantity concerns – increasing water's overall supply, availability at critical times of the year, and the like. Quality concerns often take equal or greater precedence. One of the main reasons for expanding a municipal water system, for instance, is to lessen households' dependence on polluted wells and streams. Likewise, food processors, bottlers, and other industrial users pay at least as much attention to water quality as they do to its general availability.

The contingent valuation method (Mitchell and Carson, 1989) can be used to estimate consumers' willingness-to-pay (WTP) for just about any environmental good or service imaginable, including cleaner water. Whittington *et al*. (1993) have carried out contingent valuation studies of households' WTP for improved sanitation services. The same approach can be used in potable water valuation.

Contingent valuation has not been used very frequently in irrigation studies. A different way to address water quality as an issue in farming would be to recognize the heterogeneity of water resources in a mathematical programming model. For example, lower quality water could be distinguished from high-quality resources. One of the benefits of a project that increases the latter would relate to increased production of high-priced crops (e.g., fresh vegetables), which cannot be exposed to pollution.

Hedonic Pricing in *Ex Post* Evaluation

Aside from budget-based spreadsheets used for imputing residual water values and the application of mathematical programming models, there are other ways to assess the gains of water resource development. In energy projects, it is common to employ what is called the alternative cost method (Steiner, 1965). For example, a dam might produce electricity that would otherwise be generated by a thermal plant. If there is no cheaper way to produce electricity, generation costs at the latter plant comprise a satisfactory basis for evaluating the dam's output.

Another alternative is to engage in hedonic pricing (Freeman, 1993). In the field of irrigation, this usually involves analysis of agricultural real estate values. An econometric model relating these values to all relevant variables is estimated. Of particular interest are the price differentials between irrigated and non-irrigated land, with proper allowance for other factors influencing the market value of real estate (e.g., location and soil quality).

Hedonic pricing is often used in *ex post* evaluations of irrigation projects. In the late 1980s, for example, Whitaker and Alzamora (1990) conducted a survey of real estate values to determine the premium offered for irrigated land in Ecuador. Their sample included parcels lying inside systems that account for three-fifths of the irrigable area of the country's government-run projects. Price data for similar parcels close to, but outside, those same systems were also collected. Per-hectare premiums were found to range from $367 to $3,897. The weighted average for twenty-five projects was $1,091 per hectare, which was a little less than half the average cost of irrigating that same land. That is, *ex post* evaluation revealed that irrigation investment in Ecuador had turned out to be very inefficient.

No less than the benefit estimates that other techniques discussed in this paper yield, estimates of the benefits of irrigation obtained with hedonic pricing must be corrected for policy-induced distortions. For example, real estates values are driven up if commodity prices are maintained above efficient levels and diminished if those prices are held down by regulations. Furthermore, irrigation subsidies, which are present in countless places, drive up the market value of irrigated land both absolutely and relative to prices charged for non-irrigated parcels.

The Benefits of Non-Marginal Change

Up to this point in the paper, only the price impacts induced by distortionary government policies (tariffs, food price regulations, etc.) have been mentioned. However, it is also possible for the extra production resulting from irrigation to have an effect at the market level. Just as shadow-pricing is needed in the presence of distortionary policies, the impacts on commodity markets of non-marginal changes in output must be recognized when irrigation benefits are being estimated.

As Gittinger (1982) and all other contributors to the CBA literature make clear, evaluation of non-marginal production impacts is consistent with notions of economic well-being that are fundamental to CBA, itself. In general, net welfare is defined as the difference between consumers' WTP for goods and services and the opportunity costs of those same commodities. Within a single market, WTP is represented by the area under the demand curve and opportunity costs are represented by the area under the supply curve. Hence, net welfare in a market that has achieved competitive equilibrium is the area between the two curves (Figure 1).

If irrigation development leads to a non-marginal increase in supply – of the sort that drives down equilibrium price and causes equilibrium consumption and production to go up – then net welfare will increase. As indicated in Figure 1, the challenge for the analyst is two-fold. First, supply growth (i.e., the higher consumption level observed at any given price) must be characterized. Second, the impacts on competitive equilibrium, which are influenced by supply growth as well as the elasticity of demand (i.e., the responsiveness of consumption to price changes), have to be identified.

Of course, the lower prices caused by an increase in supply affect producers negatively. However, this loss is usually more than compensated by the cost declines underlying the outward shift of the supply curve. The big winners from a supply increase are consumers since all purchases, including those made at the old price, are now made at the new, and lower, equilibrium value. If demand is inelastic (i.e., consumption is not particularly sensitive to price), which is often the case in commodity markets and which is the situation depicted in Figure 1, then the net gains to consumers, comprising the difference between WTP and actual commodity payments (price multiplied by quantity), are sizable.

Water Markets as a Source of Information about Value

Offered in this paper is the briefest possible introduction to methodologies for estimating the benefits of irrigation development. Even the reference list is abbreviated, reporting only a small fraction of the relevant literature. Stressed here are some of the potential pitfalls of benefit estimation – not correcting for policy-induced price distortions, neglecting market-level impacts, and so forth. A fuller treatment of these topics, and others, can be found in a book like Gittinger's (1982).

Of course, the pitfalls could be avoided if water were bought and sold like other agricultural inputs. This used to be a pipe dream. However, the potential for establishing water markets no longer can be ignored. Where private rights in water – which by definition are exclusive and tradable – have been established, markets start to operate and the price signals they generate comprise a basis for evaluating irrigation projects.

There have been parallel developments in other sectors that were formerly the realm of public utilities. In the United States and a few other countries, it is becoming possible for consumers to purchase electricity and natural gas from whatever private provider they choose, with deliveries taking place via power grids and pipeline systems. For the simple reason that gravity causes water to flow downhill, the buying and selling of water will never be entirely free of geographical segmentation. However, commercial transactions within watersheds are certainly feasible.

Insofar as markets emerge, many of the issues surrounding water resource valuation will take care of themselves.

References

Bernardo, D.J., N.K. Whittlesey, K.E. Saxton, and D.L. Bassett. 1987. "An Irrigation Model for Managing Limited Water Supplies" *Western Journal of Agricultural Economics* 12 (2): 164-173.

Freeman, A.M. 1993. *The Measurement of Environmental and Resource Values: Theory and Methods*. Washington: Resources for the Future.

Gittinger, J. P. 1982. *Economic Analysis of Agricultural Projects*. Baltimore: Johns Hopkins University Press.

Hazell, P.B.R. and R.D. Norton. 1986. *Mathematical Programming for Economic Analysis in Agriculture*. New York: Macmillan Publishing Company.

Mitchell, R.C. and R.T. Carson. 1989. *Using Surveys to Value Public Goods: The Contingent Valuation Method*. Baltimore: Johns Hopkins University Press.

Steiner, P.O. 1965. "The Role of Alternative Cost in Project Design and Selection" *Quarterly Journal of Economics* 79 (3): 417-430.

Whitaker, M.D. and J. Alzamora. 1990. "Irrigation and Agricultural Development" in M.D. Whitaker and D. Colyer (eds.), *Agriculture and Economic Survival: The Role of Agriculture in Ecuador's Development*. Boulder: Westview Press.

Whittington, D., D.T. Lauria, A.M. Wright, K. Choe, J.A. Hughes, and V. Swarna. 1993. "Household Demands for Improved Sanitation Services in Kumasi, Ghana" *Water Resources Research* 29 (6): 1539-1560.

Young, R. A. 1996. "Measuring Economic Benefits for Water Investments and Policies" (Technical Paper No. 338), World Bank, Washington.

Go Back

Figure 1. The Market-Level Benefits of Irrigation