THE USE OF PLANT GROWTH SIMULATION MODELS FOR THE GENERATION OF TECHNOLOGY MATRICES IN AGRICULTURAL SECTOR MODELS

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ABSTRACT

The agricultural sector models are important tools of policy analysis in agriculture. The technology matrices constitute the core of these models. The farm surveys, farm accounts, field experiments and expert opinions are the main sources of information employed in the construction of the databases for such matrices. These data sources are limited in crop, time and space coverage and give rise to problems of consistency when used together. The subject of this paper is to demonstrate how plant growth simulation models can be employed to augment these sources in the construction of technology matrices for agricultural sector models. Two models are employed for this purpose, namely TASM-Turkish Agricultural Sector Model and EPIC-Erosion Productivity Impact Calculator.

INTRODUCTION

Agricultural Sector Models have been and are important tools of policy analysis in agriculture. With the fast advances in computer technology over the past decade it has been possible construct sector models which contain more and more micro level information to address questions- of practical importance.

The agricultural sector models consist of three basic parts. First is the objective function, which specifies the behavior of the economic agents in question. The behavior specification can be a normative or desired one or it can be an objective or hypothesized one. The models with the first type of objective functions are known as "Normative Models" and the ones with latter type of objective functions are known as "Positive Models." Second part of sector models consist of the technology matrix, which specifies the transformation of inputs to outputs or in other words, it specifies the production function. The technology specification can range between the usual Leontief type of no factor substitution, and continuousone with perfect factor substitution. The third part of sector models consist of the specification of exogenous information including resource availabilities, demand constraints and policy parameters.

The subject of this paper relates to the construction of the technology matrix which constitutes the core of an agricultural sector model. The technology matrix, together with the resource availabilities determines the choice set and hence the flexibility and richness of the model. The technology matrix on the other hand is the most demanding and time consuming part of the modeling exercise in terms of the data requirements.

The data for the technology matrix which is composed of activity vectors quantifying the amounts of different inputs required on a unit of land to obtain given amounts of outputs is generally obtained from farm surveys, farm records or field experiments. Farm surveys and field experiments are very costly and time consuming. Farm surveys suffer from respondent errors and lack accuracy. The experiments on the other hand, suffer from not reflecting the farmer conditions and from limited coverage at a given point in time. The farm records,are a rare source in many countries where agriculture is dominated by small enterprises with no recorded accounting systems. Furthermore, the farm records and farm surveys are of little use in sector models which are used to make projections into the future or analyze policies which may imply new technologies not observed at present. In those cases, the farm records and surveys are bound to work with a subset of the true choice sets.

In general, the agricultural sector modelers must resort to all three of the above sources of data in constructing the activity vectors of the technology matrix. Apart from problems of consistency resulting from the use of data generated from different sources, which are compiled for different reasons by different agencies or researchers, there are usually problems of coverage. While it may be possible to find many observations on certain regions and/or crops, it may not be possible to find enough or any observations on some regions and/or crops.This results in problems of aggregation in non-regional sector models and in empty cells in the technology matrices of regional models. In such cases, the researcher either resorts to non realistic and undesired levels of aggregation or to expert opinions to fill in the gaps.

This paper attempts to demonstrate how plant growth simulation models can be employed to complement the above sources of information in the construction of technology matrices for agricultural sector models.

The plant growth simulation models are essentially physical production function models, which bring together the laws of biology, physics and chemistry and the findings of field experiments over time and space which are short of laws but within certain degrees of statistical levels of confidence. Towards this end, two models will be introduced. TASM "Turkish

Agricultural Sector Model" and EPIC "Erosion Productivity Impact Calculator."

TURKISH AGRICULTURAL SECTOR MODEL-TASM

TASM is a comparative static, partial equilibrium positive mathematical programming model. The objective function is the maximization of the sum of consumer and producer surpluses. The model incorporates three interdependent sub-sectors in it, namely annual crops, perennial crops and livestock. The domestic and foreign demand functions are given exogenously to the model but the supply function is endogenously determined by the model. Thus the farmgate prices as well as area, production, consumption, trade of agricultural products are endogenously determined by the model.

TASM was developed by the World Bank team Le-Si, Scan- dizzo and Kasnakoglu in 1983[1] to assess the developments in Turkish agriculture and its competitiveness in the world markets. The original version used piece-wise linearization techniques to linearize its quadratic objective function containing demand and risk. The model containing 55 agricultural products which constituted nearly 90 percent of the value of output in agriculture was ran on the mainframe computers.

In 1985, Kasnakoglu and Howitt introduced the non- linear cost component referred to as PQP terms to TASM, updated the base year from 1979 to 1981 and employed nonlinear objective functions directly rather than their linear approximations.The model was ran on main- frame computers using nonlinear programming softwares.[2,3]

In 1985, Norton and Gencaga developed the regional version of TASM for Turkey, employing linearized objective functions and running them on mainframe computers.[4]

In 1987, Cakmak combined regionalization to non-linear cost components-PQP's and direct solution of the non- linear programming program on the mainframe.[5]

In 1988, Bauer and Kasnakoglu, have adopted the version of TASM with non-linear cost components to personal computers using the GAMS-MINOS software. They have also updated the base year from 1981 to 1986 and introduced substitution in the feed rations of the livestock sub- sector of the model.[6]

In 1990, a team of experts from Wye College (England), Middle East Technical University (Turkey) and Turkish State Planning Organization have expanded the foreign trade component of TASM, added products under Common Agricultural Policy regime of EC, updated the base year to 1988 and employed the model to analyze the impacts of Turkish accession to EC on Turkish agriculture as well as on the community budget.[7]

In 1991 a team of experts from Turkey and Germany have started adapting the PC version of TASM to est mate the likely developments of the agricultural sector between 1990-2010 in the GAP (Southeastern Anatolia Project) Region and Turkey. The GAP project is one of the largest irrigation and regional development projects of its kind in the world. It is expected to purpose.[10] EPIC is a sophisticated production function model which simulates the interaction among weather, hydrology, erosion, plant nutrients, plant growth, soil, tillage and management and plant environment control.

EPIC is composed of nine physically based submodels which are linked sequentially and interactively with each other.EPIC submodels are described briefly below:

Weather Submodel: EPIC's weather submodel simulates precipitation, air temperature, solar radiation and wind on a daily bases from historical observations and probabilities on daily bases. Furthermore, the weather submodel has the user option to inspect the values generated and to correct them for precipitation and temperature based on most recent information available.

Hydrology Submodel: The hydrology submodel simulates volume and peak discharge rate of surface run-off given daily rainfall, snow melt and/or irrigation. Other hydrology components include evapotranspiration, percolation, lateral subsurface flow, water table dynamics and snow melt.

Wind and Water Erosion Submodel: EPIC is capable of simulating both wind and water erosion. Water erosion is estimated using the Universal Soil Loss or the Onstad-Foster equations. EPIC calculates daily, annual and long-term erosion.The wind erosion is based on wind, soil erodibility, soil ridge roughness, field length in wind direction and quantity of vegetation cover.

Plant Nutrient Submodel: EPIC monitors three plant nutrients: nitrogen(N), phosphorus(P) and lime. Nitrogen processes simulated include fertilization, nitrogen fixation, rainfall nitrogen, mineralization, denitrification, immobilization, leaching of NO3, upward NO3 movement by soil water evaporation, crop uptake, organic N transported by sediment and NO3 in runoff. Phosphorus processes include mineralization, immobilization, sorption-desorption, crop uptake, fertilization, runoff of soluble P and sediment transport of mineral and organic P. EPIC simulates the use of lime to neutralize the toxic level of aluminum in highly weathered soils and to maintain desired soil pH in moderately weathered soils.

Plant Growth Submodel: EPIC uses a general plant growth model to simulate leaf interception of solar radiation; conversion to biomass; division of biomass into roots, above- ground biomass and economic yield; root growth; water use; and nutrient uptake. Plant growth is constrained by water, nutrient and temperature stress. EPIC is capable of simulating crop growth of both annual and perennial plants.

Soil Submodel: The soil submodel monitors change in soil properties. Initial soil properties are specified for a fixed 10 mm top layer and up to nine additional layers of user-specified thickness. Soil characteristics specified by layer are thickness of layer; bulk density; water holding capacity; minimum field capacity; wilting point; organic N; NO3; labile P; crop residue; sum of bases; organic C; CACO3; coefficients of linear extensibility and exten-extension; pH; KCI extractable aluminum content; percentage of sand, silt and clay; coarse fragment inclusion.

Tillage and Management Submodel: This submodel is controlled by irrigate about 1.6 Million hectares thus increasing irrigated area in Turkey more than 50 percent of its present level. The project is expected to be fully completed in 2010.[8]

It is this version of TASM, adopted to GAP and will be referred to as the TASM-GAP model, which is the subject of this paper. Therefore it would be useful to present some its features.

TASM-GAP consists of two main regions: GAP and Rest of Turkey(ROT). Therefore, it is an exercise where one focuses on a specific region within Turkey. The Rest of Turkey region has 8 implicit regions in it due to the specification of different activities for dry and irrigated land and for different temperature and rainfall and zones. The regionalization however is not a geographical one. A very detailed regionalization on the other hand is specified for the GAP region. The region is divided into 16 sub-regions: 15 irrigation project areas and non- project dry area. Each of the project areas are further divided into 3 land capability classes and two temperature zones. The dry area on the other hand is divided into 3 rainfall zones and 4 land capability classes. This implies over 700 regions in GAP for each of which crop patterns are to be estimated over the next two decades.

There are 8 types of inputs considered in TASM-GAP, namely labor, machinery, land, seed, feed, water, fertilizer and investment costs for perennials. Labor and machinery are specified quarterly in the ROT and monthly in GAP. Land is specified yearly in ROT and monthly in GAP. Water is specified yearly in ROT and in 10 day periods in GAP. Fertilizer (N and P), seed, investment cost and feed inputs are yearly in both sub-regions.

There are 37 field crops, 20 perennials, 6 feed crops and 20 livestock products in TUR-GAP. The technology matrix requires over 20,000 pieces of data when this information is taken together with the input detail.

Clearly, when one is working with such detail it is not possible to find observations be it farm records or surveys or field experiments to fill in the cells of the technology matrix. Furthermore, as the irrigation projects are to be completed gradually over time between 1990 and 2010, and since the region at present is almost dry, there is no way of obtaining relevant information from the region regarding irrigated practices of the future. To complicate matters further the technology of present may not be a good indicator of the technology of the coming two decades. Resorting to expert opinions and substitutions of information from other regions of the country is almost an impossible task, as it is very difficult to achieve consistency in so many pieces of information required. This is why we believe, resorting to plant growth simulation models could be a practical solution in such cases.

EROSION PRODUCTIVITY IMPACT CALCULATOR EPIC

EPIC was developed by J.W. Putman and P.T.Dyke for the Resource Conservation Act Appraisal in the United States in a cooperative effort led by the Agricultural Research Service and supported by the Soil Conservation Service and the Economic Research Service.[9] While EPIC was originally developed to measure the effects of erosion on soil productivity and long-range resource capacity, because of the many features incorporated in it, there have been several attempts to employ it beyond this original user-specified crop rotations which may vary from a single, continuous crop to a six year rotation with six crops. The tillage submodel simulates ridge height, surface roughness, nutrient and residue mixing, the change in bulk density and conversion from standing residue to flat residue. There are four harvest options:traditional, hay, multiple and no harvest.

Economics Submodel: This component of EPIC uses a crop budget to calculate crop production costs. Income is determined from simulated annual crop yields. Output and input prices are given as exogenous information.

Plant Environment Control Submodel: This sub- model of EPIC provides options for irrigation, drainage, fertilization, liming, furrow diking and pesticide application. Irrigation is controlled by specifying the plant water-stress level, the runoff ratio and whether sprinkler or furrow methods are applied. There are two options for fertilizer application: user specified (amount, date, depth) and automatic. EPIC simulates lime application as a neutralizing factor for toxic levels of acidity in the plow layer. The effects of insects, weeds and diseases are simulated in EPIC by specifying loss factors to reduce output from the plant growth model.

INTERACTIONS OF TASM AND EPIC

There are several ways of employing EPIC in the construction of the technology matrix of TASM. First of all EPIC can be employed to generate all the input output coefficients required. This requires exogenous input of tillage practices and timing into EPIC, in addition to detailed soil, weather and plant genetic parameters. EPIC can then simulate optimum fertilizer and water inputs and resulting yields. It is also possible to restrict fertilizer and water applications and obtain different yields. The problem with this approach is two fold: EPIC has to be calibrated very carefully before its absolute results can be employed, since many of the soil parameters inputed are in general not available in the level of detail required by EPIC. One has to perform many experiments with EPIC before being comfortable with absolute magnitudes. Secondly, one has to perform a pre-selection between the numerous activities generated by EPIC not to over crowd the technology matrix of the sector model with technically or economically inefficient vectors. Second way EPIC can be employed is to use it to complement the already available input-output coefficients from various sources. It can complement the available information by filling in the empty cells and by generating alternative activities around the observed ones. This also permits the safer way of using EPIC results in relative terms rather than in absolute terms. For example, the tillage practices, labor and machinery inputs of available activities can be inputed into EPIC to generate synthetic activities with higher or lower fertilizer and water use and the interactions between the two inputs. Similarly, additional activities with different timing of cultivation and harvest can be generated with EPIC to permit multiple cropping practices. Finally, EPIC can be employed towards the original purpose of its construction, by incorporating environmental by-products of activities, such as erosion, fertilizer and pesticide pollution endogenously into sector models.

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