IRRIGATION DEVELOPMENT: A FRAMEWORK FOR QUANTITATIVE ANALYSIS

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Abstract

Irrigation development continues to take place around the world. The economic feasibility of irrigation projects has generally been determined within a limited framework. The more common ways of evaluating an irrigation project is to compare the economic value of the optimum crop mix to that of the historical value of the crops produced in the area. The benefits are then compared to the costs of the irrigation project in a simple benefit-cost analysis.

Such a framework of analysis is limited in its scope. Irrigation feasibility should be analyzed from an economic perspective but within a general social context. The analysis should include not only an optimizing model (programming) of the agricultural production within the area of irrigation development, but also an econometric model of the supply and demand structures of the commodities. Therefore, the supply response of producers in other production areas can be measured and interfaced with the programming model in terms of market clearing prices. It is also desirable to use a macro economic model if the irrigation project is going to have significant impact(s) on the general economy. An input-output model can be used to estimate the impacts on sectors of an economy as well as the income and employment multipliers.

The pricing of the water used in an irrigation product should be such that equal prices are charged to all users so that marginal net benefits (MNB) are equal and the most efficient allocation of the water takes place. Different MNB procedures are useful in various decision contexts.

Résumé

Bien que l'irrigation soit de plus en plus utilisée dans le monde entier, on détermine encore la «faisabilité» économique des projets d'irrigation dans un contexte limité.

En général, afin d'évaluer un projet d'irrigation, on compare la valeur économique de la meilleure culture avec la valeur historique des cultures produites dans l'aire en question. En suite, on compare les profits du projet avec ses coûts, à l'aide d'une simple analyse coûts-bénéfices.

Il s'agit toutefois d'un contexte d'analyse de petite envergure. En effet, bien que la «faisabilité» de l'irrigation doive être analysée d'un point de vue économique, on devrait quand même la plonger dans un contexte social général. De plus, l'analyse devrait comprendere un modèle (programmation) d'optimisation de la production agricole dans l'aire à irriguer, aussi bien qu'un modèle économétrique des structures de l'offre et de la demande des produits.

On devrait en suite mesurer l'offre des producteurs d'autres aires et l'interfacer avec le modèle de programmation en termes de cours de compensation.

Il serait aussi nécessaire d'utiliser un modèle macro-économique, lorsque le projet d'irrigation a des impacts considérables sur l'économie générale. On peut aussi utiliser un modèle entrée-sortie, afin d'évaluer les impacts sur les secteurs d'une économie aussi bien que les multiplicateurs du revenu et de l'emploi.

Le prix de l'eau utilisée pour l'irrigation, doit être égal pour tous les usagers, de sorte que les profits nets marginaux (PNM) soient les mêmes et que l'allocation de l'eau la plus efficace ait lieu. Dans différents contextes de décision il devrait y avoir enfin plusieurs producteurs de PNM.

Irrigation development is a world-wide phenomenon. Historically, irrigation has used numerous technologies including free-flooding, check-flooding, furrow, surface-pipe, side-hill, and pivot or circle irrigation. The use of canals, dams, weirs, and reservoirs for the distribution of water probably began in ancient Egypt. In the initial stages technology included the use of counterbalanced poles for raising attached water vessels, adaptations of the wheel, and use of a pump called the Archimedes'screw. The use of pumps to tap underground water supplies, as well as using surface water, is a modern technological phenomenon.

Regardless of the technology employed, modern irrigation of agricultural crops is commonly found in multipurpose water sheds in which projects combine irrigation with water supply, production of hydroelectric power, flood control, and recreational use of the surface water. Multiple uses of water implies different demands for water in its various uses. The scarcity of water creates economic value. The overall value of water depends upon the scarcity of the water supply and the value of water in these competing demands.

The overall economic feasibility of irrigation development should be analyzed within the general social context. It should address the tradeoffs between economic growth and environmental quality in terms of general human welfare. Decisions concerning these tradeoffs are of both an economic and noneconomic nature. Economic issues are only a small part of the overall puzzle that must be solved. The «Spaceship Earth» vision of Kenneth Boulding is a useful framework for analyzing the relationship between economic growth and environmental issues. The basic concept is that the earth is a closed system and resources can not be exploited as if they were unlimited. Environmental (natural) resources (including water) must be viewed as irreplaceable social capital. Therefore, a major purpose of economic activity should be to conserve such stocks for future generations. This vision is in contrast to traditional philosophies which contend that society should maximize the value of current output. In this view the capital stock which is passed on to future generations is simply the outcome of decisions in the private market as modified by some non-market, governmental or political policies. Of course, political policies directly reflect the preferences of the individuals that comprise society.

The purpose of this paper is to present a framework for analyzing the use of water in irrigation. The framework reflects a synthesis of production economics, marketing, and natural resource economics points of views. Institutional considerations will not be addressed because they are unique to each country and political system.

The format of this paper will consist of: 1) discussion of the efficient allocation of water; 2) an interactive modeling framework to analyze a proposed irrigation project from a production economics viewpoint — including the adoption of irrigation technologies, marketing considerations, and general economic consequences of irrigation development; and 3) the overall advisability of irrigation development from a natural resource economics perspective including the appropriate technique of analysis.

Efficient allocation of water

Water is indispensable for life. It is necessary not only for human consumption, but for the production of foodstuffs. Surface and ground water have long had some other uses such as for transportation. In modern times, surface and ground water have gained additional uses including recreation, hydropower generation of electricity, industrial uses, and waste assimilation-absorbing effluent. Each of these uses has a different demand for water.

According to economic theory, the most efficient allocation of water occurs when the net marginal benefits (NMB) are equal for all users. (See Just *et al.* for detailed discussion of efficiency.) Any other allocation would

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result in a lower level of society's well being. This basic economic principle can be shown best with two individual water user groups demand functions (d_A and d_B), an aggregate demand functions (D_T), and a supply function for water (S) (**figure 1**). In **figure 1**, the aggregate demand (D_T) is the horizontal summation of the individual demand functions (d_A and d_B) at a given price level. The aggregate demand is equated to the supply function at a market clearing price (Pe). This results in an allocation in which the marginal net benefits (MNB) are equated for all users of the resource. This is accomplished by all users paying the same price — the price which equates the aggregate demand (D_T) with the aggregate supply (S).

While the above approach appears simple, it must be remembered that the forces determining the shape and position of the demand functions will vary by type of water user. As an example, for a demand function representing human consumption, the quantity of water demanded will depend upon the price of water, the prices of all other goods and services available for purchase, and the level of income. The arguments of such a structural demand function arise from the constrained maximization problem in which the consumer maximizes his or her utility function subject to his or her budget constraint.

In contrast, another type of demand function arises for water used in the production of other commodities, for instance, by irrigators, hydroelectric power companies, or industrial manufacturers. In this case the relevant demand function is an input demand function. The input demand function is obtained from the solution to the firm's profit maximization subject to the production function it faces in the production of the goods and services that it sells in a product market. For example, an irrigator's input demand is an argument of, not only the price of water for irrigation, but also prices of other production inputs and the prices of the products produced with the irrigation water.

Another type of demand for the use of water is exemplified by recreational use. In this type of use water is not sold through a market. Estimating the recreational demand function for such a non-marketed resource can be extremely complex. There are basically three «non-market valuation» techniques for estimating such demands (see, e.g., Pearce and Morkandya, 1989, for survey). Perhaps the most sophisticated, most empirical, and most complex technique rests on household production theory. In the household production approach the utility function is not directly composed of market goods as is the case with an ordinary utility function. Rather the household (the individual) produces the goods he or she ultimately values by combining market goods, goods the individual might produce, and public goods, together with the individual's own input of time and labor. This theory is the basis of the hedonic pricing method of analysis for all goods including those of a public nature such as recreation. For instance, it has been widely used in studies of air quality in which air quality is one aspect of the value of a home or of the «real wages» of a worker. The major drawbacks to the hedonic approach are that it requires econometric sophistication and a good data set. The appropriate data set is available only for a few types of non-market resource uses, and rarely for water uses.

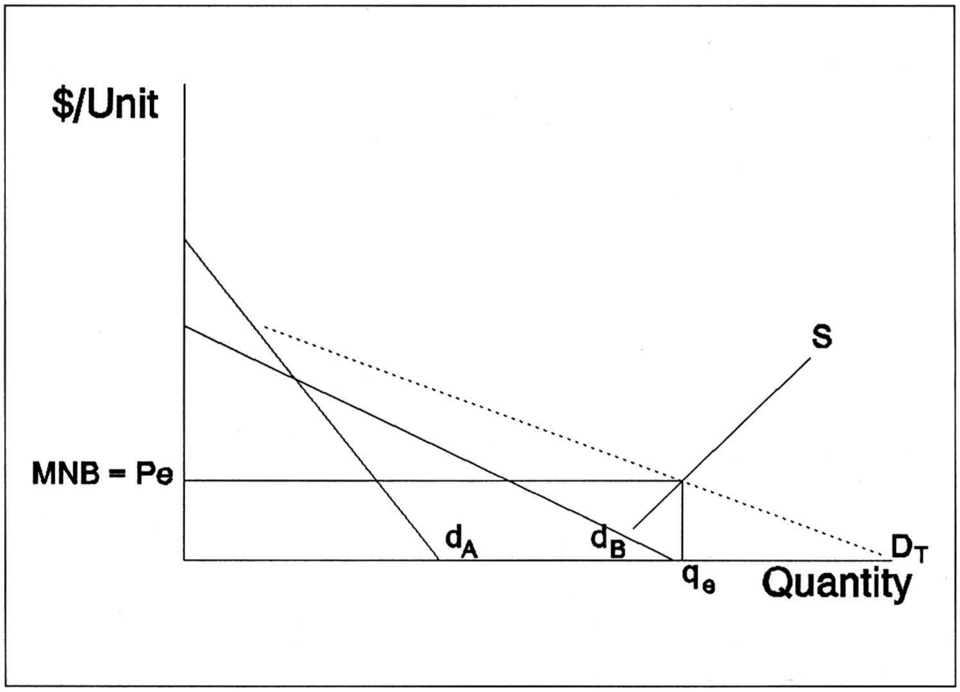

Figure 1 - Individual user demand function, aggregate demand and supply, and market clearing quantity and price.

Another technique used to estimate the demand for a non-market good (such as recreation), is the Clawson-Knetsch method which uses travel and other access costs as a proxy for how much individuals are willing to pay for recreation (see, e.g., Pearce and Morkandya, 1989; Smith and Desvouses, 1986). This technique is well developed and is very useful in those cases where the non-market water use can be associated with (technically, is «weakly complementary» to) a market priced commodity such as the cost of access (largely transportation costs to the site). It is used often to value recreational water uses.

The third method of non-market valuation is the survey technique, often referred to as the Contingent Valuation Method (CVM) (see, e.g., Pearce and Morkandya, 1989; Smith and Desvouses, 1986). This technique is the most versatile but the most distantly connected to observed behavior. The method is comprised of describing a hypothetical market for the resource and then directly asking the informant what he or she would pay for the resource. The value generated is therefore «contingent» on the hypothetical market. Since the hypothetical market is invented by the researcher, virtually any imaginable commodity can be valued using this technique. However, the method is also plagued by problems stemming from the fact that the market is hypothetical and the response is based on verbalized intentions rather than observed behavior. The survey may be poorly designed, the respondent may not understand, or the respondent may even deliberately distort his or her «true» preferences (strategic behavior) to increase or reduce the support for the proposed commodity-presumably some public good.

Whatever non-market valuation method is used, the demand for water for recreational use is dependent upon its own price and also numerous socioeconomic factors as the case is for other types of consumer demands.

The final type of demand for water is for waste assimilation — to absorb effluent and hence to produce — or control pollution depending on one's perspective. Water quality has both a benefit and a cost side. On the one hand there are damages from various levels of pollution. On the other hand one must value the water resource for its waste assimilation role compared to other methods of waste handling. Therefore, there is an «efficient» level of water contamination or pollution.

The most noticeable of the damages involves the state of health of the human beings affected by the pollution. The literature on this subject is numerous and varied in the approaches to measuring such damages (see, e.g., Smith and Desvouses, 1986). Depending on the type of damage either the non-market techniques described above, or the input demand function approach might be used. To fully discuss this aspect of water demand is beyond the scope of this paper. Overall, the efficient allocation of water is dependent upon knowing the demand functions for water in its various uses. The remaining sections of this paper will discuss a global framework needed to analyze the impact of the demand and use of water for irrigation. The final section addresses the best method to evaluate the economic feasibility of an irrigation project.

Framework of analysis

As indicated above, the demand for water in its many uses is dependent upon numerous economic and noneconomic factors. All too often, the economic analysis of irrigation development projects has centered upon the production of various agricultural commodities within the project area while largely ignoring the project's interface with the other segments of the economy. The list of references contains a sampling of the numerous studies which either: 1) look solely at the feasibility of producing various products; or 2) analyze the tradeoff in the use of water between irrigation or some other single use such as hydropower generation; or 3) analyze irrigation development taking into account market price effects by using a point or demand schedule. All of these approaches are only a partial analysis of the economic aspects of irrigation development.

Figure 2 depicts a global framework for the various aspects of irrigation development which should be considered in a comprehensive socioeconomic analysis. The framework is built around the allocation of the water among the various users and the value of water in its multiple uses as indicated by its price. To achieve economic efficiency, the final water allocation should result in equality of the marginal net benefits among the various user groups which occurs when the same price is charged to all groups. However, the response (price elasticity of demand) of the user groups to varying prices will differ because the different demands for water are functions of different factors. Therefore, it is paramount that all demands and other economic factors influencing these demands be analyzed.

The focus of this paper will be on the demand for water as a production input in agricultural production. After all, the use of water for irrigation is the presumed main rational for an irrigation project. Therefore only three key components of the irrigated agricultural sector — production programming, commodity supply and demand, and regional input-output — will be discussed in any detail. The actual modelling of the other uses and economic effects will not be discussed. First, we briefly review the major elements in the global framework.

The use of water in agricultural production should be viewed as any other input. From an economic perspective the analysis is «normative» in nature. In this context the model is normative in the sense that it mimics the profit maximizing (normative) behavior of production units. Linear or nonlinear programming is the usual modeling technique. The constrained maximization problem consists of maximizing the profits of the agricultural producers in the area under consideration. However, the methodology should account for the endogenous nature of prices (both input and output) when the response form all farm firms in the irrigation project is aggregated. Several means of reflecting the phenomena exist and are the discussed later within the paper.

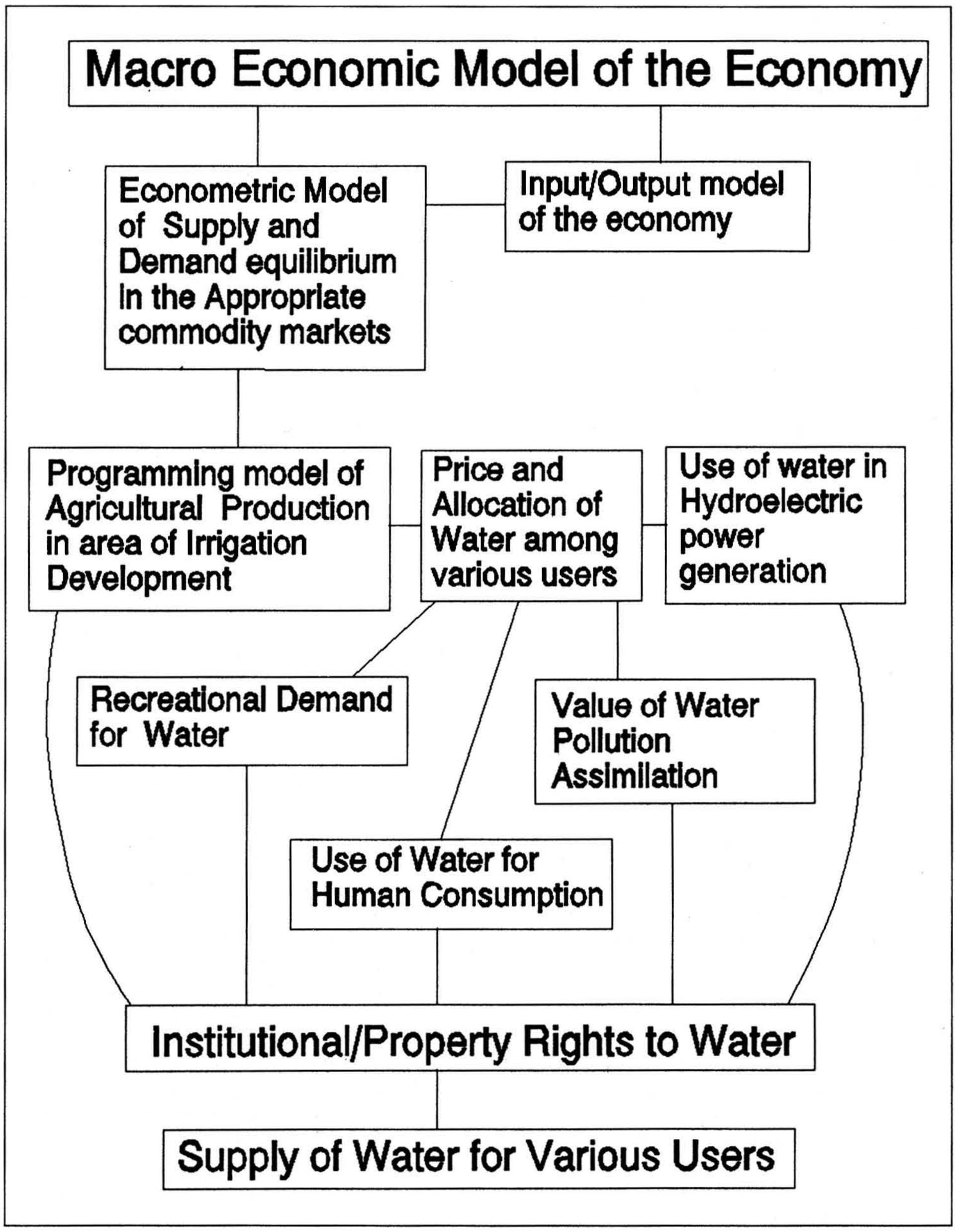

Figure 2 - Global framework to analysis irrigation development.

An irrigation development project can have impacts on a national economy if the project is of a significant size. The macro economic effects from irrigation development may include impacts on the gross output of the economy (Gross National Product — GNP), on employment, and on income distribution. These national level impacts often feedback to have implications for the markets in which the agricultural products produced with the water are sold. The major implications are likely to be on income and price levels which, in turn, are factors in the structural supply and demand functions for the project's agricultural products. Recent approaches to these economy-wide models include the computable general equilibrium (CGE) method. A detailed description of a macro model such as a CGE is beyond the scope of the present paper. Moreover, such a model would vary considerably from country to country.

Regional impacts on employment, population, and income which can result from irrigation development can be best analyzed with an input/output model of the general area in which the development is to occur. The level of population and the redistribution of the population can be best estimated through the employment multipliers of an input/output model. We now discuss the programming, supply-demand, and input/output models in more detail.

Programming model

The traditional approach to the economic analysis of irrigation development has been a programming model, usually a linear programming model. This approach to modeling the project agricultural production activities determines the profit maximizing allocation of the area's scarce resources among competing products. The model is usually constructed to maximize the overall profitability (π) from the production of the *n* different agricultural products (q_i) given product (P_i) and input (r_j) prices and the *m* resource constraints (b_j) such as land and water availability. In general notation, the model would be:

$$\text{Maximize } \pi = \sum_{i=1}^{n}(P_i q_i - \sum_{j=1}^{m} r_j a_{ij})X_i$$

Subject to:

$$\sum_{i=1}^{n} a_{ij}X_i \leq b_j \qquad (j = 1, 2, \ldots, m) \qquad [1]$$

$$\text{and } X_i \geq 0 \qquad (i = 1, 2, \ldots, n) \qquad [2]$$

The choice variables represented by X_i are units (hectares) of production and coefficients a_{ij} are use of resource j per unit of X_i. Constraint set [1] limits total resource use to less than total availability and set [2] ensures nonnegative levels of activities X_i. The resource constraints may reflect varying qualities of land or water including such facets as soil productivity or water salinity. Aspects such as limited water availability in a given time period may also be reflected. In all cases, special care should be taken to reflect the technologies, and corresponding a_{ij} coefficients, which would be relevant to the developing irrigation project.

Expected prices for both inputs and outputs, the size of farming units, as well as human capital including management levels, are also factors which affect the choice of irrigation technologies, and therefore production activities (Dinar and Yaron). The adoption of advanced irrigation technology greatly affects water use efficiency and the supply response of agriculture to various pricing policies, including government subsidies.

In many instances the relevant production functions q_i will be nonlinear and the pure linear model presented above will no longer be adequate. Separable or nonlinear programming techniques (Taha; Hazell, and Norton) may be used in such cases. Additional constraints, reflecting other nonlinear agronomic considerations and/or institutional considerations may also be needed. As an example, many agricultural policies reward certain actions with subsidies. Such conditions may require the use of zero-one programming methods (Williams) to reflect the yes-no nature of the decision environment facing the producer.

The model developed thus far generally applies at the firm level. Use of such a model for an entire region or irrigation project will result in overly mobile resources, overspecialization of crops, and a tendency to understate input and output price effects. Several means of dealing with this aggregation bias have been devised. One approach entails cost minimization for exogenously determined production levels. Such models, reviewed in Heady and Srivistava, generally divide the total region of study into numerous subregions. Representative farm-level models are imbedded at the subregion level and the cost of meeting exogenously determined total demand is minimized. Typically such models exhibit relatively poor replication of regional crop mix (Schaller; Young), primarily due to a lack of detail concerning micro-level response.

A second approach attempts to iteratively link econometrically determined demand for outputs and possibly input supply, with large-scale programming models (Huang *et al.*, 1990; Shrader and King, 1962). Results from the econometric component such as regional crop price and production (and possibly cost of production) may serve as input coefficients in the mathematical programming component. Once solved, then aggregate supply from the programming model serves as an input to the econometric model and the process continues until the market clearing price and quantity are determined.

A third approach involves fully price-endogenous programming models which seek to maximize welfare. Such models are based upon initial work on spatial equilibrium (Takayana and Judge, 1964), but have been improved to allow for the nonexplicit nature of supply in the linear or nonlinear programming context. Product demand appears explicitly in such composite sector models. McCarl and Spreen review several studies utilizing this approach including those employing quadratic and/or separable programming techniques to reflect the nonlinear measures of total surplus. Baker and McCarl note that these models also often exhibit quite different response characteristics from actual aggregate output because of unrealistic crop specialization and resource mobility.

An alternative approach employs the Dantzig-Wolfe decomposition principle (McCarl, 1982) in order to reflect the endogenous nature of prices and to reduce problems of aggregation bias. Firms within the region of study are first classified into similar groups based upon selected criteria such as primary production activity, resources, or firm size (Anderson and Stryg; Johansson). The resulting representative farm models are then optimized for a multitude of potential input and output price combinations. Results are then aggregated across firm classifications for a given price vector, with the subsequent aggregate response (extreme point) serving as an activity in a sector model. Convexity constraints within the sector model force the choice of a linear combination of the extreme points included. If needed, shadow prices on the common constraints in the sector model (generally accounting rows to aggregate individual commodity production) may be used to alter the objective function coefficients in the farm level programming problems. The latter are resolved, generating a new extreme point for the sector model. The process continues until shadow prices in the sector model are stable, indicating equilibrium supply in the representative farm models and demand at the sector level.

Theoretical presentations of this methodology appear in Onal and McCarl as well as the 1982 article by McCarl. The major applied study to date (Hamilton *et al.*) evaluates the economic effects of reduced ozone pollution levels in the Corn Belt of the United States. The predictive performance of the Dantzig-Wolfe procedure was compared to that of three other aggregation procedures, with the Dantzig-Wolfe method appearing to have less aggregation bias.

Supply and demand specification

For the majority of aggregation procedures outlined above, supply is not explicitly reflected econometrically. Total production of each commodity is simply summed within the programming model. Demand may be reflected explicitly as an identify within the programming model, or demand response may be reflected in an external econometric model. In either case, site specific econometrically estimated demand or supply equations will likely not be available for commodities produced in a newly developed irrigation project.

The econometric supply and demand equilibrium model needs to be linked to the programming model to obtain estimates of the market clearing prices that equate the aggregate supply and demand for the commodities under consideration in the irrigation development along with all substitute and complementary commodities. The market clearing price(s) that would be estimated by the model would reflect not only the supply of commodity from the irrigation development but the supply from other sources including producers in other production areas, inventories, and imports. In addition, the demand side of the market will exert its influence on the price through changes in domestic demand, export demands, and inventory demand.

In general notation the structural supply and demand model would be:

$$\Gamma Y_t + B_1 Y_{t-1} + B_2 X = U$$

where Y_t denotes the current endogenous variables, Y_{t-1} are first order lagged endogenous variables, X are the exogenous variables, U are the current disturbance terms, and Γ, B_1, and B_2 are the estimated structural coefficients associated with each class of variables as described above.

The exact specification of the model will vary depending upon the commodity. However, the basic underlying principles that should be followed in specifying the structural equations should be neoclassical micro economic theories of supply, demand, inventory, and excess supply functions. The structural equations must not only capture the behavior of the market participants but also the technical aspects of the production and marketing of the commodity(s).

By linking the econometric supply and demand equilibrium model with the programming model of the irrigation development project there is consistency in terms of market clearing prices with the programming model. In order for the econometric and programming models to be in agreement in terms of solutions, it is necessary that the two components of the overall analysis be linked. This has been historically accomplished by having the programming model contain an accounting activity which places a significant economic cost in the profit function associated with having the estimated forecast of aggregate production from the econometric model not in agreement with the programming solution (Huang, *et al.* 1980). This procedure is adequate as long as the irrigation development represents the entire industry. However, if the production of the agricultural commodities does not constitute the major share of the total production/supply of the commodities, it is necessary to interface the programming and econometric models in a manner more consistent with how agricultural markets actually operate and with economic theory.

The suggested method of linkage should be through the prices. The linkage variables should be the quantities flowing from the programming model to the econometric supply and demand equilibrium model. The econometric model then determines the market clearing price as mentioned above and this information is transmitted to the programming model via linkage variables. However, instead of modifying the objective function with a significant economic cost to force the two models to be in agreement, the programming model utilizes the new market clearing prices and recalculates the optimum mix of agricultural products to be produced. The new production levels are then sent to the supply and demand model to calculate a new set of market clearing prices. The process is continued until the prices used in each model are the same within some tolerance level specified by the researcher. Note that this interactive procedure does not guarantee that a consistent set of prices and quantities can be obtained for both models.

The degree of sophistication required in the econometric model is dependent upon the objectives of the analysis and the importance or dominance of the market supply that will be forthcoming from the irrigation project. If the production of the various products from the irrigation project will represent an insignificant share of the total supply and not impact product prices which would lead to a supply response from producers of the same products outside the irrigation project, then simple price-dependent demand functions would be appropriate. In such cases the prices of the products will be a function of the quantity supplied, the supply of other products, income, population, and the marketing margin. The latter is necessary since the prices are at the farm level and thus the derived demand function is the focus of the analysis. In this case, there is not a supply response to price signals by producers outside the irrigation project area and all quantities are treated exogenously.

In contrast, if the supply coming forth from a proposed irrigation project is significant and will dramatically impact product prices, there is a need to model the supply response of the producers outside the irrigation project. This type of model would include the supply and demand components of the structural model described above. The price information fed back to the programming model would be market clearing prices based upon equating all supply components to demand components. In such a case, only the production levels coming forth from the irrigation project would be treated «quasi» exogenously within the entire analysis. The term «quasi» exogenous is used because once the initial production level from the programming model is used in the supply and demand structural model, a new set of market clearing prices will be fed back to the programming model for recalculation of the optimum product mix. This interaction between the programming and econometric models results in the total quantity being supplied being composed of that determined endogenously within the econometric model and that determined within the programming model based upon normative behavioral assumptions.

Input-output model

Once a consistent set of prices and quantities are found in the programming and econometric models, the price information and production solutions are sent to the input-output model. The input-output model is a form of general equilibrium analysis. The technique yields information about the economic impacts on all sectors of an economy and employment levels as the level of economic activity changes in the sector of interest. The technique does not explain how supply and demand interact in commodity markets. Rather, it is a «supply-side» approach. Input-output analysis is based upon a detailed model of the interindustry flows of the regional economy. It shows the direct and indirect demand for inputs in all industries stemming from increased (decreased) demand in each sector. The usual analysis specifies an exogenous change in final demand in some sector, and traces the production and employment effects on all other sectors. In this case the change in final demand would be the increase in commodity production generated by the commodity supply-demand model.

The general input-output model consists of the gross output of all industries (Y), the input-output matrix translating some output into intermediate demand (A), and final demand (D). The general model is:

$$Y = AY + D$$

or through the use of an identity matrix (I)

$$(I - A)Y = D.$$

Solving for Y yields

$$Y = (I - A)^{-1}D$$

where $(I - A)^{-1}$ is the Leonteif Inverse or total requirements matrix which contains the direct and indirect requirements per dollar of delivery to final demand.

The input-output model is generally used by adjusting final demand (D) categories for the appropriate commodities. Use of the $(I - A)^{-1}$ matrix estimates the economic impact on final output (Y) in all the sectors of the commodity. The information can be expanded through use of the income and employment multipliers which are traditional economic measures arising out of input-output analysis.

Costs, returns, and benefit analysis

The development of a project to produce commodities under irrigation is a long-term venture and is complicated by property rights issues. Since there often needs to be some type of public sector (judicial, administrative, or legislative) intervention to obtain the most efficient allocation of the water, a framework for analyzing all costs, returns, and benefits over the temporal dimension should be used.

The usual approach is a financial analysis of the project. A financial analysis evaluates the project from the monetary point of view of (usually) the sponsoring agency. It uses financial criteria such as profits (returns minus costs), rate of return, break-even analysis, and cash-flow analysis. Financial analysis counts impacts in actual dollars. Financial analysis may be highly formal, using professional accounting methods and personnel, or it may simply comprise the informal calculations (back of the envelope) of parties affected by the project.

In a large project with many interests, each interest may make its own financial analysis. These financial analyses will inform participants in any procedural negotiations over a project.

Financial analysis plays a key role in evaluating a proposed irrigation project. Obviously a project must pass a financial test for key participants to support the project and therefore for the project to be viable. Certainly the project must appear financially sound to all those involved or impacted. But financial analysis does not represent overall social interests. For instance producers will not generally take into account the alternative uses of the water; they will simply count the cost of the water at the rate charged to them.

A benefit-cost or maximum net social benefits (MNB) approach can be used to analyze the overall net social benefits of the irrigation project. A maximum net benefits approach to decision-making is based on three or four key concepts. A fundamental concept is that all effects are considered from a social point of view. This social perspective is a major difference between the financial accounting systems described above and a maximum net benefit perspective. Where a financial analysis considers only monetary costs and revenues, the social maximum net benefits approach requires counting all the socially relevant effects. Thus effects that are not counted in commercial markets, such as pollution, are counted in a MNB framework. Moreover, even where they exist, market prices must be modified to reflect «social» rather than «private» costs and benefits (for instance, taxes are transfers and not costs from an MNB perspective).

Another key idea is that the benefit cost approach is a systematic decision-making process using a system of accounts. All potential effects of the alternatives under consideration are identified, measured where possible, and recorded. A related idea is that opportunities missed are included in the tabulation. In economic jargon these are labeled opportunity costs. The system of accounts and the concept of opportunity cost facilitates the consideration of trade-offs among various resource uses.

A wide variety of approaches to a MNB or Benefit-Cost type test are possible. For instance benefit cost analyses differ in their choice of a decision criterion. The benefit/cost ratio has been the most frequently used criterion. The positive net-present value criterion is closely related. A favorable decision for implementing an irrigation development project would obtain if the present value of the benefits exceeds the present costs (ratio > 1.0) in the case of the former, and when the present value of the net benefits is positive in the case of the latter.

However, benefit cost analysis has a number of disadvantages and short-comings. One major issue is that no single discount rate can be agreed upon by all policy analysts. The two most commonly used interest rates are:

1. market interest rate that private firms would face in borrowing funds for large capital investment projects; and
2. social discount rate which somehow reflects overall social values.

For benefit cost analysis the social discount rate is the conceptually correct concept, but the correct social discount rate is the subject of much discussion among economists. One group argues that the social discount rate should simply reflect society's rate of «time preference». For instance, where private markets might discount impacts on future generations, an argument is sometimes made that a social perspective might treat future benefits and costs and current costs and benefits the same; i.e., the social discount rate should be zero. Other economists argue that the social discount rate should reflect the lost opportunity of spending resources on one project over another and so is non-zero. In the end the social discount rate must reflect both the demand for spending resources and the supply of capital available to the government. One can argue that the government's cost of borrowing adjusted for risk and distortion's in the economy such as income and commodity taxation is such an «equilibrium» social discount rate — though it is heavily weighted to the «supply» side of the equation. Nonetheless, it is typically less than that of the private sector interest rate. As an aside it should be noted that risk can be introduced to the benefit cost method by assigning probability levels to present values of net benefits over the planning horizon.

Different types of MNB procedures are useful in different decision contexts. The MNB concept includes a wide variety of approaches:

Standard benefit-cost test. The standard benefit-cost test converts all effects to dollar equivalents and adds them up. It directly compares the benefits and costs so measured in a single indicator (net benefits, B/C ratio, or internal rate of return). Alternatives can then be ranked by the value of this indicator. In the modified or «social» benefit cost analysis, the effects are first measured in the units of account (dollars) but weights are attached before the quantities are added. Thus one might value benefits accruing to poor at two times the value one counts benefits to upper income groups, or one might count extra value for local benefits compared to distant benefits, or one might count environmental benefits at a greater weight than consumer benefits.

In the multidimensional or matrix benefit-cost analysis approach several different accounts are kept rather than just one. The results are displayed in a matrix showing which groups benefit and lose by categories considered relevant-for instance, in-state and outside the state, or low and high income. Accounts can be kept in several different units of accounts, so one displays the «dollar» amount of fish loss and/or the biologically measured amount. This approach explicitly accounts for the non-commensurability of some human values.

Finally, it should be understood that a MNB is not a substitute for policy decisions, it is a tool to be used to aid decision making. It is generally one factor in the policy makers decision, but its role can vary from rather rigid requirements that a MNB must be satisfied to a role of informing the decision makers.

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