PROCEEDINGS

44th Annual Meeting

WESTERN AGRICULTURAL ECONOMICS ASSOCIATION

Squaw Valley, California
July 25, 26, 27, 1971

Samuel H. Logan, Editor

LINEAR PROGRAMMING SIMULATION OF FIRST-ROUND EFFECTS OF A DECLINING WATER SUPPLY

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Linear programming is a commonly understood tool which may easily be adapted to simulate the agricultural sectors of a community for specified changes. As an unsophisticated approach to simulation, linear programming has two main assets. First, linear programming provides an orderly system of accounting for agricultural activities. Secondly, unlike most impact tools, linear programming allows incremental or marginal analysis and is not confined to proportional or average changes. The advantage of predictions based on marginal analysis is that they are more likely to occur and thus to carry more helpful policy implications during the change period than would estimates based strictly on proportional changes. In order to estimate secondary and tertiary impact of changes, multipliers must be generated elsewhere, such as by incorporating the linear program model into an input-output model which reflects the whole economy. Such secondary and tertiary impacts are not included in this report. Finally, linear programming facilitates traditional sensitivity analysis. This paper will attempt to demonstrate two things: (1) how easy it is to adapt a linear program for simulation purposes, and (2) potentially important differences in policy implications from proportional as opposed to incremental analysis.

Problem Situation

A linear programming model was used to simulate the agricultural economy of Curry and Roosevelt counties of New Mexico. These are adjacent counties lying along the Texas border in the High Plains. They each have irrigated farming, dryland farming, and ranching. Most of the Curry irrigated lands lie in large wheat and sorghum operations. Most of the Roosevelt irrigated lands lie in smaller, more intensive operations.

The agricultural product of the community is expected to shrink as the water supply declines. First, with many other places in the Southwest, the Curry and Roosevelt water supply involves a mining operation; there are no regularly running streams in the area, and there is essentially no recharge to the ground water. Water will run out for irrigated uses. Further, rising water costs as the aquifers are depleted are expected to "price out" irrigation uses before industrial and municipal uses of the area are affected; in the immediate future, the effect of the decline in water supply on the local community is expected to be confined to the effects of changes in the agricultural product. The general decline of the agricultural sector and its various components were traced to act as a basis for community planning.

The Basic Model

A linear program is a constrained maximization model. For simulation purposes in the Curry-Roosevelt problem, attention was concentrated on the constraints while the maximization process of the computer routine simply forced iterations of the model until the constraints were met. The activities of the linear program were land-use budgets developed for each major crop enterprise, for ranching, and for the various government programs associated with the production enterprises. For the original solution, the actual 1969 acreage for each budget was used. A land constraint was specified for each activity--as an equality with the 1969 acreage for that activity. Thus the model was not allowed to arrive at some optimal solution but was forced to a solution specified by the equality constraints, the 1969 land use. The linear program aggregated the various components of the budgets (activities). These components were then interpreted as purchases from various sectors, employment, land taxes, and the like--first-round effects of agriculture upon the rest of the community.

Modifications

For each successive iteration, each land use was again specified as an equality constraint. The total irrigated acreage for each decenium from 1970 to 2020 was set equal to state engineer office projections, with dryland farming and ranching absorbing the released lands. Within the shrinking irrigated acreage, the individual land uses had to be specified. How? Each individual use could be shrunk proportionate to the reduc of the whole, an average reduction. Or, the decrease in acreage could be derived by dropping first the least profitable crops, similar to traditional linear program maximizing, traditional marginal analysis. A third method was preferred for simulation purposes, traditional maximizing modified by judgement; the least profitable crop was not necessarily the one dropped first. This was a modified marginal analysis.

The "composite acre" with assumptions of proportionate change as used by Grubb [1] is helpful for an initial understanding of what is involved in changes while reducing the irrigated acreage. But Martin and Young [2], following Stults [3], have pointed out that adjustments to a falling water table take place with marginal crops. As described below, there are important differences in predicted changes when using average instead of marginal changes. In most instances, the proportional change model overstated the amount of change to be expected as compared to either of the marginal change projections (figure 1). Sometimes the proportional change model projected major changes to occur at different time periods from the projections of the marginal models.

The traditional maximizing linear program first selects the most profitable activities and as it runs into constraints it leaves out the least profitable, an incremental or marginal concept.1/ This is most reasonable; one would expect that as farmers start to run out of water they will stop irrigating broomcorn ($1.18 net return to management per acre) before peanuts ($99.50 net per acre). However, a maximizing model may run into serious difficulty as a simulation model. For example, Roosevelt County dryland broomcorn showed a higher net return per acre than did 48,300 acres (60 percent) of Roosevelt County irrigated crops and 87,200 acres (51 percent) of the Roosevelt County dryland crops.2/ To be used as a simulation model, nonoptimal solutions must occur. For the base year, as previously stated, equality constraints were used for all land-use activities. Thereafter, for each 10-year interval the change in land-use acreage by category--irrigated land, dryland, and rangeland--was specified as a constraint. Within the acreage change for each category, the computer routine specified the individual land-use changes on the basis of net profit. In figure 1, the results of this model are labeled "traditional marginal".

The preferred model, "modified marginal", was totally specified using equality constraints for each land use. To determine the changes in land use, three arrays were formed. In the first, net profit to management was the sole criterion, equivalent to the traditional marginal model. The second array was made by an agronomist according to his criteria. The third and final array was a "last out" or "most likely" array made by the economist on the basis of the first two arrays plus his knowledge of special items. Such knowledge included knowledge of an area of moderately profitable irrigated pasture located on rolling land overlying "good" water which could not be converted to high value intertilled crops, knowledge of the judgements of soil scientists and other residents of the area, knowledge of the relative merit of crop enterprise budgets, and the like. In general, the least profitable irrigated crops were the first out, the more profitable dryland crops were expanded more than the less profitable, and large ranches absorbed the increase in rangeland (note the proximity of the two marginal lines in figure 1).

The general difference in appearance of the Curry County figures (figure 1), which are roughly concave, and Roosevelt County's, which are roughly convex, lies in two things. Irrigation plays a larger part in the agriculture of Curry County. Secondly, most of Roosevelt County irrigation lies within an administered basin where the water is expected to be pumped out more slowly than in Curry County where most of the irrigation lies outside of any administered basin.

Differences in Policy Implications

The projections of the proportional model and those of the marginal models frequently were different, both as to the amount of change and as to the timing of the change. This could have significantly different policy implications as illustrated by interpretation of figure 1.

The 1980 Curry County gross receipts of farms and ranches -- community income from the farm and ranch sector -- is projected to be 91 percent of 1970 according to modified marginal estimates and 83 percent of 1970 according to proportional estimates.3/ For policy purposes, this is an important overstatement of change by the proportional model. The overstatement for the same projection is not quite as great in Roosevelt County -- 92 and 87 percent of 1970.

When considering net income, under the modified marginal projections for both counties, net in 1980 will be 97 percent of 1970.4/ Under proportional projections, these will be

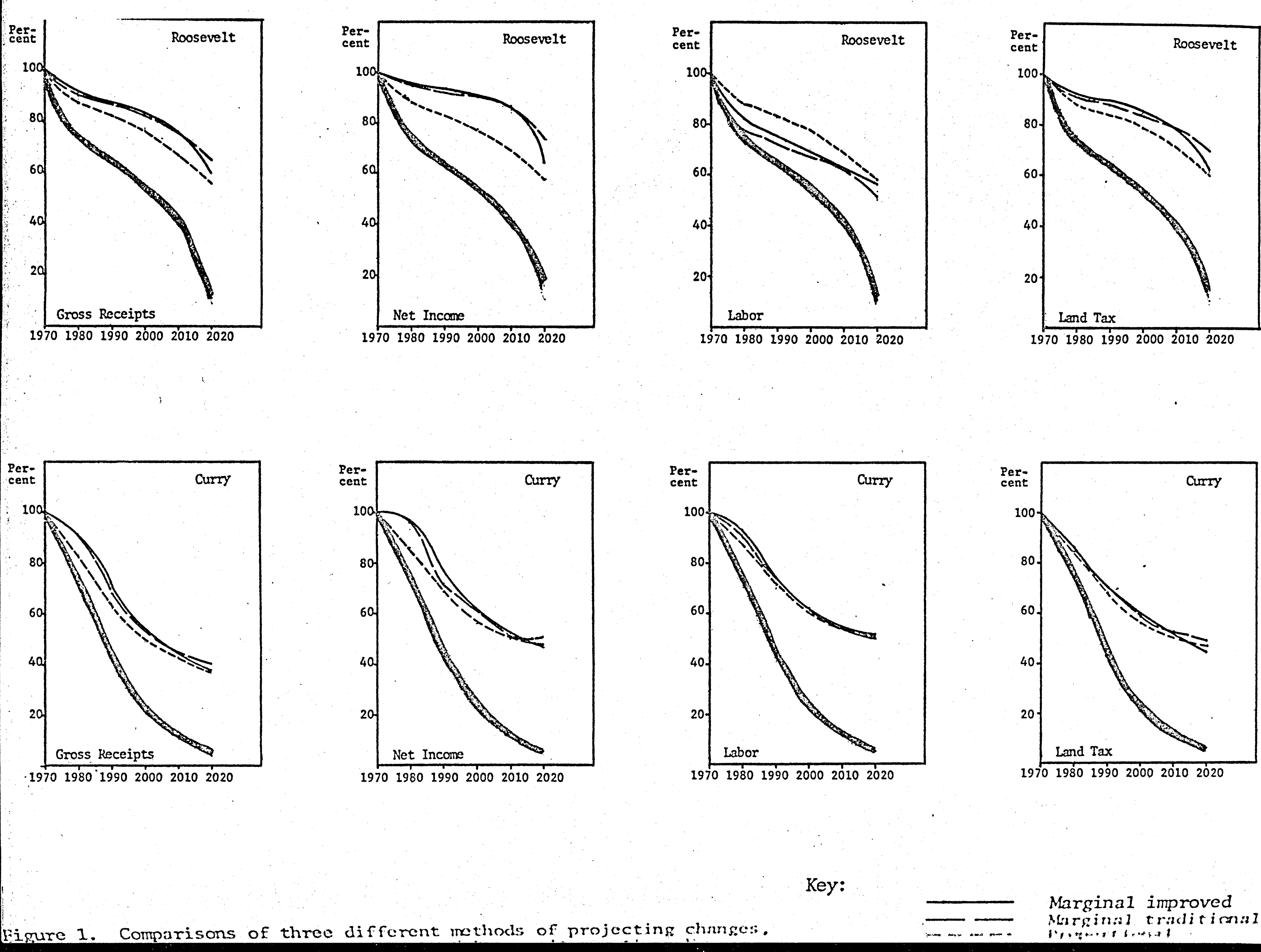

Figure 1. Comparisons of three different methods of projecting changes.

86 percent of Curry County and 88 percent for Roosevelt County. In themselves, the differences are significant. But of far more importance is that according to modified marginal projections, the income of the community from the farm and ranch sector in the next 10 years will be down considerably further than will be the decrease in net income to farmers and ranchers.5/ Farmers and ranchers will be making adjustments, but the net "pinch" will not be as great to them as a group as it will be to the non-farm community. Proportional projections show each group, farm and non-farm, hit quite hard by about the same amount, and early; thus the two groups would have similar income pressure changes and could be expected to work quite closely together for any overall adjustments to such things as a reduction in land tax revenues. In contrast to proportional projections, modified marginal projections in Curry County show that it won't be until the second 10-year period that farmers as a group get a sharp reduction in income, as opposed to the early reduction in income of non-farmers closely associated with the farm and ranch sector. In Roosevelt County, farmers as a group will not be severely affected for an even greater length of time. Thus proportional projections would indicate that income pressures would affect both the farm and non-farm sectors rather equally and have them work together for community adjustments; modified marginal projections indicate the income pressures to be generally different with farm and non-farm groups.6/

Further Interpretation and Use

Two subsectors are illustrated by the land tax and labor figures. The decrease in labor on farms and ranches is understated by the proportional model for Roosevelt County. The decrease in Roosevelt land tax from farms and ranches is overstated by the proportional model. Similar information is available for other first-round effects to those dealing directly with farms and ranches. Secondary and tertiary impacts are not generated through linear programming models.

Linear programming models lend themselves to traditional sensitivity analyses. Although interpretation is primarily a matter of taste and judgment, they can provide useful information. For example, what would be the effect of estimation errors or change in prices? A 10 percent change in price of all products sold would have about a 6 percent change in farm and ranch gross receipts, 16 percent change in net cash income, and no effect on labor used or land taxes. A 10 percent change from original yield estimates would have the same effect on farm and ranch gross receipts as a similar change in price; net cash income would be a little less than a price change due to the cost of handling the extra product.

Summary and Conclusions

Linear programming is an easily understood, easily used, model for simulating. Along with providing an orderly accounting of the components of the activities, linear programming allows incremental projections of first-round effects. The Curry-Roosevelt study demonstrates the reasonableness of marginal changes and that policy implications based on marginal change may be quite different from recommendations drawn from proportional analysis.

Presumably an input-output model which was being used to estimate changes in a regional economy due to changes in a particular sector could take advantage of the above findings. For the sector under scrutiny, it could make marginal or incremental changes. All other sectors would be held constant by using traditional proportional changes. The result should be an improved analysis from the input-output model.

FOOTNOTES

1/ Most profitable is defined not as return to an acre-foot of water but as profit per acre of land which is irrigated. As in other common pool situations, there is no incentive to the individual to conserve water, for the benefit accrues to all with very little to the person doing the conserving. Thus, the farm operator thinks in terms of maximizing net returns to his farm unit, not per unit of water. In the study upon which this report is based, this does not turn out to be important: only one pair of crops is switched in order within an array based on net return per acre-foot of water as compared to an array based on net return to management; this correlation appears to be coincidental.

2/ This does not include associated diverted acreages or fallow land. Even if Roosevelt County farms wished to maximize net returns, such a shift in cropping pattern could not be accommodated by either the market or available harvesting labor. In fact, the acreage of dry-land broomcorn in Roosevelt County has remained very stable over the last 10 years.

3/ Gross receipts include receipts from farm and ranch products plus associated revenue from participating in government programs.

4/ No opportunity cost is credited to land investment; if depreciation is considered akin to replacement costs, this net is roughly equivalent to available cash.

5/ Farm and ranch gross receipts.

6/ Projections were also made under two other models. Each was identical to the described traditional marginal and modified marginal, except that neither took water into account. Each took the irrigated acreage projections of the state engineer's office directly without consideration for the differences in amount of water used by the various crops. (The marginal models described herein were constrained by the amounts of water used.) In Roosevelt County, high water-use crops were called for; the models projected even greater differences from the proportional model -- there would be even less change from the base situation. The Curry County projections were less regular in their effect.

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