Chapter 1

Introduction

1.1 THE PURPOSE AND SCOPE OF THE BOOK

Mathematical programming has been used in agricultural economics for more than 30 years. It has become such a useful tool of analysis that its basic principles are taught in all colleges of agricultural economics, and its applications have been spreading geographically, particularly in the last decade. Programming models for agriculture have been used in a large number of developed and developing countries.

In the last 10 to 15 years there also have been a number of methodological advances in this field. The improvements have been in the direction of incorporating more economic theory and observed institutional and economic reality into the models. The more noteworthy advances have occurred in the areas of modeling consumer demand, market equilibrium in both product and factor markets, risk and risk aversion, and the role of instruments of economic policy. The profession's ability to model decisions of the farming household has improved as well. The cumulative effect of these advances has been to provide a tool of analysis that is much more adaptable to different situations and a potentially more realistic portrayal of agricultural reality.

This book draws together many of the recent methodological contributions in the field, and it also provides a reasonably comprehensive review of the state of the art as regards agricultural programming models at the farm and the sector levels. Two principal aims have guided the writing of the book: to provide a textbook of the relevant theory and methodology, and to provide detailed guidelines for practitioners regarding the process of building and implementing these models. To be useful, a model has to be well grounded in theory, but it also has to fulfill many practical requirements. It has to be appropriate to the problem at hand and to the available data, it requires an appropriate institutional framework, and the economics must be expressed in the model in an appropriate and interpretable way.

Models provide the link between economic theory and data, on the one hand, and practical appreciations of problems and policy orientations, on the other. They are imperfect abstractions, but by virtue of their logical consistency frameworks they can provide the analyst and policy maker with a valuable economic representation of the sector and a laboratory for testing ideas and policy proposals. However, experience has shown that the construction of a model requires not only a grasp of the relevant economics and an understanding of the issues to be addressed, but also a familiarity with sound techniques of building and applying models. Yet these techniques are rarely stressed in university curricula, and for agricultural programming models there are very few workshops that the practitioner can attend. Given the frequency with which agricultural models are built, and the fact that they usually are fairly complex constructions, this gap is an important one. Hence a central focus of this book is on technique, both for building and for applying models. A subsidiary aim is to provide an appreciation of the range of possible applications that have been and can be made with these models.

The book is intended for students, practitioners, and researchers. It is suitable for individual reading and for use in university courses. The theory and techniques presented are usable in widely differing situations, in both industrialized and developing countries. Existing texts give little attention to developing countries, so we have used a number of illustrations from case studies in those countries.

The presentation is generally aimed at the level of the master's student who has some familiarity with quantitative techniques. A few sections are more accessible to the Ph.D. student. The mathematical proofs in those sections may be omitted without loss of understanding of either the economics or the model-building procedures. The level of economic and mathematical preparation required includes microeconomic theory, introductory calculus, and linear algebra, except for the above-mentioned proofs which require multivariate calculus. Chapters 5 and 10, which deal with risk, also require some knowledge of basic statistics. For the student interested in a concise presentation of the relevant mathematical theory, a self-contained appendix is provided which develops the mathematics of linear programming with emphasis on economic interpretations. On the other hand, the reader who is looking for an introduction to linear programming for farm models will find all the material in Chapters 2, 3, and 6 accessible without much mathematics. The same can be said for Chapters 11 and 12 which concern practical techniques for building and using sector models.

The book is organized in three parts. The first part (Chapters 2 to 6) lays the microeconomic foundations for most of the rest of the book, with emphasis on modeling farm-level production functions and farmers' objectives. It also introduces the ways of organizing information in a linear programming framework, and discusses the principles and procedures for obtaining and interpreting a model's solution. Part II provides the model framework at the sector level, along with some additional theory for modeling market equilibrium and practical procedures for model construction and validation. Part III discusses the principles underlying useful applications and gives many examples of applications.

In algorithmic terms, the material is written for use in the context of either linear or nonlinear programming algorithms. Common examples of the latter are quadratic programming and mixed integer programming. However, for the treatment of risk, consumer demand, and the objective function, emphasis is placed on linear programming, because it still is the most widely available algorithm and because it has some advantages in interpretability and it is amenable to extension to the general equilibrium case. As the material in this book shows, linear programming models are not necessarily linear in the economic behavior they represent.

1.2 THE AGRICULTURAL PROGRAMMING MODEL

Mathematical programming in agriculture had its origins in attempts to model the economics of agricultural production, including its spatial dimension. The mathematical programming format—sometimes known as process analysis or activity analysis—is a particularly suitable one for agriculture. Farmers, agronomists, and other agricultural specialists share a common way of thinking about agricultural inputs and outputs in terms of the annual crop cycle, and about input-output coefficients per acre or hectare or other unit of land. Yields are conceived of in tons or bushels per land unit, fertilizer applications in kilograms per hectare or like units, and so on. In farm-level cost-of-production studies, input costs are typically disaggregated into labor, machinery services, draft animal services, fertilizer costs, other chemical costs, credit costs, etc., per land unit. For this way of visualizing agriculture production in numbers, it is but a short step to forming the column vectors of inputs and outputs that constitute the backbone of the programming model.

Similarly, agriculturalists often pose their problems in terms of inequality constraints, such as upper bounds on seasonal resource availability. And they are accustomed to the existence of slack resources in some seasons while the same resources are fully utilized in other seasons. This kind of thinking fits naturally into an analysis via programming models. For these reasons, experience has shown that it is feasible to review the production coefficients of a model directly with field experts, and to either verify or revise them accordingly. While the model has a mathematical expression, much of its empirical content is accessible to experts in other professions.

Thus the programming model provides a rather natural framework for organizing quantitative information about the supply side of agriculture, whether at the farm level or the sector level. Indeed, one of the uses of a model is to help reconcile initially inconsistent data (as discussed in Chapter 11).

Other uses of the model often involve different kinds of sensitivity analysis. At the farm level, the model can be useful in calculating the implications of different resource endowments, different market conditions, improved or new technologies, etc. This kind of information is generated by the model via variations in parameter values, with a new solution obtained for each set of parameter values.

At the sector level, parametric variations can be used to generate response functions that are implicit in the model's structure. Examples are factor substitution surfaces, supply response functions, response functions associated with particular policy instruments, and so forth. When used in this way, the model becomes a device for translating micro-level (farm-level) information into macro-level (sector-level) functions that are more familiar to many economists. At both the farm level and sector level, the model's solution also assigns valuations to fixed resources, such as land and water supplies, whose prices may not reflect their economic values.

It may be asked why the supply response functions are not taken from econometric studies. At the sector level, a set of estimated supply and demand functions can indicate equilibrium levels of production and prices, toward which the sector would tend to move. Supply functions are estimated in agriculture, and of course they can be quite useful in understanding the sector's behavior. The main problem with relying only on econometrics is twofold: data difficulties and changes in underlying economic structure. The data problem arises because, in many cases, large numbers of crops compete for the available fixed resources, and, therefore, cross-supply effects are important components of the supply functions. Normally there are not enough degrees of freedom in a time series data set to estimate both own and cross-supply elasticities. This is especially true in developing countries. Also, aggregate time series on production are often quite unreliable, again especially in developing countries. The programming model relies on cross-sectional farm budget data, which usually are more reliable, and other micro-level information to generate supply functions.

The question of changes in economic structure applies especially to technologies of production, market opportunities, and prices. Public policies can influence all of these, and in the policy options analyzed with the model, policy instruments may need to take on values lying outside the range of values observed historically. This possibility can make it unwise to base policy analyses on extrapolations from historically estimated parameters. Also, programming models can be used to analyze the consequences of direct changes in economic structure, such as those that would arise from the introduction of new crop varieties or from land reform that changes the size distribution of farms. The consequences of these kinds of changes are difficult to capture in econometric models of supply, and yet failure to do so means that the estimated supply elasticities are not reliable if the structural changes are introduced.

In addition to these considerations, a programming model's supply functions provide information on associated responses of inputs, such as labor, agrochemicals, and the like. Seasonality of the responses also is taken into account. Thus the study of supply response by means of a programming model can answer many policy-oriented inquiries and not just provide supply elasticities. Other examples of policy applications can include evaluations of comparative advantage, assessment of the employment effects of different policies, generation of input demand functions, and joint evaluation of sets of investment projects. These and other applications of sector models in several countries are discussed in Chapters 12 and 13.

When the transition from farm model to sector model is made, an important shift occurs in the model's role, and that shift has not always been recognized by model builders. At the farm level, the programming model is explicitly a *normative* or *prescriptive* tool. The decision maker, who may be the farmer himself, specifies his decision rule (profit maximization, cash-flow improvement, profit maximization subject to risk aversion, etc.), and the model helps simulate the consequences of that decision rule and the associated constraints on the farmer's choices. On the other hand, in a decentralized economy there is no single decision maker at the sector level. There are basically two levels of decision makers, the policy makers and the farmers, whose interests do not necessarily coincide. A model's solution that is designed, say, to maximize agricultural export earnings will give an export-intensive cropping pattern but it will not indicate which, if any, policies exist that will induce farmers to adopt that cropping pattern. To deal adequately with maximization of a policy goal, the model would have to contain a specification of policy instruments and also a set of relationships that describe how producers will react to possible policy changes.

As discussed in Chapter 7, it is difficult to specify mathematically and solve this two-level policy problem, and so in many cases it is more productive to develop a model that will help explain producers' reactions to external changes. While the policy model alone is normative, this second kind of model is *descriptive* or *positive*. Among other things, the descriptive model can be solved under different assumptions about policy parameters, and the corresponding solutions provide some information about the consequences of policy changes. For these reasons, this book places most of its emphasis on developing the descriptive model, although parts of Chapters 7 and 12 discuss the policy model.

Since policy goals are not necessarily the farmers' goals, the descriptive model must be set up to maximize something other than a policy goal function. On the other hand, if, for example, all producers aimed to maximize profits, then a sector model that maximized aggregate profits would not be correct either, for it would give the monopolistic outcome. This is the well-known paradox of the competitive market. For the model a different kind of objective function is needed, one that drives its solution to a market-equilibrium outcome in the presence of downward-sloping demand curves. These matters are taken up in the last part of Chapter 7 and in Chapters 8 and 9. Extensions to the case of simulating market equilibrium under risk are given in Chapter 10, on the basis of the farm level risk analysis given in Chapter 5.

A common thread through all the chapters is the emphasis on ways of putting economics into agricultural models. Properly constructed, programming models can reflect a wide range of economic and institutional behavior, and they can be powerful tools of analysis. They provide an analytic and empirical link between economic theory and observed behavior. We hope this book helps stimulate others to continue with the challenging task of matching theory with the real world.