APPRAISAL OF IRRIGATION PROJECTS AND RELATED POLICIES AND INVESTMENT

This study arose in response to problems encountered in the appraisal of irrigation projects in Mexico. It deals with methods of handling interdependence in project appraisal. The kinds of interdependence analyzed are: a) between investment projects and other policy instruments such as guaranteed prices, b) among different types of investment projects, and c) between local and sector-level decisions on investment outlays.

The method of analysis is linear programming, and the paper is organized in terms of seven numerical examples of treating interdependence with this tool. In each case, illustrations are provided of prescriptions which may be inferred logically from the analysis. The cases serve to call attention to three elements of a proper project appraisal: a) the other relevant government policies in the project district must be specified, b) the investment choice set must be fully specified, and c) it may be necessary for the district-level investment to be evaluated as part of an overall sector program.

The paper also shows how partial information may be used to make indirect project evaluations, and how linear programming may be used for screening and ranking alternative projects as well as evaluating a given project. The technique is applied for both the case of an efficiency goal (profit maximization) and the case of an equity-oriented goal (employment generation).

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This paper discusses appraisal of irrigation investment projects at the micro-level, or, more specifically, the level of an irrigation district. It consists of seven different examples of the application of optimization models to public policy decisions in an environment in which decision makers are concerned with the simultaneous use of several instruments of economic policy. There are two overall themes in the discussion. The first one is types of interdependence that affect the evaluation of irrigation investment projects. The second theme is the use of linear programming as a tool for capturing this interdependence and for reflecting alternative goals in project evaluation. The paper synthesizes and extends the project evaluation aspects of a research project in agricultural planning sponsored jointly by the Mexican Government and the International Bank for Reconstruction and Development. Further details may be found in Bassoco et al. [1973], Bassoco, Norton, and Silos [1972], Duloy and Norton [1973], and Duloy, Kutcher, and Norton [1973].

The interdependence discussed here affects in some cases only the benefit side, and in other cases both the benefit and cost sides of a project.
evaluation. One example is the set of interrelationships between an investment program and other instruments of government policy, such as guaranteed prices. The stream of benefits to a proposed irrigation project is affected significantly by the government's decision on whether to guarantee the prices of crops grown with the aid of irrigation in that area. It also is affected by the availability of short-term credit, the price of chemical inputs and other factors which can be influenced by public policy.

In all, this paper deals with three kinds of interdependence:

a) between investment projects and other policy instruments;
b) among different kinds of investment projects; and
c) between local and sector-level decisions.

All three kinds have been analyzed by means of linear programming models of irrigated agricultural producing areas - mostly with parametric programming experiments on these models.

Generation of additional agricultural employment has been selected as illustration of an alternative policy goal, and linear programming analyses of employment possibilities are presented. Unlike most mathematical programming treatments of alternative goals, these models do not maximize a function of employment, but rather they simulate producers' responses under different specified public policies. This approach ensures the possibility of implementation for a program outlined with the model.

The application of linear and dynamic programming to irrigation planning is by now common practice. To cite some examples of previous work, Soltani-Mohammadi [1972] used linear programming to analyze the choice of irrigation technique given the cropping patterns, and with the same method Rogers and Smith [1970] explicitly allowed for the interdependence between
cropping patterns and selection of investment project. With strongly restricted variability in the cropping pattern, Gisser [1970] also used linear programming to estimate the demand for water as its marginal value product in agricultural activities. Cummings and Winkelmann [1970] made use of dynamic programming to discuss the optimal rate of release of stored water and its relation to the determination of the cropping pattern. Dudley, Howell and Musgrave [1971a] have utilized stochastic dynamic programming to study alternative rates of release of stored water during successive ten-day stages in the growing season, given uncertainty about weather. They treated the case of one crop on the basis of detailed experimental biological data on the effects of various root moisture conditions. In a companion paper [1971b], they solved for the optimal acreage planted, again for one crop, in the face of stochastic water supplies and demands. Both the Rogers and Smith study and a paper by Young and Bredehoeft [1972] are concerned with joint management of surface water and groundwater resources, and in this respect they treat interdependence of type (b) above. However, none of the studies have addressed the interdependence between investments in water and in other resources (e.g. agricultural research outlays) or the interdependence between investment on the one hand and product pricing and other non-investment policies on the other hand.

To make this study as relevant as possible in a policy context, care has been taken to construe the results of the analysis in a potentially applicable way. The article is organized in terms of seven analytic "experiments," and for each experiment, italicized examples are provided of prescriptions which may be inferred logically from the analysis.

Two producing areas have been selected for study: the Bajío region in Mexico's Central Plateau and the Río Colorado district in northwestern Mexico. Both areas are endowed with irrigation water – from tubewells as well
as river control systems - but they offer interesting contrasts in production patterns. El Bajío is an older producing area with irrigated farms of an average size of eight hectares. Relatively labor-intensive techniques are used. There is considerable rainfed cultivation in the areas around the irrigation zone, and these, too, are represented in the model. The Río Colorado irrigation district is newer and is located in an arid region in which no cultivation is possible without irrigation. The typical farm is more than two times larger than in El Bajío and mechanization is more extensive. The mechanization is influenced not only by farm size but also by interregional differences in the cost of farm labor. The population density is much less in the Northwest than in the Central Plateau; this, combined with the proximity of the Río Colorado district to the United States border, has resulted in a farm labor wage which is more than twice as high as in El Bajío.

The Bajío area, as defined for the model, comprises 432,000 cultivated hectares in the states of Guanajuato and Michoacán, of which 360,000 hectares are rainfed, 112,500 hectares are irrigated by gravity-fed water and 60,000 hectares are irrigated with pumped water from tubewells. The production pattern in the rainfed area is based on corn, beans, sorghum and chickpeas. In the irrigated zones, a greater variety of crops is produced, including wheat, barley, tomatoes, alfalfa, garlic and strawberries.

The average annual net income per producer in El Bajío, as estimated by solution of the linear programming model, is 12,400 pesos. (Since the mid-1950's, the exchange rate in Mexico has been fixed at 12.5 pesos to the dollar.) This amount varies in accordance with the size of the plot and whether it is irrigated or not. The large irrigated farms that average 23 hectares in size generate about 55,000 pesos of annual net income, while at the other extreme a small rainfed farm of seven hectares generates only 5,800 pesos.
The Río Colorado irrigation district embraces 203,000 hectares, of which about 120,000 hectares are irrigated from gravity-fed water of the Colorado River, whose use is regulated by an international treaty, and about 80,000 hectares are irrigated by pumping from deep wells.

The production patterns show that cotton and wheat are the most important crops grown in the area. Other crops are barley, alfalfa, safflower, oats, garlic, sorghum and corn. Cotton traditionally has been the single most important crop in the region. However, because of salinity problems and infestation of pests, the cotton yields and the number of hectares planted in cotton have decreased. Wheat has become the most important crop due to its increases in yields and the fact that it has had a guaranteed price for sales to the government marketing agency.

The annual net income per producer in the Río Colorado area, as estimated by the linear programming model, amounts to 25,880 pesos. This income is obtained from a representative farm of about 18 hectares. In both the Bajío and Río Colorado models, casual livestock raising and tree crop operations are excluded. They are relatively insignificant parts of the annual-crop farms.

DEFINITIONS AND APPROACHES

The first type of interdependence, between investment and other policy instruments, was mentioned above with reference to guaranteed prices, short-term credit availability, etc. The second kind refers to complementarity or substitutability among investment projects. For example, an appraisal of a potential project in canal lining may yield a given estimate of its benefits; but if land is levelled simultaneously the returns to canal lining may decline.
This would occur because both kinds of projects result in increases in effective water availability, by reducing conduction losses and waste, and because the marginal productivity of water per hectare declines as more water is made available. In general, a proper assessment of the returns to irrigation investment requires specification of all the alternative potential irrigation investments in the same locale.

The third kind of interdependence is the relation between sector-wide investment programs and investments in a particular district. Since many producing areas compete for the same markets, investment (and expansion of production) in one area may affect market prices and hence may affect returns to investment in other areas. For this to occur, it is necessary only that the district's share of national supply be significant in at least one crop. ("Significance" in this context depends in part on the magnitudes of the price elasticities of demand for the products. Five percent of national production can be a significant share for products facing inelastic demands.) It can also occur when a few districts are used as illustrative examples to analyze a hypothetical policy which could be applied to the majority of the districts in the sector once approved. In this case, the supply response of one district could effectively represent the response of a large part of the sector.

In brief, then, this paper calls attention to three elements of a proper project appraisal:

a) other government policies in the district must be specified;

b) the investment choice set must be fully specified; and

c) it may be necessary for district-level investment to be evaluated as part of an overall sector program.
Some of these questions, such as the effects of variations in guaranteed price policies, are often avoided by assuming shadow prices for inputs and outputs. Of course, there are many ways of determining shadow prices, and this has led to a well-documented and lengthy controversy in the profession.

Implicitly or explicitly, a set of shadow prices refers to a desired or forecast long-run equilibrium. But implementation of a project which appears justified in a shadow-price evaluation may require extensive fiscal schemes. For example, if the shadow wage of labor is assumed to be zero in the project evaluation, farmers who have to pay the actual wage to hired labor may receive low or even negative net income in the project area. In reality, the fiscal measures required to implement a shadow-priced project may not be feasible.

In this paper, "fiscal feasibility" is insured by using shadow prices only when the market forces or policy instruments required to induce those price levels are identified and included in the model.

Essentially, the approach to pricing adopted here depends on the degree of fixity of the good or resource. Toward this end, the models discussed below distinguish among three levels of spatial mobility for goods and factors: local, sectoral and national. Local resources are land, irrigation water, and the labor of farmers and their families. Sectoral resources include, for example, fertilizers, draft animals and farm machinery. National resources include day labor and short-term credit. For the analysis, the prices of national and sectoral resources are given exogenously. The sectoral resource prices may be set at alternative levels in parametric solutions, since they fall within the purview of sectoral policies. National resource prices are taken as immutable since they are presumably opportunity costs determined by marginal productivities in other sectors. Local resource prices are determined, with certain qualifications, endogenously within the models.
In the case of product markets, depending on the circumstances, the district is assumed (a) to be a price-taker or (b) to face downward-sloping product demand functions. In the former case, product prices may be taken to be (a) completely fixed or (b) variable as a representation of alternative levels of guaranteed prices.

In the latter case, when demand curves are downward sloping, a modified version of the Samuelson [1952] procedure is used to guarantee that the model replicates the competitive equilibrium on product markets. See Duloy and Norton [1973] for discussion of the procedure and Takayama and Judge [1971] for a full development of the quadratic programming case. It is in this sense that the models discussed here are simulation models: they simulate the behavior of a competitive market, given downward sloping demand curves and profit-maximizing behavior on the part of producers. Simulations are conducted repeatedly under different hypothetical policy packages to explore the market response to possible policy interventions.

In other words, at the sector-wide level, products or sector-wide inputs are assigned shadow prices which are different than prevailing market prices only if it is possible to identify either the supply-demand behavior or specific policy instruments which have the potential to make the shadow prices into reality. For example, if a product is protected by a tariff, and therefore its price lies above the world-market price, an experiment would be conducted by using the world-market price in order to show the impact on investment returns of removing that tariff. However, other experiments with other price levels would also be conducted to simulate the situation under which the tariff remains unchanged or is altered but not removed. The reader who is disturbed by our acceptance of existing market "distortions" is referred to Baumol and Bradford [1970] who point out that in general prices
must deviate from marginal costs in order to insure efficient resource allocation. When, out of millions of prices, many are distorted, moving a few prices toward the international level (or some computed level) is no guarantee of moving toward a Pareto optimum.

At the local level, the following assumptions are made for irrigation water:

a) farmers pay the actual gravity-water fee or pumping costs; but

b) water is allocated over crops optimally, i.e., according to its marginal productivity in each crop and class of soil.

These two assumptions need not be inconsistent, given that water allocation is governed by a district-wide management committee, even though the actual price of water is below its marginal productivity. Thus, the water price (tax) becomes a policy instrument which can be varied in alternative solutions. Land is assumed to be allocated over crops according to its marginal productivity in alternative uses.

The labor of farmers and their families is priced at least at a monthly reservation wage which is set at half the market wage. In months when farmer labor is fully utilized, the reservation wage may rise as high as the day labor wage, owing to the element of economic rent accruing to the use of farmer labor. This reservation wage accounts for only one-fifth to one-third of the total net farm family income, the rest deriving from economic rent to the land and water rights plus the rent to the family's labor which accrues over and above the reservation wage. The reservation wage clearly is a type of opportunity cost. It is a short-term (monthly in this case) opportunity cost which the farmer demands as a minimal acceptable return to his labor before undertaking an agricultural task, in the knowledge that in the longer run he
will receive substantially higher returns in the form of rent to fixed resources. His medium-term (e.g., annual) opportunity cost, translated to a monthly basis, would be substantially higher. This discrepancy between the short-run and long-run opportunity wage reflects the farmers' lack of perfect job mobility in the short-run: the decision to leave the farm is a major one. In particular, it would be more costly to leave in the middle of the crop year than at the end of the crop year. Various simulation experiments were made to evaluate the reservation wage level in terms of its impact on the cropping pattern and the labor hiring pattern; they have indicated that about half of the rural market wage (day labor wage) is an appropriate level for irrigated agriculture in Mexico. It appears to be lower for non-irrigated agriculture [Duloy and Norton, 1973]. The level of the reservation wage is clearly quite important, for example, in the case of the decision regarding acceptance of an agricultural innovation which promises higher returns per hectare but also involves more labor by the farmer himself.

Lastly, it is stressed again that the models used here are behavioral simulation models although optimization is the mathematical tool used. They simulate the responses of constrained profit-maximizing producers to alternative government programs. This does not imply that the goal of public policy is maximal producers' profits. When the policy goal is, say, higher employment or foreign exchange earnings, a model like this is used to find out, for example, which programs induce the farmers to use those crops and techniques which are more labor-intensive or to grow more export crops. The approach adopted is to systematically explore the responsiveness of irrigated agriculture to various pre-specified policies, so that a more rational selection can be made from among these policies.
EXAMPLES OF INTERDEPENDENCE IN PROJECT EVALUATION

Given the existing production technology set, i.e., the known possible practices on fertilization, pest control, etc., the economic returns to additional water are determined by three factors:

1) the biological effects of water on each crop;
2) the prices of the crops; and
3) the cropping pattern, or composition of crops cultivated.

The dimensions of the first factor can be established through agricultural research based on the soils and climate of the particular area in question. The second factor is a matter of market forecasting and government interventions in product markets. The third is determined by the profit maximizing behavior of producers. When relative prices of crops change, producers change their cropping patterns. The models presented here are designed to capture the functioning of the second and third factors, given the first factor.

The Río Colorado model contains eight alternative crops, each of which may be cultivated under two alternative degree of mechanization. Up to four alternative planting dates are specified for each crop; in all there are over 200 cropping activities in the model. This set of cropping activities is defined for each of four zones which had been established by the Mexican Ministry of Water Resources according to degree of efficiency in water use. (Various factors determine efficiency in water use. For example, ceteris paribus, farms which are located further from the dam will incur more water losses through evaporation and seepage as the water travels longer distances through canals.)
The cropping activities are constrained by the monthly availability of water, land, and the labor of farmers and their families. Other inputs are assumed to be available in perfectly elastic supply at the market prices. These include day labor, agricultural chemicals, services of farm machinery and draft animals, improved seed, short-term credit, and miscellaneous cost items. Water is priced according to whether it is drawn from tubewells or from the dam, and land is not priced \textit{a priori}, although the dual solution reports its marginal productivity on a monthly basis. The monthly specification is important to the allocational decision because the monthly cropping schedules differ among crops (and among planting dates for the same crop). Some crop combinations permit double-cropping in a 12 to 18 month period, and others do not.

Products in the Río Colorado model are assumed to be sold against infinitely elastic demand schedules, with the exception of some high-value crops for which marketing bounds are imposed. The price may be either a free-market price or a government-supported price. A more complete description of the Río Colorado model is contained in Bassoco, Norton and Silos [1972].

As experiment no. 1, the Río Colorado model was solved under a wide range of assumptions on the support price of wheat, from 780 pesos to 930 pesos per ton, holding other crop prices constant. In each case, the model determined the (private) marginal value product of water, in pesos per 10,000 cubic meters. This experiment addresses the interdependence of price supports and irrigation investment. Table 1 shows the main results. In the table the marginal product of gravity water is valued in terms of contributions to producers' profits. The table also records the level of district income, which includes three components:

a) producers' own-wage payments;
b) producers' profits (beyond their reservation wage); and
c) wages paid to day laborers.
Several conclusions can be drawn from Table 1. First, regarding the price supports alone, the cropping pattern changes significantly over the range of wheat prices studied (see also Figure 1). Substitution between wheat and cotton, however, does not begin until the wheat price is raised above 900 pesos. (Below this wheat price, cotton stays at an upper bound determined by the extent of soils suitable for cotton.) Employment declines irregularly as the cropping pattern changes, but when the wheat-cotton substitution begins, employment declines monotonically and noticeably. This occurs because cotton is much more labor intensive than wheat. Total district income also moves irregularly, since the number of day laborers hired depends on the cropping pattern. On the whole, the wheat price support is quite effective in increasing the wheat supply, but it has negative effects on employment and uncertain effects on regional income.

Regarding irrigation, the (private) marginal value of water increases markedly with the support price of wheat. The "elasticity" or percentage responsiveness of the value of water to changes in the wheat price is about 1.9 over this range of prices. These particular marginal values of water, however, have a strictly limited meaning: they refer to the annual contribution to producers' profits of an additional 10,000 m$^3$ of water. They do not measure the contribution of water to total regional income or to other policy goals such as employment.

In other words, the marginal water values constitute measures of the annual benefits in terms of a conventional private rate of return criterion. The quantitative implication of experiment no. 1 for investment programs is the following: if a conventional rate of return criterion is used to justify Rio Colorado irrigation projects, at a support price of wheat of 930 pesos projects are justified which cost 37% more per unit of water supplied than those which are justified at 780 pesos for wheat; a 19% increase in the wheat price
TABLE 1. Río Colorado Results Under Different Support Prices Of Wheat

<table>
<thead>
<tr>
<th>Support price of wheat (pesos/ton)</th>
<th>780</th>
<th>800</th>
<th>820</th>
<th>840</th>
<th>860</th>
<th>880</th>
<th>900</th>
<th>913*</th>
<th>930</th>
</tr>
</thead>
<tbody>
<tr>
<td>Production (tons):</td>
<td></td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>wheat</td>
<td></td>
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<td></td>
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<td></td>
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<td></td>
<td></td>
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<tr>
<td>barley</td>
<td></td>
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<td></td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>safflower</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>cotton</td>
<td>184.0</td>
<td>184.0</td>
<td>184.0</td>
<td>184.0</td>
<td>184.0</td>
<td>184.0</td>
<td>184.0</td>
<td>159.3</td>
<td>128.8</td>
</tr>
</tbody>
</table>

| Employment (thousand man-years)  | 33.4 | 33.4 | 33.9 | 32.1 | 32.1 | 32.3 | 32.3 | 31.3 | 27.5 |

| Marginal product of gravity water (pesos/10,000 m³) | 797 | 802 | 824 | 863 | 922 | 981 | 1040 | 1077 | 1091 |

| Annual district income of farmers and day laborers, in million pesos | 391.2 | 391.2 | 391.9 | 387.7 | 390.8 | 395.5 | 400.0 | 388.0 | 374.7 |

* At the time these experiments were made, 913 pesos/ton was the actual support price of wheat.
Figure 1. Rio Colorado: product supply levels as functions of the price of wheat.
permits a 37% increase in the cost of supplying water. (The relevant calculation is as follows: the marginal value product of water is 1091 pesos at a wheat price of 930 pesos, and it is 796 pesos at a wheat price of 780 pesos; \( \frac{1091}{796} = 1.37 \).)

However, a conventional rate of return criterion may not be the desired criterion for judging irrigation projects. Employment effects, for example, may be more important from the viewpoint of policy makers. In the next section, comparisons of projects in terms of employment effects are made, but first some more examples are offered regarding the use of linear programming to evaluate projects purely in terms of private returns criteria.

A frequent concern in agriculture is how to define the relation between agricultural research and extension, on the one hand, and other programs, on the other hand. A brief example of measuring this particular relation with linear programming is also offered for the Río Colorado district as experiment no. 2. Again, the benefit side, rather than the cost side, of the program is analyzed. In some parts of the irrigation district, cotton yields are declining, so a sample solution was conducted under the assumption that cotton yields were 13% lower, averaged over the entire district. Extrapolating from recent history, without enhanced efforts in agricultural research, it appears that this 13% decline in yields could well occur within four to five years. At a wheat support price of 913 pesos, this yield reduction reduced the marginal product of gravity water from 1077 pesos to 794 pesos, a reduction of 26% (Table 1). In other words, the returns to investment were reduced by 26% by a decrease in cotton yields of 13%.

Since the benefits of expenditures on agricultural research have a large stochastic element, it is difficult to translate these results into precise operational implications. However, for this particular case, the
following kind of statement may be made from experiment no. 2: *if, in the judgment of experts, allocating 10-15% of the investment budget to research and extension would be likely to halt further decline in cotton yields, then such an allocation would be easily justified in terms of enhancing the returns to the total investment package in the district.* Strictly speaking, if this result on cotton yields could be guaranteed with certainty by allocating no more than 26% of the investment budget to research, then such an allocation would be justified. However, owing to the difficulty of ever predicting research results with certainty, the italicized wording is likely to be more meaningful for decision purposes. This is a clear example of interdependence (complementarity) between different kinds of investment expenditures. In actuality in this case, such a budgetary allocation would augment the current research effort in the Río Colorado area several-fold, and specialists feel that it would be very likely to result in arresting the decline in cotton yields. In other words, the current allocation of investment funds to different uses in the district may not equalize expected returns among uses.

More generally, if several investment activities are fully specified, a linear programming model can be used to establish a joint ranking among them and to trace out a schedule of marginal efficiency of capital (MEC). This brings the cost side of project appraisal explicitly into the picture. As experiment no. 3, the MEC schedule was traced out with the model of El Bajío on the basis of the following four kinds of alternative irrigation investment activities: levelling land, lining irrigation channels with concrete, digging tubewells on rainfed farms, and sinking tubewells on already-irrigated land. Several alternative canal lining activities were distinguished according to the width of the channel to be lined.

The Bajío model is structurally similar to that of Río Colorado.
However, in place of the four water-efficiency zones, the following distinctions are made: irrigated and nonirrigated, and within each, large and small farms; within irrigated, tubewell and gravity-fed irrigation, and within each irrigated category, levelled and non-levelled land. Also, in addition to the constraint set specified for Río Colorado, El Bajío contains management constraints. Farmers are divided into three levels of management efficiency on the basis of sample field data, and constraints are placed on the availability of management skills at the upper two levels. For a complete description of the model and a presentation of some numerical results, see Bassoco et al. [1973].

In experiment no. 3, the model was solved for the levels and types of investment (as well as cropping patterns and water allocation) at different rates of return, the schedule of marginal returns to capital shown in Figure 2 was traced out. The schedule shows that the justifiable amount of investment more than doubles when the criterion rate of return is reduced from 24% to 12%.

Experiment no. 3 also revealed that, for this particular area, digging wells on rainfed farms turned out to be the most profitable investment, followed by land levelling, digging wells on irrigated farms, and canal lining, in that order. Canal lining did not enter the solution at any of the interest rates used, so its rate of return is estimated by the model as being less than 12%. This kind of result is useful for establishing both the size and composition of the investment program for a given area. Details of this computer experiment are presented in Duloy, Kutcher and Norton [1973].

INDIRECT PROJECT EVALUATION

In the foregoing discussion, explicit investment projects have been considered for the Bajío model but not for the Río Colorado model. By
Figure 2. El Bajio: marginal efficiency of capital schedule given by the linear programming model for investment in water resources
indicating the possible consequences of investments (and other public policies) without making the cost side explicit, the Río Colorado model has been used indirectly for project evaluation. In an ideal procedure, this step would be followed by an engineering-economic evaluation of potential project costs, and then benefit-cost comparisons could be made. Since it is often the case that complete cost information is lacking when potential projects are initially screened, the analysis with the model helps assess first, whether it is worthwhile to make a full engineering appraisal of the cost side and, later, when cost data are available, whether the project is economically justified.

In experiments no. 1 and 2 above, the Río Colorado model was applied in this indirect sense to wheat pricing options (or pricing plus investment options) and to possible expenditures on research and extension. In experiment no. 5 below, this indirect approach is extended by varying the amount of irrigation water assumed to be available in the Río Colorado district, in order to show the consequences of irrigation investments without yet specifying costs. In that experiment, both "economic efficiency" (private returns) and "equity" (employment) are analyzed as alternative objectives of public policy. But first another brief experiment with El Bajío is presented as a further illustration of indirect project evaluation under the efficiency goal.

As experiment no. 4, the Bajío model was used without explicit investment activities to compute the shadow price of land for both rainfed cultivation and irrigated cultivation. In the latter case, the land price includes the value of the associated irrigation water. The difference between the two prices, per hectare, shows the value of water per hectare. The computation was made by taking an infinite discounted sum of annual economic rents to land. The model gave the annual economic rents as part of the dual solution. (The
discount rate as used here corresponds to the concept of the opportunity cost of capital for the landholder. Table 2 gives these results for three alternative discount rates.

The price differences in the table may be regarded as an upper limit on the permissible cost per hectare of supplying irrigation, according to efficiency criteria. In other words, the benefit-cost ratio equals 1.0 when the cost if equal to this difference in land values. The linear programming model for El Bajío has determined these land prices on the basis of (a) the set of cultivable crops, (b) available technologies which transform inputs into outputs, (c) prices of purchased inputs, and (d) product prices. Given input and output prices, the model has selected the cropping patterns and technologies which maximize producers' profits. The model's primal solution in fact closely paralleled the actual situation. The selection of crops and techniques implies a certain return ("economic rent") to land, which is the basis for the figures in Table 2. The results for the 18% discount rate correspond closely to prices which prevailed in 1968, which was the model's base year. (A drawback of this approach in practice is that the differences in Table 2 show the resource values only at the margin. The values may decline substantially with investments in more land and/or water.)

Indirect evaluation techniques can be used also when economic efficiency is not the only goal of public policy. In experiment no. 5, for the case of Río Colorado, several solutions were conducted for successively larger water endowments, in order to represent the impact of irrigation investment packages of different sizes. Table 3 summarizes the results. As would be expected, the marginal value of water ("shadow price" in the table) declines noticeably as more water is made available on a fixed land endowment [Gisser, 1970]. The shadow price of water shown in the last line of the table again
**TABLE 2. Computed Prices of Land in El Bajío**  
(In 1968 pesos per hectare)

<table>
<thead>
<tr>
<th>Farm Type</th>
<th>12%</th>
<th>15%</th>
<th>18%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Large rainfed</td>
<td>3,960</td>
<td>3,060</td>
<td>2,460</td>
</tr>
<tr>
<td>Large irrigated</td>
<td>19,150</td>
<td>14,875</td>
<td>11,958</td>
</tr>
<tr>
<td>(difference)</td>
<td>(15,290)</td>
<td>(11,815)</td>
<td>(9,498)</td>
</tr>
<tr>
<td>Small rainfed</td>
<td>4,268</td>
<td>3,642</td>
<td>2,651</td>
</tr>
<tr>
<td>Small irrigated</td>
<td>21,956</td>
<td>14,875</td>
<td>11,958</td>
</tr>
<tr>
<td>(difference)</td>
<td>(17,688)</td>
<td>(11,233)</td>
<td>(9,307)</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th></th>
<th>Base Solution Value</th>
<th>Percentage increase in water</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>10%</td>
</tr>
<tr>
<td>Farmers' incomes, million pesos</td>
<td>305.0</td>
<td>335.4</td>
</tr>
<tr>
<td>(% change)</td>
<td>(+10.0)</td>
<td>(+11.9)</td>
</tr>
<tr>
<td>District income, million pesos</td>
<td>388.0</td>
<td>425.4</td>
</tr>
<tr>
<td>(% change)</td>
<td>(+9.6)</td>
<td>(+12.0)</td>
</tr>
<tr>
<td>Employment, thousand man-years</td>
<td>31.60</td>
<td>34.14</td>
</tr>
<tr>
<td>(% change)</td>
<td>(+8.0)</td>
<td>(+12.6)</td>
</tr>
<tr>
<td>Shadow price of gravity water, pesos per 10,000 m$^3$</td>
<td>1077</td>
<td>1052</td>
</tr>
<tr>
<td>(% change)</td>
<td>(-2.3)</td>
<td>(-13.0)</td>
</tr>
</tbody>
</table>
refers to the private returns (increments in producers' profits) associated with the additional water supplies. If this were the criterion for defining project benefits, then to maintain the benefit-cost ratio at or above 1.0, the project costs (per 10,000 m$^3$) could not exceed the shadow prices reported in Table 3. The shadow price declines by 13% as the water availability is increased by 15%, and by 32% as water availability is increased by 30%.

Farmers' incomes, district income, and employment all increase with additional water, but at a decreasing rate. For example, the "water elasticity of employment" (defined as the percentage increase of employment divided by the percentage increase of water availability) is 0.80 as water is increased to 110% of the base amount, and it drops to 0.50 as water is further increased to 120% of the base amount. It further drops to 0.22 as water is increased to 130% of the base amount. Rapidly diminishing returns in terms of employment generation set in after the water supply reaches 115% of the base amount. In contrast, the "water elasticity of farm income" remains in the range 0.80-1.00. Clearly, it is up to policy makers to decide where the cut-off point is for the investment, but experiment no. 5 shows that if employment concerns are paramount, then the cut-off point is lower than if efficiency concerns predominate, in the case of Río Colorado. We do not feel that it is possible to know explicitly the policy makers' preference function as regards employment and efficiency (or other multiple goals), but we feel that the decision process can be facilitated by showing the program consequences for each goal. A similar attitude is put forth by Freeman and Haveman [1970]. More precisely, the policy makers themselves normally would not have articulated precise trade-offs among aggregate goals, but they may react with unambiguous choices when confronted with detailed alternatives for particular cases.
DISTRICT VS. SECTOR

To gain perspective on these results from the viewpoint of formulating sectoral investment programs, it is important to compare several producing areas. This is done in the following paragraphs, but first a distinction must be made among three ways of providing additional water. It can be provided to an existing irrigation district without increasing the land area under cultivation in the district. It can be supplied on land which is already cultivated but only on the basis of rainfall. Or it can be supplied in areas which were formerly uncultivated because of insufficient rainfall. (Or, equivalently, water control projects can be established in areas which are uncultivated because there is too much rainfall and natural run-off.) In the last case, new farms are created. In the second case, rainfed farms are given water. In the first case, the amount of water per hectare is increased on existing irrigated farms.

Clearly the employment-generation effects of water are different in the three cases. They also depend on the crops cultivated and on the farm size, which influences the degree of mechanization in cultivation techniques. Nevertheless, some generalizations can be made. Experiment no. 6 consists of comparing the employment aspects of the solutions reported earlier.

Take first the case of creating new irrigation districts in arid zones. With the existing endowments of land and water, the Río Colorado model gives an estimate of 2.5 man-months of annual employment per hectare cultivated. (This is employment at a marginal productivity equal to or greater than the prevailing wage of 42.5 pesos/day for hired laborers and equal to or greater than 21.25 pesos/day for farmers.) Given the average farm size in the area, this is about 32.7 man-months per farm. Since farmers work in crop cultivation less than 12 full months a year, and day laborers much less, due to the seasonality of agriculture, 32.7 man-months means more than 3 jobs. These figures would
presumably apply to newly-created farms if the land and water endowments were increased proportionately, maintaining at the margin the same farm size. Also for Río Colorado, experiment no. 5 shows that increasing only the water on existing irrigated land by 20% increases employment by 0.5 man-months per hectare.

For the case of adding water to zones which are already cultivated, but with rainfall only, it is illustrative to look at the results for El Bajío. The following employment rates per hectare were calculated with the model:

<table>
<thead>
<tr>
<th>Type of Farm</th>
<th>Annual employment per ha (man-months)</th>
<th>Annual employment per farm (man-months)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Large rainfed</td>
<td>1.3</td>
<td>15.5</td>
</tr>
<tr>
<td>Small rainfed</td>
<td>1.7</td>
<td>7.5</td>
</tr>
<tr>
<td>Large irrigated</td>
<td>4.3</td>
<td>53.3</td>
</tr>
<tr>
<td>Small irrigated</td>
<td>8.7</td>
<td>17.9</td>
</tr>
</tbody>
</table>

Thus, supplying irrigation to large rainfed farms in El Bajío increases annual labor absorption by about 3.0 man-months per hectare, and on small farms it is increased by about 7.0 man-months per hectare. These figures are higher than the corresponding ones for Río Colorado. Increasing both land and water proportionately increases employment by 4.3 to 8.7 man-months per hectare in El Bajío, whereas the same steps in Río Colorado would increase employment by only 2.5 man-months per hectare. The differences are due to differences in cropping patterns and in farm sizes. Smaller-scale farms have a comparative advantage in labor-intensive techniques of cultivation and labor-intensive crops, such as fruits and vegetables.
While the various effects cannot be separated easily it is legitimate to say that, given prevailing farm sizes and cropping patterns, irrigation investment in El Bajío increases employment per hectare at least twice as much as in the Río Colorado district. Since El Bajío is located close to the Mexico City Market, it may be said to have a permanent advantage over Río Colorado in the production of high-value fruits and vegetables. The differences between the two areas as regards both cropping patterns and farm size are likely to persist for at least decades.

Thus, the lessons of experiment no. 6 may be summarized as follows: while irrigation investment creates additional employment in Río Colorado, a comparison with other parts of the sector reveals than an employment-oriented program must assign priority to areas which are similar to El Bajío in terms of farm size and cropping patterns. Similar comparisons should be made for many producing areas before completing the formulation of the sectoral investment program. (As of this writing, some further comparisons have been made and they confirm that the Bajío-Río Colorado comparisons may be generalized to the entire Central Plateau vs. the entire Northwest.)

This is one example of viewing an investment decision from the viewpoint of the locality (district) vs. the sector. There are other ways to illustrate the district-sector relationship. In fact, the discussion above of the interdependence between the sectoral wheat price support level and the returns to a local investment program is one example. Earlier research with the Bajío model [Duloy, Kutcher and Norton, 1973] probed the sector-district relation more fully, by means of formal linkages between the district model and a sector-wide model. Here a brief summary of that work is presented as the final experiment, no. 7.
If a district or region is large enough to account for about 5% or more of total production, it appears that there can be significant interdependence between the investment program in that area and the program for the entire sector. With this share at the total value of production in all crops, a district is likely to account for 10%-20% or more of the production of at least one individual crop. If there is such a relation, analyzing the investment program for the district alone, without taking into account the rest of the sector, almost always results in an overestimate of the returns to producers. Investment in the district under study expands sectoral production levels and tends to decrease agricultural prices relative to non-agricultural prices.

This occurs because of the generally price-inelastic nature of the demand for agricultural products. While demand certainly grows over time with income growth, it is also true that ceteris paribus, more production decreases prices, at least relative to the economy-wide price level. Some obvious exceptions to this statement occur for crops exported at a constant price or for import-substitute crops. Nevertheless, the statement holds for the vast bulk of agricultural cases.

The Bajío area produces a significant share of the national supply of some crops, so an analysis with the district model alone was found to lead to a substantial overestimate - as much as 50% - of the amount of investment justifiable at a given criterion level of the rate of return, in comparison with the case in which the district model was solved as part of the sector model.

It was also found that the district-alone solutions could be improved substantially without formal linkage to the sector model if the sector model were used as a price forecasting device prior to setting up solutions of the district model. Prices from the sector model then became inputs into the
district model. In effect, this permits evaluation of the district's investment program as part of the entire sector investment program (which has been estimated approximately). Since a single district's investment program can significantly influence sectoral price levels, a fortiori this is true of the entire sectoral investment program.

What are the operational implications of these findings? One possibility is to construct, and continuously revise, a sector model which includes details on particular producing areas, but even a large sector model can be addressed to detailed project evaluation questions only in a few selected areas. A more practical approach would be to use a somewhat aggregative model as a sector-wide price and production forecasting tool which takes into account approximate overall investment magnitudes. In a second stage, then, an individual's district's program can be assessed in a framework of an approximately consistent sector-wide investment program, so that the district-sector linkage is captured, even if imperfectly. If the second-stage analyses yielded a sum of district investments which differed significantly from the initial sectoral estimates, then further iterations of the procedure might be required.

CONCLUSIONS

Several kinds of interdependence have been outlined which are crucial to evaluation of an agricultural irrigation project. Parametric linear programming has been shown to be a useful tool for coping with this interdependence even in the absence of full project cost information. However, the models were not structured to arbitrarily maximize various policy objectives, but rather to simulate producer's production responses to alternative specific interventions of public policy. It has been found that when a model does contain project specification, it is important that all related forms of investment in the area be specified. It is also important to parametrize on non-investment policies.
which may affect the area's production response. Lastly, the district-sector relationship can be significant even when the district accounts for only five percent of national agricultural production. At present a two-stage procedure involving sectoral then local analyses seems most practicable.
REFERENCES


