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Models Incorporating the Technology Factor

Development Policy and Dynamic Comparative Advantage

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I. INTRODUCTION

It is now generally recognized that foreign exchange and international trade considerations should form key elements in the rational planning of development in most economies. However, it is also commonly believed that there is relatively little in the traditional theory of international trade that seems immediately applicable to development planning. We are often told, on the basis of theory or fact, that the received comparative cost doctrine, for example, has little to offer in this context because its assumptions and frame of reference are for various reasons irrelevant. This claim is not without foundation. Most formal theory is confined to two-country, static systems in which commodities, factor endowments, and (uniform) production functions are specified for both trading partners and the static optimal trade pattern is analyzed under the assumption of a trade balance. Only lip service is paid to the fact that any one country has numerous trading partners, that trade is in the present context hardly ever balanced, and that foreign aid and foreign investment is the rule rather than the exception. Last, but not least, trade like growth

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is a process that takes place over time, and dynamic considerations must play a central role in a theory of comparative advantage.

Between orthodox adherence to existing theories and summary dismissal of them, there should be some useful, intermediate standpoint. What seems most important as a first step is to set up systematic general equilibrium frameworks in which dynamic considerations of both development and trade could be dealt with simultaneously. Otherwise, there is no way of formulating empirically workable alternative hypotheses, and arguments of a rather imprecise kind can just flourish.[1]

Rather than grafting growth aspects to a two- (or multi-) country trade model, we shall look at trade from the point of view of the individual optimizing economy. In this situation foreign exchange is just another, albeit rather special, factor of production—largely complementary but partly substitutable—which possesses a given endowment (foreign aid), and certain intertemporal borrowing is allowed. Foreign exchange can be earned or saved by producing "trade" goods (exports or import substitutes). The economy produces other "final" goods (consumption, investment) and also directly and indirectly uses "primary" inputs (labor, capital of one or more kinds). The technology is assumed to be a discrete activity-analysis type technology. This is both flexible enough to allow for the introduction of some important nonlinearities and externalities and at the same time is of the kind that lends itself best to empirical implementation and verification.[2] Optimization takes the form of the maximization of some welfare function subject to the production, foreign exchange, and trade (and possibly institutional) constraints.

An important difference between the single country optimization approach and that of the usual two-country analyses of international

[1] The clearest and one of the earliest discussions of the dichotomy between the existing trade and development theory approaches is Chenery's [7]. Bhagwati in his excellent survey [3] also stresses the need for a more systematic analysis of the bordering fields. There certainly is more empirical work available now than there was four or seven years ago. Still one feels that a lot remains to be done, especially on improving the analytical tools to handle empirical situations falling outside existing theory. The rapid progress of the more systematic formal growth (as distinct from "development") theory in its preoccupation with closed economies only testifies to the same lacuna.

[2] In this connection one should mention the tools used in the analysis of the Leontief [10] paradox, and also the development planning literature of the linear-programming type.

trade is in the way comparative advantage ordering is established. A change in the availability of foreign exchange in relation to the endowment of other factors will call forth a change in the optimal bundle of foreign trade activities. The theory of comparative advantage in our analysis, whether in a static or dynamic context, consists of spelling out the resulting order of choice of these optimal bundles. In a static two-factor (plus foreign exchange) world, the result is something less simple but probably more generally applicable than Heckscher-Ohlin. However, an unambiguous ordering of activities can be established.

Section II of this paper briefly discusses a number of alternative static, single-period-optimization formulations of the problem. This is used in order to set the stage for the subsequent more realistic dynamic models and also helps to relate the development planning approach to the more common trade theory formulation. This is followed by a short digression (Section III) from the main theme—a discussion of the empirical possibility of interpreting the fixed coefficients approximation of a static model on the basis of *marginal,* rather than average, coefficients. This may have markedly different implications for the price structure and the pattern of comparative advantage and is probably worth exploring further in empirical work.

Section IV, entitled "An Intertemporal Analysis of Trade and Growth," forms the center of our study. In this section we also concentrate on the implications for comparative advantage of a number of important dynamic factors. Apart from the usual capital investment relations, these implications are the possibility of interperiod borrowing and lending of foreign exchange and the existence of externalities in the export process itself. Productivity changes and growth factors come in and trade goods can no longer be ordered independently of time. Nevertheless, under a fairly general set of assumptions a dynamic analogue of comparative advantage ordering can be established, involving both activities and the optimal time of their expansion. We also briefly discuss the possibility of incorporating labor training effects in the linear model.

In the subsequent and final section, (V), there are some empirical illustrations of the workings of the dynamic model based on Israeli data. This is not meant as a test of hypotheses but rather to show that such policy formulation can be given empirical content.

II. A STATIC PROLOGUE

This section deals with an optimization version of a number of alternative static production and trade models. These are related to the kinds of production frameworks also used in the trade theory literature. We start with a relatively straightforward Ricardian model.

A. A simple Ricardian system

Consider an open economy producing a composite consumption good (C) and choosing from among m foreign trade activities T_i ($i = 1, 2, \ldots, m$). These can be either exports or import substitutes and their net marginal foreign exchange revenue per unit is fixed ($= v_i$).[3] The economy is assumed to be small enough to take its import prices as given. At the same time this formulation allows for monopolistic export markets.

Apart from foreign exchange of which an equivalent of m_0 per incremental unit is used in producing the consumption good, suppose the economy uses a primary factor (labor) whose input coefficients in the various activities will be denoted by l_i ($i = 0, 1, \ldots, m$; the subscript 0 refers to the consumption good) and all refer to some given (future) planning period. We shall presently extend the technology to include capital goods, but for the moment we are sticking to the one-factor Ricardian case.

Let us now assume that our economy maximizes the single period consumption level C, subject to two net supply[4] constraints: a constraint on foreign exchange transfers (denoted by F); and a constraint on the primary input (L). To make for a more realistic choice of foreign trade activities, we also assume that the range of operation of each activity is bound by exogenously fixed minimum ($\underline{T}_i$) and maximum ($\bar{T}_i$) levels (see constraint (1)). ("Trade activity" as used here is the production and sales of goods for export or for the substitution of imports, by specified industries.)

Our problem can now be expressed in the following form:

[3] This is "net" in the sense that we subtract from gross revenue all direct and indirect import requirements. In the case of an import substitute, v_i is net foreign exchange *saved* by one unit of the activity in question. (See also [5]—here we depart in a number of ways from the notation used in that paper.)

[4] "Net" here means that we subtract from the gross supply whatever fixed exogenous demand of the factor that is required (see [5]).

Maximize C subject to:

(1) $\underline{T}_i \leq T_i \leq \overline{T}_i$ (trade activity constraints: $i = 1, 2, \ldots, m$)

(2) $m_0 C - \sum_{i=1}^{m} v_i T_i \leq F$ (foreign exchange constraint)

(3) $l_0 C + \sum_{i=1}^{m} l_i T_i \leq L$ (labor constraint)

No profound analysis is needed to see the nature of the solution in this case. The trade activities can be unambiguously ordered by their (Ricardian) comparative advantage ratios—v_i/l_i i.e., net foreign exchange revenue per unit of labor input. With a given supply of F and L the economy will produce its consumption level optimally if it follows the v_i/l_i scale for expansion of the trade activities, up to the point at which all labor is exhausted. Put in more formal terms, if we denote the shadow price of foreign exchange (in terms of consumption units) by q and that of labor (the real wage) by w, there will always be one trade activity (suppose it is the jth activity) that is just profitable at that price pair, so that we get:

(4) $l_j w - v_j q = 0$ (domestic costs in the jth trade activity = its net marginal revenue)

(5) $l_0 w + m_0 q = 1$ (total costs in consumption = the price of consumption = 1)

from which we obtain:

$$w = \frac{v_j}{l_j m_0 + l_0 v_j}, \quad q = \frac{l_j}{l_j m_0 + l_0 v_j}$$ [5]

[5] The full formal solution would be obtained by looking at the dual linear-programming formulation. Let us denote the shadow prices attached to the maximum and minimum constraint in (1) by $\bar{p}$ and p respectively. We then have:

$$\text{Minimize } wL + qF + \sum_{i=1}^{M} (\bar{p}_i \overline{T}_i - \underline{p}_i \underline{T}_i)$$

subject to

(7) $wl_0 + qm_0 \geq 1$

(8) $wl_i - qv_i + \bar{p}_i - \underline{p}_i \geq 0 \quad (i = 1, 2, \ldots, m)$

Obviously for each good we will always have either $\bar{p}_1$ or p_i equal to zero with one case ($i = j$, say) at most in which both are zero and the good is just profitable. It is also the case that both (7) and (8) will always be satisfied with equality.

If we define the (static) *exchange cost* of an activity to be its real domestic costs of production per unit of foreign exchange earned (or saved) when it is just profitable (denoted by R_i), we obtain

$$(6) \qquad R_i = \frac{l_i w(i)}{v_i} = \frac{l_i}{l_i m_0 + l_0 v_i} = \frac{l}{m_0 + l_0(v_i/l_i)}$$ [6]

With the given F and L supplies, all trade activities i for which $R_i < R_j = q$ will be produced to the maximum ($T_i = \bar{T}_i$), i.e., they will be intramarginal, and all those for which $R_i > R_j = q$ will remain at their minimum values ($T_i = \underline{T}_i$).

The easiest way to describe the order and process of choice in such a model is to keep the supply of labor (L) fixed and change the relative scarcity of foreign exchange by varying F and watching the sequence of optimal "bases" in the linear programming solution. Clearly the order of expansion (or contraction) of the trade activities will be the order of R_i as measured by (6) above. Comparative advantage has an unambiguous meaning here and depends on a single technical coefficient, just as we would expect.

Before introducing more factors of production, let us make a few additional remarks on other aspects of the system represented by (1) to (3):

(i) As is explained elsewhere, our formulation of trade activities is quite general. They may represent physically different commodities or they may also represent stepwise linear portions of upward-rising supply curves or downward-sloping demand curves of a single export commodity. In the case of import substitutes the minimum bound formulation in (1) may allow for negative import substitution, and in the case of exports for the introduction of institutional limitations (e.g., vested

[6] A slightly different way in which we could define the "exchange cost" (also the form more likely to be used in cost benefit calculations) is to compare costs in terms of the *same* shadow prices (here w)—those which happen to hold at the point of comparison. For our present purpose, however, it is more meaningful to evaluate R_i in terms of the prices that will hold when *it* will be just profitable (here denoted by $w(i)$). In this way we can, whenever possible, try to obtain a complete measure of comparative advantage ranking that is independent of factor prices. The alternative procedure of using $l_i w/v_i$ (rather than $l_i w(i)/v_i$) to compare with q is consistent with the use of the simplex criterion to decide whether a given activity is or is not pofitable. It does not, in a more general model, necessarily help to establish ranking independently of prices.

interests forcing a minimum positive level of exports of certain unprofitable goods).

(ii) The primary input coefficients (here and in all the subsequent more general formulations) should be understood in the Leontief sense of *total* (direct and indirect) input coefficients, i.e., there are underlying intermediate inputs in our economy and their impact is embodied in our calculations of the total primary input coefficients. Ever since the Leontief paradox discussion this has become common practice. One might only note that the primary input coefficients for any future planning period should incorporate any known (or best practice) technological change, here assumed to be exogenously given.

(iii) Our economy is assumed to receive some amount of foreign exchange (F) from abroad at no direct cost. Borrowing costs could be incorporated without difficulty but this would distract our attention from the main issues (we shall return to a more satisfactory, dynamic view of foreign borrowing in Section IV). The explicit role of F here is to represent a policy variable whose change we use as a means of characterizing patterns of comparative advantage.

(iv) The aggregation of C in this framework can be justified empirically on the basis of linear approximations of Engel curves for the components of the consumption bundle. Moreover, the model could be generalized to allow for different ways of supplying aggregate utility, but this would not affect the main trade features with which we are concerned here.

B. Incorporating capital in a Ricardian approach

Let us now introduce capital goods and investment into the system in a specific form which will preserve the system's Ricardian nature. Suppose we have an underlying capital output matrix in the original interindustry system and suppose also that in maximizing total consumption we do so subject to a priori specified *rates* of growth of the various capital goods. As is shown in my previous study made in 1967 [5], the reduced form of our system will retain the same structural form given by constraints (1) to (3), providing we now give a new interpretation to our coefficients v_i, m_0, and l_i ($i = 0, 1, \ldots, m$). They will now incorporate not only the indirect effects of ordinary intermediate goods but also the direct and indirect allowance for the future steady growth of capital stocks.[7] These specified rates of growth can of course be adjusted by successive approximation so as to conform to an internally consistent development "program." We could thus retain the simple Ricardian nature of our system, even though we have introduced capital goods, providing we do so in a somewhat special form which will leave only one truly primary input in the system.

Even though this "Ricardian" way of looking at capital is more useful than might seem at first sight, our preliminary discussion would not be complete without discussing the alternative, more common, Heckscher-Ohlin way of introducing capital into our system. Moreover, we shall also make use of the Heckscher-Ohlin formulation in the subsequent dynamic analysis.

C. The static two-factor system

Let us now explicitly add one capital good to our system of which a fixed endowment K is available for use during the planning period. The economy also produces the investment good (I) (for use in later planning periods) with total input coefficients m_k, l_k, k_k. Capital per unit k_0 is used in consumption goods and k_i ($i = 1, 2, \ldots, m$) in trade goods.[8]

Suppose that the economy now maximizes GNP ($= C + p_k I$, where p_k is given) subject to the extended set of constraints. So we have:

Maximize $C + p_k I$ subject to:

(1) $$\underline{T}_i \leq T_i \leq \overline{T}_i$$

(2c)* $$m_0 C + m_k I - \sum_{i=1}^{m} v_i T_i \leq F$$

(3c) $$l_0 C + l_k I + \sum_{i=1}^{m} l_i T_i \leq L$$

(9)† $$k_0 C + k_k I + \sum_{i=1}^{m} k_i T_i \leq K$$

* The numbers (2c), (3c), etc., refer to the new version of the original equations which are appropriate to the model contained in this section.

† Equations (7) and (8) are found in footnote 5.

[7] In this case one obtains a modified Leontief inverse matrix of the productive system $(I - A - HK)^{-1}$ where A is the ordinary input-output matrix, K is the capital stock-output matrix, and H is a diagonal matrix having the exogenously fixed rates of growth of the capital goods in the respective boxes.

[8] Again the understanding is that the k-coefficients are total (direct and indirect) in the Leontief sense and that K is "net" supply of capital.

To see the pattern of choice in this case we must again look at the price structure of our system. Let us denote the shadow price corresponding to (9), i.e., capital rentals, by s. Leaving out the less interesting corner solutions we shall assume that both consumption and investment goods are produced and that both labor and capital are fully utilized.[9] In that case there will again be *one* trade good that is just profitable, say the jth. Let us denote the shadow rate of exchange relevant for that case by $q = R_j$. We now have three equations to determine three prices $q\ (= R_j)$, w, s:

$$l_j w + k_j s - v_j q = 0 \tag{4c}$$

$$l_0 w + k_0 s + m_0 q = 1 \tag{5c}$$

$$l_k w + k_k s + m_k q = p_k \tag{10}$$

and we obtain:

$$R_j = q = \frac{l_j w + k_j s}{v_j} = \frac{w + s x_j}{y_j} = \tag{6c}$$

$$= \frac{(k_0 p_k - k_k) + (l_k - l_0 p_k) x_j}{(k_0 m_k - k_k m_0) + (l_k m_0 - l_0 m_k) x_j + (l_k k_0 - l_0 k_k) y_j}$$

where $$x_j = \frac{k_j}{l_j},\ y_j = \frac{v_j}{l_j}$$

We note the following: If we keep the supply of capital (K) and labor (L) fixed and vary the amount of foreign exchange transfers (F) we go through a process of changing the relative scarcity of foreign exchange. As F changes monotonically the economy will choose its trade activities by order of comparative advantage which will be the order of

[9] The conditions for the latter to hold can be spelled out explicitly by looking at the solution of (4c), (5c) and (10). If the basic determinant (written out in full in the denominator, last expression of (6c)) is positive, the condition for w, s, and q, respectively, to be positive with the jth activity in the base, requires:

$$(k_j/v_j)(m_0 p_k - m_k) > (k_k - p_k k_0) \qquad (\text{for } w > 0)$$

$$y_j(l_k - l_0) > (m_0 m_k) \qquad (\text{for } s > 0)$$

$$x_j(l_k - l_0 p_k) > (k_k - k_0 p_k) \qquad (\text{for } q > 0)$$

If the above determinant is negative, the signs must be reversed. If one of the conditions does not hold then the activity in question can be profitable only when we are back to a two-dimensional world. We ignore this possibility here since it does not add anything to what we already know.

the R_j's ($j = 1, 2, \ldots m$) as given by the last expression of (6c). This order will depend on two intensive magnitudes, x_j ($= k_j/l_j$) and y_j ($= v_j/l_j$).[10]

As in the previous model (A) the economy will fully operate all T_i for which R_i is less than the exchange rate (q) corresponding to the given F and partially operate that T_j for which R_j just equals q.

Consider a set of activities which produce the same amount of foreign exchange per unit of labor (i.e., they have the same y). For this set the capital:labor ratio x can provide the sole measure of internal ranking.[11] This is reminiscent of Heckscher-Ohlin. But the important thing is to note that in general both x and y may vary as between different activities and the ranking will depend on *both* parameters,[12] and not on capital intensity alone.

Although our technology for the one economy is the same as in the Heckscher-Ohlin framework, the whole frame of reference is different. We don't have a simple two-country system but could have as many trading partners as we like; we don't make any assumptions about the production functions of the trading partners or about competition and the whole notion of capital or labor being relatively abundant is of little meaning here because, strictly speaking, we have a third factor (foreign exchange), a change whose quantity may alter the relative price of labor and capital in a nonmonotonic fashion. It seems to us that the present way of looking at the optimal trade pattern is empirically more relevant from the point of view of a single country.

There is, however, one important general conclusion that still remains correct here, and this is that in a static model trade activities can be ranked unambiguously and depending only on technology.

[10] As a check one can see that when $k_0 = k = 0$, we are back to (6) in terms of (v_j/l_j) only.

[11] This follows from the monotonicity with respect to x of the function $R = (ax + b)/(cx + d)$ where a, b, c, d are regarded as constants. (Proof: $dR/dx = (ad - be)/(cx + d)^2$, which is either positive or negative or zero throughout.)

[12] Leaving out cases of complete dominance in production, we can assume that across activities $dy/dk > 0$. It is easy to see, however, this is not enough to make for monotonicity of R with respect to x. More restrictive assumptions on the shape of the economy's technology would be required, and there is no reason to suggest that these conditions should hold in practice. (Examples of situations where such ranking becomes possible are: the case of a linear relationship between x and y, or if $l_k/k_k = l_0/k_0$ and in similar special cases).

D. Adding more factors

Nothing in principle will change if instead of one capital good we were to add more capital goods to the system, providing we assume that these are producible capital goods and for each K_s, say, we also add a final good, I_s, with price p_s. The dimensions of the problem will increase but from counting goods and constraints we can see that the nature of the solution will remain similar, except that now R_j will involve not only one capital intensity but capital intensity factors equal to the number of different capital goods in the system.

Things become much messier when we assume that there is more than one nonreproducible primary factor in the system. For example, consider adding another primary factor or domestic resource to our previous Ricardian system. We must now add a constraint, say,

$$g_0 C + \sum_{i=1}^{m} g_i T_i \leq G \tag{11}$$

Let the relevant shadow price be donated by z. Domestic (combined) *resource* costs will now be $l_i w + g_i z$, and the exchange cost ratio R_i will now become

$$R_i = \frac{l_i w + g_i z}{v_i} \tag{6d}$$

If both primary inputs are fully utilized we can no longer rank goods unambiguously. The ranking will not be independent of relative factor prices, or quantities. A related complication now will be the fact that we need a *pair* of trade goods to be just profitable at any optimal solution.[13] In theory we could now rank all possible *pairs* on the basis of their coefficients, but this will no longer be the simple notion of identifying comparative advantage by looking at single activities.

Much of my analysis in [5] consisted of the ranking of trade goods under two extreme Ricardian situations[14] in which only one of two primary input constraints is effective. This served to illustrate how the

[13] This follows from the *LP* property that in the optimal solution there will usually be as many activities as there are constraints in the system.

[14] The treatment of capital in that model was like the one indicated in Section IIB.

introduction of labor skills may change the optimal composition of foreign trade.

Finally it should be pointed out that comparative advantage might be affected by the existence of other institutional or political constraints in the system, as, for example, a constraint on the domestic savings ratio. When such constraints are introduced, comparative advantage will also involve each activity's differential claim on the additional institutional constraint. This is almost self-evident but may nonetheless be of practical importance in a policy context.

Before we move on to consider a fully intertemporal model, in which the above results have to be modified, we ought to discuss briefly a possible "dynamic" interpretation of the technical coefficients, still within a "static" framework.

III. DIGRESSION: MARGINAL LABOR COEFFICIENTS

So far we have said very little about the way in which the input coefficients l_i and k_i are estimated in practice. What is usually done in input-output analysis, and taken over in development planning, is to adopt a simple time-trend to represent technological improvement. Average labor and capital coefficients, both the original sectoral direct coefficients as well as the derived *total* (direct and indirect) coefficients in each final demand activity, are fixed at each point in time, independently of the scale of operation. This also is the view taken implicitly or explicitly in the computations performed in connection with the Leontief paradox.

There is a serious problem here which often tends to be overlooked: An assumption that may look rather harmless for purposes of prediction of approximate input levels of any one sector would produce wrong results for the *price* structure of a system and, for that reason, for the analysis of comparative advantage. Consider the following simple example:

For most industries in a growing economy a reasonably good approximation for predictions of capital and labor requirements of an industry would be to assume that the capital-output ratio remains constant and that the labor-output ratio falls at a constant rate over time. In other words, the following production function is assumed:

(12) $$X = \text{Min}\left(\frac{K}{k}, \frac{L}{l_0} e^{\lambda t}\right)$$

where X = output level, K and L are the capital and labor inputs respectively, k and l_0 are fixed coefficients and λ is a fixed exponential time-trend. Suppose we use time series covering past years to estimate these coefficients. Now try to fit an alternative production function to the same time series. Consider the following:

(13) $$X = \text{Min}\left(\frac{K}{k}, \left(\frac{L}{A}\right)^{\frac{1}{\beta}}\right)$$

or in other words:

$$K \geq kX$$

$$L \geq AX^{\beta} \text{ where } 0 < \beta < 1$$

This includes no time trend and instead assumes labor per unit of output to be a function of the level of output. Put differently this means that the rate of growth of labor productivity is a positive function of the rate of growth of output.[15]

In any time-series regression of X on K and X on L it will be practically impossible to distinguish between the two alternative hypotheses represented by (12) and (13). In the same way they might work equally well, for prediction purposes. However, the pricing (i.e., marginal productivity) implications might be very different indeed. This is best seen if we consider the effect of marginal increments of labor in both situations, assuming capital to adjust automatically.

In the time-trend case (12) we get:

$$\frac{\Delta X}{\Delta L} = \frac{X}{L}$$

In the second case (13) we have:

$$\frac{\Delta X}{\Delta L} = \frac{l}{\beta} \frac{X}{L}$$

Now suppose we employ a linear tangential approximation to the function (13), i.e., we assume the *marginal* labor-output ratio to be fixed

[15] This has been used, for example, by Verdoorn [12].

around some reference values, $\bar{X}$ and $\bar{L}$. Now, we take the marginal labor-input coefficient as $l\ \bar{K}/\beta\bar{L}$ instead of $\bar{X}/\bar{L}$, adding a constant intercept to the demand for labor so as to have labor requirements at the level $\bar{X}$ the same for both models.

Suppose we do that for the labor-input coefficients of all industries in the economy for which this procedure is relevant. Let us go back to one of our previous trade models, say the Ricardian model (incorporating capital—see Section IIB). The formal structure of our model will remain the same, except that the labor coefficients l_i will now be *marginal* instead of average coefficients, and the constant L on the right of constraint (3) has to be reinterpreted as the supply of labor less all the constant intercepts.

Obviously the pattern of comparative advantage may now be different. An export industry for which labor productivity (in the direct and indirect sense) grows very fast will have a high β factor and therefore a correspondingly lower marginal labor coefficient.

Table 1 below provides the results of a very rough experiment of this kind performed on Israeli data. The columns in the table give the computed total labor coefficients under the two hypotheses and also the resulting comparative advantage rankings.

There are five activities which move by five ranks or more in the direction of higher comparative advantage. These are the three agricultural activities—livestock, field crops, and miscellaneous agriculture—and two in manufacturing—meat and dairy products and chemicals. There are two activities which move at least five steps in the opposite direction—rubber and plastics and leather goods.

The results of Table 1 should be taken with some very large grains of salt as they are based on very rough time-series estimates. Besides, the alternative method was applied to all sectors although there are certainly some activities to which it is less relevant than to others. These results should only serve to make the general point that ranking may be sensitive to the kind of assumption underlying our linear approximations. More work on the estimation of production relations would be needed to get more robust results.

We are not aware of any attempt to use some such alternative formulation in the literature connected with the Leontief paradox. It should be a worthwhile experiment to perform some calculations of

TABLE 1

Labor Productivity Measured by Trade Activity

Trade Activity (1)	Total Labor Productivity ($1,000 per man-year) Average (2)	Total Labor Productivity ($1,000 per man-year) Marginal (3)	Ranking Average (4)	Ranking Marginal (5)
Fuel	6.1	19.6	1	2
Services and tourism	4.0	8.7	2	5
Metal products	3.9	6.5	3	7
Mining	3.2	7.5	4	6
Cement	3.2	6.5	5	8
Basic metals	2.9	5.9	6	9
Machinery	2.6	4.5	7	11
Shipping and aviation	2.5	5.8	8	10
Rubber and plastics	2.4	3.6	9	14
Paper and printing	2.3	3.7	10	13
Polished diamonds	2.2	3.5	11	15
Equipment	1.9	3.5	12	16
Leather goods	1.9	2.0	13	21
Livestock	1.8	12.4	14	4
Textiles	1.7	2.1	15	19
Field crops	1.6	12.9	16	3
Vehicles	1.6	2.0	17	20
Miscellaneous agriculture	1.6	25.4	18	1
Food products	1.5	2.6	19	18
Meat and dairy products	1.4	4.4	20	12
Miscellaneous transport and communication	1.2	3.4	21	17
Wood products	1.0	1.6	22	24
Chemicals	1.0	2.4	23	18

[a]Labor productivity (columns 2 and 3) is v_i/l_i (in $1,000 per man-year) i.e., the foreign exchange revenue per unit of total labor (direct plus indirect plus allowance for capital growth). Column 2 gives the estimates under the simple time trend assumption and column 3 under the alternative hypothesis. In both cases the estimates are projections for 1970. Sector definitions are as in my paper [5], but data for column 2 should not be compared with that study as they were based on earlier and now outdated estimates. They are only used for consistent comparison with column 3. Citrus is not included in the present comparison.

the total labor (and capital) content of $1 million incremental exports or import substitutes using *marginal* rather than average coefficients.

The use of marginal coefficients within a static framework would be an indirect way of bringing in dynamic considerations. We now turn to a model in which time appears in a much more explicit form.

IV. AN INTERTEMPORAL ANALYSIS OF TRADE AND GROWTH

So far we have only dealt with one-period maximization problems. With the tools at hand one could tackle multiperiod planning by looking at each period as a separate optimization problem, i.e., we would set up for each period, separately, all the required information on the spectrum of trade activities relevant to that period, with the corresponding information on the supply of the various exogenous factors of production, etc. This, however, would at best give us comparisons of stationary or steady states. Both growth and foreign trade planning involve time in an essential way—the correct way of looking at the problem requires the simultaneous analysis of the key variables over all time phases of the planning horizon taking into account the intertemporal relations on both the supply and demand side.[16]

Clearly there are many ways in which a dynamic trade and development model could be set up. We choose to concentrate on a number of relations that seem to us to be of major importance and at the same time can, in principle, be empirically applied.

Just as in the static model, we limit ourselves to a model in which an aggregate consumption good (C) is produced, as well as an investment good (I), and in which there are m trade activities, which for simplicity we shall assume to consist only of different export goods (denoted by E_i, $i = 1, 2, \ldots, m$).[17] We shall use superscripts to date variables

[16] This is not to argue that a multiperiod model cannot be decomposed into a sequence of single period optimization problems. However, as indicated later in the text, this must be done in a way that is consistent with the underlying dynamic structure.

[17] The empirical illustration to be given in the next section involves a model by Dougherty, Fraenkel and myself [6] that is slightly more general, because it has a greater number of factors and also involves import substitutes. The present analysis will be slightly simplified in order not to obscure the main issues.

over a planning horizon of T periods (i.e., E_i^t = the quantity of the ith export in period t, where $t = 1, 2, \ldots, T$).

The technology will consist of the generalization over time of the single-period activity model, i.e., for E_i^t we have a marginal revenue coefficient, v_i^t, and input coefficients, l_i^t and k_i^t, for labor and capital respectively. All of these may, of course, be different for different time periods, t, but will be assumed to be exogenously fixed coefficients. A similar assumption will be made for the input structure in the production of C^t and I^t (l_0^t, k_0^t, m_0^t, and l_k^t, k_k^t, m_k^t respectively). As before, all these coefficients are meant to be interpreted as *total* (direct and indirect) coefficients in the input-output sense.

The supply of the primary factor (labor or some specific skill, say) at each point in time ($L^t, t = 1, 2, \ldots, T$) is given (usually growing over time). Capital, on the other hand, is accumulated by a process of investment and is subject to a fixed depreciation rate, μ, so we have:

(14) $$l_0^tC^t + l_k^tI^t + \sum_{i=1}^{m} l_i^tE_i^t \leq L^t \qquad \text{(replaces (3c))}$$

(15) $$k_0^tC^t + k_k^tI^t + \sum_{i=1}^{m} k_i^tE_i^t \leq K^t \qquad \text{(replaces (9))}$$

(16) $$K^t = K^{t-1}(1 - \mu) + I^{t-1} \qquad t = 1, 2, \ldots, T$$

(K^t is the stock of capital at the beginning of the year t and K^1 is given).

The following are the other main intertemporal ingredients of our model:

FOREIGN AID

We shall assume that foreign exchange can be borrowed and lent at a fixed rate of interest (α) within the planning horizon.[18] The economy starts with an initial endowment of foreign exchange, B, which it can lend or augment by additional borrowing providing that at the end of the planning horizon the economy is left with no more debts than it had

[18] More realistic formulations involving upward sloping supply curves of foreign loans can be introduced. This forms the subject of an independent study by M. Fraenkel of the Bank of Israel. Even in the present case, however, as indicated at a later point in this paper, borrowing will be effectively limited.

at the beginning, i.e., all additional debts have to be returned before the planning horizon comes to an end. Instead of having a separate foreign exchange constraint like (2) or (2c) for each period separately, we get one overall intertemporal foreign exchange constraint, as

$$(17) \qquad m_0^t C^t + m_k^t I^t - \sum_{i=1}^{m} v_i^t E_i^t - F^t \leq 0 \qquad \text{(replaces (2c))}$$

$$\sum_{t=1}^{T} \frac{F^t}{(1+\alpha)^{(t-1)\cdot}} \leq B$$ [19]

EXPORT CONSTRAINTS

In the static framework we assumed the existence of absolute exogenous bounds on the range of operation of the various trade activities. Here, in coming to deal with a dynamic setting we make a major departure from our previous assumption.

The development of exports is a process that takes time. An export activity involves a certain amount of irreversible investment both in terms of capital goods and manpower. At the same time, the ability to expand exports both on the demand side (penetrating new markets and developing goodwill) and on the supply side (learning to overcome supply bottlenecks) is certainly not independent of the past scale of operation. A simple way of taking into account the irreversibility of the process is to assume that exports in period (t) cannot be smaller than exports in period ($t - 1$). The second point we express by postulating that it is the *rate* of increase rather than the absolute level of each export, that is constrained in the short run. In other words, to each export activity we attach an exogenous maximal growth factor, h_i^t, and we have:

$$(18) \qquad E_i^{t-1} \leq E_i^t \leq (1 + h_i^t)\, E_i^{t-1} \qquad (t = 1, 2, \ldots, T)$$

E_i^0 is given.

Obviously this is a highly simplified formulation of what may in fact be a much more complex phenomenon, but in our view it does catch at least a certain aspect of increasing returns or external economies

[19] To prevent confusion, whenever we mean a power rather than a superscript we shall add a dot after the power, e.g., $(1 + \alpha)^{t\cdot}$ means the brackets to the power of t.

which one often feels are there but which are difficult to quantify. By learning to export a good now, one is investing for greater future exports, and, even if technical progress is given, it takes time to reap its full benefits. Also this is one, albeit simplified, way of expressing the fact that there are "growth" industries (with high h-factors) and there are more stagnant fields of activity. These differences are not necessarily reflected only in productivity growth rates (e.g., differential changes in l_i^t over time) but may also be evident in the sheer ability to expand sales and production. As we shall see presently, this way of formulating the model has some interesting and highly plausible implications for the price structure of a dynamic trade model.

THE OBJECTIVE FUNCTION

In the static model we had the economy maximizing consumption or GNP at each point in time. Here we take the objective to be the maximization of the discounted flow of consumption over the planning horizon (with a given social discount rate, ρ) plus the imputed value of the post-terminal capital stock (K^{T+1}):

$$(19) \qquad \text{Max} \sum_{t=1}^{T} \frac{C^t}{(1+\rho)^{(t-1)}} + \frac{p_k{}^T K^{T+1}}{(1+\rho)^{(T-1)}}.$$

The maximization of discounted consumption is consistent with the procedure adopted in Ramsey-type optimal growth models. It can also be shown (by using modern control theory) that this maximand is consistent with a period by period GNP maximization, subject to the various single period constraints and choosing the right price for investment (see below). Our treatment of terminal capital is analogous to an alternative procedure often used—the assumption that the terminal *quantity* of capital is given.[20]

To sum up—formally we have a multiperiod linear programming problem which involves maximizing (19) subject to constraints (14)–(18). Again, from a formal point of view we have $[2(m+2)T+1]$ constraints[21] to determine $(4+m)T$ variables E_i^t, C^t, I^t, F^t. At first

[20] A proper choice of $p_k{}^T$ will make the two methods identical. In practice, clearly, some guesswork or successive approximation must be employed, or else we can use the steady state estimate.

[21] We have: $T(14)$, $T(15)$, $T(16)$, $(T+1)$ (17), $2mT(18) = [2(m+2)\,T+1]$ in all.

sight it seems that a numerical solution would be required to see what happens in a model like this. A closer inspection of the structure of the model and in particular its associated price system, however, reveals the general characteristics of the optimal solution. As before, we proceed by considering simple cases first and then generalizing from them. It turns out that the essence of dynamic comparative advantage in this model can be learned from inspection of a truncated version of this model in which $m = 2$, $T = 2$ and capital does not appear (at least not explicitly). This we proceed to do first.

A. The dynamic Ricardian system

We start with a simplified version of the equations in which I^t and K^t do not appear explicitly.[22] This means that we leave out constraints (15) and (16) and delete I^t from constraints (14) and (17), K^{T+1} from (19). Suppose we write down our truncated system for the case $m = 2$, $T = 2$, and consider the associated ("dual") price system.

Let us use the following notation for the *undiscounted*[23] prices:

w^t = the real wage at time t (associated with (14))

q^t = the exchange rate at time t (associated with the first part of (17))

$\bar{q}$ = the overall shadow rate of exchange (associated with the B constraint in (17))

$\bar{p}_i^t$ = the shadow price attached to the maximum bound in (18)

p_i^t = the shadow price attached to the minimum bound in (18).

As before we confine ourselves to the case in which C^t is always produced in positive amounts[24] so that the costs of production in

[22] When we say that investment and capital do not appear explicitly, we mean that they might still appear implicitly in the very special "Ricardian" form discussed in Section IIB. In that case all that is required is a modified interpretation of the various labor and import coefficients in (14) and (17) to take account of exogenously fixed growth rates of the capital stocks.

[23] The way the model is written the shadow prices for the various periods would be *discounted* prices (because the price attached to a unit of consumption in time t is $[1/(1+\rho)^{(t-1)}]$). To obtain *undiscounted* prices these have to be multiplied by the discount factor. Our notation here is for convenience related to the prices after this correction, so they are the actual (undiscounted) prices relevant to each period in time.

[24] This can be shown to depend on a minimum L^t and the coefficient matrix. These conditions are met in our empirical investigation [6].

consumer goods will always add up to one. In the 2 × 2 case we obtain the following equations.

For the *first period* ($t = 1$):

(20.1) Equation for C^1: $l_0{}^1 w^1 + m_0{}^1 q^1 = 1$

(20.2) Equation for $E_1{}^1$: $l_1{}^1 w^1 - v_1{}^1 q^1 + \bar{p}_1{}^1 - \underline{p}_1{}^1$

$$-\left[\frac{1 + h_1{}^2}{1 + \rho}\right]\bar{p}_1{}^2 + \frac{1}{1 + \rho}\underline{p}_1{}^2 = 0$$

(20.3) Equation for $E_2{}^1$: $l_2{}^1 w^1 - v_2{}^1 q^1 + \bar{p}_2{}^1 - \underline{p}_2{}^1$

$$-\left[\frac{1 + h_2{}^2}{1 + \rho}\right]\bar{p}_2{}^2 + \frac{1}{1 + \rho}\underline{p}_2{}^2 = 0$$

(20.4) Equation for F^1: $-q^1 + \bar{q} = 0$

For the *second period* ($t = 2$)

(21.1) Equation for C^2: $l_0{}^2 w^2 + m_0{}^2 q^2 = 1$

(21.2) Equation for $E_1{}^2$: $l_1{}^2 w^2 - v_1{}^2 q^2 + \bar{p}_1{}^2 - \underline{p}_1{}^2 = 0$

(21.3) Equation for $E_2{}^2$: $l_2{}^2 w^2 - v_2{}^2 q^2 + \bar{p}_2{}^2 - \underline{p}_2{}^2 = 0$

(21.4) Equation for F^2: $-\dfrac{q^2}{1 + \rho} + \dfrac{\bar{q}}{1 + \alpha} = 0$

On the basis of a priori reasoning we may assume that (20) and (21) can properly be written as equations, i.e., *exactly* satisfied. We can further assume (cf., also footnote 5) that for each i and t either $\bar{p}$ or $\underline{p}$ will be zero and for *one* of them *both* $\bar{p}$ and $\underline{p}$ will be zero ("just" profitability). This leaves us with eight equations to determine eight variables. We shall presently see how we can determine which variables to equate to zero and thus establish the relevant rule of comparative advantage for this case. Before we do that, however, there is one simple rule that follows from inspection of the equations for F^1 (20.4) and F^2 (21.4).

$$q^1 = q$$

(22) $$q^2 = \bar{q}\left[\frac{1 + \rho}{1 + \alpha}\right] = q^1(1 + r), \text{ say}$$

where we have approximately: $r = \rho - \alpha$

This expresses a simple and intuitively plausible rule for the intertemporal relationships of the forward foreign exchange rates which is completely analogous to corresponding rules in other fields of capital theory: The own rate of return in the use of real balances of foreign exchange must approximately (and in the continuous case, exactly) equal the difference between the own rate on consumption goods (i.e. the social rate of discount) and the rate of intertemporal borrowing or lending of foreign exchange.[25]

In the general case ($T > 2$) we get, by induction,

$$q^{t+1} = q^t(1 + r) = q^1(1 + r)^t.$$

If the social internal rate of return is $\rho = 10$ per cent, say, and the rate of interest on intertemporal borrowing $\alpha = 6$ per cent, arbitrage or proper planning must see to it that the real rate of exchange in relation to the domestic (consumer goods) price level will grow at approximately 4 per cent per annum. In the case of Israel, for example, there is empirical evidence that, at least in the 1950–60 decade, some such increase had in fact taken place. The empirical fact (without theoretical explanation) has been established by Michaely [11]. In the context of our model, a positive r implies that it pays to borrow foreign exchange now and return debts later providing, of course, that such foreign exchange can be productively used, or alternatively, that the productivity growth in exports makes such deferment profitable.[26] The special formulation of our trade constraints reduces our ability to postpone abrupt export expansion, a point to which we shall return later. Thus, the productivity argument and the existence of a limiting primary factor also see to it that we do not go to excesses in borrowing at the expense of the future.

It should be clear from the structure of the model that one could introduce more complicated assumptions about increasing marginal costs of foreign borrowing (i.e., increasing α), or decreasing marginal utility of consumption (making for an effectively falling ρ), thus retaining the intertemporal relations between the q^t's but making them variable.

[25] A more detailed analysis of this relationship, in particular when there are varying borrowing rates, has been undertaken by M. Fraenkel [8].

[26] A positive r (in other words, q^t growing over time) also means that with time as F^t being decreased (to keep a total B constant), the economy has to go into less and less productive export industries.

Alternatively, one could take an extreme view that the various F^{t}'s are exogenously and independently given so that no intertemporal borrowing or lending is possible and q^t becomes independent (closer to a static model).[27] Here we confine ourselves to the present simple but plausible case.

Let us now turn to our main subject—the pattern of choice of foreign trade activities. It will make things easier if we start by hypothesizing a specific optimal solution and then go on from there to find the conditions under which it will be valid. Consider the following specific choice of activities in the "optimal base": We produce (fully) both exports in period 2, i.e., E_1^2 and E_2^2 are at their relative maxima. In period 1, E_1^1 is just profitable and E_2^1 is not produced beyond its minimum bound. In terms of the p-variables in equations (20) and (21) this implies:

$$\bar{p}_1^1 = \underline{p}_1^1 = \underline{p}_1^2 = \bar{p}_2^1 = \underline{p}_2^2 = 0; \underline{p}_2^1 > 0, \bar{p}_2^2 > 0, \bar{p}_1^2 > 0.$$

Substituting from (20.1) into (20.2), we obtain an equation involving only q^1 and $\bar{p}_1^2$. Similarly, using (22) and substituting from (21.1) into (21.2) we obtain another equation involving only the same two variables. From both these resulting equations we extract $\bar{p}_1^2$ and obtain an expression for the shadow rate, $\bar{q} = q^1$, which we shall also denote by Q_1^1:

$$(23) \quad Q_1^1 = q^1 = \bar{q} = \frac{\dfrac{l_1^1}{l_0^1} + \left[\dfrac{1 + h_1^2}{1 + \rho}\right]\dfrac{l_1^2}{l_0^2}}{\dfrac{l_1^1}{l_0^1}\left[m_0^1 + \dfrac{v_1^1}{l_1^1}\, l_0^1\right] + \left[\dfrac{1 + h_1^2}{1 + \rho}\right]\dfrac{l_1^2}{l_0^2}\left[(1 + r)\left(m_0^2 + \dfrac{v_1^2}{l_1^2}\, l_0^2\right)\right]}$$

Alternatively this can be inverted and written in the form:

$$(23.1) \qquad \frac{1}{Q_1^1} = \frac{1}{a_1^1 + a_1^2}\left(a_1^1 \cdot \frac{1}{R_1^1} + a_1^2 \cdot \frac{1}{R_1^2}\right)$$

and, in the general case, we shall define (for a good i that is just profitable at time t_o and intramarginal in all subsequent periods):

[27] In our empirical study [6], some such formulations have been experimented with.

$$\frac{1}{Q_i^{t_0}} = \left(\sum_{t=t_0}^{T} a_i^t\right)^{-1} \cdot \sum_{t=t_0}^{T} \left(a_i^t \frac{1}{R_i^t}\right) \tag{23.2}$$

$$\text{where } \frac{1}{R_i^t} = (1+r)^{(t-1)} \cdot \left[m_0^t + \frac{v_i^t}{l_i^t} l_0^t\right]$$

$$\text{and } a_i^t = \frac{l_i^t}{l_0^t}(1+\rho)^{(1-t)} \cdot H_i^t \text{ with } H_i^t = \prod_{n=t_0+1}^{n=t} (1+h_i^n)$$

$$(\text{and } H_i^{t_0} = 1)$$

In our present special example we have: $i = 1,\ t_0 = 1,\ T = 2$. We see that the reciprocal of the shadow rate [28] is a *weighted average* of the reciprocals of the expressions R_i^t (in the special example these are R_1^1 and R_1^2). As one can immediately discover from our discussion in Section II (6), the latter are the *static* exchange costs for the various periods (evaluated per today's unit of foreign exchange). The weights a_i^t are the ratios of the labor unit input in the trade goods divided by the labor unit input in consumption expanded at the cumulated growth factor h, and divided by the relevant rate of discount factor (ρ). These weights may grow with t or fall, depending on the direction of change of l_i^t/l_o^t over the planning periods (t) and the sign of $(h_i^t - \rho)$ (more on this below).

Now the individual R_i^t's might again in principle rise or fall with t. R_i^t will fall with t providing $(m_0 + \frac{V_i}{l_i} l_0)$ has a rate of change (over different periods t) that is less than r. In our empirical application this happens to be the case,[29] and we therefore assume $R_1^2 < R_1^1$. If we look at (23.1) and remember that the weights a are positive, it follows that Q must lie between the two R's, i.e.,

$$R_1^1 > Q_1^1 > R_1^2 \tag{24.1}$$

In the more general case if R_i^t falls over time one can similarly show that we have $R_i^{t_0} < Q_i^{t_0} < R_i^T$. In the general case it will also

[28] The reciprocal of the shadow rate is in the nature of the marginal productivity of foreign exchange in terms of domestic resources.
[29] More on this is found in footnote 37.

follow that $Q_i^{t_0} > Q_i^{t_0+1}$,[30] for any t_0 between 1 and T, a fact of which we shall make use below. So we can write:

$$R_i^{t_0} > Q_i^{t_0} > Q_i^{t_0+1} > \ldots > R_i^T \qquad (t_0 = 1, 2, \ldots, T-1) \tag{24.2}$$

Returning to our specific example and (24.1), it follows from the latter that if E_1 is just profitable in the first period it must be intramarginal in the second period and will certainly be produced then, which is exactly what we have assumed in this specific solution. That (24.1) is a necessary condition for this to hold also follows from spelling out the conditions under which $\bar{p}_1^2 > 0$ (using (20) and (21)). Similarly $\bar{p}_2^2 > 0$ implies that we must have $Q_1^1 > R_2^2$ and finally $p_2^1 > 0$ implies $Q_1^1 < Q_2^1$. Now Q_2^1 would be the shadow rate if E_2 would be just profitable in period 1 and E_2 not. Further, we see from (23.2) that $Q_i^2 = R_i^2$ $(i = 1, 2)$, and in general $Q_i^T = R_i^T$.[31] All of this justifies calling the term Q_i^t the *dynamic exchange cost,* since it provides the dynamic analogue of the exchange cost concept, i.e., the measure of *dynamic comparative advantage* ranking.

What this measure means is: If we perform the experiment of changing the quantity B in (17), leaving all other exogenous parameters fixed, we shall get a series of optimal solutions for our dynamic model. The choice of export activities in the optimal solutions will follow the order of the various Q_i^t's $(i = 1, 2, \ldots, m;\ t = 1, 2, \ldots, T)$.[32] Suppose we fix a certain level for B and obtain a shadow exchange rate $\bar{q}$ at which $\bar{q} = Q_i^t$ for some i and t. This implies that the export activity E_i is just profitable at time t. But not only that, it also means that the process of its expansion is *started* at time t and that it will be produced to the full amount (i.e., at the maximal growth rate based on its level at time t) in all *subsequent* planning periods up to T. All E_i^t for which $Q_i^t < \bar{q}$ will remain at their minimum bounds, and those for which the inequality is reversed will be at their relative maximum.[33] When we say that an export activity is just profitable here, we

[30] This will usually hold if $h_i^{t_0} > \rho$.

[31] I.e., in the last period the shadow rate coincides with the static exchange cost (providing, of course, R_i^t falls with t).

[32] Strictly speaking, we should use t_0 as a running index here instead of t, but we hope this will cause no confusion.

[33] Counter to the static model, maxima here will usually be *relative.* An *absolute* maximum is achieved only when an export is fully produced from the *first* period.

ought to say that it is profitable in the *dynamic* sense. The importance of distinguishing between profitability in a static and a dynamic sense can be illustrated if we return to our 2×2 example. When E_1^1 is just profitable we have $\bar{q} = q^1 = Q_1^1 < R_1^1$. This clearly shows that producers or planners acting on the basis of static profitability considerations of the kind discussed in Section II would opt *against* the production of E_1. This can also be seen directly by looking at (20.2):

$$l_1^1 w^1 - v_1^1 q^1 = \frac{1 + h_1^2}{1 + \rho} \bar{p}_1^2 > 0$$

i.e., marginal (static) cost is higher than marginal (static) revenue, and yet in a dynamic sense it pays to *expand* production. The economic reason here is the existence of external benefits which accrue only in the future. The externality consists in the ability to expand future exports, which can be achieved only by undertaking present-day export efforts. Clearly this follows only because of our specific choice of maximal export constraint. For suppose we were to postulate that it is the absolute level of exports that is exogenously bounded. In terms of our 2×2 example this would amount to letting a_1^2 approach zero. From (23.1) we would then get $Q_1^1 = R_1^1$ and we would be back to a static world.[34]

The main point we would like to make is the following: in the static Ricardian model we saw that one could unambiguously rank activities by factor productivity alone. In a dynamic world this is no longer possible. Ranking involves both goods and time [35] and there is no reason to suppose that goods could still be ranked independently of time.[36] Our measure now incorporates technical coefficients of various periods, "growth" factors, and the discount rates.

Before we turn to the more general model with capital let us go back to look at the various factors determining Q in the present model. The general term a_i^t/R_i^t appearing in the expression (23.2) can also be written in the form (remembering that $(1 + \alpha)\ (1 + r) = 1 + \rho$):

$$(25) \qquad \frac{a_i^t}{R_i^t} = H_i^t (1 + \alpha)^{-(t-1)} \cdot \left(\frac{l_i^t}{l_0^t} m_0^t + v_i^t\right)$$

[34] The other extreme would be to assume that there is no maximum bound at all, in which case we obtain $a_1^2 \to \infty$ and we get $Q_1^1 \to R_1^2$, i.e., it is only the future performance that matters.

[35] Commodity x at a *different* time being a different commodity.

[36] In Section V we give empirical illustration of this fact.

Consider the rate of change of this term over the different planning period t. This approximately equals the sum of the rates of change of the individual components of (25). Calculating these we obtain that the rate of change equals approximately $h_i - \alpha - \beta_i d_i$, where β_i denotes the difference between the rate of change of labor productivity in the ith export industry and in the consumption good (i.e., rate of change of l_0/l_i) and $d_i = 1/(1 + v_i l_0/l_i m_0) < 1$. Even for h values that are not very large, this expression is most likely to be positive.[37] When it is positive this means that a_i/R_i rises over time (and not only $1/R_i$) which throws some additional light on the relative importance of the various components of $1/Q_i$ in (23.2).

We now turn back to the more general model in which capital is included as a separate factor of production. This complicates the expressions somewhat but, as we shall see, does not change the findings in any essential way.

B. The model with explicit capital

Consider the full model (14) to (19) with capital as an endogenous factor. This now turns out to complicate matters only slightly, for we can make use of some known properties of capital models and the static analysis of Section II to write down the solution for this case. We shall not go through the arduous details of the analysis but consider the main results.

An analysis of the dual price system associated with constraints (14) to (19), or recourse to known results from capital theory, reveal the following intertemporal relation involving the prices and rentals of the capital good:

$$p_k^{t}(1 + \rho) - s^{t+1} - p_k^{t+1}(1 - \mu) = 0 \qquad (t = 1, 2, \ldots, T - 1) \tag{26}$$

[37] In our empirical illustrations (for example Section V), h_i is of the order of at least 10 per cent, α is 6 per cent and β_i is not likely to be above 2–3 per cent, say (it can of course also be negative). On a priori grounds one could argue that the first (h_i) and the last (β_i) element in this expression are not entirely independent, as a high growth factor might be expected to appear together with a high relative productivity growth rate. In any case this must be a subject for empirical investigation in each case.

or: $$\frac{p_k^{t+1} - p_k^t}{p_k^t} = \frac{1}{1-\mu}\left(\rho + \mu - \frac{s^{t+1}}{p_k^t}\right)$$

where[38] $$p_k^t = l_k^t w^t + k_k^t s^t + m_k^t q^t$$

and p_k^t is given (see 19)). This establishes a recursive relation for p_k^t and s^t, going backward from the last period T.

For each period we now obtain a set of price relations like the triple set (4c), (5c), and (10) in Section IIC, with the relevant p variables added as in (20) and (21). Going backward, for period T, in which p_k^T is given, we get the same triple set determining among other prices s^T. We then have the recursive relation (26) determining p_k^{T-1}. We now go to period $(T-1)$ and so on backward in a series of triple price equation sets in each of which p_k^t can be treated as if given.[39]

What we have to do now is to write down the modified solution for the case in which capital appears, using what we already know about the modifications required in the static model when passing from the Ricardian to the more general capital model. If we do this, following the same kind of steps as in the Ricardian model, we obtain an expression for dynamic comparative advantage, $O_i^{t_0}$, which is analogous to (23.2). The R_i^t's are the ones relevant to the static capital model (see (6c)) involving both the capital intensities (x_i) and labor productivities (y_i) and a_i^t are generalized weights:

(27) $$\frac{1}{Q_i^{t_0}} = \left(\sum_{t=t_0}^{T} a_i^t\right)^{-1} \cdot \sum_{t=t_0}^{T}\left(a_i^t \cdot \frac{1}{R_i^t}\right)$$

where $R_i^t = (1+r)^{(t-1)} \cdot$

$\times$ (R_i of (6c) evaluated at time t)

and $$a_i^t = H_i^t(1+\rho)^{(1-t)} \cdot \left(\frac{l_i^t}{l_0^t}\right)\left[\frac{(k_k - k_0 p_k) - x_i(l_k - l_0 p_k)}{k_k - l_k k_0/l_0}\right]^t$$

(H_i^t defined as in (23.2))

[38] We are only considering the case in which investment is produced at all times, and we obtain (26) by looking along the column-vectors I^t and I^{t+1} (multiplied by $(1-\mu)$) and then subtracting the two expressions.

[39] As is known from optimal growth theory, a Ramsey model of this kind is, in fact, equivalent to a series of single period GNP maximizations plus the system of dynamic relations combining the p_k's and p's and q's of the various periods.

Next, as in the previous case, we write out the expression for the general term a/R and obtain, after some manipulation:

(28)

$$\frac{a_i^t}{R_i^t} = H_i^t (1 + \alpha)^{-(t-1)} \cdot \left[\frac{l_i}{l_0} \frac{\left(k_0 \frac{m_k}{l_k} - m_0 \frac{k_k}{l_k}\right)}{\left(\frac{k_0}{l_0} - \frac{k_k}{l_k}\right)} + k_i \frac{\left(\frac{m_0}{l_0} - \frac{m_k}{l_k}\right)}{\left(\frac{k_0}{l_0} - \frac{k_k}{l_k}\right)} + v_i \right]^t$$

First of all, we check and find that in the special case $k_i = k_0 = 0$ all the expressions in (27) and (28) become identical with the ones found in (23.2) and (25). Next let us specifically compare (28) with (25) to see what we can say about the expected change in a/R over time in the more general case. Consider the empirically reasonable case in which the m and k coefficients are more or less constant over time and labor productivity in the consumption and investment goods rises at an approximately even pace (i.e., l_0 and l_k fall together). In that case the expression in square brackets can be written formally as $((l_i^t/l_0^t)b_1 + b_2)$ where b_1 and b_2 are constants.[40] If we now compare (28) with (25), we can also apply all the previous arguments about the rate of change of a/R in this case, and the previous conclusions (including the one about the decrease of R_i^t over time) also remain valid for the case in which capital appears explicitly.

We have thus found that the main characteristics of dynamic comparative advantage determination in the model are not markedly different in the more general model. Ranking involves both commodities and time. Dynamic exchange costs are a weighted average of static exchange costs (or rather the reciprocals thereof are), in which the "growth" factors also enter. Finally we still have a rule of ranking that can be applied without having to measure factor rentals.[41]

[40] Constant capital coefficients is an assumption that is often made and also usually makes good empirical sense. As for the constancy of foreign exchange coefficients m_0 and m_k (and indirectly also m_i through the "net" definition of v_i), we have to remember that in the way we have constructed our (static) model import substitution can appear separately in the form of "trade" goods. Constancy of m does not have to imply lack of import substitution. This was not carried over in the dynamic discussion but can easily be done (and was in fact incorporated in our empirical analysis [6]). However, let us note that we do not need such extreme constancy assumptions to get the stated result.

[41] Providing, of course, we know that these rentals are positive.

This dynamic model can be extended in various ways without bringing about any drastic change in these general findings. First, we could introduce a number of heterogeneous capital goods instead of one. This would involve us with more than one capital intensity (and price p_k) appearing in the various expressions but would otherwise leave the essence of the model the same. Also, there is no need to make the assumption that there is a one-to-one correspondence between activities and export goods.[42] One can allow choice of a number of activities per commodity, leaving the rate of growth constraint as applying to commodities, rather than to the component activities. In that case, the Q-formula remains the criterion of choice, as before, except that the individual coefficient entries in each time period may run over a number of alternative sets of data.

As in the static case, the introduction of another nonreproducible primary factor of production does not present any practical difficulty, but one cannot in that case give the explicit single activity-time formulae which characterized all the other cases that were discussed here.

FURTHER CONSIDERATIONS—LABOR TRAINING EFFECTS

Clearly one could think of further complications and additional dynamic aspects of trade and development which we have not analyzed here. We have confined our discussion to a case in which the solution of the model can be given more or less explicitly without having to solve a complete numerical model. Also, using a linear framework has considerable appeal from a practical point of view but might pose some limitations from the analytical point of view.[43] Of the possible further refinements we shall briefly discuss one form of externality which is relevant to dynamic trade theory and can be incorporated in our linear model—labor training effects.

From the preceding analysis it should be clear that we could without difficulty introduce human capital and investment in education into the model, by treating human capital of one or more kinds like other capital

[42] As already mentioned, there is no problem of adding import substitutes to the model; in that case, one applies the same formulation as in the static case.

[43] For example, the strict, textbook type of increasing returns production function cannot be incorporated in a simple linear-programming framework. However, the burden of much of our discussion here is to show that certain aspects of increasing returns and external effects can be usefully explored within the confines of a linear model.

goods. Suppose, however, there is some specific form of skill (management, say) which can only be acquired through experience in production itself. We would then introduce another separate skilled labor input in the economy and let certain activities in the economy produce as a by-product, and at a time lag, trained labor.[44] Suppose this is the case with certain trade activities. Put formally, in the context of our model, we would introduce another primary factor as in Section IID (11). But now, instead of having an activity only described in terms of a foreign exchange output (v_i) and a list of inputs (l_i, k_i, g_i) all dated at time t, we now assume that it has an additional output at time $(t + n)$, say, which consists of λ_i units of trained labor $(-\lambda_i^{t+n} < l_i^t)$. $\lambda_i E_i^t$ units of trained labor will appear as an output (or negative input) in the skilled labor constraints of period $(t + n)$. Correspondingly we will get, in the price equation corresponding to the ith export good, an additional benefit (or negative cost) element $\lambda_i z^{n+t}$ (where z is the shadow wage of trained labor).[45] Although one can no longer give a simple price-free formula for dynamic comparative advantage ranking (Q) in this general model, it can be seen that optimization may, in this case as in the previous dynamic model, point to a choice of activities which might in the short run look unprofitable. This is after all what the infant-industry argument is all about. Unlike the previous case, however, this type of refinement seems a more difficult one to fill with empirical content. Our present empirical illustration, at least, will be given without this extra refinement.

V. *EMPIRICAL ILLUSTRATIONS OF THE DYNAMIC MODEL*

In the present section we give a short description of a trial application of the dynamic model to data based on the Israeli economy. A fuller

[44] The micro aspects of this type of on-the-job training have been analyzed by Gary Becker [2]. In the context of development this phenomenon has been used by Hirschman [9] as an argument for promoting capital-intensive lines of production because of the labor training externalities involved (it is not a priori clear, however, why they have to be capital intensive). Finally Arrow's [1] "learning by doing" is not exactly the same thing but is a close relative.

[45] In an unpublished study a few years ago, I analyzed the optimal growth process in a linear model where such training effects occur as a by-product of the production of certain consumption goods, and growth is obtained by gradually switching from unskilled export goods to more productive, high-skill, export production. That model was simple enough to allow for full analytical solution.

description of the actual model and of solutions has been given elsewhere.[46]

The model is structured more or less according to the system described in the previous section with a few modifications. It includes one composite consumption good, three capital goods, and thirty trade activities (four import substitutes and twenty-six export activities), and there are two primary labor constraints—total and "skilled" labor. The model is formulated for six future planning years, spaced at two and one-half year intervals ranging from 1967/68 to 1980.

The first experiment is one in which we maximize an objective function like (19) ($T = 6$) subject to a set of constraints like (14) to (18), modified as above, but assuming for the moment that the skilled labor supply is adjusted automatically.[47] In this case only the total labor supply provides an effective constraint on long-run growth. Maximization is repeated for a wide range of change of B, the supply of foreign exchange transfers. Following the discussion of Section IV, we allow interperiod borrowing of foreign exchange so that the actual import gap at each point in time becomes an endogenous variable and part of the optimization process itself. The resulting optimal time pattern of foreign borrowing is in itself an interesting subject of discussion [6]. Here, however, we confine ourselves to the trade aspects.

Table 2A summarizes the order of profitability (i.e., dynamic comparative advantage) as defined in the previous discussion. The ranking is the over-all ordering of activities and expansion times. As seen in Table 2B, it starts from number 1 at the most abundant foreign exchange endowment (equivalent to an annual F-flow of $1,917 million and a shadow rate of 1.86 IL/$) and ends with number 124 at an almost zero endowment (annual equivalent flow of $18 million and a shadow rate of 5.15 IL/$, at 1962 prices).[48]

[46] See joint paper with Dougherty and Fraenkel [6].

[47] In the Israeli context this would imply adjustment through the composition of immigration. In general, a more realistic approach would be to bring in the educational system.

[48] For reference purposes one could consider an average expected F-level of $400 million to be a reasonable guess for the future. This would point (see Table 2B) to a shadow rate of 4.20 (at 1962 prices), which amounts to about 5 IL/$ at 1968 prices. The official market rate now is 3.50, but with export premiums and other subsidies it amounts to an effective rate of about 4.25 IL/$ on most exports, with a somewhat higher rate for some "progress" industries (the effective protective rate on imports is much higher and runs to about 6–7 IL/$—see [11]).

TABLE 2A

Trade Activities and Expansion Times
(ranked by order of profitability)

Trade Activities	Period 1967/68[a]	1970	1972/73	1975	1977/78	1980
Export Increments						
Livestock	69	58	40	35	28	19
Citrus	83	75	61	46	36	32
Mining	21	14	8	4	1	–
Food products	92	87	82	79	71	68
Textiles	101	98	95	91	89	94
Wood products	110	105	100	96	93	97
Paper and printing	77	70	65	59	52	54
Rubber and plastics	33	30	26	22	16	15
Chemicals	–	123	121	116	109	118
Fuel	25	20	11	7	5	2
Diamond polishing	74	66	57	48	43	47
Basic metals	62	55	45	37	34	31
Metal products	29	27	23	17	13	10
Machinery	63	60	51	44	39	38
Household equipment	67	64	56	49	42	41
Vehicles	86	84	80	78	72	76
Shipping and aviation	120	117	113	106	102	111
Other transport	115	107	99	90	85	81
Services	24	18	12	9	6	3
Import Substitutes						
Livestock	–	–	–	124	108	112
Chemicals	–	–	–	122	104	114
Machinery	119	103	88	73	50	53

Source: Table is based on Table 2, Bruno, Dougherty and Frankel [6].

[a]The model is formulated for six future planning years, spaced at two-and-one-half-year intervals from 1967/68 to 1980.

TABLE 2B

Activity Ranks and Associated Shadow Rates of Exchange

Annual Equivalent of Foreign Aid ($ million)	Ordinal Number Ranking	Period	Shadow Rate of Exchange (I£/$ at 1962 prices)
1,917	1	1977/78	1.86
1,777	10	1980	2.36
1,100	28	1977/78	2.61
997	40	1972/73	3.03
980	50	1977/78	3.14
947	59	1975	3.22
817	71	1977/78	3.43
741	76	1980	3.49
654	86	1967/68	3.83
400	98	1970	4.20
115	114	1980	4.59
18	124	1975	5.15

Source: See Table 2A.

Table 2A conforms to the rule that $Q_i^t > Q_i^{t+1}$ (see Section IV (24.2)). There are a few exceptions in the last period.[49] The table also illustrates our general point that activities and time periods are intermixed in the ranking, and we cannot say that one activity is more profitable than another unless we attach a time subscript to it.[50]

[49] These exceptions come from an aberration in the present solution of the model for the last period. A trial value of unity has been chosen for p_k^T in the objective function (19). This apparently is too high because it abruptly forces construction activity up and consumption down to zero in the last period (in previous periods consumption rises smoothly, as would be expected). Apart from being unrealistic it also violates one of the conditions underlying the analysis in Section IV (namely positive C throughout).

[50] One might note, however, that *within* periods the sector ranking turns out to be quite similar. This comes from the fact that at our level of aggregation the sector differences in productivity change and in "growth" factors are not sufficiently marked to make for considerable variation in this respect. This is consistent with a similar finding for the static model [5] but only so as long as variations in the labor skill constraint are not introduced.

VARIATIONS IN THE SKILL CONTENT OF LABOR

In the first experiment we assumed that no constraint was imposed by labor skills. To see the effect on comparative advantage of relaxing this assumption, we perform the following experiment: We let the foreign exchange endowment be fixed at the equivalent of an *average* discounted annual flow of $400 million. Now we gradually change the share of skilled labor in the total labor supply of all periods from "relatively abundant" (zero price of "skill") to a time pattern consistent with the "naive" forecast of no change in the skill composition of labor. The final state is one in which skilled labor is highly scarce and the basic shadow wage for nonskilled is zero. In this process the optimal trade pattern will change with the variation in the skill composition and will indicate the role of human capital in the analysis of comparative advantage.

The results are recorded in Table 3. All cells enclosed to the right of the *thick* line are occupied by activities which at the $400 million foreign exchange level were profitable in the previous experiment (i.e., all activities numbered 1 to 98 in Table 2B). Now, with the gradual reduction in the supply of skill, new trade activities come in ("+" sign in Table 3), and existing ones go out ("−" sign in Table 3). The order at which they enter and exit is given by the ordinal number in the various cells. In the final state all cells enclosed to the right of the *dotted* line are occupied by activities that are profitable in the scarce-skill situation, given the $400 million foreign exchange endowment.

We note that textiles, wood products, vehicles, and diamond polishing are partially or wholly removed from the optimal trade bundle. For the first three industries this more or less conforms to one's intuitive judgment of the Israeli export industries. These industries enjoy a highly protected domestic market and a relatively high effective exchange rate. "Correct" pricing of their use of skills places them, at least partially, lower down in the list. For diamond polishing this seems intuitively wrong and the explanation here (as in the static analysis [5]) comes from the fact that we have aggregated diamond polishers, who on the whole are semiskilled and have a short training period, with highly skilled labor, which is really scarce.

It is also worth noting that there are several cases in Table 3 in which activities switch in and out several times in the course of the

TABLE 3

The Effect on Trade of Varying Skill Composition of Labor

Trade Activity	Period 1967/68[a]	1970	1972/73	1975	1977/78	1980
Export Increments						
Livestock						
Citrus						
Mining						
Food products	15+	24-				
Textiles	18-	26+ 32-				25-
Wood products				2 - 13+ 19-	4 - 6 + 23-	22-
Paper and printing						
Rubber and plastics						
Chemicals						
Fuel						
Diamond polishing	12-	11-	31-	35-	34-	27-
Basic metals						
Metal products						
Machinery						
Household equipment						
Vehicles	20-	30-	33-			28-
Shipping and aviation						
Other transport	10+	7 +	1 +			
Services						
Import Substitutes						
Livestock				3+		21+
Chemicals				14+/18- 26+/30-		
Machinery						

Note: + denotes entry of activity; - denotes exit; number denotes order of entry or exit.

[a]The model is formulated for six future planning years, spaced at two-and-one-half year intervals from 1967/68 to 1980.

analysis. This is consistent with our assertion that in the case of two primary factors one cannot rank activity-time cells independently of relative factor supplies.

This analysis of labor skill variation is, of course, only a very rough indicator of the importance of introducing the quality of the labor force. One additional calculation that could be performed with the present model is to make an actual forecast of the supply of skilled labor, taking into account the expected increased output of the educational system, and then repeat the experiment of changing the supply of foreign exchange (as in Table 2B). Better still would be to give a finer breakdown of the labor force and to explicitly introduce the educational system into the planning model (as for other physical capital goods).[51]

Finally, for an indication of the past change in the quality of labor input in Israeli exports,[52] let us disaggregate the labor force in input-output calculations into four main categories (see below) and compute the change in the direct and indirect labor input in the export of manufactures (excluding diamonds) from 1958 to 1965, using base-year input coefficients and taking into account *only* the change in *composition* of exports. The following figures result:

Ratio of Direct Plus Indirect Man-Year Input, 1965 Over 1958 *

Total labor (unweighted):		2.36
unskilled	(5.1)	2.33
semiskilled	(9.7)	2.35
skilled	(11.7)	2.37
academic and technical	(14.7)	2.53

* Figures in parentheses refer to approximate training period in years.

We see that there has been a small but consistent shift toward the use of higher grades of skilled labor in manufacturing exports. One should stress that this calculation has been performed without taking into account the actual increase in the skill content *within* individual

[51] One would introduce a submodel of the educational system of the kind presented by Bowles [4].

[52] I am indebted to M. Hershkovits of the Bank of Israel for performing this computation at my request (this is a by-product of a study that he is presently conducting).

industries. With the upgrading of the labor force during this period, such change had no doubt taken place. This would only strengthen the above finding.

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COMMENTS

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The topic of this session might be, "The Ranking of Economic Models for Analysis of Dynamic Comparative Advantage." Unfortunately, the competition is limited; only one model is available. Were competing models available, the immediate question is the criteria that might be used for ranking.

The difficulty of predicting how dynamic comparative advantage changes is illustrated by the paper in this volume of Professors Ruttan, Houck, and Evenson on the richness and variety of the process of transfer of agricultural technology. Domestic developments in the packaging of bananas, in disease resistant varieties, in the ability to use seeds and techniques developed elsewhere, change comparative advantage; similar developments abroad affect domestic comparative advantage. The implication of this experience is that predicting how world prices may change may be more important than predicting how supply functions may change.

One of the major criteria applicable to a model like Bruno's is usefulness—the test is whether the model facilitates better decisions. In other activities the feedback from a decision is rapid: firms fail, and coaches lose ball games and get sacked. With long-term planning models, the feedback is not nearly as quick. The investment errors of this generation of planners may only become evident to their successors. Economists developing models are also concerned with their usefulness—they want the models to be computational. The question is whether a model which is operational is necessarily better than none.

Professor Bruno's paper on dynamic comparative advantage does an elegant job of highlighting some of the issues in development policy. No term has been invoked more often to explain away the errors of planning and trade policy than *dynamic comparative advantage:* today's errors are defended as tomorrow's bonanzas. A model is desirable to provide a basis for analyzing where the investments should be placed as comparative advantage changes through time. To Professor Bruno, comparative advantage is defined as the set of activities which keeps the set of existing factors employed. A country either has or does not have comparative advantage in a product; it cannot have a comparative advantage for a certain level of output. This is because supply functions are linear—average costs and marginal costs are the same. Changes in comparative advantage involve changes in the mix of industries. In the Bruno model, comparative advantage changes through time in response to changes in external assistance; he demonstrates the interdependence among such assistance, the exchange rates, and the set of productive activities in which a country will have a comparative advantage. The model recognizes that changes in external assistance alter the trade deficit, hence the need to produce exports and substitutes for imports. To satisfy these needs requires a certain configuration of factors. Such changes, therefore, alter the relative supplies of factors available to produce a different set of domestic products and exports. If some industries are more fully subject to labor training skills or export externalities than others, the investment priorities are clearly affected. The model can be used to answer questions about trade-offs between aid level and the exchange rate, between interest rates and the level of foreign borrowing, and the labor training skills or export externalities required if a particular industry is to have comparative advantage at some future date. The model is dynamic in several senses—on its view of intertemporal borrowing and the relationship in a given period among production levels, export externalities, and labor training. The dynamic component in the model involves changes in external assistance and externalities in exports or labor training skills; in their absence, the dynamic element drops out.

To ask whether such a model is useful is to ask whether it facilitates the investment decisions. Since the logic can be assumed to be impeccable, attention should be given to the explicit and implicit assumptions. The model provides a useful way to organize some information not readily available. The limitation of the model is that certain aspects of dynamic comparative advantage—changes in relative prices due to changes in factor endowments, demands, or technologies—are ignored, even though their impact on dynamic comparative advantage may be greater than those of the export externalities. In a conference on trade and technology, the model seems barren in its treatment of technological change.

As the exchange rate changes, certain industries drop out of the domestic comparative advantage set, and others drop into this set. The reason is that the comparative advantage set is determined largely by average labor productivity. Given its stock of capital, labor, and the available technologies, this approach looks at the industry mix which keeps all domestic factors fully employed. If foreign aid to Israel should rise to $2 billion a year, the model suggests there is only one profitable export activity; as the aid level declines, the number of such industries increases. For Bruno, the question is which activities comprise the comparative advantage set; in the real world, the question is how much of each activity. This difference reflects that Bruno's model assumes linear production functions, even though his data shows substantial differences between average and marginal productivity. Perhaps one might decompose various productive activities into a number of tranches, with each tranche a different activity—thus the first million-dollar increment of mining is one activity, the second million-dollar increment is another, and so on. But while this approach might seem helpful for conceptual purposes, it may not be operational. The data for one industry may not be sliced into tranches in this way—the need for the model to be operational and computational is overriding. A suggestion of this approach is implicit in Bruno's data on marginal labor productivity. Ideally, one would like such data for each of the relevant tranches.

Perhaps an approach based on a portfolio balance model might be useful for meeting the problem of dynamic comparative advantage. Such a model would be superior to that of Professor Bruno's in some respects and inferior in others. The portfolio balance model would be no better at predicting changes in relative prices, technologies, and export externalities—attempts to predict change on any basis probably depend more on comparative or cross-sectional analysis. The portfolio balance model would be superior to Bruno's with regard to the intertemporal aspects of development policy, including the choice between adjustment through changes in reserves and adjustment through changes in the comparative advantage set. The portfolio balance model would be superior with regard to assigning probabilities and payoffs to alternative views of the future; the planning minister might offer his president the choice of *n*-development strategies. The portfolio balance model would be inferior in its capacity to identify efficient solutions to the static comparative advantage set—that is, to determine the industrial structures which, given the technology, the trade balance, and the capital stock, would result in full employment of domestic labor. And in the near-term at least, and perhaps forever, the Bruno model has a computational advantage.

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Technological change is, itself, one of the major growth industries in the economics profession. In the last ten or twelve years, beginning with the work of Solow and Abramowitz, growing concern with the impact and consequences of technical change has provided a fruitful basis for a substantial redirection of empirical research. I would like to record my judgment, at the outset, that I think this has been a highly desirable movement, and to say also that I would welcome a similar regrouping of our intellectual forces in the field of international trade. For the role of technical change is as badly neglected in trade theory today as it was in growth theory fifteen years ago. Perhaps in ten years' time we will all have the satisfaction of looking back upon this conference and saying that we participated, in one way or another, in the beginning of this revolution. I have even given some thought to the matter of providing a suitable slogan to this movement of potential revolutionists. Unfortunately, the only slogan I have been able to think of is one which is not well calculated to generate an appropriate sense of revolutionary fervor among international trade economists, although it does express the sense of part of what I have to say to them. It goes: "Trade theorists of the world arise! You have nothing to lose but your comparative advantage." I have a nagging intuition that this is likely to have only a very limited appeal.

I am in the somewhat awkward position of having to comment on two papers each of which, in its own way, I regard as excellent. This leaves me with the alternative of either quibbling in a somewhat pedantic and graceless way over small points or addressing myself in a more general way to the issues raised in the paper by Bruno and that of Evenson, Houck, and Ruttan.[1] Having expressed my alternatives to you in this fashion, it must be obvious that I have chosen the latter course.

Bruno, in his extremely interesting paper ("Development Policy and Dynamic Comparative Advantage"), attempts to introduce dynamic considerations into the theory of comparative advantage in a way which will eventually provide a basis for making decisions concerning trade and development policies. The model which results is, perhaps inevitably, somewhat complex. Its main element of novelty is an explicit consideration of intertemporal relations, including the treatment of externalities in the export process and suggestions concerning an incorporation of certain labor-training effects. Bruno shows considerable ingenuity in demonstrating how some kinds of externalities can be considered within the framework of a linear model. Although such a model has practical attractions, and Bruno has demonstrated its versatility, it should also be said that it has some severe analytical limitations, such as the inability to handle increasing returns to scale in production.

In spite of the fact that Bruno has gone to some pains to cloak his model in the traditional dress of comparative advantage, the novelty of his analysis keeps poking through the traditional garb. The question I want to raise is whether once we have introduced dynamic considerations, of the sort raised by Bruno, we are not in a somewhat different ballpark, with somewhat different ground rules and goals, from the one where comparative advantage is typically played. Clearly the question which I am raising does not concern the logic of comparative advantage (which is impeccable) but its relevance and the extent of its usefulness. I am suggesting that in a world where rapid technological change is taking place we may need an analytical apparatus which focusses in a central way upon the process of technological change

[1] For comment on Evenson, Houck, and Ruttan, see pp. 481–483, below.

itself, rather than treating it simply as an exogenous force which leads to disturbances from equilibrium situations and thereby sets in motion an adjustment process leading to a new equilibrium. If technological change is as important as it now appears to be (since Abramowitz and Solow woke us from our dogmatic slumber), then I suspect that an effective way of understanding the future pattern and prospects of world trade, together with its impact on individual economies, will be by focussing attention more directly than we now do upon the characteristics of a technology, together with its requirements, its opportunities, and its constraints.

Of course, it is possible to say that I am just asking for a shift in relative emphasis, and if, out of some sense of filial piety, the basic framework of comparative advantage is retained, I would not raise strenuous objections. I would then say that when we accord a more prominent role to the effects of a dynamic technology comparative advantage appears in a somewhat different light. It is no longer based upon cost differences which are rooted in immutable forces of climate or geology. Rather, it is the continually changing result of human ingenuity and inventiveness, reflecting the differential capacity of different countries to *develop* techniques which enable them to take advantage of opportunities which are only implicit in their resource endowment. The *primacy* of resource endowments recedes as an explanatory variable in a country's economic activities. Thus the barren stretches of the Negev have produced the barest subsistence under Bedouin nomadism but have a very different response when subjected to the forces of modern technology and water control at the disposal of an Israeli kibbutz. The difference in emphasis, then, is far from trivial. It is the difference between emphasizing an unalterable natural resource endowment as the prime determinant of economic performance and emphasizing the level of technological sophistication and versatility. For the fact is that not only do different countries employ different technologies; countries also vary considerably in their ability to *produce* appropriate technical changes and to adapt and modify the technology of other countries to their own requirements. This differential ability of countries to produce technical change is, it seems to me, of enormous importance, but it is not something which has been incorporated into our theorizing about international trade relations.

I think, then, that we must begin to inquire into the *sources* of technological versatility. If it can be established that certain kinds of economic activities are more successful than others in contributing to the development of inventive abilities and entrepreneurial and organizational talents, such information would have important policy implications. Technological change is not, after all, something which has emerged in a random way from all sectors of the economy. It is the result of a problem-solving skill which, historically, has been heavily concentrated in some specific sectors of the economy. In the early stages of industrialization these skills were heavily concentrated in machine tools and engineering; later, partly as a result of scientific advances, this focus shifted to chemistry-based and more recently to electronics-based industries.

In his paper, Bruno has made some comments on the learning process insofar as it pertains to workers acquiring *existing* skills—labor-training effects. I find these comments useful, but I would like to raise in addition the intriguing question of the process whereby society as a whole acquires new skills: either knowledge which previously did not exist, or applications or modifications of general principles which previously had not been undertaken. If industries differ drastically, as I suspect they do, in their capacity to prepare an economy for these "voyages of discovery," the acquisition of further information about these differences ought to be high on our list of research priorities. If one productive process involves a learning activity which leads to new techniques or products, and another does not, these are externalities of the greatest importance. Somehow we must take account of the fact that, whatever else may be said of the silk industry, it represented a technological "dead end." No amount of messing around with silkworms and mulberry leaves could ever have produced nylon. This innovation was dependent on an elaborate learning experience concerning the molecular structure of materials which would hardly have taken place in the absence of association with a large chemicals industry. Once this learning experience had taken place, it became in turn the basis for a veritable flood of innovations based upon the newly developed capacity to produce synthetic materials with specific characteristics. Similarly, the experience of the successful industrialization of countries in the nineteenth century indicates that the learning experiences involved in the design and production of machinery were vital sources of technological dynamism and flexibility for the country as a whole. Countries which rely upon the importation of foreign technology derive much benefit from doing so, but they are also cut off from what may be a critical learning experience. Generally, then, our theory must deal with the fact that industries have "outputs" other than the final product itself—the production of knowledge, skills, and talent which in turn determine the level of technical competence of the economy in the future. How do we incorporate into our theory the fact that certain kinds of activities may give an economy a comparative advantage in the capacity to *generate* technological change?

The growing awareness of the significance of technological change raises a related point about which we have hardly begun to theorize: Countries possessing a dynamic technology will also be the leaders in the introduction of new products. But we have not yet begun seriously to explore the consequences of this sort of technological leadership. Economic theory has always had a difficult time coming to grips with the problems posed by new products. Our analytical apparatus and our techniques of measurement have been notably deficient in the handling of product innovation as opposed to cost-reducing process innovation. But clearly product innovation has been playing, and will probably continue to play, a major role in the changing pattern of international trade, and it is very important that we develop analytical tools which can handle it. Raymond Vernon's suggestive article "International Investment and International Trade in the Product Cycle" [2] is a useful step in this direction. But clearly we still have a long way to go.

[2] *Quarterly Journal of Economics,* May 1966, pp. 190–207.