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A generalized technology gap trade model

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In this model, the technological gaps *will be related to absolute advantages (for instance in terms of product innovations) and comparative advantages (for instance in terms of process innovations approximated by differences in unit labour costs, productivity and wages). Other asymmetries related to the demand structure and labour market however will also be considered and jointly determine – with the differences in technology – the process of international specialisation and the delimitation of the growth possibility "set" for each country.*

The model illustrate for example, that it is particularly in the case of countries with relatively less of a technological gap that the technological gap multiplier *will have its most significant effect on the pattern of specialization,* i.e. *in the case of North-North or South-South trade, rather than in the extreme stylised North-South case. It is worth noting in this respect that the evidence with regard to the dominance of "intra-industry" trade between advanced countries and the importance of product differentiation in such trade flows fits this results neatly.*

Dans ce modèle les technological gaps *sont associés à la fois aux avantages absolus (par exemple en relation avec les innovations de produits) et aux avantages comparés (par exemple en relation avec*

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les innovations de processus expliquées par les différences de coût unitaires de travail, dans la productivité et dans les salaires). En outre les asymétries introduites dans la structure de la demande et dans le marché du travail, ainsi que les asymétries associées à la technologie, permettront de déterminer le processus de spécialisation internationale et les possibilités de croissance pour les deux pays.

Le modèle montre, par exemple, que, seulement dans le cas particulier d'échange entre pays ayant un technological gap *bas, on aura un effet important de* technological gap multiplier *sur le pattern de spécialisation, comme dans le cas d'un échange Nord-Nord et Sud-Sud, alors que dans l'échange Nord-Sud l'effet du multiplicateur diminue fortement. Dans ce cas, il faut souligner l'émergence et la prééminence des échanges "intra-industry" et l'importance de la différenciation de produit dans la détermination du pattern de spécialisation.*

INTRODUCTION

Since the 60's, the central purpose of most contributions in the field of technology and trade has been to highlight the crucial importance of technological change and innovation in explaining international trade patterns [(1)]. In doing so many of these studies have undoubtedly scored many points with policy makers who have increasingly come to recognize the significance of technology for international competitiveness. The theoretical basis of these contributions remains however poor. This is in fact not surprising. The introduction of "technology" in any kind of trade model, whether of the classical or neo-classical sort, raises many challenges. The complexity of the phenomenon of technological change on the one hand (with its dual impact on efficiency *and* new demand) and the essential dynamic "change" perspective implicit in the concept of technological change on the other, are difficult to handle in their globality in any kind of economic model.

First attempts at a more formal introduction of some of the dynamic features of the evolution of technological capabilities between countries considering both product and process innovation were developed by Krugman (1979), Dosi and Soete (1983)), Dollar (1986), Cimoli (1988) and Dosi, Soete and Pavitt (1990)).

Building on these ideas we shall demonstrate here that the growth of the trading partners relative to one another depends not only on

(1) See in particular Posner (1961), Freeman (1963) (1965), Hirsch (1965), Hufbauer (1966) and Vernon (1966).

the demand structure of each economy constrained by the balance of payment conditions, but also on differences in technology. Furthermore, the technological gap will be introduced as one of the main variables explaining the pattern of growth possibilities though the effect of what we will refer here to as the *technological gap multiplier*. In a sense, this concept can be considered a new element for the definition of a larger *taxonomy* of trade interdependences from which one can also obtain the standard results of the traditional approaches to balance of payments constrained growth as a sequence of particular cases. We shall also demonstrate that the traditional results associated to the multiplier mechanism in the determination of Keynesian levels of activity in open economies, the elasticity and the absorption approaches to the balance of payments and the Harrod-Kaldor foreign trade multiplier are valid only for the particular case of a fixed pattern of specialization or small technological gap multiplier. The model developed here is from this perspective fully generalisable, *i.e.* to explain trade between countries with different technological gaps (North-North, North-South or South-South).

I. THE PATTERN OF SPECIALISATION AND TECHNOLOGICAL GAPS

As in Cimoli (1988) and Dosi, Pavitt and Soete (1990), the model with be based following Dornbush, Fisher and Samuelson (1977), Wilson (1980), and Collins (1985), on a continuum of goods. We shall consider the technological capabilities of trading parterns in the production of two sorts of commodities: *Ricardian* and *Innovative commodities*. In our model the technological asymmetries between countries will be related to *both* comparative and absolute advantages, leaving aside the issue about the dominance of one over the other. Technological "gaps" can be related to absolute advantages (for instance in terms of product innovations) and comparative advantages (for instance in terms of process innovations approximated by differences in unit labour costs, productivity and wages). Other asymmetries related to the demand structure and labour market will however also be considered and determine jointly with the differences in technology the process of international specialisation and the delimitation of the growth possibility "set" for each country. In other words, we shall be considering a highly stylised model whose purpose it is to account *jointly* for the impact of these asymmetries and the balance of payment constraint upon the growth possibility of each economy.

The main characteristics and assumptions of the model are the following:

1) there are two countries, a home and foreign country, producing n commodities and using one factor of production. In other words we will consider a highly stylized $2 \times n \times 1$ model;

2) there are two sorts of commodities: Ricardian (or standardized) and innovative ones;

3) the Ricardian commodities can be produced and exported by both countries, the innovative commodities only by the foreign country. In other words, it is the home country which can be considered as the technologically backward one;

4) markets are not assumed to clear. In particular in the case of the labour market, wages can be considered as being exogenously determined and related to institutional factors in each country;

5) it is assumed that each country faces a different import demand structure associated mainly to the income and price elasticity for each commodity: *i.e.* we do not assume homotheticity of the demand function.

We start with the idea of a continuum of goods which can be ordered by a real index on an interval $[0, z_1]$, where z_1 is the number of commodities produced in the world economy. A continuum of goods implies that each good corresponds to a real number on the interval. We propose to order the set of commodities in terms of the increasing *technological intensity* of each commodity, from 0 to z_1. A many empirical studies (2) in the trade and technology area have shown, the assumption that product can be ranked by some proxy of technological intensity, to a large extend irrespective of the particular country, is very much supported by the available empirical evidence. Technology intensity can, in other words, be translated into empirical terms in a relatively straightforward manner; *e.g.* expenditures (direct and indirect) on R & D (David 1988) or the number of patents granted (Pavitt and Patel 1988). In the model which follows, we will assume that the technological intensity of the commodities is monotonically related to the technological gap between the two trading partners: *i.e.* the difference in production efficiency in the two regions grows

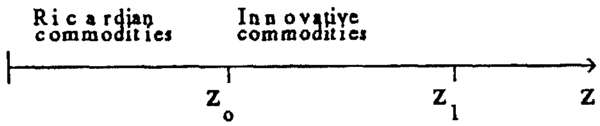
(2) For an overview see Soete (1987) and Dosi, Soete and Pavitt (1990).

monotonically with the technological complexity, difficulty of imitation and lack of appropriate skills for the production of the commodities [3].

We can now analyse the process of the introduction and imitation of new commodities. The technology gap and product life cycle approaches have emphasised the fact that the introduction of new products is not uniform across countries. This international difference in the capability of developing product innovations is an important feature of the pattern of trade. In our model, we will assume that most of the new products are introduced by the foreign country, and only later by the home country once it has learnt (and/or imitated) how to produce these goods. In order to introduce the innovation commodities into the pattern of trade the range of commodities $[0, z_1]$ must be rearranged. The range of commodities is divided into two distinguishable sets: $[0, z_0]$ and $[z_0, z_1]$, where $z_1 > z_0$. In the first set are ranked the established, "old" commodities: z_0 is the number of old commodities produced in the world economy. These commodities, which we will call *Ricardian commodities*, are characterized by a lower technological intensity than the innovative commodities, and can be produced by the home and foreign countries. The second set are orders the innovative commodities which can only be produced by the foreign country.

At any given point in time there will be a notional equilibrium distribution within the whole product range between Ricardian and innovative commodities which is given. We develop the model below by assuming a given z_1 and z_0. The whole set of commodities will be distributed over the innovative and Ricardian sets, as show in figure 1. It will be clear, that this is only an analytical device which will help us in exploring the properties of the system: as a matter of fact the process of technological change will continuously increase the whole range of commodities over time.

Figure 1



Let us now define the group of Ricardian commodities and the specialization criteria associated with them. These commodities are

(3) This is of course a theoretical abstraction; one can cite plenty of empirical examples of high technology goods quickly imitated and efficiently produced by less developed countries. However, as a general assumption, it does not do too great a violence to historical evidence.

produced and exported either by the home or the foreign country according to the relative production costs (denominated in a common unit), which are explained by the technological gap. By technological gap in Ricardian commodities we mean the unequivocal difference between the home and foreign country in input efficiency; that is the superiority/inferiority of the input efficiencies independent of relative prices. The production of these commodities in one region or another depends in other words on the differences in *e.g.* labour and capital input efficiencies. These differences can be applied to cases where the techniques of production – in terms of quality and type of machinary employed, etc. – are similar and/or different. The specialization pattern sets can thus be specified in terms of our definition of the technological gap in Ricardian commodities, in the first instance differences in labour productivities.

To begin with and for the sake of simplicity, let us assume that labour is the only factor of production. The level of wages is related to the specific labour market features of each country's economy. Profits are zero in both regions. The Ricardian commodities can now be indexed on the interval $[0, z_0]$ of our continuum of goods, where z represents one particular commodities associated with a point on the interval. These commodities can be produced in the home and the foreign countries, the constant labour input coefficients are denoted by a_i^* for the home country and a_i for the foreign country for each commodity; thus, the Ricardian commodities are ranked on a continuum according to the relative input coefficients in both countries. In others words, on this interval, we can superimpose the ordering related to the home-foreign relative labour input efficiencies.

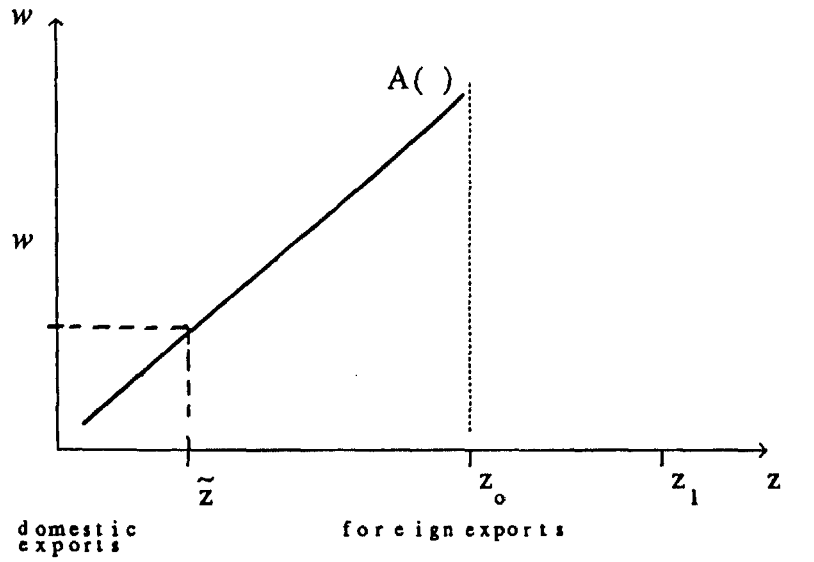
Moreover, it can now be assumed that the home economy is more efficient in the production of the commodities with low levels of technological intensity, whereas foreign relative efficiency is higher for the commodities nearer to the innovation interval. With regard to the Ricardian commodities, we may thus define the following function: $A(z) = a^*(z)/a(z)$, where $A'(z) > 0$ [4]. Thus, the function A( ) ranks

[4] Note that the domain of the function $A(\ )$ is $[0, z]$, which is assumed to be differentiable and invertible. We can also note an important point about the assumed *unit labour requirement function* $A(\ )$: this ensures that the goods are ordered by an increasing comparative advantage of the foreign country relative to the home country. With both Labour and Capital inputs, and assuming the labour force is homogenous – in terms of capabilities to use different and similar machinery – in the home and foreign countries the commodities are ranked in terms of the increasing capital input efficiencies. The results obtained from this simplified model also apply in those cases where there are capital inputs and positive profits when there is no "reswitching of commodities". See Dosi, Pavitt and Soete (1990).

the Ricardian commodities in terms of an increasing foreign-home technological gap.

Within the range $[0, z_0]$, international specialization will take place in the foreign of home country depending on wherever it is cheaper to produce at current wages and labour productivities. Let w* and w denote the home and foreign wages, so that any commodity z will be produced in the foreign country when $a(z)w \leq a^*(z)w^*$. This inequality with an equality sign defines the bordeline commodity $\tilde{z}$, which can be written as the following function: $\tilde{z} = A^{-1}(w)$ where $w = w/w^*$ denotes relative wages and $A^{-1}(\ )$ the inverse function of $A(\ )$. The process of specialization is shown in figure 2. For a given relative wage w, the home country is specialized in the set of commodities $[0, \tilde{z}]$, and the foreign country in the set $[\tilde{z}, z_1]$. An increase in the foreign wage relative to the domestic wage reduces the set of commodities that the foreign country can competitively produce, and vice versa. The effect of any change in the relative wage on the borderline commodity $\tilde{z}$ is related to the slope of the $A(\ )$ function [5].

Figure 2



[5] Whithin this framework we can note two extreme cases of possibility of "non specialization", that is, when $A(\ )$ is vertical or horizontal the specialization is indeterminate. In the latter case when $A(\ ) = 1$, the labour productivities in both regions are identical for each commodity and consequently there are no technological differences between both countries.

Following the technological-gap definition discussed earlier, on the slope of the $A(\ )$ function gives us a representation of the domestic (and/or foreign) relative efficiency in the production of Ricardian commodities. The pattern of specialization for a given $A(\ )$ function (and thus also a given technology gap) is determined by relative wages. Insofar as a change in the borderline $\tilde{z}$ is a function of the change in relative wages, we can write:

$$\Psi^{\tilde{Z}W} = \frac{w}{\tilde{z}} \frac{\partial \tilde{z}}{\partial w} = \frac{1}{\Psi^{A\tilde{Z}}} \tag{1}$$

we shall call $\Psi^{\tilde{Z}W}$ *the technological gap multiplier*, where $\Psi^{AZ} = z/A \partial A/\partial z$ (6). The technological gap multiplier approximates the sensitivity of the pattern of specialization of the changes in relative wages for a given $A(\ )$ function. Thus for a large $\Psi^{\tilde{Z}W}$, an increase in relative wages will considerably increase the amount of the commodities domestically exported; when $\Psi^{\tilde{Z}W}$ is small an increase in w implies a small change in specialization. Changes in relative wages thus have a significant effect on the share of commodities produced only when the technological gap multiplier is large. For an increasing (decreasing) technology gap in Ricardian commodities, changes in relative wages produce a small (large) change in the specialization.

Another pattern of specialization emerges when the foreign country produces only the innovative commodities and the domestic country all of the Ricardian commodities, that is $\tilde{z} = z_0$. Figure 2 shows that in this case an increase in relative wages will not have any effect on the pattern of specialization, which is solely explained by the relative innovation and imitation capabilities related to product innovations in each country. The pattern of specialization assumed in Krugman and Dollar's model can thus be considered as a particular case of our model. In this case the model assumes a given pattern of specialization and the relative growth between countries will be related mainly to the differences in the demand structure and the length of the Ricardian and innovative commodity sets.

(6) The parameter Ψ^{AZ} may be interpreted as the elasticity of the comparative advantage ratio with respect to the index z or the elasticity of the technological gap with respect to Ricardian commodities. A larger (smaller) Ψ^{AZ} implies a steeper (flatter) $A(\ )$ function which is associated with a large (small) variation in the technology gap. When the technology gap is large in several commodities, domestic relative efficiency will decrease considerably with the increase in the number of commodities produced and exported. In other words, the domestic economy is confronted with a large technology gap when an increase in z is associated with a large increase of foreign relative efficiency.

III. SPECIALIZATION, THE STRUCTURE OF DEMAND AND THE BALANCE OF PAYMENTS CONSTRAINT

In the analysis which follows, we shall now investigate how the asymmetrical effect of demand can be integrated into the model presented in the previous section.

Let us start the specification of the demand functions. We have chosen to specify the domestic and foreign demands for imports, since in our model that is what counts in determining the balance of trade equilibrium condition. In the first instance we are interested in per capita demand. This will make it easier to relate the analysis with the levels of employment in both regions. The demand for a commodity z can be expressed as follows:

$$\beta^*(\mathrm{z}) = \frac{p(z)m^*(z, \mathrm{w}^*, p(z))}{\mathrm{w}^*} \tag{2}$$

$$\beta(\mathrm{z}) = \frac{p^*(z)m(z, \mathrm{w}, p^*(z))}{\mathrm{w}} \tag{3}$$

where:

$\beta^*(\mathrm{z})$ and $\beta(\mathrm{z})$ represent per capita domestic and foreign import expenditure shares;

$m^*(\mathrm{z})$ and $m(\mathrm{z})$ the per capita domestic and foreign demands for imports; and

$p^*(\mathrm{z})$ and $p(\mathrm{z})$ the domestic and foreign prices of commodity z.

The demand function that emerges from equations (2) and (3) can be different for each commodity z and the import expenditure shares will not be constant. Consequently, as prices and wages change the domestic and foreign expenditure shares will also change depending on the income and price elasticities of the commodities imported into each country.

Dornbush, Fisher and Samuelson (1977), proceeded to close the model by assuming strong homotheticity of the demand function; Wilson (1980) extended this model with respect to the demand structure and the number of countries. Both models have been closed by requiring the labour market to clear. In this respect, our model is radically different. We consider fundamental the differences between countries in the structure of demand and the institutional arrangements in the labour market, which in our view will be more generally of a non-clearing nature rather than vice versa. More precisely, we will try to account for: (a) the large range in price and income elasticities of the different commodities represented by the continuum of goods;

and b) the determination of real wages as a result of the forms of organization and the norms of adjustment which prevail in the home and foreign country. By bringing these hypotheses into the picture we will be able to bring together the technological differences, the pattern of specialization and the labour market specificities of each country.

It will be clear that the latter assumption will allow for the possibility of introducing asymmetries in income and prices elasticities between domestic and foreign import demand, so that the model can reproduce the *usual* result of growth models with balance of payments constraints.

Assuming that $0 < \widetilde{z} < z_0$, which defines a pattern of specialization between the home and the foreign country, we can write:

$$B^* = \int_{\widetilde{z}(w)}^{z_1} \beta^*(z)\, dz \tag{4}$$

$$B = \int_0^{\widetilde{z}(w)} \beta(z)\, dz \tag{5}$$

where,

B^* is the share of the wage in the home country spent on the innovation and Ricardian commodities produced in the foreign country; and

B is the share of the wage in the foreign country spent on the Ricardian commodities produced in the home country.

To get an expression of the balance of trade equilibrium condition we must now specify total domestic and exports. These can be expressed as [7]:

$$M^* = Y^* B^* \tag{6}$$

$$X^* = YB \tag{7}$$

where M^* is the total demand for imports in the home country, X^* domestics exports (*i.e.* the demand for imports in the foreign country), and Y^* and Y stand for the domestic and foreign incomes in which wages are the only component. The trade equilibrium condition is then:

$$Y^* B^* = YB \tag{8}$$

[7] The model will be considered under the conditions of $0 < B < 1$ and $0 < B^* < 1$. In the two extreme cases when $B = 0$ $B^* = 0$ and $B = 1$ $B^* = 1$ we have either no trade or 'total' trade (*i.e.* everything which is produced is exported) between the two countries.

Rearranging (8) and substituting for B^* and B, we obtain

$$Y = \frac{Y^*}{Y} = \frac{\int_0^{\tilde{z}(w)} \beta(z)dz}{\int_{\tilde{z}(w)}^{z_1} \beta(z)dz} \tag{9}$$

Equation (9) tells us that the domestic relative income which ensures the open-economy macroeconomic equilibrium is a function of the foreign and domestic shares spent on imported commodities. It is clear that B^* and B can also be interpreted as the import propensities in the home and foreign country, respectively. In this sense, equation (9) can be taken as a static formalization of Harrod's foreign trade multiplier, as revived by Kaldor and Thirlwall [8].

Our approach is however significantly different from the latter since we are also allowing for the possibility of changes in the pattern of trade. That is, changes in the domestic relative income are not only a function of foreign income and the demand for imports, but are also dependent on changes in the pattern of specialization. In this respect, the changes in the real wage affect the demand for imports, the impact of which is weighted by the price and income elasticities of each commodity, and the range of commodities produced and exported by both countries. The impact of the latter effect is itself determined by the relative differencies in the input labour efficiences in the production of Ricardian commodities, defined as the technological gap. By introducing the possibility of changes in the pattern of specialization, we will be able to link the technological gap and differencies in demand structure, which will explain simultaneously the domestic growth possibilities.

The domestic relative income depends on: (a) relative wages which have itself an impact on relative prices, the demand for the commodities domestically imported and exported, and the pattern of specialization; (b) differences in the parameters that define the demand structures; and (c) the technological gaps that together with wages determine the limit of integration $\tilde{z}(w)$.

Let us now summarize the implications of our model so far.

First, the model allows one the link the pattern of specialization with differences in the demand structure between the two countries. Technological gaps determine the set of possible patterns of specialization and

[8] As in Kaldor (1975), Kennedy and Thirlwall (1979), (1980), Thirlwall and Dixon (1979), Thirlwall and Hussain (1982).

the asymmetry in demand determines the different effects on the quantities produced and exported of each commodity. From this picture, we will now be able to provide a link between the conditions which determine the pattern of specialization and a «Keynesian» determination of the levels of activity.

Second, it is important to stress the difference between our present model and the standard approach to growth based on the balance of payment constraint. In the latter the pattern of specialization is given, and the only factor that affects relative income is the difference between the two countries in the demand for imports and growth rates. In our model the quantity of different commodities that each country produces – determined by the specialization pattern – and the demand effect – that determines the quantity of each commodity produced – are simultaneously factors in the determination of relative income.

IV. TECHNICAL PROGRESS AND THE TECHNOLOGICAL MULTIPLIER WITH A BALANCE OF PAYMENT CONSTRAINED GROWTH

In this last section, we shall put forward the dynamic extension of the model. We begin by analysing the effect of uniform technical progress on relative efficiencies in the production of Ricardian commodities in the two countries. Technological change does not only lead to the introduction of new commodities, it will also be a crucial factor for the efficiency with which existing products are being produced. In other words, the innovative and imitative capabilities in the two countries will be used in the development of both new products and the improvement of production processes. In the latter case, technological progress will be defined by the reduction in the unit labour requirements for the production of Ricardian commodities. All *process innovations* will increase labour productivity in the foreign country and its relative efficiency. Conversely, all *process imitation* will increase domestic relative efficiency in the production of Ricardian commodities. In other words, process innovations induce divergence whereas process imitations induce convergence of the productivity levels between countries.

The increase of labour productivities in the two countries depends thus on the innovation and imitation capabilities as they are translated into the production of Ricardian commodities in the foreign and home respectively. Under the assumption of uniform technical progress across commodities in both economies, the per cent change in the labour required to produce domestically a unit of good z, $\dot{a}^*$, or abroad, $\dot{a}$, can be expressed as:

$$\dot{a}^* = \alpha^* g \tag{10}$$

$$\dot{a} = \alpha i \tag{11}$$

where g is the domestic rate of imitation and i the foreign innovation rate. Uniform technical progress implies that $-1 \leq \alpha^* < 0$ and $-1 \leq \alpha < 0$, where α^* and α can be interpreted as the translation of the imitative and innovative capabilities in the production of Ricardian commodities. If $\alpha^* = \alpha = -1$, the innovative and imitative capabilities developed in the production of new commodities are fully used in the production process. It is clear that the differences in productivity growth will depend on α^*, α and the innovative and imitative rates.

As illustrated in figure 3 uniform technical progress in the home country (or a uniform reduction of unit labour requirements) will shift the schedule $A°A°$ downwards, thus allowing for a given relative wage ratio a wider specialization pattern with a gain of some products. The opposite applies in case of a uniform reduction of the unit labour requirements in the foreign country. Two extreme cases are illustrated in figure 3. For example when $\alpha = 0$ *e.g.* (technical progress takes only place domestically), the schedule $A°A°$ in figure 3 would shift downwards to $A''A''$. For $\alpha^* = 0$, a uniform reduction of unit labour requirements in the foreign country would shift the schedule $A°A°$ upward to $A'A'$.

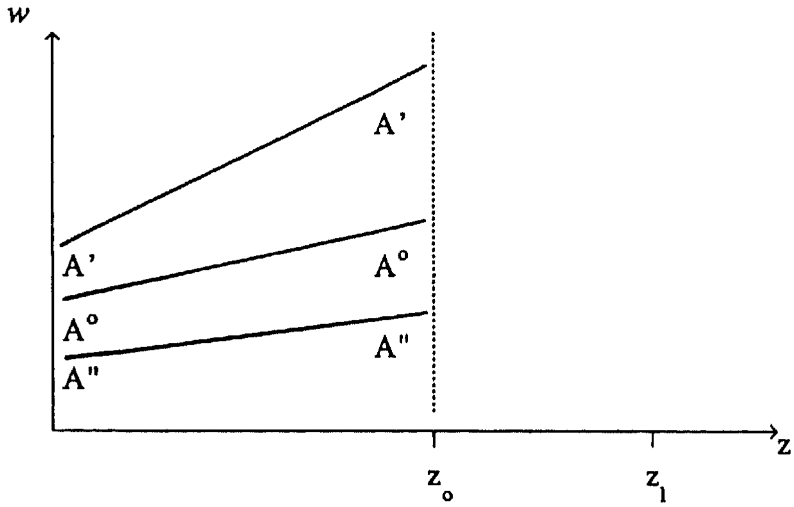
The model accounts thus the general divergent and emergent technology gap patterns: an increase in innovative capabilities in the foreign country – related to more efficient production methods – implies divergence in technological gaps; an increase in imitative capabilities in the home country convergence. Under the hypothesis of uniform technical progress the changes over time in $\tilde{z}$ can be expressed as:

$$\frac{d\tilde{z}}{dt} = \tilde{z}\Psi^{\tilde{z}W}(\dot{\mathrm{w}} - \dot{\mathrm{w}}^*) - (\alpha i - \alpha^* g) \tag{12}$$

As equation (12) illustrates, the time derivative of $\tilde{z}$ is a function of the per cent change in wages and productivities in both countries. Two important aspects of equation (12) need to be stressed.

First, the change in $\tilde{z}$ gives the adjustment in the pattern of specialization among Ricardian commodities, which captures mainly the

Figure 3



sensitivity of the system to changes in relative wages and productivities (the relative unit labour cost in both economies). Thus, the (imitative) home country willing to increase its wage at the same rate as the (innovative) foreign country without losing competitiveness in the production of Ricardian commodities has to sustain a rate of imitation in production processes (productivity improvements) equal to the rate of innovation of the foreign country. The home country may catch up if its rate of productivity is higher than in the foreign country. Conversely, a smaller rate of imitation (or rate of productivity growth) implies a reduction in the range of commodities produced domestically; the pattern of specialization moves in favour of the foreign country increasing its relative efficiency in the production of Ricardian commodities.

Second, the significance of the multiplicative form that assumes the differences in technology between the two countries ($\Psi^{\tilde{z}W} = 1/\Psi^{A\tilde{z}}$). The changes in the pattern of specialization are weighted by the *technological gap multiplier*, which accounts for initial distance in productivity levels between the two countries. There is thus a limit to how wages and productivity improvements can induce changes in specialization when the existing technological gap is already high (think, for example, of the case of trade between less developed and industrialized countries). Conversely, in case of a small technological gap, adjustments in the pattern of specialization will be very sensitive to changes in wages and productivities (think, for example, of trade between industrialized countries).

The different possible impacts on changes in the pattern of specialization are summarized in table 1.

Table 1

	$w = w^*$	$w > w^*$	$w < w^*$
$\alpha^* g = \alpha i$	0	+	−
$\alpha^* g > \alpha i$	+	+	+ or −
$\alpha^* g < \alpha i$	−	+ or −	−

* where: + stands for in favour of the domestic country, and − stands for in favour of the foreign country.

Decomposing equation (12) we have:

$$\dot{\vartheta}_w = \tilde{z}(\dot{w} - \dot{w}^*) \tag{13}$$

$$\dot{\vartheta}_h = (\alpha i - \alpha^* g) \tag{14}$$

where $\dot{\vartheta}_w$ can be interpreted as the weighted per cent change in relative wages and $\dot{\vartheta}_h$ as the difference in productivity changes in the two countries.

In order to get an expression for the domestic relative income growth, we need now the specify the per cent change in the share spent on imports. Let $\dot{\Phi}^*(z)$ and $\dot{\phi}(z)$ denote the per cent changes in the domestic and foreign shares spent on the import of commodity z, so that:

$$\dot{\phi}^*(z) = \frac{1}{\beta^*}\frac{d\beta^*}{dt} = \dot{w}^*(\varepsilon^*(z) - 1) + \dot{p}(z)(1 - \eta^*(z)) \tag{15}$$

$$\dot{\phi}(z) = \frac{1}{\beta}\frac{d\beta}{dt} = \dot{w}(\varepsilon(z) - 1) + \dot{p}^*(z)(1 - \eta(z)) \tag{16}$$

where ε^* and ε are the income elasticities, and η^* and η the price elasticities in the home and foreign country respectively. Equations (15) and (16) capture the demand absorption and price effects; note that the changes in prices can be decomposed as: $p = \dot{w} + \dot{a}$ and $\dot{p}^* = \dot{w}^* + \dot{a}^*$.

The demand function for the domestic and foreign imports are assumed to take a multiplicative form with wages and prices as the two components, weighted by the income and in price elasticities. The model thus accounts for differences in the demand structure as another determinant of the relative growth between the two countries.

The per cent change in the domestic relative income follows then from the following equation:

$$\dot{Y} = \frac{1}{B}\int_0^{\widetilde{z}(w)} \beta(z)\dot{\phi}(z)dz - \frac{1}{B^*}\int_{\widetilde{z}(w)}^{z_1} \beta^*(z)\dot{\phi}^*(z)dz + (\Psi^{\widetilde{Z}W}\dot{\vartheta}_w - \dot{\vartheta}_h)\left(\frac{\beta(\widetilde{z})}{B} + \frac{\beta^*(\widetilde{z})}{B^*}\right) \quad (17)$$

Equation (17) illustrates how the domestic relative rate of growth compatible with the trade balance constraint is a function of: (a) the difference in the demand structure between the two countries (*i.e.* the income and price elasticities in both economies); (b) the changes in the per capita demand absorption of imported commodities and the changes in relative prices and/or factoral terms of trade (*i.e.* $\dot{\phi}^*$ and $\dot{\phi}$); and (c) the technological multiplier and the relative changes in the pattern of specialization (*i.e.* $\Psi^{\widetilde{Z}W}$, $\dot{\vartheta}_w$ and $\dot{\vartheta}_h$). The net effect on domestic relative income will depend on how these changes are compensated.

Table 2 indicates a large taxonomy of different cases resulting from this model according the intensity of technological multiplier; the changes in the specialization pattern associated to differences in wages and labour productivities; and the changes in the respective import propensities. More precisely, the following general properties of our model can be derived from equations (15), (16) and (17):

(i) As illustrated in the previous section, when the technological gap multiplier is small the pattern of specialization will remain stable. Thus, the change in domestic income depends on how the deterioration of the terms of trade and the increase in foreign imports will be compensated. For an technology gap multiplier near zero, the model will tend to reproduce the same conclusion as in the case of complete specialization: the home country does not benefit from an increase of the wage and/or labour productivity abroad, since the domestic relative income will have deteriorated. A similar case exists when $\widetilde{z} = z_0$, *i.e.* when the foreign country produces only the innovative commodities and the home country the Ricardian ones; domestic relative income will again only be affected through the demand and price changes.

(ii) If the pattern of specialization remains stable (*i.e.* ignore the third term on the right hand side of equation 17), and if both countries have a similar demand structure with income elasticities equal to unity and

Table 2
A Taxonomy of Trade Interdependence in a Technological Gap Model

Import demand effect	Factoral terms of trade effect	Technological and specialisation effect	Domestic relative rate of growth
$\underline{\dot{w} > \dot{w}^*}$	$p > \dot{p}^*$	depends on Technological gap multiplier	
$\varepsilon = \varepsilon^* = 1$	$\eta > 1,\ \eta^* < 1$ $\eta < 1,\ \eta^* > 1$	a) small Ψ^{ZW} b) large Ψ^{ZW} c) small or large (Ψ^{ZW})	a) decrease b) depends on which effect prevails c) increase
$\underline{\dot{w} > \dot{w}^*}$	$\dot{p} > \dot{p}^*$	depends on Technological gap multiplier	
$\varepsilon > 1,\ \varepsilon^* < 1$ $\varepsilon < 1,\ \varepsilon^* > 1$	$\eta = \eta^* = 1$	small or large (Ψ^{ZW}) a) small Ψ^{ZW} b) large Ψ^{ZW}	increase a) decrease b) depends on which effect prevails
$\underline{\dot{w} > \dot{w}^*}$	$\dot{p} > \dot{p}^*$	faster increase of Domestic productivity $\dot{\vartheta}_T > 0$	depends on which effect prevails and elasticities
$\varepsilon = \varepsilon^* = 1$ $\varepsilon < 1,\ \varepsilon^* > 1$	$\eta = \eta^* = 1$ $\eta = \eta^* = 1$	a) small Ψ^{ZW}, $\dot{\vartheta}_T > 0$ b) large Ψ^{ZW}, $\dot{\vartheta}_T > 0$ a) small Ψ^{ZW}, $\dot{\vartheta}_T > 0$ b) large Ψ^{ZW}, $\dot{\vartheta}_T > 0$	increase depends on which effect prevails
$\varepsilon = \varepsilon^* = 1$ $\varepsilon < 1,\ \varepsilon^* > 1$	$\eta^* < 1,\ \eta > 1$ $\eta^* < 1,\ \eta > 1$	a) small Ψ^{ZW}, $\dot{\vartheta}_T < 0$ b) large Ψ^{ZW}, $\dot{\vartheta}_T < 0$ small Ψ^{ZW}, $\dot{\vartheta}_T < 0$	a) decrease b) depends on which effect prevails decrease

price elasticities less than unity (*i.e.* ignore the first part on the right hand side of both equations 15 and 16); a faster increase in domestic than foreign prices will lead to a higher domestic relative rate of growth ($\dot{\phi}(z) > \dot{\phi}^*(z)$). Conversely, a deterioration in the domestic factoral terms of trade will be associated with a lower equilibrium growth rate. In this case (and under the additional assumption of constant labour input coefficients) the effects of an increase in domestic relative wages will be identical to an improvement in the domestic factoral terms of trade. An improvement of the domestic terms of trade can however also be associated with a deterioration of domestic relative income when the home country's price elasticities are high (*i.e.* $\eta^* > 1$), *i.e.* as in the celebrated case of immiserizing growth.

(iii) Under the assumption of (again) a stable pattern of specialization, a similar demand structure in the two countries but with domestic and foreign price elasticity equal to 1, (ignore this time the second part on the right hand side of both equations 15 and 16), a faster increase in per capita domestic import demand than in the foreign country will lead to a relatively lower domestic rate of growth ($\dot{\phi}^*(z) > \dot{\phi}(z)$). The demand absorption effect will be related to the asymmetry in the domestic and foreign income elasticities; thus for the extreme cases when $\varepsilon^* < 1$ and $\varepsilon > 1$ the domestic relative rate of growth, as a result of a faster relative per capita income demand could actually be higher.

In others words, and as emphazised in much of the trade and development literature, the effect of the asymmetry on import demand is associated to the "type" and the income elasticities of the commodities produced and exported in both countries (one can think of the case of primary and manufactured commodities or the different income elasticities associated with low and high tech products).

(iv) In so far as changes in wages and productivities have also an impact on the specialisation pattern most of the effects described above can be neutralised by the changes in the pattern of specialization, which could move in favour or at the detriment of the domestic country. What emerges, in other words, is that the traditional income growth effects due to relative changes in prices and wages and differences in the demand structure are not so clear (let alone obvious) once the possibility of *changes in the pattern of specialization* are considered. An increase in the home wage will for instance reduce the range of commodities domestically produced and exported and will change consequently the pattern of specialization in favour of the foreign country. The domestic relative rate of growth will decrease proportionally with the technological gap multiplier. Thus in case of a large technology gap multiplier, a large number of commodities might be lost for the home country. By contrast in case of a small technological gap multiplier, the model will take the form of complete specialisation and changes in the domestic income will be primarily explained by the demand structure and price effects.

An increase in the foreign wage, on the other hand, when the technological gap multiplier is small – with consequently little impact on the pattern of specialization –, will affect the domestic rate of growth negatively via the worsening of the terms of trade. If the technological gap multiplier is large, however, the negative effect for the home country on the terms of trade can again be compensented by an increase in the amount of commodities exported by the home country.

The model illustrates for example, that it is particularly in the case of countries with relatively less of a technological gap *that the technological gap multiplier* will have its most significant effect on the pattern of specialization, *i.e.* in the case of North-North or South-South trade, rather than in the extreme stylized North-South case. It is worth noting that the evidence with regard to the dominance of "intra-industry" trade between advanced countries and the importance of product differentiation in such trade flows fits this results neatly.

In the case of a large technological gap on the other hand, it is the reduction of the technological gap which will improve most clearly the domestic relative rate of growth. Here, as in the Krugman model, it is the reduction in the difference in technology with the North which will increase most directly the relative of growth of the South.

Looking back at the results obtained in equation (15) and (16) and recalling the definition introduced in equations (13) and (14), one might consider three particular "stylised" cases. As before all these cases will be under the assumption of asymmetry in import demand, different behaviour in wages but uniform technical change in the two countries.

In the *first* case, the rate of productivity growth is identical in both countries ($\dot{\vartheta}_h = 0$); domestic wages do not grow ($\dot{w}^* = 0$) and the rate of growth of the foreign wage is given by $\dot{w} = -\alpha i$. The difference in wage behaviour can be expressed as $\dot{\vartheta}_w > 0$. Under these assumptions, $\dot{\phi}^*$ will be equal to and $\dot{\phi}$ less than nil. It then follows from equation (17) that domestic relative income will grow, if the change in the specialisation effect prevails over the negative effect of the asymmetry in import demands, or in other words if the technological gap is reduced. If however, as we already mentioned above, the technological gap is very large (*i.e.* the technological gap multiplier $\Psi^{\widetilde{Z}W} \cong 0$), domestic income will in any case decrease.

In the *second* case, we consider that labour productivity growth occurs only in the home country ($\alpha = 0$) or $\dot{\vartheta}_h < 0$, whereas wage growth is the same in both areas ($\dot{\vartheta}_w = 0$). The resulting changes in import demands are again given by $\dot{\phi}^* = 0$ and $\dot{\phi} < 0$. As in the Prebisch-Singer case, the negative impact on domestic income is represented as a deterioration in its terms of trade. The positive effect, however, is given by the change in the specialization. If the deterioration in the terms of trade prevails, the net effect will be a diminution of domestic relative income.

In the *third* case, we assume that is the home country which produces only the Ricardian commodities and the foreign country only the innovative ones ($\tilde{z} = z_0$). The pattern of specialization is now "fixed" and the changes in wages do not affect the quantity of commodities produced in both countries. The difference in the relative rate of growth is only related to the length of the set of Ricardian versus innovative commodities and the asymmetries in import demand. Growth in domestic relative income will now depend on the imitative and innovative capabilities in the home and foreign country in product innovations as in the stylized case of Krugman and Dollar.

CONCLUSION

Even though the model presented here was highly stylised and restrictive in its assumptions about the nature of technological change and the international differences in technological capabilities, a number of interesting features with respect to technological catching up, patterns of specialization and relative income growth emerge from the broad, generalised two country model presented here.

On the one hand, the model points to the importance of the interplay between absolute and comparative advantages as determinants of the participation of each country in world trade, and the dominance of technological gaps in the process of international specialisation which provides the outer-boundaries of the Keynesian process of the level income and the growth possibility "sets" of each economy. On the other hand, the model presented here provides a link between the conditions for the changes of international specialisation and the "keynesian" determination of the level of activity in open economies.

In contrast to previous analyses, this was done here introducing formally the concept of technological gap multiplier. This is a concept that can be considered as a straightforward approximation of the empirical fact that products can be ranked in terms of their technological intensity which allows us to analyse in a more formal and systematic way the impact of large and small technological gaps between countries on the pattern of specialization and the domestic relative rate of growth.

From this perspective the model presented here is truly generalizable, allowing is to derive both the more traditional balance of payments constrained growth results, as well as the more technology North-South trade models.

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