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A MODEL OF ECONOMIC-DEMOGRAPHIC INTERACTION IN DEVELOPMENT*

McCarl, Bruce A., T. Kelley White, Frederick W. Obermiller and David R. Martella**

Bruce A. McCarl is assistant professor and T. Kelley White is professor at agricultural economics at Purdue University where David R. Martella is graduate research assistant. Frederick W. Obermiller is assistant professor of agricultural economics at Oregon State University.

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A MODEL OF ECONOMIC-DEMOGRAPHIC INTERACTION IN DEVELOPMENT

Economic development is a subject of great interest to economists, politicians, planners and ordinary people. Many studies have focused on the definition, measurement and causes of economic development. Although great strides have been made in the area, much work still needs to be done.

Population dynamics has recently come into the spotlight. The "population explosion" and "world food crisis" have raised questions relative to the effect of population growth on economic development. Recently there have been attempts to identify linkages between economic and demographic processes. An extensive review of the literature in these areas is presented by White, et al.

This paper abstracts the results of an effort to develop a conceptual model representing the simultaneous consideration of the demographic and economic phenomena within the development process. The model; called the Purdue Development Model (PDM), has been operationalized into a package of computer programs. However, the model is conceptual and requires a great deal of empirical data to operate.

While the PDM is designed to simulate the overall economic development process, it primarily focuses upon the agricultural sector. A special attempt was made to include those variables which represent the agricultural sector's development and interactions with the rest of the economy and the world. Output is produced in a format which is seen to be meaningful and useful to policy makers.

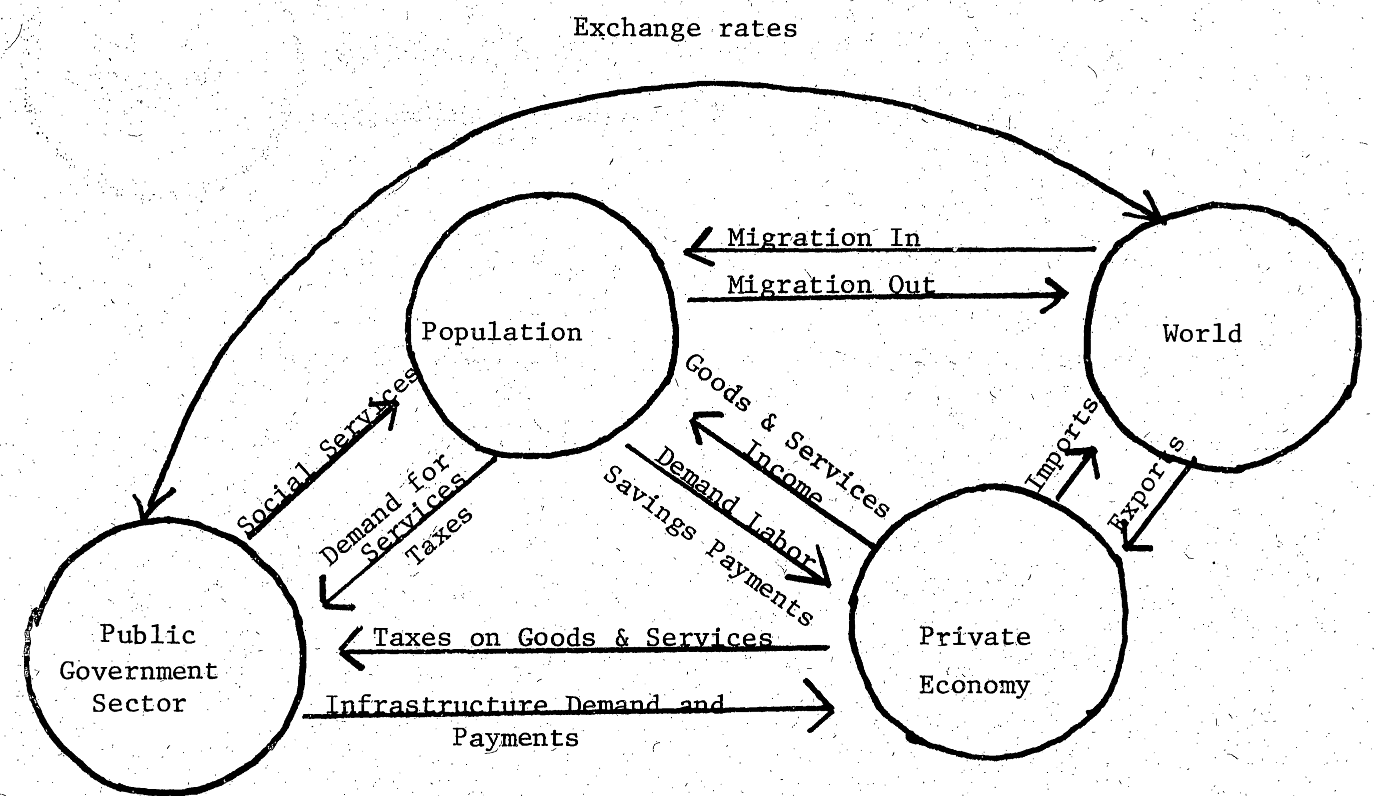

Figure 1. Components and major flows comprising the structure of the PDM.

The essential purpose of the PDM is to quantitatively illustrate the interrelationships between agricultural and nonagricultural development; and between population change and economic development. The model may also be useful in evaluating the multiple impacts of programs and policies designed to affect rates of economic or demographic change.

Model Overview

The Purdue Development Model (PDM) represents the economic and demographic processes involved in development. The economy and the population are treated as two components of an interactive system. The PDM is dynamic, yielding descriptions of activity over each of many time periods. Basically the PDM contains four components: the private economy, the government, the population and the rest of the world. Major components and linkages are presented in Figure 1.

The private economy produces goods for export or domestic consumption while using inputs of land, labor, capital and intermediate goods. Seven aggregate economic goods are represented. These goods are produced and demanded by the two sectors (agricultural and nonagricultural) and the government. The economy is open to imports and exports for each of the seven goods. The economic model is formulated as a one period linear programming model. Each sector has demand curves for each of the seven products. Supply is specified for imports, with an implicit domestic supply curve defined by the interaction of constraints and technical production alternatives.

The government produces services for the domestic economy, collects taxes and uses labor and goods. Services produced by the government are principally health, education, and research and extension. The production of these activities (services) requires taxes, labor and intermediate goods. The government disperses its tax funds in the form of wages and payments for consumed goods and services. Government is assumed to operate on a balanced budget. The government is also seen as a regulatory body placing restrictions on flows of inputs, labor and foreign exchange.

The population component demands goods and services, receives wages, saves, changes structure and provides a labor force. The population is stratified by location, age, sex and educational attainment. Consistent with this stratification, the population structure changes through the processes of birth, death, migration and education. The resultant population structure influences the size and composition of both economic demand and the labor force.

The world component interacts with the domestic economy through the import-export mechanisms and interacts with the population through migration. Explicit export demand and import supply functions are present for each of the seven commodities. Migration activity may result in either a net inflow or a net outflow of people, depending upon demographic and economic indicators.

Given this general overview of the PDM components and their functions, the remainder of the paper is dedicated to a discussion of the specific modeling of each component.

The PDM Models

The PDM is operationalized as a computerized, integrated set of routines written in FØRTRAN. [1/] The package consists of:

1. A population accounting mechanism - takes input on base population and rates of birth, death, migration, educational enrollments and graduation; creates revised population.
2. A competitive-market-simulating linear programming model - takes input on demand, foreign trade, and availability of factors of production; creates a production-consumption pattern.

3. A set of economic-demographic forecaster equations - takes economic results (such as per capita income) and past demographic results (such as population pressure); creates a predicted set of demographic rates (birth, death, migration, enrollment, graduation).
4. A set of demographic-economic forecaster equations - takes demographic results (population composition) and past economic results (per capita income); creates demand for goods, labor force and savings.
5. A forecaster of government services - generates information on supply of services, taxation amounts, exchange rate, allowable trade surplus-deficit, use of goods, labor and pyaments for services used.
6. A foreign sector - supplies imports, demands exports, and interacts through international migration.

These models are related in a dynamic structure. Figure 2 shows the sequence of operation of model components. Any model in the sequence has information on the past behavior of all models.

Population Accounting

The population is disaggregated by age (65 single year age groups, plus one cohort for older people), sex, location (rural agriculture, rural nonagriculture, urban) and educational attainment (five levels of years of schooling completed: less than 4, 4 but less than 8, 8 but less than 12, 12 but less than 16, 16 or more). Overall the population is disaggregated into 1980 cells. Generally, the complete detail of the population is well beyond the interest of policy makers. However, the differential impact of birth, death, migration and education rates makes the detail necessary. Demographic rates are

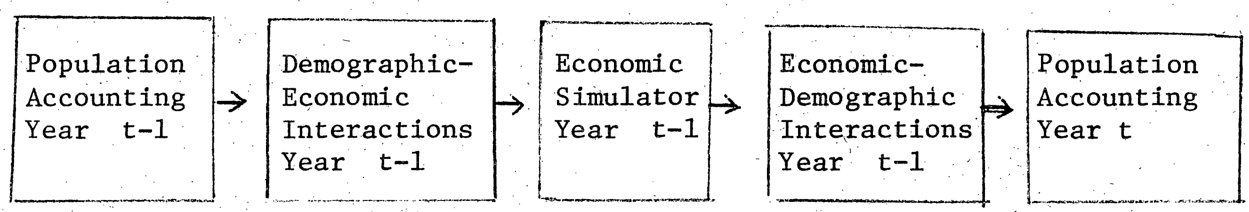

Figure 2. Sequence of model operation in the dynamic PDM system.

applied to the population following standard demographic procedures (Shyrock, Siegel and Associates) and U. S. Bureau of the Census. These demographic rates are generally specific to five-year age groups and to other demographic dimensions when relevant. The multi-year rates are first interpolated converted to one year rates (by Sprague Multipliers as explained by Shyrock, et al.) and are then applied to the disaggregated population. The ordering of rate application is displayed in Figure 3.

Private Economy Model

The private economy is modeled as a disaggregated two-sector, competitive market economy. The two sectors, agriculture and nonagriculture, each produce and import economics goods[2/] (services) which may be used for (1) final consumption by either private sectors, (2) intermediate production by either the private economy or the government, (3) investment capital, or (4) export. Sectoral production is modeled as sets of production possibilities (up to 12 for each good) constrained by factor availabilities which are sector specific and predetermined within a production period (one year). Factor availabilities are modeled as in CHAC (Goreaux and Manne).

The supply of goods and services (domestic plus import) interacts with a set of predetermined (sectoral) and export demand schedules[3/] to yield a constrained market equilibrium solution. This solution produces endogenously determined prices and quantities for all goods in all markets. In addition to the traditional resource availability restrictions (land, labor and capital), the economic model is constrained by research and extension availability, nutrition requirements, goods balances, demand control,[4/] foreign trade balances, and domestic income accounts.

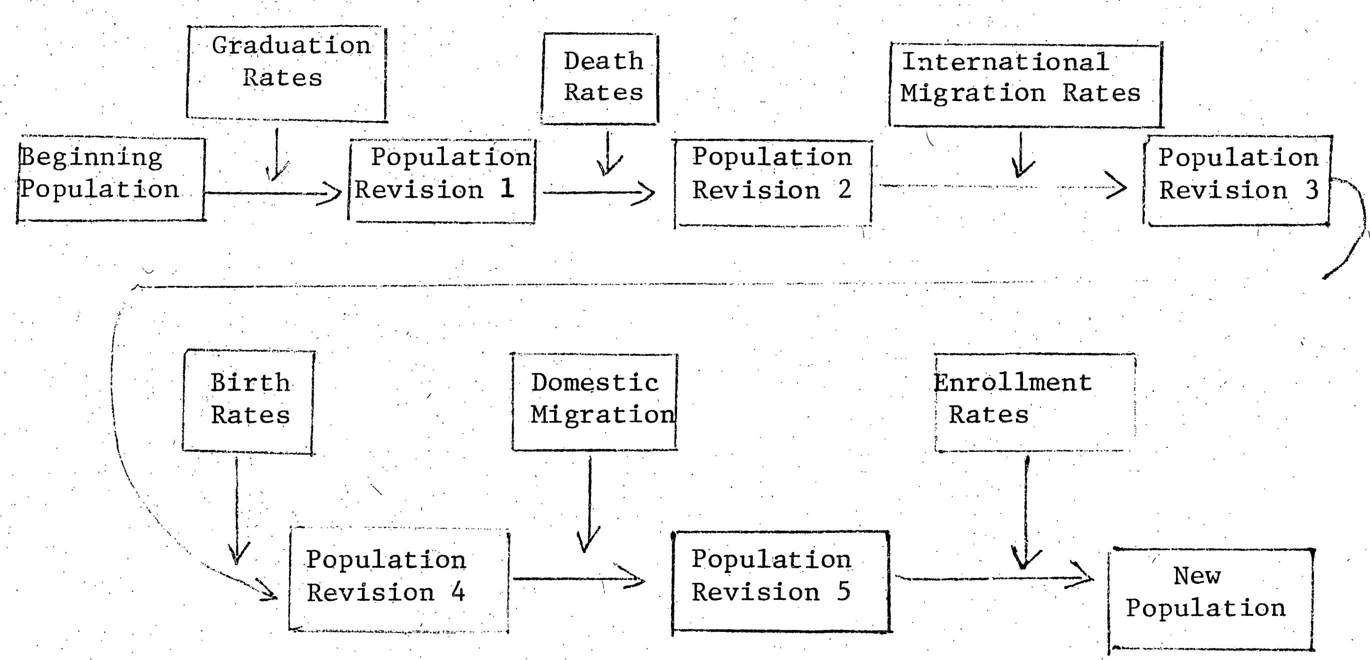

Figure 3. Order of application of demographic rates to period (t) population to calculate period (t+1) population.

Supply and demand schedules and model constraints which are all fixed for a given year are adjusted between years as is explained in the section on demographic-economic interactions. Limited flexibility for land, labor and capital availabilities is provided within a year by transformation activities. Land of lower quality may be improved at a cost. Labor of each class is absorbed by labor reservation activities and if its value productivity is not above a certain reservation price is considered unemployed. Labor from higher skill classes may be substituted for less skilled if the return exceeds the reservation price. New investment capital available each year is allocated among and within sectors on the basis of its productivity. Once allocated, capital is immobile and is depreciated as a function of time and rate of utilization.

Income accounting, sectoral and national, is on a value added basis. Intersectoral income transfer is explicitly accounted for by the model to facilitate optimization of the objective function which results in equilization of the social value of consumption, and thus income, in the two sectors. For a detailed exposition of this component of the model see McCarl or White. The model does not contain a monetary sector, and thus the general price level is arbitrary.

The private economy model is formulated within a static linear programming framework. The competitive equilibrium solution is obtained from the linear programming formulation by incorporating an objective function designed to maximize the area between explicit demand (domestic and foreign) and import supply curves, given implicit domestic supply defined by model constraints. The general structure of the linear programming formulation of the private economy model is shown in Figure 4.[5/]

The objective function is modeled as in Duloy and Norton and will be discussed only briefly here. The objective function maximizes consumer plus

Figure 4. Schematic representation of the linear programming formulation of the private economy model.

	Ag. Production	Non-Ag. Production	Export Demand - Ag. Goods	Export Demand - Non-Ag. Goods	Import Supply - Ag. Goods	Import Supply-Non-Ag. Goods	Ag. Demand - Ag. Goods	Ag. Demand - Non-Ag. Goods	Non-Ag. Demand - Ag. Goods	Non-Ag. Demand - Non-Ag. Goods	Ag. Labor Reservation	Non-Ag. Labor Reservation	Land Improvement	Labor Underemployment	Ag. Intermediate Goods	Non-Ag. Intermediate Goods	Artificial Production	Before to After Tax Income Transfer	Interschool Income Transfers	Capital Investment	Trade Balances	RHS
Objective Function			−	−	+	+	−	−	−	−	−	−					+					
Ag. Product Balance	−+		+		−		+		+				+		+		−					≤ −
Non-Ag. Product Balance		−+		+		−		+		+						+	−					≤ −
Ag. Calorie Consumption							−															≤ −
Non-Ag. Calorie Consumption									−													≤ −
Balance of Trade			−	−	+	+															−+	= 0
Agricultural Capital	+												+							−		≤ +
Non-Agricultural Capital		+																		−		≤ +
Land Supply	+												−									≤ +
Agricultural Labor	+	+									+		+	−+								≤ +
Non-Agricultural Labor	+	+										+		−+								≤ +
Research and Extension	+																					≤ +
Ag. Protein Consumption							−															≤ −
Non-Ag. Protein Consumption									−													≤ −
Land Improvement Limit													+									≤ +
Export Demand Control			+	+																		≤ +
Import Demand Control					+	+																≤ +
Ag. Demand Control							+	+														≤ +
Non-Ag. Demand Control									+	+												≤ +
Before Tax Income - Ag.			−		+		−		−						−	+		+				= −
Before Tax Income - Non-Ag.				−		+		+		−					+	−		+				= −
Ag. Intermediate Goods		+													−							≤ 0
Non-Ag. Intermediate Goods	+												+			−						≤ 0
After Tax Ag. Income							+	+										−	+−			= +
After Tax Non-Ag. Income									+	+								−	−+			= +
Capital Investment																				+		≤ +
Trade Balance																					+	≤ +

producer surplus which Samuelson indicated leads to a competitive solution. Our specific objective is developed as follows. Given a demand curve and a supply curve, both of which are linear (Figure 5) the area between these curves can be represented by the area under the demand curve less the area under the supply curve to a point. This area can be seen to be:

Demand Curve $P_D = A - Q_D' B$

Supply Curve $P_S = C + Q_S' D$

$$\text{Area} = \int^{Q_D^*} [A - Q_D'B] \; dQ_D - \int^{Q_S^*} [C + Q_S'D] \; dQ_S$$

$$= AQ_D = 1/2 \; Q_D'BQ_D - CQ_S - Q_S'DQ_S$$

where: P is the vector of prices for the goods,

Q is the vector of goods quantities,

A is the vector of zero quantity demand prices,

B is the matrix of price-quantity demand relationships,

C is the vectors of zero quantity supply prices, and

D is the matrix of price-quantity supply relationships.

If the matrices B and D are diagonal[6/] (i.e., the price of a good only depends on its own quantity), the function may be written in summation notation as:

$$\text{Area} = \sum_{i=1}^{n} [a_i \, q_{di} - .5 \, b_{ij} \, q_{di}^{2}] + \sum_{i=1}^{p} [a_i \, q_{Si} - .5 \, d_{ij} \, q_{Si}^{2}]$$

This function is clearly separable and convex (if b_i and $d_i > 0$ for all i). Duloy and Norton take this problem and express it as a Separable Programming problem by choosing representative points. Furthermore, they drop the adjacent restrictions due to the convexity of the functions.[7/] The PDM adopts the above assumption and thus the objective function has a form allowable in programming context permitting simultaneous analysis of supply-demand trade-off.

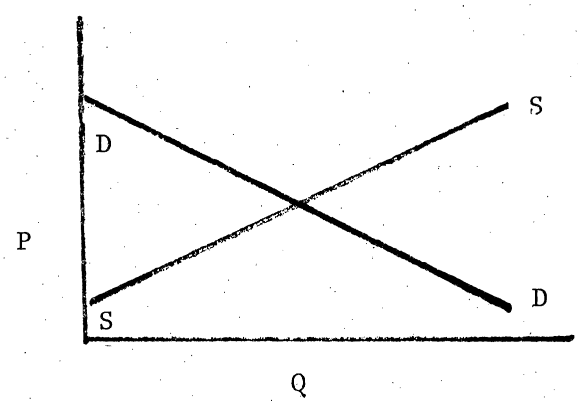

Figure 5. Linear supply and demand curves.

Economic-Demographic Interaction

Given the above economic and demographic models, the questions of linkage become important. These sub-models are linked by a series of equations which combine past demographic information with current economic data and predict demographic change rates. All demographic rates (birth, death, migration, enrollment and graduation) are predicted annually. Each of the rate prediction equations will be discussed below. All functional forms are nominally linear.

Birth rates are predicted as the probability of a female of a specific location, age group and educational level giving birth during the year. This rate is predicted as a function of: (1) per capita income in the location-- reflecting current material welfare; (2) locational rate of change in per capita income-- reflecting material welfare expectations; (3) mortality rate of children-- reflecting expected number of births required to reach desired family size; (4) educational levels-- reflecting the education of parents, expected education of children and accompanying attitudes; and (5) female wages-- reflecting the opportunity cost of mother's time.

Death rates are defined as the probability of an individual of a given age group, sex and location dying during the year. The death rates are predicted as a function of: (1) per capita income-- reflecting material welfare, (2) per capita consumption of calories and protein-- reflecting nutritional welfare, (3) physicians per capita in the location-reflecting the availability of medical services, (4) child dependency ratio-representing crowding in the home, (5) population pressure-- representing crowding in the country, (6) ratio of urban to rural inhabitants-- representing accessibility to urban services, and (7) sanitation index-- representing general cleanliness of the environment.

Migration rates are predicted as the probability of individuals of a given age group, location, sex, and level of educational attainment migrating to another specified location. Propensity to migrate is predicted as a function of demographic and economic variables, each of which gives the difference between the area of residence and the potential destination area. The differences are represented by: (1) the ratio of physicians per capita, (2) the ratio of school enrollment rates, (3) the ratio of regional average education, (4) the ratio of per capita incomes, (5) the ratio of per capita income changes, (6) the ratio of expected wages and (7) the ratio of population pressures.

Enrollment rates are predicted as the probability of an individual of a given age group, sex and educational attainment level enrolling in each level of school. The tendency to enroll is predicted as a function of current characteristics and expected gains from additional education. The explanatory variables are: (1) per capita income--representing regional material welfare, (2) changes in per capita income--representing general expectations, (3) expected wages--representing the opportunity cost of working rather than enrolling, (4) average education--representing the regional attitudes toward education, (5) child dependency ratio--representing the need to support the family, and (6) expected wage of better educated--representing economic incentive for additional schooling.

Graduation rates are predicted as the probability of an enrolled individual of a given age, sex and educational attainment level graduating. These rates are predicted as a function of the same variables as are the enrollment rates.

Demographic-Economic Interactions

Demographic change has its primary economic effect, in the PDM, by influencing resource availabilities, nutritional requirements for food, and demand levels. Predictive equations provide the linkage by which the demographic sub-model interacts with the economic sub-model. Each of the predicted items will be discussed below.

Resources affected by the demographic processes are labor and investment capital. Labor is predicted through a complex process wherein laborers are drawn from the population through predicted labor force participation rates. The labor force participation rates are defined as the probability that an individual of a given location, sex, age and educational attainment level will seek work. These rates are predicted as functions of: (1) per capita income--reflecting regional material welfare, (2) expected wage--representing incentives to work, (3) average education--representing the educational alternatives for younger workers, (4) male to female ratios in the population--reflecting propensity of females to work, and (5) child dependency ratios--indicating other bids for females' time. The labor force is converted into equivalent workers segmented by seven labor forces through a scaling process. 8/

Another resource which is linked to demographic variables is new investment capital. New investment is equated to savings which in turn is determined from predicted per capita savings rates. The per capita savings rate is predicted by regional equations containing as independent variables (1) old age dependency ratio--representing dis-saving, (2) per capita income--representing potential savings, and (3) average education--representing attitude toward savings.

Demand is predicted for the two sectors (agriculture and nonagriculture). Principally quantity demanded is treated as a linear function of price. However, intercept and slope shifters are included in the model. The intercept shifters are (1) equivalent consumers--the number of effective consuming units in the region, and (2) per capita disposable income. Slope shifters are (1) child dependency ratio and (2) old age dependency ratio. The slope shifters are included to account for changes in population composition and different consumption patterns embodied therein.

Nutrition needs are also predicted. Sufficient food to meet minimal nutrition needs is required of the economic model. The minimal nutrition levels are predicted by a function involving population and minimal (subsistance) per capita consumption levels.

Government

The government component in the PDM produces services for the economy, uses resources, collects taxes, pays for goods and regulates foreign trade. Services produced by the government are medical, research and extension, educational and other. Each service is supplied to a level prescribed by a point demand forecast. The forecast for medical services is determined by the population and an index indicating the amount of medical services required per capita. Similarly research and extension, and education are specified with respect to the population. A residual "other" sector is provided which is forecast by an equation relating the level of service to (1) per capita income, (2) regional population, (3) national population and, (4) labor use by the other government activities. Within each of the government services there is a requirement for both labor and intermediate goods. Each type of government production may require any of the seven labor types or seven goods. Requirements for goods and labor are a function of the level of each service provided and are imposed on the economic model. The public sector also collects taxes. Given that a balanced budget is required, taxes are equated with government expenditures on goods and labor. The essential question then is one of incidence. Taxes are allocated to the sectors according to prespecified user parameters.

Finally the government interacts with the foreign sector through a revaluation-devaluation process. Given that the cumulative foreign trade account reaches an undesirable level action is forced. The valuation shifts are identical to those discussed in Duloy and Norton.

Foreign Sector

The foreign sector interacts directly with both the economic and demographic models. Interaction with the economic model is carried out through export and import of goods. The trade levels are simultaneously determined by the economic model. However, the trade levels are guided by explicit export demand and import supply curves. These curves are forecast as a function of (1) price, (2) lagged quantity and (3) time.

The foreign sector also interacts with the domestic population through international migration. International migration rates are predicted as a function of differentials between the country and areas outside the selected foreign countries. The differences on which migration rates are predicted are: (1) per capita income, (2) rate of change in per capita income, (3) wages, (4) employment possibilities, (5) average education, and (6) population pressure.

Summary

The foregoing overview of the Purdue Development Model has described an integrated economic-demographic system designed to facilitate the evaluation of economic and demographic interactions in the development process. The system, firmly rooted in existing theory,[9/] is operational, behavioral, and general. While empirical specification based on the characteristics of a single identified population and economy has not been attempted, numerous options are available permitting the user to modify the system. Such modifications can serve a wide variety of purposes, including the analysis of alternative policies, reformulation of assumptions, and specification of variables and coefficients to conform with the structure of a specific economy.

The PDM can provide the policy maker with useful information. Since the design of the system requires little additional input once initial values have been established, both short-term and long-run impact of policy alternatives upon economic performance and population growth can be simulated. It is recognized that the accuracy of PDM output is dependent on the validity of underlying assumptions and the quality of input data available. A comparable qualification is applicable to any modeling effort. The strengths of this model are in the total systems framework within which economic and demographic processes are conceptualized and in the explicit recognition of two-way economic-demographic interaction. Its greatest weakness lies in the limited availability of data.

Footnotes

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1/ One of the considerations in developing this model was to allow for installation on computers available in LDC's; consequently, the design language is FØRTRAN.

2/ Agriculture produces five goods, nonagriculture produces two.

3/ Overall there are 28 schedules, 14 domestic demand, 7 export demand, and 7 import supply.

4/ Necessitated by the objective function formulation.

5/ In the model as represented by Figure 4, the following modeling conventions are adopted:

1. Within the body of the matrix and in the objective function a positive coefficient reflects a usage of the row's commodity, a negative coefficient reflects a receipt.
2. Within the right hand side a positive indicates a stock of resources for use, a negative represents a requirement.

6/ This may appear to be a restrictive assumption; however, in most empirical work this assumption is prevalent.

7/ Valid by Hadley (page 124).

8/ Agricultural unskilled, semi-skilled and skilled labor, and nonagricultural illiterate, literate, educated and professional labor.

9/ For a review of the theoretical background see White.

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