Economic Modeling of Farm Production and Conservation Decisions in Response to Alternative Resource and Environmental Policies

John R. Ellis, David W. Hughes, and Walter R. Butcher

Growing concern over resource use and protection of the environment has prompted greater demand for agricultural policy analysis at the local, regional, and national levels. Faced with declining surface-water quality, silting of reservoirs, and contaminated groundwater supplies, the public has demanded greater protection of the environment. With the call for more regulation of agriculture comes the need for policy analysis. What policy is best? Should a national standard apply, or do local conditions warrant local standards? Who will benefit, and who will lose, and by how much?

Past analyses have examined policy options at all levels. The initial focus here is on current means of analyzing policy impacts at the farm level. Components include various means of reflecting the decision environment in which agricultural producers operate as well as alternative behavioral assumptions within that environment. That decision environment generally includes stochastic production of both positive (generally crops or livestock) and negative (primarily pollutants) outputs. Alternative means of reflecting production of these biological and physical outputs are examined. Selected past studies are reviewed, coupled with suggestions for methodologies for future research efforts.

Means of aggregating farm-level results to regional or national levels are then discussed. Resource and conservation policies, such as the Conservation Reserve Program, Conservation Compliance (Glaser), or the Clean Water Act (Harrington, Krupnick, and Peskin), were all initiated at the federal level. Imposition of a national policy, even if enforced locally, has both national and local implications. In most cases, regulation of resource use alters input demand and/or output supply, with subsequent impacts on prices in those and related markets. Altered prices on either side of the market impact personal incomes, with subsequent impacts throughout the national and world economies. This paper examines selected means of aggregating farm-level results in order to make statements concerning national impacts of alternative resource polices. In closing, the role that concise, accurate modeling of farm-level response may play within policy formulation is reemphasized.

Current Modeling Efforts

As available methodologies and technology have progressed, researchers have increasingly turned to simulation and/or mathematical-programming techniques in order to evaluate alternative resource-policy strategies. Such tools allow not only the reflection of a rich array of decision objectives and environments, but also a large degree of realism in depicting the stochastic nature of agricultural production. Lacking the luxury of an actual laboratory to test proposed policies, the analyst turns to the computer as his or her tool of empirical investigation.

Use of the mathematical-programming portion of farm policy analysis has a long history, with the various techniques well documented (Hazell and Norton; Agrawal and Heady). Linear programming (LP) studies abound, primarily because of ease of implementation and relative flexibility in depicting a large array of economic conditions. Multiperiod studies using recursive programming techniques have also been employed in attempts to incorporate behavioral dynamics (Day and Singh; Ellis, Lacewell, and Reneau; Mapp and Dobbins). Such models are also useful when policies to be modeled have varying parameters over time and one wishes to examine impacts during the transition to full implementation of a policy.

John Ellis is an assistant professor, David Hughes is a postdoctoral research associate, and Walter Butcher is a professor, all in the Department of Agricultural Economics, Washington State University, Pullman, WA.

A host of techniques, including quadratic programming (QP), MOTAD, Target MOTAD, safety-first, discrete stochastic programming, and chance-constrained programming, have been used to incorporate the various impacts that risk components may have on the relevant objective function and constraint set (Anderson, Dillon, and Hardaker; Hazell and Norton). Specific uses vary, especially with one's assumptions concerning the relevant objective function for the producer. Lin, Dean, and Moore found better predictive performance of actual producer behavior when using utility in lieu of profit maximization. Lambert and McCarl carried this further by incorporating direct utility maximization into farm planning models.

Resulting resource usage, and consequently impacts of alternative policies, does vary with the assumed producer objective function (Setia; Brink and McCarl). Practical policy analysis, however, tends toward use of a profit maximization framework (Rola, Chavas, and Harkin; Setia and Magleby; Prato and Shi), especially if results are to be aggregated. Use of the risk-oriented methodologies requires more, sometimes heroic, assumptions concerning variables such as the distribution of risk-aversion parameters or relevant covariance matrices among producers.

A third objective alternative includes that of multiple goal programming (MGP). With this approach, efforts may be made to allow for both utility maximization as well as other goals such as the well-being of the farm family and increasing farm size. A narrower definition of MGP is concerned with goals in addition to profit maximization, but it usually excludes models that are principally concerned with the trade-off between expected returns and various measures of risk, such as Target MOTAD.

MGP models may be categorized based upon the degree of decision-maker control over relevant decision variables. Such models can be divided into two types: (1) those that assume all decision variables are under the complete control of the decision maker (as characterized by many private decision makers) and (2) models where the decision maker may directly control some decision variables but can only influence other decision variables through the use of policy instruments (as characterized by many public decision makers) (Candler, Fortuny-Amat, and McCarl). A second categorization of MGP decision models is between models that require a complete knowledge of the decision maker's preferences, either prior to the model's creation or in an interactive model with the decision maker, versus models that make no such requirement (Cohon and Marks; Willis and Perlack).

Techniques that do not require complete knowledge about preferences of decision makers are especially amenable whenever a public entity, such as government policy makers, is the decision-making group. One such technique is compromise programming (Zeleny), which has been used to evaluate public-policy trade-offs in situations where decision makers' preferences are not known (Romero, Amador, and Barco; Atwood, Lakshminarayan, and Sposito). For example, Atwood, Lakshminarayan, and Sposito used compromise programming to examine the trade-offs between farmer production costs, on-farm productivity loss, and off-site sediment damage levels for various soil conservation policies for a watershed centered in Iowa. They obtained the set of compromise solutions by initially optimizing the model with respect to each goal while ignoring all other goals. These results were reduced to the Pareto efficient set of solutions, where the obtainment level of one goal cannot be increased without imposing an opportunity cost on at least one of the other goals through noninferior set estimation methods. Vector optimization routines were then used to examine trade-offs between the three objectives and filter efficient policy solutions to a small enough number of choices (the compromise set) from which a decision maker could conceivably choose.

Goal programming (GP) models can be employed under the assumption that the preferences of the decision maker are completely known (Willis and Perlack). As opposed to linear programming models, the objective function in a GP model seeks to minimize the difference between the desired level of goal achievement and the level that is actual achievement, as represented by deviation variables (Dobbins and Mapp). Decision makers can either give a preference ranking for all goals, or all goals can be assumed to be of equal value. In the former case, the GP may result in a lexicographic ordering where the initial model solution will exactly obtain the level of the most desired goal. The obtained goal is then treated as a constraint and the second goal is exactly solved for. Next, the second goal is added to the constraint set that the model solved to exactly obtain the third goal, and so forth (Dobbins and Mapp; Willis and Perlack).

Weights that represent the trade-off between goals are given to the deviation variables if all goals are not of equal value. Substitution between goal achievement levels can then occur and solutions can be obtained through normal LP methods (Dobbins and Mapp). Dobbins and Mapp used both GP methods in conjunction with a simulation model to examine long-run plans for a typical Oklahoma farm. They found model results to be sensitive to the assumption of equal preference of goals as opposed to a strict goal preference ranking.

Neely, North, and Fortson used a mixed-integer GP model to examine economic and environmental goals for a set of public water projects. Similarly, Thampapillai and Sinden employed a multiple-objective LP model in evaluating possible tradeoffs between income maximization and environmental quality goals for a region in northern New South Wales, Australia. Both studies concluded that actual levels of resource use were suboptimal because higher levels of both environmental and economic goals were obtainable under alternative plans.

The Thampapillai and Sinden research may suffer, however, from a deficiency given that the authors optimized the objective function for a public decision maker when, in fact, actual use of many of the appropriate decision variables was controlled by private resource users such as farmers. Candler, Fortuny-Amat, and McCarl have demonstrated that treating such a two-tiered objective-function problem as a single optimizing problem for a public decision maker can lead to erroneous policy recommendations. This especially applies in instances where those public decision makers may be only able to indirectly influence the decisions of private resource users with their own individual objective functions. The same authors demonstrate that optimizing a two-tiered mathematical programming model, where the public and private decision makers each have separate objective functions, may lead to a local optimum even if all constraints and objective functions are linear.

The emphasis in this paper is on modeling the effect of private decisions on natural-resource conservation and environmental quality. However, we have been unable to find any empirical studies that examined environmental effects and resource conservation decisions by private decision makers using an MGP approach. This research gap exists despite the demonstrated importance of noneconomic goals, such as bequeathing a sound farm operation to heirs (Carlson and Dillman), on resource conservation decisions at the farm level.

This research gap also exists in the area of applied studies employing adaptive economics (Day; Baum). The complexity of actual human decision behavior is better reflected in adaptive economic theory, yet applied studies are even less tractable than those that can be addressed using the more standard static mathematical programming approaches. Even recursive schemes employing mathematical programming have difficulty reflecting Kenneth Boulding's additional decision factors of love/altruism and coercion (Troub).

In practice, firm-level programming models have difficulty in predicting producer behavior. Alternative goals, as well as correctly specifying all relevant resource constraints, are likely the main culprits. Producers also likely operate with multiple time horizons for varying goals. Reflecting such a decision framework is no easy task, and, in practice, profit maximization or univariate utility becomes the objective by default.

Process Models

A host of physical process models have been developed by physical scientists to model processes such as wind and water erosion, chemical loading, and crop and livestock growth. Such models have become key components of current efforts at modeling the stochastic nature of agricultural production of both commodities and pollutants. A partial list of models and their realm of application appears in Table 1. In general, such process models provide physical-response data for use in more comprehensive mathematical programming or farm-firm simulation models.

Agricultural economists have the most experience (Musser and Tew) with the biophysical crop-growth models such as EPIC or CERES. Probability distributions of yield under stochastic weather conditions and varying tillage/irrigation practices are the general output of such models. A more recent survey (Joyce and Kickert) lists forty-two crop-growth models for single-crop species. Multiple-crop models, such as EPIC, sacrifice some precision in modeling crop growth for particular crops in exchange for greater flexibility in modeling crop rotations. Applied studies employing EPIC include analyses of wind erosion impacts on production (Lee, Ellis, and Lacewell), risk impacts of alternative cotton irrigation schemes (Ellis), and potential greenhouse-effect impacts (Robertson et al.). EPIC's greatest use to date has been in the 1985 RCA resource appraisal (Putman, Williams, and Sawyers).

Additional process models (Table 1) have been developed to reflect sediment and pollutant loading in streams and groundwater. EPIC has limited capabilities in performing these functions. Applied studies are numerous, including the use of SWRRB (Arnold et al.) by the National Oceanic and Atmospheric Administration to estimate nonpoint-source loadings from nonurban lands in all coastal counties of the U.S. (Singer et al.). Additional studies (Braden et al.; Lee, Lovejoy, and Beasley) employ process models to avoid the constant damage-to-delivery ratios of past work (Montgomery;

Table 1. Selected Process Models

Name	Application	Level of Resolution	Reference
EPIC (Erosion Productivity Impact Calculator)	Crop growth Wind and water erosion	Multiple crop, field size	Williams et al.
CERES-CEREAL	Crop growth	Multiple cereal crops, field size	Singh et al.
CREAMS (Chemicals, Runoff, and Erosion from Agr. Mgmt. Systems)	Chemical and sediment fate and transport (surface water)	Field size	Knisel
GLEAMS (Groundwater Loading Effects of Agr. Mgmt. Systems)	Chemical and sediment fate and transport (groundwater)	Watershed	Leonard et al.
SWRRB (Simulator for Water Resources in Rural Basins)	Crop growth, hydrology, runoff	Watershed	Arnold et al.
AGNPS (Agricultural Nonpoint Source)	Erosion, sedimentation	Watershed	Young et al.

Taylor and Frohberg). Prato and Shi employ a geographical information system (GIS), coupled with a simplified erosion model, to evaluate alternative erosion management practices in a watershed.

One should note that a great deal of expertise is required to properly use such models, and these authors highly recommend a team approach utilizing close cooperation between physical scientists and policy analysts or economists. Mere calibration of the models, especially crop-growth models, should not be left to the uninformed (Bryant and Lacewell).

Once calibrated, such process models are often used conjunctively with some form of economic analysis or formal farm-level programming model. The FLIPSIM farm simulation model (Richardson and Nixon) is probably the best known of such models. Aspects of government farm programs, family withdrawals, machinery replacement, and income taxes may be reflected in multiple-year simulations employing stochastic or fixed prices and yields. Ellis used EPIC-generated crop yields along with FLIPSIM to simulate the impacts of different irrigation schemes on firm survival. Standards for continuing operation of the firm (i.e, a maximum debt-to-equity ratio) may be used to reflect firm failure. One may then estimate the probabilities of firm survival under alternative policies using multiple simulations under different initial debt loads. FLIPSIM also has a yearly crop-mix planner employing LP or QP techniques.

Combining Systems

Cole and English provide an excellent review of the decision process used when linking several subcomponents into an overall policy-analysis system. In their first stage of selection, they considered the following:

1. *Generalized commodity selection:* The model should be flexible in the types and combinations of commodities that can be analyzed. Single-commodity models or specific crop models are not acceptable.

2. *Crop-oriented:* The model should be crop-oriented but not crop-specific.

3. *Current time period:* Only recently developed models will be considered. Earlier models would require substantial updating to be useful.

4. *Transferable:* The model must be transferable or have a general model structure and database to enable it to be easily transferred to other users and regions for analytical purposes.

5. *Multiperiod time horizon:* The model must be dynamic and must reflect impacts of the decision-making process over a specified simulation period.

6. *Alternative-sized farms:* The model must be able to handle various farm sizes.

After performing an extensive literature review, the models that were deemed acceptable by the above criteria were subjected to a second stage of criticism. Qualities sought in that stage included the following:

1. *Government policy:* The model must permit incorporation of various agricultural commodity and resource programs.

2. *Cash-flow analysis:* The model must have a capability to simulate the cash-flow process in the farm operation decision-making routine. This would include such items as refinancing, depreciation, and taxes.

3. *Decision-making or adaptive process:* The model must have some type of decision-making simulation routine such as when to buy land, refinance loans, or which agronomic practices to select.

4. *Resource use and availability:* The model must include provisions for resource endowments and distribution. Ultimately, what is achievable will be influenced by the level and location of resources available for production. Knowledge of land quantity and quality, initial cash endowments, and machinery and buildings available for production purposes is necessary if analysis at the farm level is to be meaningful.

5. *Professional acceptance:* The model must have been tested and determined to be reliable.

Upon completion of their review, they chose a four-component system comprised of a biological simulator, a farm budget generator, an optimizer, and a whole-farm simulation model. The resulting system employed the EPIC and FLIPSIM simulation models coupled with the North Carolina Budget Planner (Hoag) and two possible optimizers. The latter two components consisted of the LINDO package (Schrage) for some applications and the North Carolina Crop Planner (Edmund, Rogers, and Hoag) for others.

The resulting system, MOAPS (Micro-Oriented Agricultural Production System), was designed to analyze farm-level impacts of resource-policy issues, including low-input sustainable agriculture, cross-compliance policies, and other environmental issues. An immediate application occurred in an analysis of the 1985 Food Security Act Conservation Compliance Standards (Thompson et al.).

Subsequently, MOAPS was incorporated into an even more comprehensive system of models known as CEEPES (Comprehensive Economic Policy Evaluation System). This model was developed through the cooperation of the Environmental Protection Agency (EPA) and the Center for Agricultural and Rural Development (CARD) at Iowa State University. The major application to date involves study of the banning of corn rootworm insecticides in Iowa (Cole et al.). CEEPES is easily the most comprehensive modeling system built to date. Within CEEPES a suite of simulation models has been assembled to address a variety of resource-policy questions (CARD and U.S. EPA). The development group is currently attempting to simulate alternative policies toward atrazine use in agriculture. The system is designed to account for market consequences as well as transport of atrazine and its substitutes in multiple media (air, land, and water). Final evaluations of the consequences to human health and the environment are also key components.

Aggregate Analysis

Increased interest in national policy effects during the 1970s prompted a major emphasis on development of sector models to reflect aggregate response to alternative policies (Lee). One approach entailed cost-minimizing models such as the CARD model (English et al.). 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 for one or more commodities is minimized. Marketing linkages between subregions and semiaggregate resource constraints across subsets of the total sector may also be reflected. Typically such models exhibit a somewhat poor replication of regional crop mix (Schaller; Young), primarily due to a lack of detail concerning microlevel response.

Earlier versions of this methodology relied on fixed prices, ignoring any quantity impacts on input or output prices. Later versions, including the CARD-RCA model used in the 1985 RCA resource inventory analysis, employed an iterative procedure to determine equilibrium prices and quantities (Huang, English, and Quinby). For an initial set of prices, a demand (econometric) model is solved for commodity quantities. The aggregated programming model is then solved such that the desired demand is produced at minimum cost. Shadow prices on the demand constraints from the programming model then serve as prices in the demand model, and the process continues until the prices in the demand model are approximately equal to shadow prices in the supply model.

Later refinements in this methodology included fully price-endogenous programming models that sought to maximize welfare instead of minimizing costs (Takayama and Judge). The equilibrium conditions of supply equal to demand imply that total surplus, or the sum of producer and consumer surplus, will be maximized at the point of equilibrium. McCarl and Spreen review numerous studies utilizing this approach. Quadratic-programming formulations are numerous (Judge and Takayama; Hall et al.), and Duloy and Norton employed separable-programming techniques to maximize a linearized version of the quadratic objective function implied when maximizing total surplus with linear demands. Applied work employing these methodologies includes Meister, Chen, and Heady's study of price supports or storage policy. Several studies (Taylor and Frohberg; Taylor and Swanson; and Meister, Chen, and Heady) employ such approaches to examine the impacts of limiting fertilizer use. Langley, Heady, and Olsen examined the macro implications of a transition to organic farming, while Burton and Martin investigated the impacts of restricted herbicide use.

Despite fairly rigorous development, the sector models noted above often exhibit quite different response characteristics from actual aggregate output because of unrealistic crop specialization and resource mobility (Baker and McCarl). An alternative approach is to simultaneously model a large group of homogeneous farms and/or aggregate subgroups of heterogeneous farms, and to aggregate the results of the numerous optimized farm models. On a national or regional basis such aggregation is obviously impossible. The required input data and computing time are too onerous. McCarl proffers one partial solution by employing a formulation involving Dantzig-Wolfe decomposition principles. Once firms within each subregion have been classified into similar groups based upon selected criteria, such as primary production activity, resources, or firm size (Anderson and Stryg; Johansson), representative farm models are run for a multitude of potential input and output price combinations. Results are then aggregated across firm classifications for each price vector. This process produces extreme points of the feasible space for a possible sector model shown below.

$$\text{Max } C \cdot X$$
$$\text{subject to } X - \Sigma \hat{X}_i \lambda_i = 0,$$
$$\sum_i \lambda_i = 1, X \geq 0, \lambda_i \geq 0 \text{ for all } i.$$

Here $\hat{X}_i$'s are the extreme points obtained by aggregating the output of the farm models, and λ_i represents the proportion allotted to each of the extreme-point solutions.

In practice all extreme points will not be known, and the full Dantzig-Wolfe (D-W) decomposition algorithm requires choosing a set of shadow prices for the convexity constraints, solving the representative farm models using the chosen shadow prices as objective-function coefficients, and inserting the resulting extreme-point solutions into the sector formulation. One may then solve the sector model for a new set of shadow prices and resolve the subproblems with the updated shadow prices. A second set of extreme points is generated and is added to the sector model. The process continues until the prices and/or subproblem solutions remain unchanged between two iterations. The algorithm also provides for upper and lower bounds on the objective-function value at each step (Dantzig and Wolfe).

One should note in the simplified example above that output prices are exogenous. Endogenous prices could easily be incorporated by employing a quadratic objective function to maximize total surplus. In addition, measures of relevant externalities, such as soil loss or groundwater contamination, could be aggregated across the optimal farm models and incorporated into the sector model via an additional accounting constraint. The optimal sector-model solution would then also provide the corresponding total externality generated (assuming additivity is appropriate).

Önal and McCarl note that a great deal of detail and effort is required to generate the numerous farm-level LP solutions across the relevant ranges of output and input prices. An alternative approach is to use historically observed crop mixes for the regions under consideration. These are assumed to be aggregates of feasible solutions for the unknown firm models in each region. Aggregate output and crop mix for the various regions are usually available in county or state statistics. Estimates of aggregate inputs are less reliable, yet use of representative budgets on known acreage may provide a reasonable approximation. Some aggregation bias is likely to occur because the historical crop mixes may not span the full set of possible aggregated optimal extreme points. Proposed policy changes that might alter the production choice set farmers face would render this approach less attractive since historical regional crop mixes may be incomplete.

Theoretical presentations of this methodology appear in Önal and McCarl as well as the 1982 article by McCarl. The major applied study to date (Hamilton, McCarl, and Adams) evaluates the economic effects of reduced ozone-pollution levels in the Corn Belt under alternative aggregate-model assumptions. The authors compare various aggregation schemes and their relative performance. In general, the Dantzig-Wolfe procedure, using either a large array of pregenerated whole-farm plans or historical crop mixes, strongly outperformed the use of detailed firm-level LP models with constant prices as well as a quadratic sector model with regional land and labor constraints.

Overall Evaluation of Policies

Agricultural and environmental policy also requires additional evaluation in terms of its administrative cost, feasibility, and institutional requirements. Such considerations about policy implementation range from the costs and feasibility of invoking a given policy under the current set of policy institutions to using a new set of institutions in carrying out a policy.

Administrative costs include any additional expenditures in equipment and personnel necessary to enforce the policy in question. For example, strict adherence to soil conservation and commodity program cross-compliance provisions may require additional funding of local and state Agricultural Stabilization and Conservation Service (ASCS) and Soil Conservation Service (SCS) offices. Feasibility problems include the probability of farmers eluding policy regulations (enforcement slippage) as well as the probability of successful court challenges to the policy. The accuracy of models used to implement and track the implications of policies is an especially important concern in the latter case (Hauser). A broader question is the desirability of using the current ASCS institutional complex to administer a relatively strict erosion- and pollution-control policy. The ASCS, with its tradition of subsidizing, rather than regulating agriculture, and with farmer control of its local and state offices, may be an inappropriate tool for carrying out environmental policies (Lovejoy).

Less mundane, but equally important policy criteria include equity and fairness concerns, property-rights implications of the policy, and a social desire to maintain the family farm. Ceterus paribus, society generally favors policies that narrow rather than expand income distribution (Seitz). A policy where more wealthy farmers would receive a disproportionate share of government subsidies or a policy where relatively poor farmers may be burdened with a disproportionate portion of costs may violate this equity criterion. Fairness concerns include the notion of shared consequences, where society alleviates some of the hardships imposed on individuals by government policies that meet a social end (Seitz), and the concept of earned rewards that hold "firms and individuals should receive what they pay for and should pay others for the damage they cause" (Seitz, p. 318). Shared consequences and earned rewards may together imply that while farmers should not bear all costs of reducing farm-source environmental pollution, neither should taxpayers pay all pollution-abatement and resource-conservation costs.

The form that policies take also has property-rights implications. For example, under subsidy policy, farmers are given implied pollution rights because a given action involves bribing the farmer not to pollute (purchasing the right) and society bears the costs of pollution abatement. Regulatory policies, on the other hand, imply that pollution rights rest with society if farmers are forced to bear the lion's share of pollution-abatement costs.

Finally, society holds goals for agriculture, including a supply of food that satisfies the wants and needs of American consumers at reasonable costs. A second goal is preserving the family farm because it provides a blueprint for social behavior in a democracy (Thompson). A third goal that affects farm policy is that of efficiency in government expenditures. Fewer government expenditures are desirable as long as the other overriding goals of the policy are maintained. Accordingly, environmental policies that are perceived as threatening the family farm, or requiring large increases in food costs or government expenditures may be rejected by the public.

Role of Farm-Level Analysis

Given the preceding discourse, one might question what role farm-level analysis has within policy formulation. John E. Lee, director of the Economic Research Service, summarized the micromodeling needs of that agency as:

- To understand likely responses of farms in various regional, commodity, size, financial, and other situations to various market conditions and policy provisions in order to qualitatively understand, but not necessarily quantify, likely aggregate responses;
- To understand likely distributive effects and farmer responses to various policy and market situations; and
- To use micromodels with macro- and econometric models to help provide additional detailed information and likely behavioral responses not well specified in the macromodels (Lee).

Lee sees little reason to use micromodels to estimate aggregate behavior due to the large data requirements and aggregation problems. These concerns are likely doubly emphasized given the status of the federal budget.

Demand for micromodeling of farm-level response to alternative environmental policies may grow, however, at the state or regional level. Greater concern over resource use at that level has prompted many states to more closely regulate agriculture. The "Big Green" proposal currently under consideration that would phase out much or all agricultural chemical use in California is one example. Detailed knowledge of the resource base, farm characteristics, and producer decision environment can only help in such analyses. Estimates of local effects of alternative policies can also aid in targeting areas for treatment.

One might argue that farm-level modeling also has a place in serving individual agricultural clientele. Experience, however, has shown little derived demand for such analyses by agricultural management firms or individual producers. Use of highly detailed process and optimization models similar to those described here may not be possible for the majority of individual producers. Use of subcomponents, however, such as the crop-growth models, is already common among more progressive producers in several states. Their efforts may eventually encompass self-analysis of resource use employing many or all of the tools examined here. Such efforts may become more common as expert-systems applications mature. One program (CARMS by Richardson et al.) serves as a front-end data input and matrix generator for FLIPSIM. These types of applications greatly reduce the process of building detailed farm-level models.

Summary and Conclusions

Agricultural economists, working in cooperation with their fellow agricultural scientists, have made great strides in reflecting the decision environment faced by producers as well as the stochastic nature of agricultural production. Advances in computer technology, optimization algorithms, and knowledge/reflection of biological and physical processes have allowed us to examine more complex problems and evaluate more comprehensive resource-policy options. As expertise has been gained in using such optimization and process models, the tendency to develop more comprehensive policy-analysis systems has occurred, resulting in the "marriage" of seemingly diverse components. These efforts have extended from firm-level response to aggregate national price and safety impacts.

Such gains should not be accepted blindly. Our ability to accurately predict producer decision behavior is still somewhat poor, likely due to incorrect objective and constraint specification. Process-model development continues with physical responses, such as the deterioration of crop residues, effects of alternative tillage practices, and means of accurately reflecting rotational considerations, requiring more work. Dealing with the large quantities of physical data necessary to model pollutant transport, for example, is still a problem despite the use of GIS and other advanced technologies.

In practice, regional effects will likely have greater emphasis due to the regional nature of many resource problems. Policies mandated at the national level will likely be too general to have large effects unless very specific standards, etc., are employed. If highly specific national policies are used, regional differences will be exaggerated and relative comparative advantage among regions greatly changed. Research into what level and form of policy administration is appropriate for a particular resource problem is greatly needed. Care should be taken to account for unintended spillover effects of a given policy. Some very challenging tasks are before us. Let us hope that we are not too late in recognizing symptoms of past excesses.

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