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Modelling Region-Specific Agricultural Production and Resource Use Within a National Market

Abstract

A multiperiod regional-national recursive system is formulated to model the interrelationships between agricultural production, resource use, and the environment, in a region nested within a national market. The system consists of three main components: a linear programming model of a region; an econometric simulation model for the nation; and, a linkage procedure which transfers information between the programming and econometric models. An example is presented which is capable of investigating alternative production practices in the State of Iowa operating in the U.S. agricultural economy.

Disciplines

Agricultural and Resource Economics | Agricultural Economics | Economics

MODELLING REGION-SPECIFIC AGRICULTURAL PRODUCTION AND
RESOURCE USE WITHIN A NATIONAL MARKET

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Abstract

A multiperiod regional-national recursive system is formulated to model the interrelationships between agricultural production, resource use, and the environment, in a region nested within a national market. The system consists of three main components: a linear programming model of a region; an econometric simulation model for the nation; and, a linkage procedure which transfers information between the programming and econometric models. An example is presented which is capable of investigating alternative production practices in the State of Iowa operating in the U.S. agricultural economy.

Questions of agricultural production potential and long run sustainability are becoming increasingly more important as concern over maintaining our natural resources and the continued availability of productive inputs begin to appear. Quantitative analysis of the complex interrelationships between agricultural production potential, resource use, technical change, and the environment requires much detailed information on the site-specific nature of resource inputs and alternative land-use practices over time. Information on many economic, agronomic, social, and institutional aspects are needed for a complete investigation.

Many quantitative techniques, primarily econometric simulation and programming models, have been used in the past to investigate these problems (Martin, 1977). Generally, a programming or normative modelling framework is necessary in situations where environmental interactions are important simply because there is no time series basis for estimating highly disaggregated regional coefficients for water runoff, soil loss, and other forms of environmental damage, for different land classes, crop systems, and cultivation practices. Most of the time there are only one, or a small set, of regional cross section observations on production and environmental interactions. However, while normative models may be needed to assess potential production, econometric or positive components are needed to estimate prices and related outcomes if potential environmental improvement, soil conservation, and productivity maintenance were to actually be attained (Heady, 1981).

If the constraints imposed by the underlying assumptions of both programming and econometric models could be offset, it would appear that a benefit would be realized in terms of opening up new areas of investigative research. A joint research endeavor between the Center for Agricultural and Rural Development (CARD) at Iowa State University, and the Natural Resource Economics Division (NRED) of the U.S. Department of Agriculture, has developed and tested a combined econometric simulation-programming policy analysis system which attempts to accomplish such a task (Heady and Langley, 1981). This Regional-National Recursive Hybrid System consists of three main components: a linear programming model of a region; an econometric simulation model for the nation; and, a linkage procedure which transfers information between the programming and econometric models. Benefits are gained from the integration of information on the spatial pattern of regional supply, resource use, technical means of production, and the environmental implications (generated by a regional programming model) with the detailed information on market structure and prices of

commodities and inputs (generated by a national econometric simulation model). The regional-national framework developed here is a direct outgrowth of other research on hybrid modelling being carried out between CARD and NRED (Baum, 1978; Huang, et al, 1980a, 1980b; Huang, Weisz, and Heady, 1980; Langley, Huang, and Heady, 1981; Langley, English, and Heady, 1982).

The purpose of the present paper is to provide an overview of the background and logic of the Regional-National Recursive Hybrid System. Following this overview, a case example is outlined which models the State of Iowa nested within the United States agricultural economy. Conclusions are drawn along with suggestions for future work.

Advantages can be gained from linking a regional linear programming model with a national econometric simulation model within a regional-national recursive framework. Since a system can be formulated such that only one region is explicitly modelled within a national framework, a detailed site-specific evaluation of the impacts of state and federal government policies or environmental interactions becomes practical. Problems such as soil erosion vary in intensity and concentration even across a single state. The region under study can be broken down into as many subregions as necessary to evaluate the impacts of conservation practices in different parts of the region. In general, it can be stated that the lower the level of aggregation, i.e., the smaller the average size of the regions considered (whatever the size indicator chosen), the higher the probability that explanatory variables will be located "elsewhere". The econometric component aids in estimating the variables which are not regionally determined. A programming formulation can easily handle the discrete (qualitative) choices associated with institutional change, while conventional econometric models focus on the continuous (quantitative) changes in policy instruments over time. This further suggests that policy model specification can be enhanced by a proper blend of the two techniques (Rausser and Just, 1981). Also, the model can be expanded to a multiregional model of the entire nation as resources become available and such a model is needed.

As an example of this system, a model developed in conjunction with Task 2 of the International Institute for Applied Systems Analysis' Food and Agriculture Program is outlined. Task 2 is concerned with examining the important site-specific relationships between agricultural production technologies, resource use, and the environment, which will affect the stability and sustainability of the global food and agricultural system in the long run. A group of

researchers at the Center for Agricultural and Rural Development, Iowa State University, have formulated a case study for the State of Iowa in which a regional-national recursive hybrid model is used to evaluate these relationships with respect to crop production patterns, commodity supply, demand, and price, and other economic factors. Focus is upon the State of Iowa with necessary attention given to Iowa's relationship within the agricultural economy of the United States. A more detailed description of each model component appears in Heady and Langley (1981).

The model developed for the Iowa Case Study consists of three main components: a regional linear programming (LP) model for the State of Iowa, a national econometric simulation (ES) model for the United States excluding Iowa, and a linkage procedure which transfers information between the programming and econometric components. The LP component maximizes the net returns from the production of crops subject to a set of resource constraints, and includes 12 spatially delineated producing areas consistent with Iowa soil conservancy districts. The objective function is of the form:

$$\max \text{OBJ} = \sum_{ij} P_{ij}^s C_{ij}^s - \sum_{iklm} T_{iklm} L_{iklm} - \sum_i P^{\text{nb}} Q_i^{\text{nb}}$$

where: $i=1,12$ for the producing areas; $j=1,8$ for the crops produced; $k=1,9$ for the conservation-tillage practices; $l=1,48$ for the crop rotations defined in each producing area; $m=1,5$ for the land classes; $P_{ij}^s C_{ij}^s$ = gross return received by farmers for selling crop (C_j^s) at price (P_{ij}^s) in producing area (i); $T_{iklm} L_{iklm}$ = cost of production (T) of rotation (l) with conservation-tillage practice (k) on land class (m) in producing area (i), multiplied by the level of crop production activity (L); and, $P^{\text{nb}} Q_i^{\text{nb}}$ = price of nitrogen fertilizers (P^{nb}) multiplied by the quantity of nitrogen purchased (Q_i^{nb}) in producing area (i). All variables are for time period t .

Crop production activities simulate rotations producing corn grain, corn silage, legume and nonlegume hay, oats, sorghum grain, soybeans, and wheat, in crop management systems incorporating rotations of one to four crops. Each rotation is defined for three conservation methods (straight-row, strip cropping, and contour plowing), with each conservation method being associated with three tillage practices (conventional tillage, residue removed, and reduced tillage). Thus, each rotation, combined with a specific conservation-tillage practice, defines a unique crop management system. Coefficients defined for each activity include the cost of production, land use (one acre), the quantity of nitrogen required, the yield adjusted for conservation-tillage practice, and the average number of tons of soil leaving the field during a one-year period.

The purpose of the U.S. simulation component of the Iowa regional-national recursive system is to estimate resource use and commodity output originating in the United States other than Iowa. These estimates are summed with those originating solely within the State of Iowa (from the programming component) to determine important economic variables in the national market. The econometric component is based upon the CARD-National Agricultural Econometric Simulation model (CARD-NAES) originally specified by Schatzer, et al (1981), and Roberts and Heady (1979, 1980), with some restructuring being done for this study. CARD-NAES depicts farmers' behavior in the purchase of major inputs and can be used to characterize the response of farmers to many changing variables which relate to production decisions.

Major categories of agricultural production are included in the simulation sector by five crop submodels--feed grains (corn, sorghum, oats, and barley), wheat, soybeans, cotton, and tobacco; and, five livestock submodels--beef, pork, lamb and mutton, chicken, and turkey. The submodels can be described in general terms as follows: (a) resource demands in the current year depend directly or indirectly on lagged commodity and resource prices, lagged

resource demands, and other variables; (b) current production depends upon the current quantity of resources demanded; (c) supply in the current year depends on current production, carryover, and imports; (d) average current year commodity prices depend on current supply, exports, and other variables; (e) commodity demand in the current year depends on current price, and other variables; (f) gross income in the current year depends on current price and production; and, (h) quantity supplied is required to equal quantity demanded primarily through inventory adjustments.

CARD-NAES consists of 210 equations (151 for crops and 59 for livestock) formulated primarily in a sequential framework. Annual time series data are used to estimate the structural parameters of the model using appropriate statistical estimation techniques. Most equations are estimated from 1949-76 data with portions of the livestock submodels using 1953-76 data.

The purpose of the Linkage Component of the Iowa regional-national system is to retrieve and transfer information between the programming and econometric components; and, to revise and adjust selected variables between time periods to simulate the recursive sequence of agricultural production and its interaction with the environment. The Linkage Component can be decomposed into three subsectors: Retrieval, Adjustment, and Revision. Linkage variables, defined as variables providing information from the regional model to the national model, and vice versa, must be specified for these three subsectors.

In the current version of the Iowa model, information retrieved from the Iowa LP component includes production levels for the endogenous crops, soil loss, nitrogen fertilizer use, and land use in each of five land groups for each of 12 producing regions for each of 9 conservation-tillage practices. Crop production and fertilizer use are inputs to the econometric component, while soil loss and land use are inputs to the Adjustment and Revision subsectors.

The Adjustment subsector adjusts the estimated crop yields between time periods due to the impacts of soil loss and other environmental and agronomic aspects. It has been repeatedly documented through field observations that as topsoil depth declines due to erosion, crop yields also decline, ceteris paribus (e.g., Wetter, 1977; Kaiser, 1967; Pawson, et al, 1961). Most empirical yield functions of this type rely on changes in topsoil depth, estimated by the Universal Soil Loss Equation (Wischmeier and Smith, 1965), as the primary independent variable. This is because of the lack of relevant agronomic information which can be readily incorporated into simulation models (Dumsday, 1971). Recent work by Konijn (1982a, 1982b) provides a more empirically-based approach to the adjustment of crop yields due to changes in such important agronomic factors as organic matter, soil moisture content, and other soil chemistry properties.

The Revise subsector of the Linkage Component takes information from the Retrieval and Adjust subsectors and revises the LP component for the next time period. The revision reflects the expected yield and commodity prices for next year's production response.

The basic solution procedure for the Iowa model is as follows. The regional LP component is first solved for the profit maximizing level of crop production and resource use for the State of Iowa. These values are summed with estimates of production and input use occurring in the United States excluding Iowa (from the national econometric simulation component) to obtain national totals. Commodity prices and other important economic variables are estimated in the econometric component. Crop yield adjustment factors are determined based on inches of top soil lost and, are used to revise the crop yields in the LP sector. The newly estimated commodity prices are used to update the crop sell coefficients in the LP objective function. After the LP input data matrix has been revised, the programming component is solved for the next time period, thus, repeating the entire process again until the predetermined number of annual simulations are completed. The Econometric

and Linkage Components are written in FORTRAN while the LP Component has been formulated in two ways, depending upon whether the program is run at Iowa State on an ITEL AS/6 or at IIASA on a VAX computing system. The IBM-MPSX with the READCOMM procedure is utilized at Iowa State, while the MINOS package is used at IIASA.

The Iowa Regional-National Recursive Hybrid model is currently operational and has been used for some preliminary analysis to investigate crop production activity under alternative soil loss limits. Such limits have been imposed by the State Legislature of Iowa in order to alleviate the impact of soil erosion on Iowa's agricultural lands. The results indicate that limiting the use of crop management practices which cause soil loss in excess of the 5 tons/acre tolerance limit leads to highly erosive land being idled and an increased use of small grains (oats and wheat) in the selected crop management schemes. Average gross soil loss is reduced from a state average of 7 tons/acre with no restrictions to 4 tons/acre with tolerance restrictions, with the most noticeable benefits occurring in the highly erosive lands of Western Iowa. A more complete analysis of selected results is forthcoming.

Plans have been drawn up to expand and enhance the LP and Linkage Components of the Iowa model. The Iowa LP Component will be elaborated to include subsectors for energy use and availability, and for crop residue management. The LP Component may also be expanded to include sediment delivery ratios. A major improvement in the Linkage Component will be the integration of the crop module being developed at IIASA by Konijn, which adjusts crop yields and soil fertility levels from year to year based on certain agronomic relationships. Potential scenarios include analysis of the implications of controlling soil erosion by means of tax or subsidy schemes; restricting the availability of selected inputs into the production process (e.g., nitrogen fertilizer, energy supplies, etc.); and, shifts in production patterns in Iowa due to changes in relative input and output prices.

The modelling framework developed here has many other potential applications. This framework may be readily applied to an analysis of soil erosion and related environmental impacts in targeted regions of the country where these problems are believed to be most severe, e.g., Western Iowa, Western Tennessee, and the Palouse area of Washington. Also, the LP Component may be expanded to include a larger spatial area, such as the Great Plains, or even the entire United States. The modelling framework can be used as an aid to farmers in planning the conversion to soil-saving practices. If the Regional-National Recursive Hybrid model follows the same evolutionary process as econometric simulation and programming models have over the past several years, then many more refinements and uses of this modelling technique will be developed within the agricultural research community.

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