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ABSTRACT

This article describes the macroeconomic model used in an ongoing study of technology policies and North–South relations. Other aspects of the study have been described elsewhere [1, 2]. We examine here the rationale for the theoretical structure used in the model, the details of the equations, and a computation of solutions. To illustrate the dynamics of the model, a brief discussion is also given of the preliminary results that indicate critical relationships between domestic technology and income distributions and the North–South terms of trade. The results are based on a calibration of the model using data for Brazil and the United Kingdom.

Introduction

One major factor in the world economy at present is the growing importance, both real and potential, of the economies of the South.[1] It is apparent, for instance, that governments of the North increasingly take into account the effects of the economies of the South on their own economies. Furthermore, relationships between Northern and Southern economies are not only restricted to traditional variables of international trade. In an increasingly integrated world economy, variables previously regarded as mostly internal to the domestic economies are seen to be interacting across international borders. For instance, inflation and employment levels and income distribution within countries of the North are affected by the patterns of development in the South.

The relationship between the problems of income distribution and growth of the North and of the South is a particularly complex one. For example, although cheaper imports from the South may benefit the lower-income consumers in the North through lowering the prices of goods they consume, they may at the same time hinder employment in the North. From the point of view of a country in the South, similar contradictory effects arise. For example, although an export-led growth policy can be consistent with

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[1] As it is by now usual, the word *North* is used to designate the industrialized economies, mostly of the Northern Hemisphere, and Japan; the word *South* is used to designate developing countries, mostly in the Southern Hemisphere.

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higher rates of GNP growth, it may also deteriorate the income distribution and diminish in absolute as well as relative terms the welfare of the very poor. One way this latter effect may come about is through the implied choice of products and of prices by producers in a Southern country engaged in an export-led growth path. Producers may in these cases tend to regard the bulk of the local population more in terms of labor cost than as consumers when making decisions about what products to produce and their prices. If their production is mostly for export, it may be in their interest to produce luxury products and, if possible to pay lower wages in order to decrease costs. This may be done without regard to the possible effect of such policies on their revenues, since a relatively lower aggregate income of the wage earners may not, in certain cases, negatively affect demand for their products.

These issues are the focus of the ongoing study of technology and North–South relations; this article deals with the present version of the economic model constructed to study them, and with the results obtained so far. Future work is also indicated. The model described here is one part of the study only; the whole uses a broader interdisciplinary methodology, including sociopolitical scenario analysis. The experiments performed with the model use it as an intermediary tool to project certain possible paths of economic development of the world economy, thus contributing both to the internal consistency of the scenario analysis and to disclose options left open to future North–South development. Other aspects of the work have been described elsewhere [1, 2].

In the second section of this article (Main Features of Macroeconomic Model) we discuss the main economic assumptions and relations of the macro model constructed by Chichilnisky [3]. This builds on previous work of G. Chichilnisky in the Bariloche model [4, 5]. Some of the features that distinguish this model from other models of the world economy such as Bariloche [6], Leontief [7], and Pestel-Mesarovic [8] [see also Refs. 8, 9] are: a simulation of interrelated market behavior, both domestic and international, for the explanation of prices, quantities and types of goods produced and exchanged; a high level of aggregation of actors—North and South, high and low income groups in each region; two types of labor, skilled and nonskilled; and an explicit treatment of the relationship between macrolevel technology coefficients with income distribution and with trade patterns. Microlevel studies of technology (including certain case studies) are to be examined in other parts of the model and are not reported here [1]. The third section (A Domestic Economy) gives the equations describing the basic model of a domestic economy. The fourth section (International Production-Exchange Model) discusses the international production-exchange model.

In the fifth section (Technology, Income Distribution, and North–South Terms of Trade) we give results based on runs that explore the properties of these relationships. These runs are based on a preliminary calibration with Brazil and U.K. data. It is shown that domestic income distributions and the availability and elasticity of supply of factors of production (skilled and unskilled labor, and capital—in the case of labor, e.g., due to internal migration patterns from rural to urban areas) interact with the domestic technologies in the determination of the terms of trade between the North and the South. The results of the runs reported here contrast in certain cases with neoclassical trade results [11]. Certain assumptions about the system of production and income distribution patterns are shown to reinforce inequalities between North and South terms of trade. These results are reminiscent of theories of unequal exchange (e.g., Prebisch, Singer) that were given in verbal terms, with an historical outlook. A discussion and updated versions of such theories are found in Palma [12]. Under alternative conditions, however, the neoclassical results do obtain and increased trade improves the terms of trade. This underlines the importance of domestic technologies and income distributions in the determination of North–South terms of trade and the distributions of wealth among these two regions. Since the results show that under certain conditions imposed on those *domestic* variables, more trade tends to equalize the terms by trade, whereas under other conditions, to unequalize them, the model is capable of explaining neoclassical and also less neoclassical dynamics of the North–South trade and when each is likely to occur. Because of this, it seems that global models that are designed to consider questions of North–South economic relations ought to take into account the structures of markets (domestic and international), the types of technologies, and the patterns of domestic income distributions in the South and in the North, since different such structures would yield different results and associated policy prescriptions.

The results also show that certain goals of the New International Economic Order (e.g., equalization of the terms of trade) may be critically related to other NIEO policy prescriptions such as technology transfers and in ways that may be contradictory in certain cases (e.g., certain forms of transfer of technology policies may increase duality and reinforce a previous high elasticity of unskilled labor supply and thus may tend to deteriorate terms of trade). This suggests, then, a range of domestic policies (e.g., broad choices of technologies in the different sectors) that may be consistent with improvement of North–South wealth distribution. The results indicate that trade and domestic distribution policies may be linked with each other in ways that require closer examination than is usually given in the literature: Coordination of domestic income distribution and technology policies with trade policies seems necessary.

Main Features of Macroeconomic Model

As a member of a newer generation of models that attempt to analyze the functioning of the world economy, our model tends to simplify and aggregate variables so as not to obscure the reasons for the results to obtain while retaining the main categories necessary for the analysis. In addition, aware of the serious data restrictions and of the need for better analytic tools to aid the analysis of complex issues, we attempt a more sophisticated yet relatively more qualitative study of economic behavior of North–South developments than is usual in existing models. The understanding of trends and patterns is the goal; great accumulation of figures is an important but sometimes limited vehicle [9]. We now describe and give the rationale for the essential features of the model.

Most developing countries have mixed economies. To understand the workings of a mixed economy and the endogenous reactions of markets in response to shifts in a policy variable, it is necessary to model the market part of the economy. This is especially the case for the study of technology as a tool of policy. Both domestic economies and the international economy contain important market elements. For example, the short-run (or temporary) changes in the volume of world imports and exports, and their prices, are explained within the model through the interplay of international supply and demand patterns in a modified general equilibrium fashion. However, since markets are seldom perfect, imperfections such as tariffs and other protectionist barriers as well as supply constraints exist, and these can be introduced into the model. The domestic economies of countries in the North and in the South are modeled as mixed (partly planned, partly market) economies, although at this stage many planning mechanisms have been omitted. In the short run, resources (human and physical) are fixed; in the long run, for instance, investment and population growth take place generating a path of temporary equilibria of the world economy that moves into the future. One major modification of the usual general equilibrium models is introduced by the separation of the population into income groups. We study two broad income groups within the population: one lower and one higher. A third (middle) income group is added in some cases. These groups have, of course, different characteristics in the North than in the South. They are modeled in each case in terms of their patterns of consumption, wages, employment, migration, initial resources, and so on. The economic output is accordingly segregated into three broad categories: basic consumption goods, nonbasic or luxury consumption goods, and capital goods. By and large, most of the consumption of lower income consumers consists of basic goods; higher income groups consume proportionally more luxury goods. Capital goods are produced for future production rather than for present consumption, a form of savings of society. Workers are also segregated into two broad groups, the skilled and the nonskilled. Similarly, the initial ownership of consumption and capital goods, land and labor skills is different for the two income groups. Low income groups tend to own more unskilled labor, little land, and basic capital goods. Higher income groups tend to own proportionally more skilled labor, land, and nonbasic capital. There are similar relative differences between the two income groups of the North and those of the South. Our choice of these categories of income and skill groups, capital and consumer goods, and initial endowments depended largely on the analytical purposes of the model. Our choice of a modified general equilibrium approach (relating demand and supply patterns) was also influenced by the analytical purposes of the model, especially for the analysis of technology. A brief explanation follows.

Technology can be described as the form of use and organization of natural resources and different types of labor and capital in the production of goods and services of an economy. It affects supply, that is, the level of material output and its composition (i.e., the types of goods and services actually produced). It also affects demand through its effects on levels of employment of labor and capital, wages and profit levels, and also the composition of labor force and wages. Therefore, technology is at the core of the domestic supply–demand and investment patterns of economies, and of domestic income distribution and patterns of growth described above. Similar arguments apply at the international level as illustrated above. The use of resources and the relative productivity of labor and capital in different regions affects the international supply of goods, total levels of output, and also its composition. It also affects international demand; the different levels of employment of different types of factors and their associated wages and profits in different regions. Technology thus is also at the core of international supply–demand and investment patterns, and as such, it helps determine the distribution of the world's wealth.

However, when technology is modeled as a policy variable, several problems arise. For example, a variable so intertwined with the entire functioning of the economy may be suspect as a policy variable. One reason is that if it affects most aspects of economic life, it is also very affected by them, and it can be difficult to isolate it as an exogenous variable amenable to changes. However, the experience of planning indicates that the difficulty in isolating and affecting exogenous variables in desired ways is quite general. Most planning exercises show a healthy resistance of the exogenous variables to behave as such; perhaps they are less exogenous than we would like to consider them. However, this resistance can itself be modeled. Rather than simply looking for "policy handles" that are more or less exogenous, models where the endogenous response of the economy to exogenous changes in the policy variables is studied seem to be in order.

A policy should work, theoretically, with the internal dynamics of the economy. Thus a criterion for choosing a policy variable may be given by our model of the economy as well as by the variable: the importance of the variable to affect the economy in the desired ways, together with the understanding shed by the model of the endogenous behavior of the economy in response to changes of the policy instrument. As a rule of thumb, for example, one should be cautious of policy variables that tend to have a strong self-correcting endogenous behavior in response to policy changes. Hence, if one is to study technology as a policy or even as an explanatory variable, it becomes most important to model in a satisfactory qualitative way the structure of the relationships between the main variables to be analyzed: distribution, employment, growth, domestic output and trade, and market behavior.

A Domestic Economy

We describe first the short-run behavior of a domestic economy. For simplicity, we do not consider nondomestic variables such as imports or exports until the fifth section (on trade). The role of the government is not explicitly considered here, but is simulated in the runs as affecting demand and investment. Because this is a short-run model, total capital stock and population are fixed, and the solutions are determined up to investment demand values, which contain foreign investment. Changes in investment in effect link one short-run or temporary equilibrium with the next; at each point in time, this variable depends on the temporary equilibrium values of profits and growth of output. In the following discussion, the high and low income groups are denoted H and L, respectively. The three types of goods produced in the economy are basic goods (B), nonbasic goods (A), and investment goods (I). The price of goods A, B, and I are denoted P_A, P_B, and P_I, respectively.

UTILITY FUNCTIONS AND WELFARE

A utility function is an indicator of the welfare derived from different levels of consumption. To simplify the analysis each of the high and low income groups are assumed here to consume basic and nonbasic goods in fixed proportions. Alternative assumptions on elasticity of demand for basic and nonbasic goods will be made in future work. The utility function for group H is written:

$$H = \min(A, aB).$$

The utility function of group L is:

$$L = \min(bA, B).$$

Since group H requires proportionately more nonbasic than basic goods, $a > 1$. Similarly, $b > 1$ for the low-income group's utility. These equations say that if the high- and low-income groups apportion their income used for consumption so as to consume basic and nonbasic goods in the proportions a:1 and 1:b, then they will be maximizing their welfare.

BUDGET EQUATIONS OF HIGH AND LOW INCOME GROUPS

The budget equations balance wealth of each group derived from the income from employment and profit (or quasirent) on capital goods owned (together with the value of any basic and nonbasic goods already owned), with the expenditure of each group on basic, nonbasic, and capital goods. We assume that the group H has initial endowments of basic goods denoted H_B, nonbasic goods, H_A, an amount of investment goods, H_I, and is able to offer a total amount of skilled labor, $\hat{H}$. Let $w_H$denote the wage of skilled workers. Then, for each price level of the three types of goods (P_A, P_B, P_I) wages of skilled labor (w_H) user cost of capital (rP_I) and level of employment of skilled labor ($\bar{H}$, $\bar{H} \leqslant \hat{H}$), the total wealth of group H is given by:

$$P_A H_A + P_B H_B + rP_I H_I + w_H \bar{H}. \tag{1}$$

Group H demands a certain amount of investment goods that are exogenous for the time being, denoted I_H^D. The pattern of investment demand is described below in the dynamics of the model. Given the prices for A and B, if x denotes the amount of good B demanded by group H, the budget equation for group H is then obtained from the maximization of the utility U_H subject to the wealth constraint given by equation (1):

$$P_B x + P_A ax + P_I I_H^D = P_A H_A + P_B H_B + rP_I H_I + w_H \bar{H},^2 \tag{2}$$

where rP_I denotes rental rate or user cost of capital and r rate of profit or quasirent on capital.

Similarly, group L owns initial amounts L_A and L_B of goods A and B, and a total labor supply $\hat{L}$. For each set of prices of each good P_A, P_B, P_I, wages of unskilled labor w_L and level of employment level of unskilled labor $\bar{L} \leqslant \hat{L}$, if y is the demand for good A of group L, the budget equation for this group is:

$$P_A y + P_B by + P_I I_L^D = P_A L_A + P_B L_B + w_L \bar{L} + rP_I L_I, \tag{3}$$

where I_L^D is the demand for investment goods of the group L assumed to be exogenously given in a temporary equilibrium, analogously to I_H^D. In equation (3) the amount of investment goods owned and demanded by the low-income group can be quite small. A limiting case is when L_I and I_L^D are both zero.

The prices, employment levels, and wages in equations (2) and (3) are determined in the general equilibrium solution of the model. For the moment we are assuming that these levels are not affected by institutional factors. In other cases considered, the wages of the unskilled workers are institutionally related to the prices of the minimum consumption basket of basic goods.

From equations (2) and (3) we see how prices affect demand for basic and nonbasic goods A,B. For instance, if group L has a substantial endowment of basic goods, than an increase in the price of basic goods may increase this group's demand for goods, but only if their wealth has increased proportionally more than the cost of the goods produced. In fact, just the opposite may occur if there is an increase in the price of basic goods if this group has very small endowments to start with.

[2]The total quantity of good A demanded by the H group is assumed to be a times the physical quantity of B demanded by this group.

SHORT-RUN DEMAND FOR INVESTMENT AND CONSUMPTION GOODS

From budget equations (2) and (3) we can obtain the aggregate demand functions for consumption and investment goods by both high- and low-income groups as dependent on prices, wages, and levels of employment. The total demand for A is:

$$A^D = ax + y, \tag{4}$$

and demand for B is

$$B^D = x + by, \tag{5}$$

where x and y satisfy equations (1) and (2). Total demand for investment goods is exogenous in the temporary equilibrium, that is,

$$I_H^D + I_L^D = \bar{I}. \tag{6}$$

PRODUCTION OF GOODS

The three types of goods are produced using as inputs labor of two types, skilled and unskilled, and capital. The relationship between output of each good and inputs is given by a production function. In this article we exhibit production equations for the case of nonsubstitution between factors. The case with substitution is in the fifth subsection (Market for Skilled and Unskilled Labor); the use of constant elasticity of substitution functions, is detailed for instance in [13]. We assume here that the production for A can be expressed by a fixed coefficients production function of the usual type:

$$A = \min\left(\frac{L_1}{a_1}, \frac{H_1}{b_1}, \frac{K_1}{c_1}\right), \tag{7}$$

where L_1 denotes input of unskilled labor, H_1 denotes input of skilled labor, and K_1 denotes input of capital for the production of good A. The capital stock is assumed to behave in a modified "putty-clay" way: if a certain capital stock is allocated into one sector, it cannot be much moved at a later period to another sector. Most of the changes in the relative capital stock among the sectors come from new investment.

The variables a_1, b_1, and c_1 are the technical coefficients for the sector of nonbasic or luxury goods. This function implies that a given output A is obtained most efficiently when the inputs of unskilled and skilled labor and capital are a_1A, b_1A, and c_1A, respectively.

Similarly, we have:

$$B = \min\left(\frac{L_2}{a_2}, \frac{H_2}{b_2}, \frac{K_2}{c_2}\right); \tag{8}$$

$$I = \min\left(\frac{L_3}{a_3}, \frac{H_3}{b_3}, \frac{K_3}{c_3}\right). \tag{9}$$

Even though these production functions have fixed coefficients, these coefficients are only assumed to hold constant for small variations of the input and output variables. For large changes of scale or technology, we should assume the production functions have different coefficients.

The costs of production of goods we obtained from the dual cost equations associated with the production functions (7), (8), and (9). Thus the cost of production varies linearly with inputs of labor and capital; the dual cost equations for A, B, and I are:

$$P_A = a_1w_L + b_1w_H + rP_Ic_1$$

$$P_B = a_2w_L + b_2w_H + rP_Ic_2 \tag{10}$$
$$P_I = a_3w_L + b_3w_H + rP_Ic_3.$$

It can be shown that in this model the rate of profit of quasirent on capital is given by:

$$r = \frac{w_2 - 1}{w_2c_3 - w_3c_2 - c_3}.$$

The derivation of equation (16) from (10) is as follows:
From (10)

$$P_A = a_1w_L + b_1w_L + rc_1\frac{a_3w_L + b_3w_H}{1 - rc_3}; \tag{11}$$

$$P_B = a_2w_L + b_2w_H + rc_2\frac{a_3w_L + b_3w_H}{1 - rc_3}; \tag{12}$$

$$P_I = \frac{a_3w_L + b_3w_H}{1 - rc_3}. \tag{13}$$

Under a suitable normalization of prices, say, $P_B = 1$, the rate of profit can then be determined from (10) (in this case all other prices are given relative to that of B). If $P_B = 1$, then

$$1 = a_2w_L + b_2w_H + rP_Ic_2.$$

From (10) we derive

$$P_I = \frac{1 - (a_2w_L + b_2w_H)}{rc_2}; \tag{14}$$

$$= \frac{a_3w_L + b_3w_H}{1 - rc_3} \tag{15}$$

Denote $w_2 = (a_2w_L + b_2w_H)$ and $w_3 = (a_3w_L + b_3w_H)$:

$$(1 - rc_3)(1 - w_2) = w_3rc_2$$
$$1 - rc_3 - w_2 + w_2rc_3 = w_3rc_2$$
$$r(w_2c_3 - c_3 - w_3rc_2) = w_2 - 1.$$

Hence the rate of profit or quasirent on capital is given by

$$r = \frac{w_2 - 1}{w_2c_3 - w_3c_2 - c_3}. \tag{16}$$

It is, then, obvious that in this production system the rate of profit (or quasirent on capital) is determined by the technology coefficients and the wages of both types of labor relative to the price of goods for which a choice of numeraire is made.

Two alternative assumptions are made in the model about rates of profits. One is that this rate is equal in different sectors of the economy. Another is that it varies across sectors in an institutionally dependent way. This latter case is stimulated by modifying rate of profit by exogenous factors as observed in the economies.

MARKET FOR SKILLED AND UNSKILLED LABOR

We assume that the supply of skilled and unskilled labor is an increasing function of the wages of the two groups and of the prices for consumption goods. For a modern economy, this assumption is usually accepted; for a developing economy, this assumption tries to simulate the effect that wage differentials have on migration and hence on total labor supply of the region. The *supply* of skilled labor is:

$$H^s = H^s(w_H, P_A, P_B) \tag{17}$$

and of nonskilled labor, is:

$$L^s = L^s(w_L, P_A, P_B), \tag{18}$$

with $H^s \leqslant \hat{H}$ and $L^s \leqslant \hat{L}$; that is, the effective labor force is a function of available labor, wages, and prices. The effective *demand* for labor is derived from the demand for goods through the equations of the production side considered in the fourth subsection (Production of Goods) and of the demand side, in the third subsection (Short-Run Demand for Investment and Consumption Goods) as follows. For a given level of demand for goods A^D, B^D, and I^D as in the third subsection, there is a corresponding demand for unskilled labor from the production side (see fourth subsection) satisfying the equation

$$A^D a_1 + B^D a_2 + I^D a_3 = L^D. \tag{19}$$

Similarly, the demand for goods produces a derived demand for skilled labor

$$A^D b_1 + B^D b_2 + I^D b_3 = H^D. \tag{20}$$

The demand for labor of both types depends on the demand for goods, on the wage distribution and price levels, and on the rate of profit, since, as discussed in the third subsection, the demand functions A^D, B^D, and I^D depend on those variables. In equilibrium, the effective demand and supply of labor are in balance. This gives another relationship between the following variables: prices, wages, employment, and output.

SUBSTITUTION BETWEEN SKILLED AND UNSKILLED WORKERS

In the preceding description of the labor market as well as in the production side, we assumed that there was no substitution between skilled workers and unskilled workers. This was done in part to simplify the study of employment and macrolevel patterns, considering a labor market that is a limiting case of labor markets with low elasticities of substitution. In addition, given our interest in the effects of technology on the economy, it makes sense in certain cases to separate the contributions of skilled and nonskilled workers in the production function. One can thus alternatively (or simultaneously) study the effects of changes in the parameter a_i, b_i, which measure separately the contributions to the production of goods of the two groups of people. In many technologies that are capital intensive [i.e., a_3 small and c_3 large in equation (9)], managerial inputs may be very important. In such a case, a_3 may be a constant, with no substitution between skilled and unskilled labor allowed. For example, consider in the investment goods sector the construction of a large irrigation project. Capital plant requires skilled operatives, and even if this is reduced to a minimum, a corresponding increase in employment of manual (i.e., unskilled) labor will increase the demand for managerial (i.e., skilled) workers. Thus in equation (9), if c_3 is increased (capital equipment reduced) and a_3 decreased, b_3 will adjust according to the changed requirements for skilled operatives and managers.

However, in certain cases it may be realistic and/or desirable to accept a certain amount of substitution between skilled and nonskilled workers. The analysis of the production side and of the labor market must change accordingly. Alternative production functions of the CES type will be studied in future work. Here we only discuss substitution of the two labor types very briefly. Let l denote labor of both types: Equations (7), (8), and (9) now become:

$$A = \min\left(\frac{l_1}{d_1}, \frac{K_1}{c_1}\right); \tag{7'}$$

$$B = \min\left(\frac{l_2}{d_2}, \frac{K_2}{c_2}\right); \tag{8'}$$

$$I = \min\left(\frac{l_3}{d_3}, \frac{K_3}{c_3}\right), \tag{9'}$$

where the parameters d_i are some weighted averages of the a_i and b_i values of equations (7), (8), and (9). Similarly, equations (17) and (18) now would be replaced by a function that gives total labor from the two labor types according to a production function with a high elasticity of substitution.

$$l = l(K, L) \tag{21}$$

Equation (21) will have a dual cost equation that can be written as:

$$q_1 = w_L e_L + w_H e_H, \tag{22}$$

in which e_L and e_H are respectively the labor input ratios L/l and H/l.

In the model we now must find first an equilibrium (in the labor market) employment level for workers of both types l^* and aggregate wage level w_l^* and then the corresponding amount of labor of both types and wages of both types, w_L^*, w_H^*, L^* and H^*.

The equilibrium (in the labor market) level of employment of both types of workers is obtained from equating demand l^D and supply l^S, where

$$l^D = A^D d_1 + B^D d_2 + I^D d_3 \tag{23}$$

is derived from (7'), (8') and (9'), and from the supply of labor equation (21), where H and L will in general depend on prices and wages. From l^* and w_l^* we then derive the wages and the employment levels of both groups of workers in equilibrium. This is done as follows. The supply side of the labor market equation (H,L) can be thought of as "producing" total labor using as inputs two types of labor H and L with a certain elasticity of substitution. For a given output of labor at wage w_e, the optimal combination of workers of both types H^* and L^* with their wages w_H^* and w_L^* is one that maximizes

$$l(H,L)w_1 - Hw_H - Lw_L.$$

Hence for a given amount of labor l^* and average wage level w_l^*, the choice of H^* and L^* and w_H^* and w_L^* must satisfy the relations

$$w_1^* \frac{\partial l}{\partial H^*} = w_H^*; \tag{24}$$

$$w_1^* \frac{\partial l}{\partial L^*} = w_L^*; \tag{25}$$

$$w_H^* H + w_L^* L^* = l^* w_1^*. \tag{26}$$

Equations (24), (25), and (26) can only determine three unknowns. Hence we must fix one wage level given, for instance, by institutional or political factors and then find the others relative to this one. For instance, one can choose the wage of the unskilled w_L^* to be exogenous. In other words, given l^* and w_1^* we can only determine the relative wage level of skilled and unskilled workers and their absolute employment levels. We note that if one of the prices of goods, say, P_B, was already normalized, this would imply that the wage of the unskilled is pegged to the price of the basic good. This may in fact be true in economies where minimum wage laws exist. However, as can be seen from the ninth subsection of this section (Temporary General Equilibrium of a Domestic Economy), it is not necessary for obtaining a solution of the general equilibrium system to assume that any of the goods prices is equal to one. In that case, from the production-side equations (7′), (8′), and (9′) and from the four demand equations of goods, we obtain a system of four equations in the unknowns x, y, w_1, and L. These four equations will in general admit a solution x^*, y^*, w_1^* and L^*, which is then used with the procedure outlined in equations (24), (25), and (26) to determine the equilibrium values w_H^*, H^*, and L^*, which are given relative to w_L.

THE CAPITAL MARKET

We assume at this point that there is an exogenously given initial supply of capital stock. Together with the supply of investment goods produced in equilibrium, this should equal the demand for capital coming from the production side of the demand of all goods; in other words,

$$H_K + L_K = K_1 + K_2 + K_3 = A^D c_1 + B^D c_2 + I^D c_3. \tag{27}$$

Equation (27) requires a certain consistency between the exogenously determined I^D and the exogenously given capital stock. The variables H_K and L_K were already given exogenously in the budget equations(2) and (3). There is an initial exogenously determined demand for investment goods

$$\mathrm{I}^D = I_H^D + I_L^D. \tag{27a}$$

An equilibrium in the market of investment goods will then be given by the equation

$$\begin{aligned} \mathrm{I}^D &= I^s \\ &= \min\left(\frac{L_3}{a_3}, \frac{H_3}{b_3}, \frac{K_3}{c_3}\right). \end{aligned}$$

SHORT-RUN EQUILIBRIA IN MARKET OF GOODS

By definition, when the system described for the domestic economy is in equilibrium, supply and demand for each good are equal. In order to pose the equilibrium equations we equate the demand for goods given in equations (4), (5), and (6) with the supply of goods, given by the sum of the amounts of the production-side equations (7), (8), and (9), the initial endowments of goods A, B, and I.

$$A^s = \min\left(\frac{L_1}{a_1}, \frac{H_1}{b_1}, \frac{K_1}{c_1}\right) + H_A + L_A; \tag{28}$$

$$B^s = \min\left(\frac{L_2}{a_2}, \frac{H_2}{b_2}, \frac{K_2}{c_2}\right) + H_B + L_B; \tag{29}$$

$$I^s = \min\left(\frac{L_3}{a_3}, \frac{H_3}{b_3}, \frac{K_3}{c_3}\right) + H_K + L_K. \tag{30}$$

In the present solutions of the model, the H_A, H_B, L_A, and L_B are assumed to be equal to zero.

TEMPORARY GENERAL EQUILIBRIUM OF A DOMESTIC ECONOMY

The model can be decomposed into four main subsystems, as indicated in the Introduction section. These are: the demand side, the production side, the labor market, and the capital market. These four subsystems are all interrelated. There is a set of initial conditions: endowments of goods and capital stock, population in the two income groups and production relations, the technical coefficients a_i, b_i, and c_i, and exogenous demand for investment goods. The system of equations given in the Introduction will then determine the following endogenous equilibrium values (indexed with an asterisk):

a. Amounts of goods of each type produced A^*, B^*, and I^*.
b. Prices of these goods, P_A^*, P_B^*, and P_I^*.
c. Employment of both types of labor, H^* and L^* and wages of both types of labor W_H and W_L.
d. Consumption of each good by each income group x^*, ax^*, y^*, and by^*.
e. Rate of profit r^* (or quasirent of capital).
f. Amounts of capital and labor of both types used in each sector: $L_1^*, L_2^*, L_3^*, H_1^*$, H_1^*, H_2^*, H_3^*, and K_1^*, K_2^*, K_3^*.

From these variables one determines two vectors that describe the main economic characteristics of each group in equilibrium:

$$(L^*,\ W_L^*,\ y^*,\ by^*,\ L_K + I_L^D,\ P_A^*,\ P_B^*,\ P_I^*)$$
and
$$(H^*,\ W_H^*,\ x^*,\ ax^*,\ H_K + I_H^D,\ P_B^*,\ P_I^*).$$

The welfare of group L can be measured by the utility of present consumption plus the value of investment goods owned (as a proxy of possible future consumption)

$$U_L = (y^*, by^*) + r^*P_I^*(L_K + I_L^{D*})$$

and that of group H by

$$U_H = (ax^*, x^*) + r^*P_I^*(H_K + I_H^{D*}).$$

The *wealth* of group L at equilibrium is:

$$W_L = P_A Y^* + by^*P_B + r^*P_I^*(H_L + I_L^D)$$

and that of group H

$$W_H = P_A ax^* + x^*P_B + r^* + P_I^*(H_K + I_H^{D*}).$$

These definitions allow us to compute welfare and wealth distributions, at the equilibrium, and their changes, for instance, as the technology parameters change.

The equilibrium values listed in (a) through (d) above are not independent of each other. We now choose a subset of independent variables within this set of variables, of which all others are functionally dependent. In the following we prove that such a set can be made up of the seven variables below:

$$x, y, P_A, P_B, P_I, w_H, w_L.$$

We normalize the prices of goods setting B as the numeraire, that is, $p_B = 1$. All other prices are then given relative to the price of the basic good B. Hence we are left with six variables to determine:

$$x, y, P_A, P_B, w_H, w_L.$$

We now check how to obtain all other equilibrium values from those in the list above. Given the equilibrium values x^* and y^*, the equilibrium amounts of goods A^*, B^*, and I^* produced are given by

$$\begin{aligned} A^* &= ax + y \\ B^* &= x + by \\ I^* &= I^0, \end{aligned} \tag{31}$$

The third term is assumed to be exogenously given. The rate (or rates) of profit is (are) then determined by the technical coefficients, and w_H and w_L as in equation (16) and discussed in the sixth subsection (Substitution between Skilled and Unskilled Workers). Employment of both types of labor is determined from the preceding variables as follows. Given A^*, B^*, and I^*, the demand equations for both types of labor are (19) and (20). The supply equations are determined in (17) and (18), as functions of the wages and prices, which are already known. The unskilled labor is finally divided into the three sectors by

$$\begin{aligned} L_1 &= A^s a_1 \\ L_2 &= B^s a_2 \\ L_3 &= I^s a_3 \end{aligned} \tag{32}$$

Similarly, we determine the share of the skilled labor in the three sectors, H_1, H_2, and H_3 and the share of capital stock in these sectors K_1, K_2, and K_3 from equation (21) and the three production functions.

COMPUTING SOLUTIONS OF SHORT-RUN EQUILIBRIUM MODEL

From equations (10) and (16) of the production side we obtain all prices and the rate of profit as a function of wages and technical coefficients. We now return to equations (2) through (6), that is, the two budget equations (2) and (3) and the corresponding demands for A, B, and I. We replace all prices and rate of profits in these equations as functions of wages obtained as derived above from (10) and (16) and as discussed in the seventh subsection (The Capital Market). We are then left with five equations in the unknowns x, y, w_H, and H and L. However, according to Walras's law, out of these five equations only four are linearly independent. This is easy to check. From these four are obtained the equilibrium values of the four variables x^*, y^*, w_H^*, and w_L^* as functions of the unknown H^* and L^*, w_H^* and w_L^* determine r^*; w_H^* and w_L^* give us in turn the prices in equilibrium p_A^*, and p_I^* from (10), as functions of the unknown H^* and L^*, as in (25) above, since x^* and y^* are functions of H^* and L^*.

We now look at supply-equal-demand equations in the labor market for both unskilled and skilled labor. We have obtained P_A^*, P_I^*, w_L^*, and w_H^* as functions of H^* and L^*. Together with the two equations, supply equal demand for labor of both types,

(17) = (20);

(18) = (19).

We can then solve the equilibrium values of the variables H and L denoted by H^* and L^*. We then determine the values x^*, y^*, P_A^*, P_I^*, w_L^*, and w_H^*. From L^* and (19) we obtain L_1^*, L_2^*, and L_3^*. From H^* and (20) we obtain H_1^*, H_2^*, and H_3^*.

From the equilibrium values of the six variables x^*, y^*, p_A^*, p_I^*, W_L^*, and w_H^* we can, as noted in the eighth subsection (Short-Run Equilibria in Market of Goods), obtain the equilibrium values of all the other variables.

To determine the six equilibrium values of the above variables, we need six independent equations. These are the budget equations (2) and (3), the equation for supply equal demand for goods A and B.

$$\begin{aligned} A^D &= A^s \text{ or } (4) = (7) + H_A + L_A \\ B^D &= B^s \text{ or } (5) = (8) + H_B + L_B. \end{aligned} \tag{33}$$

The equation for supply equal demand for good I is dependent on the above and the two equations for supply equal demand in the two labor markets.

$$\begin{aligned} H^D &= H^s \text{ or } (17) = (20); \\ L^D &= L^s \text{ or } (18) = (19). \end{aligned} \tag{34}$$

The procedure outlined here does not prove the existence of a solution. It is rather a sketch of a method for computing a solution, if one exists. In general, the existence of a solution, that is, a zero of a set of simultaneous nonlinear equations as the ones that we have here [equations (2), (3), (4), (34)] requires special conditions, such as restrictions on the boundary behavior of the dynamic system generated by the equations on their state space. Leaving the existence problem aside, the computation of the solution can be carried by a computer routine that attempts to find a minimum of a positive real-valued function on the six variables, obtained by summing the square of the difference of the right-hand side and the left-hand side of the above equations for each value of the six variables. In effect, the program used, described by Clark, Cole and Lucas [1], solved the model by a simpler method of successive approximations.

The short-run equilibrium model described above is graphically described in Fig. 1.

DYNAMICS OF A DOMESTIC ECONOMY

We now describe the dynamics of the domestic economy (Fig. 2). In the short-run general equilibrium model presented above it is assumed that the demand for investment goods I^D is exogenously given. This is mainly a short-term assumption that allows us to "close the model." As pointed out, for instance by Sen [14] and Bacha and Taylor [15], it is very rarely the case that a model can specify equilibrium values of both the employment and wage levels as well as the investment level at a point in time, without the model being overdetermined. In a sense, the investment demand is what "drives" the economy from one period of equilibrium to the next. When we assume that it is exogenously given, we are assuming that it is determined by factors exogenous to the model, such as the past history of the economy (profit rates, income levels, etc.).

METHOD OF CALCULATION

Given an historically determined investment demand I_0^D, we obtain in turn a level of employment, a rate of interest, prices, and wages in equilibrium of the economy. So we have the two elements that will enter into the next period determination of the investment demand, the aggregate income and profits. If E_t^* is a vector describing a "temporary equilibrium" of the economy at time t, then *E_t^* is a function of the historically given I_0^D* and is given itself as a sector of the relevant variables. In other words,

$$E_t^* = E_t^*(I_0^D).$$

As we discussed above, E_t^* can be described completely by a sector of output of both types of goods, wages, rate of profit, prices, and employment levels at time t:

$$E_t^* = A^*(t), B^*(t), w_H^*(t), w_L^*(t), H^*(t), L^*(t), r^*(t).$$

From the vector $E^*(t)$ we can obtain the demand of investment $I^D(t)$ to be used in the next period. For instance:

$$I^D(t) = \phi\big(r^*(t), y^*(t)\big)$$

where $y^*(t)$ is national income at time t, obtained from the components of the vector $E^*(t)$ (wages, employment levels, levels of outputs of goods).

Hence at time $t + 1$ we have a new "exogenously given" demand for investment $I^D(t)$. Using this value, we turn to determine the new equilibrium of the economy given by output of goods, profit rate, prices, wages, and employment levels at time $t + 1$,

$$E^*(t + 1) = E^*\big(I^D(t)\big), \text{ where}$$

$$\begin{aligned} E^*(t + 1) = {} & A^*(t + 1), B^*(t + 1), \\ & w_H^*(t + 1), w_L^*(t + 1), \\ & H^*(t + 1) L^*(t + 1), r^*(t + 1). \end{aligned}$$

Hence we generate, from the initial I_0^D, a sequence of temporary equilibria of the economy

$$E_1^*(I_0^D), E_2^*(I_1^D), \ldots, E_{t+1}^*(I_t^D), \ldots,$$

where I_0^D is given, and

$$I_t^D = I_t^D\,(E_{t-1}^*)$$

This sequence of temporary equilibria is obtained from simulation techniques; it represents a dynamic development of the economy of the region. The time sequence can be represented as

$$I_0^D \to E_1^* \to I_1^D \to E_2^* \to I_2^D \to E_3^* \to \ldots.$$

This simulation process can then be used to trace medium and long-term effects of changes in the technical parameters on the dynamic path of the variables in the economy. For instance, from a change in technology at time t, one can simulate the present and future effects on employment, wages, profit, and welfare levels of high and low income groups through time within, say, a 20-year horizon.

International Production-Exchange Model

The international model considers at the present two regions, the "North" and the "South." These regions do not correspond to the whole of the North economy or the whole of the South economy. For example, depending on the parameter values (and the form of the detailed functional relationships), the two regions are taken to represent a chosen region and its economic trading environment. In further work further disaggregation of the international market will be performed.

The two regions exchange in a market fashion three types of goods, basic and nonbasic goods, and capital goods. Trade is modeled by a general equilibrium production-exchange model of the world economy in the short run. Market imperfections such as tariffs and exchange rates exogenously given are also simulated. The short-run equilibrium is determined up to financial flows. The model thus explains endogenously imports and exports of all goods and their prices in the short run. It may also explain the flow of foreign exchange that are in turn used by each region to determine exchange rates. With a correction for exchange rates and for imperfections within the regions, the prices of all goods are assumed to be basically the same throughout the world economy, given by the solution of the model. However, wages and profit rate in each region will be different since they are tied up to (or determined by) domestic technologies, distribution of income, and supply of factors and resources.

We now explain here how the international market behavior is simulated in the model. In the first place, we calibrate the data of the model of each economy, North and South, so that exogenously given data or imports and exports of goods at the initial period are incorporated. Next, we assume there is a change in population and also in investment[3]

[3]These are to be computed as a function of past income and profit differentials in the regions (as proxies for expectations). They are to be used, in turn, to compute the next temporary equilibrium of the world economy much in the same way that investment demand links one short run equilibrium of the domestic economy to the next.

Fig. 1. Short run equilibrium model of a domestic economy. Note that since this is a general equilibrium model, in fact, all variables affect each other, so that the arrows do not necessarily indicate causality and should be thought of as indication of a relationship. The choice in the direction of the arrow was made so as to give a plausible interpretation of the chain of relations in the model. The investment variable is outside the circled region because it relates more to the dynamics than to the short run equilibrium of the model. Investment demand helps connect one short run equilibrium with the next. Even though at each point in time investment depends on total income and functional income distribution of the last period, this is not indicated for simplicity. Similarly exports and imports are outside the large circle because even though they affect domestic demand they relate more to the international market.

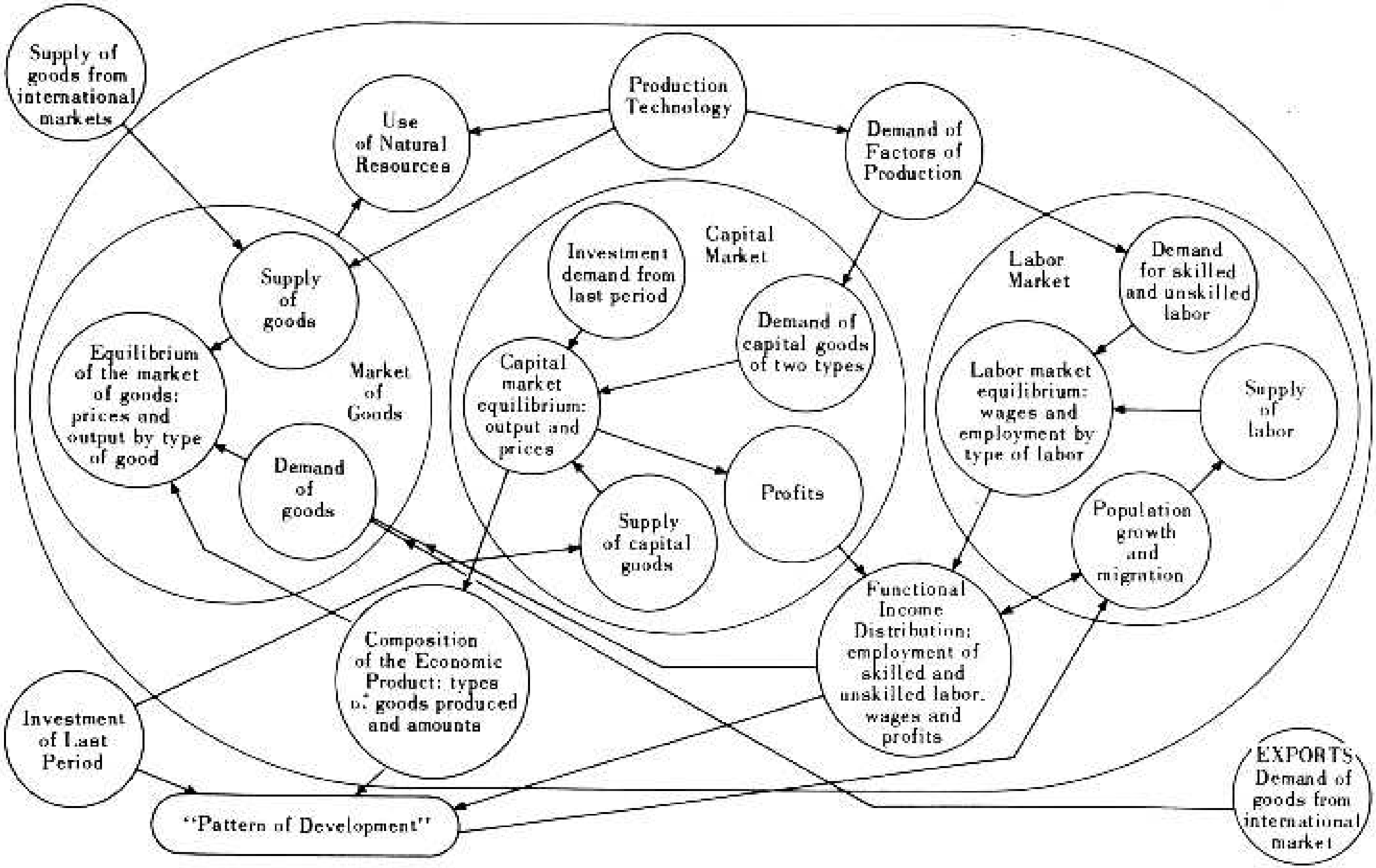

Fig. 1. (See caption p. 312.)

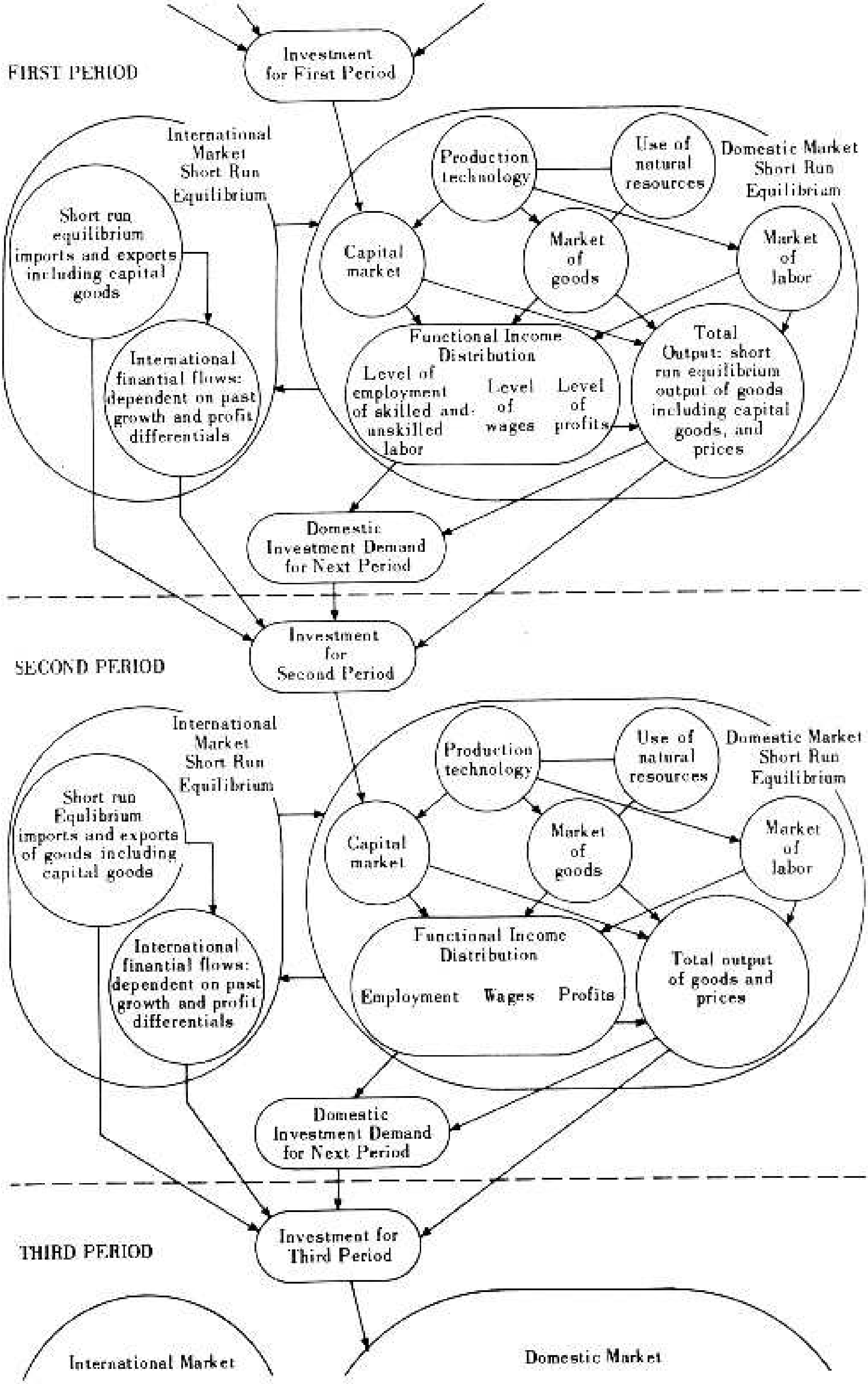

Fig. 2. Dynamics of a domestic economy.

in each region according to scenario guidelines, and depending on past and present growth and profits. With the change in investment and population in each region, the new temporary equilibria of the domestic economies of the North and the South are recomputed, yielding new domestic levels of employments, outputs of all the goods, profits and prices. The prices of the North and the South of each good in this new temporary equilibrium are then compared. The program is geared to proceed as follows. If a good (say, the basic good A) is produced at a lower price (after tariffs), according to domestic prices in the temporary equilibrium of the South, then an increase of exports from the South to the North occurs. This procedure is simulated in each market (except for labor markets). After the increased exchange is simulated, the program recomputes the domestic temporary equilibrium in each region. In this way, a nonequilibrium trade pattern is simulated. The adjustments of imports and exports made for each good, and reproduce to an extent current patterns of trade variation. They are not to exceed, after a number of iterations, the average changes in trade over changes in prices of the actual international market of these goods. Figure 3 illustrates this process.

Preliminary Calibration and Results from the Present Model Structure: Technology, Income Distribution, and North–South Terms of Trade

We now discuss an experiment with the model based on a preliminary calibration using data from Brazil (for the Southern region) and the United Kingdom (for the Northern region). Other sensitivity tests are described by Clark, Cole and Lucas [1]. The data for Brazil was based on Lysy and Taylor [13]. The U.K. data were obtained from the following sources: Her Majesty's Stationary Office [16] and the Central Statistical Office [17]. For details of the calibration of the two regions, the computation of solutions, and the programming of the trade sector, see Clark, Cole and Lucas [1]. After a classification (necessarily arbitrary to an extent) is made of workers into skilled and nonskilled and of goods into basic, nonbasic, or luxury and capital goods, Table 1 is composed, which has to be interpreted as describing more of a qualitative comparison between the two economies rather than accurate figures. The data from Table 1 enable calculation of the technical coefficients a_i, b_i, and c_i of the model. The variables a_i and b_i are measured in workers per £1,000 output, and c_i is dimensionless. The resulting Table 2 of coefficients is also in many respects arbitrary but sufficient for the preliminary testing of the model.

Table 3 compares two runs for the *temporary equilibrium* (i.e., nondynamic) model. The runs are identical except for a change in the level of investment demand assumed for the Northern region. It may be seen that this leads to an increase in volumes of trade and a lowering of the price of basic goods relative to luxury and investment goods.

The results of Table 3 can be explained as follows. The production of basic, luxury, and capital goods of the North and of the South have different factor intensities as indicated in the technological coefficients in Table 2. For example, basic goods are produced in the North in a relatively more capital intensive fashion, both with respect to the South's production of basic goods and with respect to luxury and capital goods in the North. This is seen by comparing a_2, b_2, and c_2 in Table 2. In addition, the supply of factors of production (capital and labor) is different in each region. For example, supply of unskilled labor is quite price inelastic in the South and relatively more price inelastic in the North, since unskilled labor can be quite abundant in the South and since, in addition, for small increases in wages migration from rural to urban areas increases.

TABLE 1
Production Sectors for the South and the North

North (U.K.)

Sectors	Skilled Workers (Thousands)	Unskilled Workers (Thousands)	Output (1968 £M)	Capital Stock (1968 £M)
Basic goods	3,786	2,667	8,440	24,466
Nonbasic goods	9,467	3,815	21,000	44,851
Capital goods	3,614	1,456	8,017	17,123
Totals	16,867	7,938	37,457	80,000

South (Brazil)

Sectors	Skilled Workers (Thousands)	Unskilled Workers (Thousands)	Output (1959 C$M)	Capital Stock (1959 C$M)
Basic goods	47	15,380	927	1,142
Nonbasic goods	111	5,794	518	1,073
Capital goods	77	3,985	284	738
Totals	235	25,159	1,729	2,953

In the trade model each region was initially calibrated so as to be in a temporary equilibrium with exogenously given trade patterns. This yielded a composition of the output and prices for each good. With initial changes in investment and population the South was found to produce basic goods cheaper than the North, where the new temporary equilibrium was computed. An increase of exports from the South to the North of basic goods should then occur, according to the prescribed market mechanism. Under the new trade conditions, the temporary equilibria of the North and of the South were recomputed. In a neoclassical framework, an increase of trade would tend to *equalize* the prices of the goods that the South produces more cheaply than does the North. This would occur because by increasing exports of the good that is its relative advantage, the South would tend to drive up the prices of inputs and thereby increase costs and prices relative to the prior situation. However, the model showed in this run, and with relative stability, that the dynamics of trade can have just the opposite result. More exports of the basic goods, the relative advantage of the South because of labor availability, lower the prices of those goods, and, effectively, tend to *deteriorate the terms of trade of the South with respect to the North*.

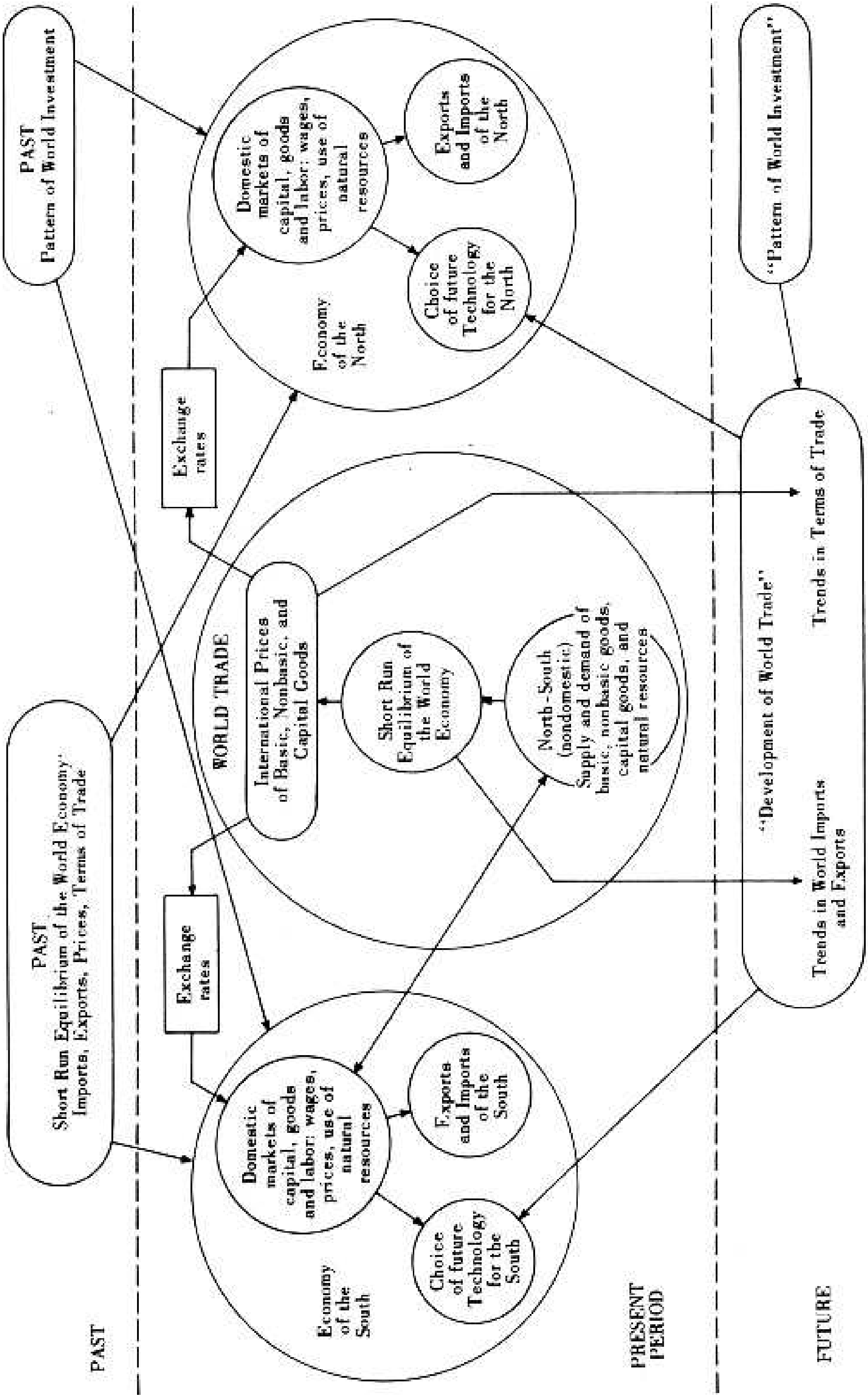
PAST
Pattern of World Investment
PAST
Short Run Equilibrium of the World Economy'
Imports, Exports, Prices, Terms of Trade
Exchange rates
Exchange rates
Domestic markets of capital, goods and labor; wages, prices, use of natural resources
Exports and Imports of the North
Choice of future Technology for the North
Economy of the North
WORLD TRADE
International Prices of Basic, Nonbasic, and Capital Goods
Short Run Equilibrium of the World Economy
North-South (nondomestic) Supply and demand of basic, nonbasic goods, capital goods, and natural resources
Domestic markets of capital, goods and labor; wages, prices, use of natural resources
Exports and Imports of the South
Choice of future Technology for the South
Economy of the South
"Pattern of World Investment"
"Development of World Trade"
Trends in Terms of Trade
Trends in World Imports and Exports
PAST
PRESENT PERIOD
FUTURE

Fig. 3.

TABLE 2
Technical Coefficients and Other Parameters of the Model

Parameter		North	South
a_1	Unskilled labor: output for non-basic goods	0.185	12.38
a_2	Unskilled Labor: output for basic goods	0.306	15.27
a_3	Unskilled Labor: output for capital goods	0.185	15.69
b_1	Skilled labor: output for non-basic goods	0.448	0.2371
b_2	Skilled labor: output for basic goods	0.459	0.439
b_3	Skilled labor: output for capital goods	0.448	0.3031
c_1	Capital: output ratios for non-basic goods	3.025	2.292
c_2	Capital: output ratios for basic goods	3.448	1.134
c_3	Capital: output ratios for capital goods	5.445	2.984
a	Utility function parameter of high-income group	3.0	1.680
b	Utility function parameter of low-income group	0.5	1.930
α	Logarithm of elasticity of labor supply depending on real wages for skilled workers	23,872	647,442
β	Logarithm of elasticity of labor supply depending on real wages of skilled workers	13,038	749
I_H	Investment of high-income group	7,215	258.2
I_L	Investment of low-income group	802	25.8
I_K	Initial endowment of capital of low-income group	13,450	268.
H_K	Initial endowment of capital of high-income group	121,050	2,684

The examination of the data shows how this effect comes about. Increased exports of basic goods increases demand for unskilled labor and capital in the South. Even though these goods are produced in quite a labor-intensive way, the supply elasticity of factors is such that with increased exports the wage's increases are minimal, while the capital costs increase relatively further. This has no major effect on the costs of basic goods, but, in a general equilibrium fashion, it tends to increase relatively further the costs of luxury and capital goods, which are more capital intensive, in the South. One could expect, however, that if demand of basic goods increases due to increased employment, then these effects on relative prices in the South could be somewhat checked. The new income distribution with increased exports, however, does not bring about such a compensating demand effect. The mirror effect occurs in the North, where basic goods are relatively more capital intensive and labor supply less elastic. As noted in the Introduction section, many market and nonmarket mechanisms are not yet accounted for in the present model. These results are preliminary and are presented as such; it is evident also that the results overestimate the sensitivity of shifts in some variables relative to others. For example, volumes of trade are very sensitive to small shifts in prices. A major reason for this is that in the present model *all* goods produced are considered tradeable when in fact potentially tradeable goods are in the main only a small proportion of those produced. Furthermore, the present assumptions about mobility of capital stock between sectors within each region exaggerate the homogeneity of capital. Similarly, the form of labor supply taken over-estimates the elasticity of the supply of factors to shifts in the real wage rate. Several modifications of the model structure are, therefore, indicated. Thus the results should only be taken to indicate *tendencies* arising from the current structure and the present calibration. Nevertheless, they tend to support arguments about the importance of underlying inhomogeneities of production and consumption within the economies of the North and South and indicate the necessity of providing a more satisfactory treatment than that contained in existing models. Further developments of the model will be reported subsequently.

TABLE 3

		Total Output of Basic Goods (B)	Total Output of Luxury Goods (A)	Total Output of Investment Goods (I)	International Price of B	International Price of A	International Price of I	Level of Exports of B	Level of Exports of A	Level of Exports of I	Employment of Unskilled Workers	Wages of Unskilled Workers	Employment of skilled Workers	Wages of Skilled Workers	Rate of Profit (Quasirent on Capital Stock)
Standard run (as in Table	North	7,407	21,499	8067	1.0	0.905727	1.160166	−85.18	29.99	60.0	7,736	0.3037	16,645.5	1.1864	0906
	South	833	571	234				+85.18	−29.99	50.0	22,469	0.031	572.2	0.7182	1.132
Run with increased investment in the North (by 5%)	North	7,281	21,623	8077	1.0	0.905782	1.160257	97.5	489.8	298	7,722	0.3033	16,648	1.1866	105,155
	South	844	112	582				−97.5	−489.8	298	23,420	0.035	573.7	0.7202	1.315

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