Shifting Consumption Patterns: A Neglected Determinant of Growth Performance?*

Bart Los
University of Groningen, Faculty of Economics/SOM Research Institute, P.O. Box 800, NL-9700 AV Groningen, The Netherlands. e-mail: b.los@eco.rug.nl

Bart Verspagen
Eindhoven University of Technology, ECIS, & University of Maastricht, MERIT, P.O. Box 513, NL-5600 MB Eindhoven, The Netherlands. e-mail: bart.verspagen@merit.unimaas.nl

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ABSTRACT: The recent availability of large international data sets which relate to productivity issues has evoked a huge empirical literature. The traditional hypotheses of converging output per capita and productivity levels have been tested extensively, by adoption of all sorts of test procedures. Roughly speaking, two categories of theories are at the heart of these empirical studies. First, most studies are based on mainstream supply-side theories, in which the dynamics of relative capital intensities and/or relative 'total factor productivity' levels determine relative output per capita levels, since unemployment and idle capital are assumed to be short-run phenomena. Second, Post-Keynesian studies mostly take another extreme perspective, in which the long-run requirement of balance-of-payments equilibrium constrains the output growth rate. Abilities to export and the growth of the world market together with the propensity to import limit output growth, even if the available resources (or their productivity levels) grow significantly.

In this paper, we take an intermediate position. In our two-country model, we assume that the balance-of-payments constraint is effective, but also assume that a country's ability to export depends on the technological standards it has attained relative to the competitor country. These standards are specified as functions of the ability to innovate and the availability of a backlog of knowledge (technological catch-up). Contrary to most contributions to growth theory, we explicitly model differences and linkages between sectors. The differences relate to input mixes, opportunities to innovate, degrees of tradability, etc. The linkages take the form of a full-blown international input-output model.

We use this model to investigate the potential importance of a third determinant of output growth, international differences with respect to consumption dynamics. It is well-known that consumption elasticities with respect to income (Engel curves) vary widely across commodities. Since productivity, import requirements and degree of tradability also differ between commodities, income-induced consumption shifts from necessary goods to luxury goods may have important implications for issues like convergence and international specialization. Such implications are studied by means of simulation analyses.

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1. Introduction

Production of commodities requires resources. In most mainstream theories, the available amount of resources and their productivity levels determine the output volume of an economy. In traditional theories following the classic contribution by Solow (1956), the resources which got most of the attention were labor and physical capital. After the emergence of endogenous growth theory (e.g. Romer, 1986, and Lucas, 1988), the research focus of mainstream growth economists shifted towards less tangible factors of production like knowledge stocks and human capital. The degrees of availability of these 'modern' resources also appeared to be important determinants of the output performance of countries in empirical studies. Whatever the exact type of the resources specified, mainstream growth models consider technological progress as the main determinant of long-run growth: innovations continuously extend the output levels attainable with given amounts of inputs.

Whereas mainstream growth economists generally assume that supply conditions determine output levels (thus implicitly assuming that demand is always sufficient to accommodate full-employment, full-capacity output levels), Post-Keynesian growth theorists often start their analyses from the opposite viewpoint. In their view, effective demand by domestic and foreign consumers, investors and governments is the variable which determines output levels. In part of these theories, a country's ability to export plays a crucial role in particular. Thirlwall (1979) and Thirlwall & McCombie (1994), for example, pose that balance-of-payments equilibrium pegs output growth rates in the long run, since imported resources are not infinitely available if the value of exports is given.[1] Long-run growth is due to the continuous increase in the size of the world market: as long as market shares are stable, more funds become available to finance imports required for production.

In this paper, we will present analyses using a two-country model in which the output levels of each of the countries are restricted by the balance-of-payments constraint (the available funds to pay for imports). As such, our model has a Post-Keynesian nature. The size of the world market, however, is mainly determined by supply-side conditions. Technological progress provides opportunities to produce increasing amounts of output with a given amount of resources. Since we assume that market shares are dependent on relative innovativeness, the two countries can experience different long-run growth rates.

[1] From the perspective that exports determine the maximum amount of imports available, one could conclude that mainstream theories and Thirlwall's Post-Keynesian theory are similar in the sense that availability of resources and production technology together determine output volumes.

The model has another feature which allows interesting analyses. Unlike most models of growth, our model does not consider economies as aggregates producing a single output, but as systems of interdependent sectors.[2] Each sector produces its output according to its own technology. The principal value added of this approach over more usual models is in the opportunities to enrich analyses of growth and convergence with effects of, for instance, comparative advantage in stagnant industries, improved capabilities for technological catch-up in specific sectors, or changes in the tradability of specific commodities. Some of these issues were already taken up in Los & Verspagen (2000), in which a more or less similar model was used. In this paper we want to focus on the relations between two phenomena the analyses of which have strongly benefited from William J. Baumol's efforts.

Baumol (1967) introduced what has become known as 'Baumol's disease', the tendency that aggregate productivity growth slows down if more and more resources shift towards sectors with low productivity growth. This tendency would be strengthened if the share of consumption expenditures devoted to commodities produced by these stagnant industries would increase with growing incomes. Empirical research generally shows that this effect is prevalent indeed, due to the increased demand for services.[3] Baumol's disease could well have impacts on aggregate patterns of convergence and divergence, the topic central to Baumol (1986). *Ceteris paribus*, convergence should be fostered by Baumol's disease, since high-productivity countries face less favorable allocations of resources than countries with lower sectoral productivity levels. It should be borne in mind, however, that in our model not only labor productivity growth may be important, but also productivity growth of imports. Both steady reductions of sectoral import requirements per unit of output and consumption shifts towards less imports-intensive goods might soften the balance of payments constraint, which would yield effects on convergence rates which are hardly predictable without empirical evidence on trends in consumption patterns and sectoral import requirements.

The rest of this paper is organized as follows. In Sections 2 and 3 we propose the matrix equations which together make up our model. Section 2 presents the short-run equations, whereas Section 3 is devoted to the intertemporal relations. Simulation results obtained with the model are discussed in Section 4. In the concluding Section 5, we draw some conclusions on growth, convergence and specialization under various patterns of consumption share dynamics.

2. Model Description: Short-Run Relations

We feel it most convenient to introduce our model in two stages. First, we will discuss the way in which industry-level variables like gross output, value added and consumption demand in both

2 Actually, our model shares some features with the model for aggregate economies proposed by McCombie (1993). Next to our intersectoral perspective, a main difference between his model and ours is that we enrich the analysis by modeling the effects of technology generation and spillovers.

3 It should be noted, however, that most services productivity figures are subject to measurement error problems.

countries are determined for each period. To this end, we explain how a two-country international input-output table is used to derive the required coefficients which reflect the prevailing technologies and trade relations. In Section 3, we will deal with the equations which determine the values of variables exogenous to the short-run equations. One of these equations will specify how consumption shares evolve over time.

2.a The international input-output structure

At every moment in time, all macro-economic aggregates are derived from a two-country input-output table. We will denote the countries by North and South.[4] Both economies consist of at most *n* industries, which use labor and materials as inputs.[5] The number of different materials used by each industry is at most *n*, and can be domestically produced or be imported from the other country, or both. The commodity produced in North's industry *i* is assumed to be identical to the one produced in South's industry *i*, but is generally produced with a different composition of inputs: at each point in time at most two production technologies are used.

Fig.1 Two-Country Input-Output Table.

		N 1 2 … n	S 1 2 … n	N f	S f	TOT
N	1 2 ⋮ n	$\mathbf{Z}_{NN}$	$\mathbf{Z}_{NS}$	$\mathbf{F}_{NN}$	$\mathbf{F}_{NS}$	$\mathbf{q}_N$
S	1 2 ⋮ n	$\mathbf{Z}_{SN}$	$\mathbf{Z}_{SS}$	$\mathbf{F}_{SN}$	$\mathbf{F}_{SS}$	$\mathbf{q}_S$
	VA	$\mathbf{v}_N'$	$\mathbf{v}_S'$	$\mathbf{0}$		
	TOT	$\mathbf{q}_N'$	$\mathbf{q}_S'$			

Commodities are sold on the home market and/or at the foreign market, with the buyers having at most two alternative uses at their disposal. They can (i) use the commodity as an intermediate input (materials), or (ii) consume the commodity. This can be summarized by the input-output table in Figure 1. In the figure, the first indices indicate the country of origin and the second the country of destination. Further, the meanings of the symbols are as follows (matrices will consistently be indicated by bold capitals, vectors by bold lowercase letters and scalars by italics):

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[4] North is not necessarily the leader in technological terms. We set up the model as general as possible. This implies that for each industry, the technological leader country is endogenously determined. An industry is defined to be leading if its production technology is characterized by lower labor requirements per unit of gross output than its foreign counterpart.

[5] This model is a simplified version of the model with capital inputs presented in Los & Verspagen (2000).

Z: (2*n*x2*n*)-matrix of intermediate input requirements by commodity by industry;

F: (2*n*x2)-matrix of consumption demand by commodity;

v: (2*n*x1)-vector of value added figures by industry;

q: (2*n*x1)-vector of gross output levels by industry.

Primes denote transposed vectors or matrices.

2.b The technology dimension

We will assume that production in each of the industries (in either country) can be described by industry-specific, time-specific Leontief production functions. Given this assumption of no opportunities for instantaneous substitution between production factors, these functions can be summarized by two sets of coefficients. That is, intermediate inputs per unit of gross output and labor inputs per unit of gross output. For these (matrix- and vector-)variables, the following symbols are used:

$\mathbf{A}^*$: (*n*x2*n*)-matrix of intermediate input requirements per unit of output by industry;

L: (2x2*n*)-matrix of labor input requirements per unit of output by industry;

For simplicity, we omit time indices for now. $\mathbf{A}^*$ can be computed from the two-country input-output table as $\mathbf{A}^* = (\mathbf{Z}_{\mathbf{N}\bullet} + \mathbf{Z}_{\mathbf{S}\bullet})\hat{\mathbf{Q}}^{-1}$, with a hat denoting a diagonal matrix (i.e. $\hat{\mathbf{Q}}$ refers to the matrix with the elements of **q** on the main diagonal and zeros elsewhere) and a dot indicating both N and S. Note that $\mathbf{A}^*$ does not distinguish between domestically produced and imported inputs, it just gives the technological relations between intermediate inputs and gross output levels. Labor is assumed to be homogeneous in two senses. First, each worker is assumed to be employable in all industries: workers possess all skills required for employment in all industries within a country. Second, all workers within a country are assumed to earn identical wages, no matter which industry they are employed in. In geographical space, though, workers are assumed to be perfectly immobile and to earn wages which may well be different. This distinction is reflected in the matrix **L**, of which the first row (corresponding to employment of Northern workers) consists of *n* mostly positive values next to *n* zeroes, whereas the second row (corresponding to employment of Southern workers) has a reversed structure:

$$\mathbf{L} \equiv \left[\begin{array}{ccc|ccc} l_{N1} & \cdots & l_{Nn} & 0 & \cdots & 0 \\ \hline 0 & \cdots & 0 & l_{S1} & \cdots & l_{Sn} \end{array}\right]$$

2.c The trade dimension

Until now we have only discussed how technological circumstances at a particular point in time can be derived from the international input-output table and the 'satellite' table on labor inputs.

In this subsection, we take the requirements per unit of output for granted, and focus on the country of origin of materials.

We define $\tilde{\mathbf{A}}$ as the (2*n*x2*n*)-matrix obtained by stacking two (*n*x2*n*)-matrices $\mathbf{A}^*$ as defined before. Following Oosterhaven and Van der Linden (1997) and Dietzenbacher *et al.* (2000) we obtain the usual (2*n*x2*n*)-matrix of input coefficients $\mathbf{A}$ as $\mathbf{T}^{\mathbf{A}} \circ \tilde{\mathbf{A}}$, in which the operator $\circ$ denotes element-by-element multiplication and $\mathbf{T}^{\mathbf{A}}$ represents the (2*n*x2*n*)-matrix of intermediate input trade coefficients. These can be seen as "import penetration coefficients" (Verspagen, 1999) with respect to intermediate inputs. For each pair of industries (*i*, *n*+*i*) producing the same commodity (in different countries, though), these trade coefficients add up to one for each of the industries buying this commodity, since we do not assume trade with any 'third' country.[6]

A similar approach is chosen with regard to the consumption demand. Total consumption demand for the commodities is given by the (*n*x2)-matrix $\mathbf{F}^*$ (the first column reflects consumption by North, the second consumption by South). If we define $\tilde{\mathbf{F}}$ as the (2*n*x2)-matrix obtained by stacking two matrices $\mathbf{F}^*$, and $\mathbf{T}^{\mathbf{F}}$ as the (2*n*x2)-matrix of trade coefficients, we can write the consumption demand matrix $\mathbf{F}$ as $\mathbf{T}^{\mathbf{F}} \circ \mathbf{F}^*$.[7]

2.d Balance-of-payments equilibrium and full employment

We take an open input-output model as the mechanism determining gross output and employment levels. In a standard model without investment in capital goods, consumption and export demand together determine these levels through the Leontief multiplier mechanism implied by the technology and trade relations. As explained above, we assume that these relations are given at the beginning of each period. Hence, we continue our exposition by a discussion of the determination of consumption demand $\tilde{\mathbf{F}}$.[8]

In the standard input-output model, the consumption vector is assumed to be exogenous. Below, we will show that in our short-run model, both gross output and consumption demand are endogenous. Nevertheless, the standard structural form input-output relationship $\mathbf{q} = \mathbf{A}\mathbf{q} + \mathbf{f}$ remains the point of departure. Using partitioned matrices (and still omitting time indices), we can write

$$\begin{bmatrix} \mathbf{q}_{\mathrm{N}} \\ \mathbf{q}_{\mathrm{S}} \end{bmatrix} = \begin{bmatrix} \mathbf{A}_{\mathrm{NN}} & \mathbf{A}_{\mathrm{NS}} \\ \mathbf{A}_{\mathrm{SN}} & \mathbf{A}_{\mathrm{SS}} \end{bmatrix} \begin{bmatrix} \mathbf{q}_{\mathrm{N}} \\ \mathbf{q}_{\mathrm{S}} \end{bmatrix} + \begin{bmatrix} \mathbf{f}_{\mathrm{NN}} \\ \mathbf{f}_{\mathrm{SN}} \end{bmatrix} + \begin{bmatrix} \mathbf{f}_{\mathrm{NS}} \\ \mathbf{f}_{\mathrm{SS}} \end{bmatrix} \quad (1)$$

For arbitrary consumption vectors, this solution would yield a balance-of-payments (current account) equilibrium only by chance. In an extreme situation, North might even provide South

6 If the commodity under consideration is not used by a particular industry, the value of the two trade coefficients cannot be defined. This poses no problem for the calculation of the matrix **A**, since these coefficients are always zero.

7 Like in the matrix of intermediate input trade coefficients $\mathbf{T}^{\mathbf{A}}$, pairs of trade coefficients for identical commodities from the two countries add up to one in $\mathbf{T}^{\mathbf{F}}$.

8 Note that exports are included either in the intermediate inputs part of the model or in the consumption matrix. This implies that a discussion of consumption is sufficient in dealing with final demand.

with commodities without South delivering anything to North. As McCombie and Thirlwall (1994) argue, nothing prevents a country from being caught in a situation of current account disequilibrium for a short time, but in the long run it is unsustainable unless capital inflows keep coming in infinitely and in steadily increasing amounts. Moreover, infinitely cumulating stocks of Southern currency would not improve North's welfare. Following Verspagen (1999), we assume that given the commodity shares in total consumption and the trade shares for domestically produced or imported consumption goods in $\mathbf{T}^{\mathbf{F}}$, total consumption levels in North and South must always correspond to balance-of-payments equilibrium. As we consider a closed system without exports and imports to and from third countries, we could write North's current account surplus (or deficit) as the difference between the value of the goods imported by South and the value of goods imported by North (see McCombie, 1993, for a similar approach). As mentioned before, both countries import commodities for two purposes, i.e. intermediate use and consumption. Hence, current account equilibrium prevails if and only if the following holds:

$$\mathbf{p}_{\mathrm{S}}'\left(\mathbf{A}_{\mathrm{SN}}\mathbf{q}_{\mathrm{N}} + \mathbf{f}_{\mathrm{SN}}\right) = \mathbf{p}_{\mathrm{N}}'\left(\mathbf{A}_{\mathrm{NS}}\mathbf{q}_{\mathrm{S}} + \mathbf{f}_{\mathrm{NS}}\right), \tag{2}$$

The (2*n*x1)-price vector $\mathbf{p}$ (partitioned into a set of Northern prices $\mathbf{p}_{\mathrm{N}}$ and a set of Southern prices $\mathbf{p}_{\mathrm{S}}$, expressed in a common currency) will be discussed below. The equation can only be solved for the consumption vectors after we have expressed $\mathbf{q}_{\mathrm{N}}$ and $\mathbf{q}_{\mathrm{S}}$, in terms of the other matrix variables present in equation (2). To this end we use the partitioned reduced form of equation (1):

$$\begin{bmatrix} \mathbf{q}_{\mathrm{N}} \\ \mathbf{q}_{\mathrm{S}} \end{bmatrix} = \begin{bmatrix} \mathbf{R}_{\mathrm{NN}} & \mathbf{R}_{\mathrm{NS}} \\ \mathbf{R}_{\mathrm{SN}} & \mathbf{R}_{\mathrm{SS}} \end{bmatrix} \cdot \left(\begin{bmatrix} \mathbf{f}_{\mathrm{NN}} \\ \mathbf{f}_{\mathrm{SN}} \end{bmatrix} + \begin{bmatrix} \mathbf{f}_{\mathrm{NS}} \\ \mathbf{f}_{\mathrm{SS}} \end{bmatrix} \right), \tag{3}$$

in which the matrix $\mathbf{R}$ is the partitioned Leontief inverse (see Miller and Blair, 1985). We adopt a notation similar to that of Luptacik and Böhm (1999), to write the submatrices as:

$$\begin{aligned}
\mathbf{R}_{\mathrm{NN}} &= \left(\mathbf{I} - \mathbf{A}_{\mathrm{NN}}\right)^{-1}\left[\mathbf{I} + \mathbf{A}_{\mathrm{NS}}\mathbf{U}^{-1}\mathbf{A}_{\mathrm{SN}}\left(\mathbf{I} - \mathbf{A}_{\mathrm{NN}}\right)^{-1}\right] \\
\mathbf{R}_{\mathrm{NS}} &= \left(\mathbf{I} - \mathbf{A}_{\mathrm{NN}}\right)^{-1}\mathbf{A}_{\mathrm{NS}}\mathbf{U}^{-1} \\
\mathbf{R}_{\mathrm{SN}} &= \mathbf{U}^{-1}\mathbf{A}_{\mathrm{SN}}\left(\mathbf{I} - \mathbf{A}_{\mathrm{NN}}\right)^{-1} \\
\mathbf{R}_{\mathrm{SS}} &= \mathbf{U}^{-1} \\
\text{with} \quad & \mathbf{U} = \mathbf{I} - \mathbf{A}_{\mathrm{SS}} - \mathbf{A}_{\mathrm{SN}}\left(\mathbf{I} - \mathbf{A}_{\mathrm{NN}}\right)^{-1}\mathbf{A}_{\mathrm{NS}}
\end{aligned} \tag{4}$$

After substituting the expressions for $\mathbf{q}_{\mathrm{N}}$ and $\mathbf{q}_{\mathrm{S}}$ in equation (2) and rearranging terms we obtain:

$$\begin{aligned}
&\left(\mathbf{p}_{\mathrm{S}}'\mathbf{A}_{\mathrm{SN}}\mathbf{R}_{\mathrm{NN}} - \mathbf{p}_{\mathrm{N}}'\mathbf{A}_{\mathrm{NS}}\mathbf{R}_{\mathrm{SN}}\right)\mathbf{f}_{\mathrm{NN}} + \left(\mathbf{p}_{\mathrm{S}}'\mathbf{A}_{\mathrm{SN}}\mathbf{R}_{\mathrm{NN}} - \mathbf{p}_{\mathrm{N}}'\left[\mathbf{I} + \mathbf{A}_{\mathrm{NS}}\mathbf{R}_{\mathrm{SN}}\right]\right)\mathbf{f}_{\mathrm{NS}} + \\
&\left(\mathbf{p}_{\mathrm{S}}'\left[\mathbf{I} + \mathbf{A}_{\mathrm{SN}}\mathbf{R}_{\mathrm{NS}}\right] - \mathbf{p}_{\mathrm{N}}'\mathbf{A}_{\mathrm{NS}}\mathbf{R}_{\mathrm{SS}}\right)\mathbf{f}_{\mathrm{SN}} + \left(\mathbf{p}_{\mathrm{S}}'\mathbf{A}_{\mathrm{SN}}\mathbf{R}_{\mathrm{NS}} - \mathbf{p}_{\mathrm{N}}'\mathbf{A}_{\mathrm{NS}}\mathbf{R}_{\mathrm{SS}}\right)\mathbf{f}_{\mathrm{SS}} = 0
\end{aligned} \tag{5}$$

Total consumption in South (in real terms) is defined as $f_S^{tot} = \mathbf{e}'(\mathbf{f_{NS}} + \mathbf{f_{SS}})$. This total consumption can be decomposed with respect to two dimensions. First, as mentioned before, the shares of the two countries of origin are given by (the second column of) the trade coefficient matrix $\mathbf{T^F}$. Second, the shares of the commodities in total consumption are given by (the second column of) the so-called 'bridge matrix' $\tilde{\mathbf{B}}^{\mathbf{F}}$, which is assumed to be given at the beginning of each period.[9] Now, we can substitute $\mathbf{f_{NS}} = (\mathbf{t_{NS}^F} \circ \mathbf{b_S^F})f_S^{tot}$ and $\mathbf{f_{SS}} = (\mathbf{t_{SS}^F} \circ \mathbf{b_S^F})f_S^{tot}$ in equation (5). Analogous expressions can be substituted for consumption in North, $\mathbf{f_{NN}}$ and $\mathbf{f_{SN}}$. After subtracting the terms including the latter vectors ($\mathbf{f_{NN}}$ and $\mathbf{f_{SN}}$) from both sides of the equation we arrive at:

$$\begin{aligned}\{(\mathbf{p_S}'\mathbf{A_{SN}R_{NN}} - \mathbf{p_N}'[\mathbf{I} + \mathbf{A_{NS}R_{SN}}])(\mathbf{t_{NS}^F} \circ \mathbf{b_S^F}) + (\mathbf{p_S}'\mathbf{A_{SN}R_{NS}} - \mathbf{p_N}'\mathbf{A_{NS}R_{SS}})(\mathbf{t_{SS}^F} \circ \mathbf{b_S^F})\}f_S^{tot} = \\ -\{(\mathbf{p_S}'\mathbf{A_{SN}R_{NN}} - \mathbf{p_N}'\mathbf{A_{NS}R_{SN}})(\mathbf{t_{NN}^F} \circ \mathbf{b_N^F}) + (\mathbf{p_S}'[\mathbf{I} + \mathbf{A_{SN}R_{NS}}] - \mathbf{p_N}'\mathbf{A_{NS}R_{SS}})(\mathbf{t_{SN}^F} \circ \mathbf{b_N^F})\}f_N^{tot}\end{aligned} \quad (6)$$

Note that the matrices and vectors present in the factor between large curly brackets in the left hand side of equation (6) are all known, except for the price vectors to which we will turn below. Further, this factor is a scalar. If we denote this scalar by r_S and denote the analogous factor for North by r_N, we obtain the following relation:

$$f_S^{tot} = -\left(\frac{r_N}{r_S}\right)f_N^{tot} \quad (7)$$

Equation (7) shows that the solutions which represent current account equilibrium together constitute a line. For the values of the coefficient matrices chosen in the simulations reported in Section 4, the slope of the line is positive. The underlying mechanism is rather straightforward. Increased consumption in North induces more imports from South, which enables South to import more from North. These imports can increase South's consumption both directly (if the additional imports are consumed) or indirectly (if the additional imports are used as intermediate inputs in South's production processes). The exact slope depends on the production technologies, the trade coefficients and the preferences of consumers.

In order to determine a unique solution for the short run, we have to impose an additional equation: consumption cannot simultaneously be balance of payments-constrained in both countries. Various alternatives are available, but in the present version of the model we follow McCombie (1993) by assuming that one of either countries is constrained by its available resources. That is, for each period, either employment in North equals its maximum labor supply (l_N^{max}) or employment in South equals its maximum labor supply (l_S^{max}). These maximum labor supply levels are given for every period, as will become clear when we deal with the long-run

[9] The (2*n*x2)-bridge matrix $\tilde{\mathbf{B}}^{\mathbf{F}}$ consists of two stacked identical (*n*x2)-matrices $\mathbf{B^F}$, which reflect the distribution of total consumption expenditures in North (first column) and South (second column) over the *n* specified commodities. The dynamics governing $\mathbf{B^F}$ will be discussed in the next section.

equations. Since employment levels in North do not only depend on North's own consumption but also on consumption in South (and *vice versa*), the full employment assumptions yield another two relations between the two total consumption levels f_S^{tot} and f_N^{tot}. First, we write

$$\begin{aligned} l_N^{max} &= \mathbf{l_N q_N} \\ &= \mathbf{l_N}\left(\mathbf{R_{NN} f_{NN}} + \mathbf{R_{NN} f_{NS}} + \mathbf{R_{NS} f_{SN}} + \mathbf{R_{NS} f_{SS}}\right) \end{aligned} \tag{8}$$

Next, we write the consumption vectors once more as a product of trade coefficients, preference coefficients and total consumption, to arrive at

$$l_N^{max} - \left\{\mathbf{l_N}\left[\mathbf{R_{NN}}\left(\mathbf{t_{NN}^F} \circ \mathbf{b_N^F}\right) + \mathbf{R_{NS}}\left(\mathbf{t_{SN}^F} \circ \mathbf{b_N^F}\right)\right]\right\} f_N^{tot} = \left\{\mathbf{l_N}\left[\mathbf{R_{NN}}\left(\mathbf{t_{NS}^F} \circ \mathbf{b_S^F}\right) + \mathbf{R_{NS}}\left(\mathbf{t_{SS}^F} \circ \mathbf{b_S^F}\right)\right]\right\} f_S^{tot} \tag{9}$$

If we denote the factor between curly brackets at the left hand side by λ_N and the factor between curly brackets at the right hand side by λ_S, the resulting linear relation between the two total consumption levels can be written as

$$f_S^{tot} = \frac{l_N^{max}}{\lambda_S} - \left(\frac{\lambda_N}{\lambda_S}\right) f_N^{tot} \tag{10}$$

Since both the numerator and denominator of the coefficient are positive, the line described by equation (10) is downward sloping. If the consumption level in North would be reduced, the consumption level in South would have to increase in order to keep the labor previously employed in the production of exports (and of the materials indirectly required) at work. The slope itself is determined by technological relations, trade coefficients and consumer preferences. Analogously, we can find a relation corresponding to full employment in South:

$$f_S^{tot} = \frac{l_S^{max}}{\mu_S} - \left(\frac{\mu_N}{\mu_S}\right) f_N^{tot}, \tag{11}$$

with $\mu_N = \mathbf{l}_S\left[\mathbf{R_{SN}}\left(\mathbf{t_{NN}^F} \circ \mathbf{b_N^F}\right) + \mathbf{R_{SS}}\left(\mathbf{t_{SN}^F} \circ \mathbf{b_N^F}\right)\right]$ and $\mu_S = \mathbf{l_S}\left[\mathbf{R_{SN}}\left(\mathbf{t_{NS}^F} \circ \mathbf{b_S^F}\right) + \mathbf{R_{SS}}\left(\mathbf{t_{SS}^F} \circ \mathbf{b_S^F}\right)\right]$.

Solving the system of equations constituted by equations (7) and (10) yields the situation in which North's consumption is both balance of payments-constrained and labor-constrained, but South's is only balance of payments-constrained:

$$f_N^{tot} = \frac{r_S l_N^{max}}{r_S \lambda_N - r_N \lambda_S} \quad \text{and} \quad f_S^{tot} = -\left(\frac{r_N}{r_S}\right)\left(\frac{r_S l_N^{max}}{r_S \lambda_N - r_N \lambda_S}\right) \tag{12}$$

Of course, we can similarly find the intersection of the upward sloping balance-of-payments line (7) and the downward sloping line (11), which corresponds to labor and balance of payments constraints on South's consumption and balance of payments-constrained consumption in North:

$$f_N^{tot} = \frac{r_S l_S^{max}}{r_S \mu_N - r_N \mu_S} \text{ and } f_S^{tot} = -\left(\frac{r_N}{r_S}\right)\left(\frac{r_S l_S^{max}}{r_S \mu_N - r_N \mu_S}\right) \tag{13}$$

The short-run equilibrium point in the (f_N^{tot}, f_S^{tot})-plane is now defined as the minimum of the points given by equations (12) and (13), since in the other intersection point one country would produce above its capacity. Given these consumption levels and their compositions with regard to sectors and countries of origin, equation (3) is used to obtain gross output levels.

Finally, commodity-specific prices (expressed in a common currency, assuming an exchange rate which is known at the beginning of each period) are determined as usual in input-output models, except for our inclusion of two wage rates and a factor which converts these rates to a common currency:

$$\mathbf{p}' = \mathbf{v}'\hat{\mathbf{X}}\mathbf{L}[\mathbf{I} - \mathbf{A}]^{-1} \tag{14}$$

The (2x1)-vector **v** denotes the nominal wage rates (in North and South, expressed in the national currencies), which we assume to be given at the beginning of each period. The (2x1)-vector **x** has the exchange rate as its first element and a one as its second. This implies that we adopt the rule to express both Northern and Southern prices in Southern currency.

The extended international input-output model we introduced in this section yields output, and employment levels by industry and country, as well as consumption levels for each of the commodities produced in North and South. These levels are completely determined by the production technologies, trade relations, consumer preferences, maximum labor supply, prices, the exchange rate and the nominal wage rates prevailing during a period. Since we are primarily interested in the long-run dynamics of the endogenous variables mentioned, we now turn to the specification of the equations which describe the intertemporal behavior of the variables which we have assumed to be fully exogenous so far.

3. Model Description: Intertemporal Relations

In this section we will present the intertemporal equations which allow us to study long-run issues like output growth, convergence and structural change. Unlike the previous section, this section does not include the derivation of solutions. Due to the mathematical complexity caused by our explicit focus on economies consisting of interdependent industries, analytical solutions are hard or impossible to derive. We will first deal with the equations describing technological progress and subsequently discuss the relations we specified with regard to trade share dynamics, exchange rate movements and the growth of labor supply. Finally, we will turn to an essential part of this paper, the specification of commodity-specific income elasticities of consumer demand.

3.a Technology Dynamics

In the previous section, we introduced the definitions of technological indicators in a static context. Since we believe that empirically observable long-run phenomena like output and productivity growth, structural change and changes in international trade patterns are mainly caused by (differences in) technological progress, we now turn to a brief discussion of the way in which technological change is dealt with. Sticking to previous contributions to interindustry modeling of technological change (Leontief and Duchin, 1986, Verspagen, 1999, and Los, 2000), we model cumulated innovations as changes of the input coefficients contained in $\mathbf{A}^*$ and $\mathbf{L}$. We define industry-specific rates of technological progress as the proportional changes of the inverse of the coefficients in $\mathbf{L}$, the ratios between gross output and labor inputs.[10] Following Verspagen (1999), we assume fixed industry-specific ratios between growth rates of industrial labor productivities and growth rates of the other output-to-input ratios. These are called 'technological biases'. For reasons of exposition, we assume that the shares of the n specified intermediate inputs in total intermediate inputs (by industry), remain stable over time.[11] We use the (nxn)-diagonal matrices $\hat{\mathbf{\Lambda}}$ and $\hat{\mathbf{H}}$ for technological progress and intermediate input bias, respectively. The elements of the first matrix are equal to one in the case of no technological progress, and the smaller the faster progress is. In case of no biases in an industry, the diagonal of the bias matrix consists of ones. An element larger than unity indicates a technological bias away from saving the corresponding inputs, whereas an element smaller than one reflects a bias towards saving the corresponding inputs. Now, we can write for the dynamics of the two types of inputs:[12]

$$\mathbf{L}[1] = \hat{\mathbf{\Lambda}}[1]\mathbf{L}[0] \qquad \mathbf{A}^*[1] = \hat{\mathbf{\Lambda}}[1]\hat{\mathbf{H}}[1]\mathbf{A}^*[0] \tag{15}$$

In the simulations reported on in Section 4, we assumed that all technological progress is purely labor-saving. This amounts to fixing the values of the technological bias matrices to the inverse of the technological progress matrix, for every period. With respect to the technological progress matrix $\hat{\mathbf{\Lambda}}$ itself, we modeled two regimes. In the first regime, the industry under consideration (say, i) has lower labor requirements per unit of gross output than its foreign competitor (industry $n+i$). In that case, we call i the leader and $n+i$ the laggard. Under this regime, innovations of a

10 This definition of technological progress does not correspond to the common measure of labor productivity growth, the proportional growth rate of value added minus the proportional growth rate of labor inputs. It is purely used for modeling purposes. In our reports on the simulation results (see Section 4) we will use the common measure to analyze convergence issues.

11 So, innovation-induced substitution (such as of glass, metal and stone inputs by plastics) are not considered. Note, however, that the mechanisms driving the model are not altered by more realistic assumptions in this respect.

12 To avoid confusion between time indices and elements of trade shares matrices, we have chosen not to use the indicator t for time. Instead, periods are denoted by numbers.

random size (in terms of labor requirement reductions) take place at random points in time.[13] In the second regime, the industry under consideration is lagging behind. In that case, innovations do no occur, but the technological gap to the leader industry is assumed to give opportunities for catching-up, for instance by imitation of the competitor's production technology. The reductions in labor coefficients under the two regimes can be represented by

Leader regime: $$\hat{\Lambda}_{ii}[1] = \frac{1}{\left(1 + Inn_i[1]\right)} \tag{16}$$

Laggard regime: $$\hat{\Lambda}_{ii}[1] = \frac{1}{\left(1 + \alpha_i \ln\left(\frac{l_i[0]}{l_{n+i}[0]}\right)\right)} \tag{17}$$

in which α (0<α<1) are industry-specific parameters.[14]

The innovations are assumed to arrive according to a Poisson process (following e.g. Aghion & Howitt, 1992, and Silverberg & Verspagen, 1994). The size of each innovation is also randomly determined, according to an exponential distribution. This distribution ensures that 'large' innovations are relatively seldom occurring.[15]

In the present version of the model, the catch-up process is modeled in a simple way: the larger the productivity gap in terms of labor inputs per unit of gross output, the more the laggard industry will catch up. Hence, this Gerschenkron (1962) specification does not include issues of lack of absorptive capacity or openness to imports. Note, however, that our interindustry specification implicitly takes account of the fact that incompatibility of output structures plays an important role. For example, if South would lag North in computer manufacturing but produces only a very small part of its output in this industry (for instance due to international specialization), aggregate labor productivity would not benefit that much from the technology gap.

3.b Trade share dynamics

Trade share dynamics are ruled by (changes in) relative competitiveness. According to traditional theory, the competitiveness of countries is determined by costs per unit of output. In such a situation, the interplay of two developments would determine changes in a country's competitiveness: reductions in the amounts of labor required per unit of output and changes in

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13 For simplicity, we do not include explicit search for innovations (R&D) in the model. See Los (2000) for an intersectoral model with endogenous growth in a single-country context.

14 Note that the (rightmost) catch-up term in the laggard regime equation is defined in such a way that *i* corresponds to a Northern industry. In the alternative case, the index for *l* in the denominator is *i-n*.

15 If two or more innovations arrive in the same period, their sizes are simply added.

the relative wage rates.[16] These factors are assumed to be summarized by prices, as follows from equation (14). More recent trade theory, however, emphasizes that countries not only compete by attempting to reduce prices, but also by attempting to produce qualitatively superior goods (see, e.g., Fagerberg, 1988, for a contribution in the Post-Keynesian tradition and Grossman and Helpman, 1991, for a mainstream approach). A proper specification of the latter, though, would require a model specification with explicit product innovation. Since the present version of the model deals with productivity growth through process innovation only, we cannot include the effects of technological competition in an explicit way: changes in a country's shares on the world markets are assumed to be dependent on price differentials only.

To determine the trade shares for each of the commodities in each of the industries, we use the concept of a (inverted) logistic curve, as illustrated in Figure 2. In mathematical terms, this relation between the price ratio and the 'equilibrium' market share of North's industry *i* on its domestic market for consumption goods is:

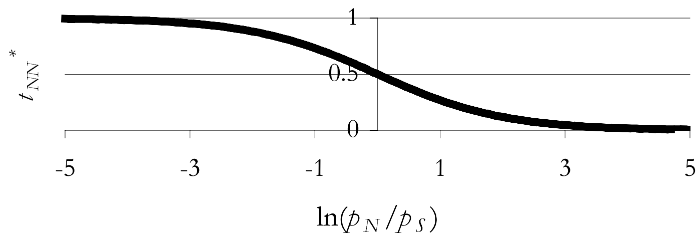
$$t_{NN,i}^{F*} = \frac{1}{1+e^{\left(-\left(-\ln\frac{p_{Ni}}{p_{Si}}-\varepsilon_i\right)/\varphi_i\right)}} \quad \text{and} \quad t_{SS,i}^{F*} = \frac{1}{1+e^{\left(-\left(\ln\frac{p_{Ni}}{p_{Si}}-\varepsilon_i\right)/\varphi_i\right)}} \qquad (18)$$

As mentioned before, the domestic and foreign trade shares add up to one, so t_{SN}^{F*} and t_{NS}^{F*} are determined simultaneously. Further, analogous equations are specified for the elements of the matrix $\mathbf{T^A}$. For every commodity, however, we used identical trade shares in our simulations reported on in Section 4, irrespective of its use as an intermediate input or as a consumption good.

The parameter ε can be interpreted as the value of the logarithm of the price ratio for which the market shares are equally divided. For a perfectly tradable good this parameter will equal zero, but for most goods the price ratio corresponding to equal market shares will have a positive value. In this case, the market shares of domestically produced inputs will be larger than fifty percent when prices are equal. The extent to which the market share at the unit price ratio differs from fifty percent is not only dependent on the value of ε, but also on the parameter $\varphi(>0)$ which represents the commodity-specific sensitivity of trade shares to changes in the price ratio. The lower φ, the more sensitive the trade shares are. The parameters φ may be affected by a number of things, such as costs of transportation and trade barriers. Further, quality differences (which, as mentioned before, are not explicitly modeled) may play a decisive role: a cheaper Russian car is not likely to change its share on the U.S. consumer market to a considerable extent.

[16] These unit labor costs are generally converted to a common currency. Hence, exchange rate changes may alter the competitiveness structure as well.

Figure 2: Trade Shares



Since we do not believe that trade shares adjust immediately to changes in prices, we model an adjustment process, in which the gap between the actual trade shares *t* and the 'equilibrium' trade shares t^* vanish gradually in the absence of shocks (omitting industry indices and indices A and F for the use of traded goods):

$$t[1] = t[0] - \eta^t \left(t[0] - t^*[1] \right) \qquad (19)$$

with η^t ($0<\eta^t<1$) denoting the speed of adjustment.

3.c Maximum labor supply, wage rates, and the exchange rate

Since we assume that total consumption levels in North and South are partly determined by either one of two full-employment conditions, the dynamics of maximum labor supply in the two countries may prove to be an important determinant of relative performance in terms of long-run output and employment growth. Although researchers in the field of development economics have found some evidence for a causal relationship running from 'welfare' to population growth, we will assume that the populations of the two countries grow at constant, country-specific rates. For simplicity, we also assume that maximum labor supply equals population. Hence, we write:

$$l_N^{max}[1] = \left(1 + \nu_N\right) l_N^{max}[0] \quad \text{and} \quad l_S^{max}[1] = \left(1 + \nu_S\right) l_S^{max}[0] \qquad (20)$$

The two country-specific nominal wage rates are assumed to be constant, at least if expressed in national currencies. Due to the fact that technological progress reduces the direct and indirect labor requirements for consumption goods, prices will consequently be lowered (see equation (14)) and the real wage rate will grow. One caveat applies, however. In a system of flexible exchange rates, the purchasing power of a given amount of Northern currency relative to an identical amount of Southern currency may change.

In the modeling of exchange rate dynamics we use a specification similar to that of trade shares: the new exchange rate is a weighted average of the actual rate and an 'equilibrium rate' based on purchasing power parity of the two currencies:

$$x[1] = x[0] - \eta^{x}\left(x[0] - x^{*}[1]\right) \tag{21}$$

The smaller η^x ($0 \le \eta^x \le 1$), the more a system of fixed exchange rates (e.g. a monetary union) is approximated. x^* is determined according to:

$$x^{*}[1] = \frac{\sum_{i=1}^{n} p_{Si}^{nat}[0]\left(q_i[0] + q_{i+n}[0]\right)}{\sum_{i=1}^{n} p_{Ni}^{nat}[0]\left(q_i[0] + q_{i+n}[0]\right)} \tag{22}$$

The superindices *nat* indicate prices expressed in national currencies.[17]

3.d Consumer preferences dynamics

Almost every contribution to development economics stresses the relation between growing levels of income per capita and changing output and employment mixes. Empirical cross-section and time-series studies justify this focus (see for example Verspagen, 1993, Ch. 4, and Los, 1999, Ch. 1): in particular agriculture's shares in output and employment generally decrease with increasing income levels, while manufacturing and (in later stages of development) services become more important. A number of mechanisms underlying these regularities have been singled out, among which interindustry differences in the rate of productivity growth feature prominently. Interindustry differences in income elasticities of consumption demand are another often stressed source of growth-related structural change. Commodity-specific Engel curves which represent these differences were introduced in growth theory by Pasinetti (1981) and later used in technology-driven models by Verspagen (1993, 1999) and Los (1999). In this model, we use a discrete-time variant of a specification introduced by Verspagen (1993), which ensures that the consumption shares for each country always add up to one:

$$\mathbf{b}_{\bullet}^{\mathbf{F}}[1] = \mathbf{b}_{\bullet}^{\mathbf{F}}[0] + \left[\hat{\mathbf{B}}_{\bullet}^{\mathbf{F}}[0]\mathbf{T}\left(\mathbf{b}_{\bullet}^{\mathbf{F}}[0] - \mathbf{b}_{\bullet}^{*}\right) - \left(\hat{\mathbf{B}}_{\bullet}^{\mathbf{F}}[0] - \hat{\mathbf{B}}_{\bullet}^{*}\right)\mathbf{T}'\mathbf{b}_{\bullet}^{\mathbf{F}}[0]\right] \cdot \left(\frac{f_{\bullet}^{tot}[0]}{l_{\bullet}^{max}[0]} - \frac{f_{\bullet}^{tot}[-1]}{l_{\bullet}^{max}[-1]}\right) \tag{23}$$

In this specification, $\mathbf{b}^*$ represents the consumption shares which prevail at an infinitely high consumption per capita level. The elements τ of matrix $\mathbf{T}$ indicate how quick current consumption levels adapt to $\mathbf{b}^*$. If $\mathbf{T}$ is chosen to have zeroes on the main diagonal and sufficiently small nonnegative values elsewhere, negative shares will not occur and actual shares will converge monotonically to their asymptotic values if consumption per capita grows.

If an initial variable configuration is specified and the parameters are assigned values, the model described by equations (1)-(23) can be simulated in order to see whether the long-run

[17] These are obtained by dividing the elements of $\mathbf{p}$ by the exchange rate for commodities produced in North and leaving them unchanged for commodities produced by South.

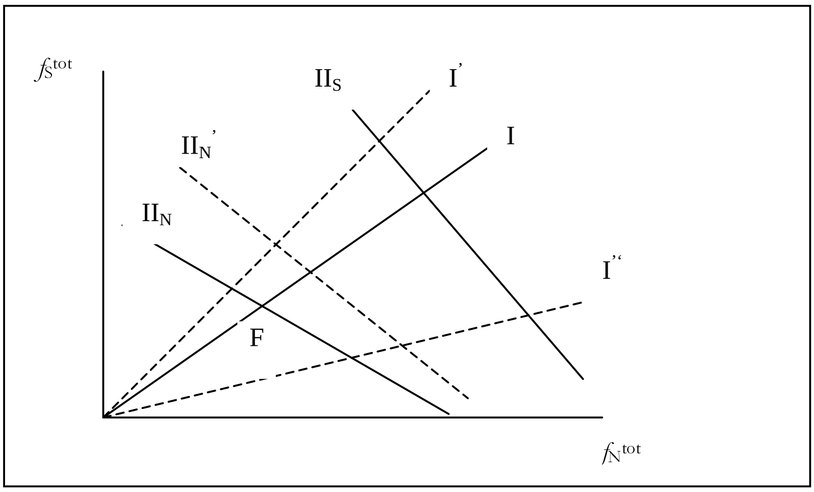
results are sensitive to particular parameters of interest or not. In the next section we will present the outcomes of a number of simulations, most of which focus on the growth effects of changing compositions of consumption demand.

4. Simulation Results

As mentioned earlier, the long-run behavior of the two national economies in our model can best be studied by means of simulation analysis. Before we turn to a discussion of some of the simulation results we obtained, it may prove insightful to illustrate the basic effects of an innovation by some diagrams which depicts some highly simplified comparative statics analysis.

In Figure 3, the axes indicate the total consumption levels for North and South. The solid upward sloping line (I) reflects all pairs of consumption levels for which the balance of payments is in equilibrium in the initial situation, see equation (7). The downward sloping solid lines (II_N and II_S) indicate all pairs of consumption levels for which full employment initially prevails in North and in South, respectively, see equations (10) and (11). The slopes of these lines will generally differ, e.g. due to different compositions of consumption bundles with respect to countries and sectors of origin. In the situation depicted, consumption levels are given by intersection point F, in which North experiences full employment and South faces excess labor supply.

Figure 3: Consumption effects of innovation.



Now, we assume that North generates a labor saving innovation. Consequently, the labor constraint will be less tight, and for given consumption levels in North higher consumption levels in South are attainable, since more 'effective' labor is available to produce exports and the required intermediate inputs. This is reflected by the upward shift of the Northern full employment line (see dashed line II_N'). In general, the slope will change as well, but the sign of this change depends on the interplay of many parameter values. Nevertheless, the 'first order' effect of technological progress in the labor-constrained country (be it through innovation or through catch-up) is an increase in both North's and South's consumption level.

The supposed innovation in North has some 'second order' effects, too. The net effects of these are ambiguous, as will become clear after studying the dashed lines $I^{'}$ and $I^{''}$. The lines represent two important opposite effects. First, innovation yields a lower price per unit of output for North. This implies that for a given amount of exports, North can buy less imports and must reduce its consumption, while South can increase its import volume at constant costs ($I^{'}$). This is a terms-of-trade effect. Second, North's reduced price enhances its competitiveness relative to South, which could cause higher market shares. Consequently, innovating North requires less imports per unit of output, which enables it to produce more consumption goods. For South the opposite holds and its attainable consumption level will fall. This effect is documented by curve $I^{''}$.

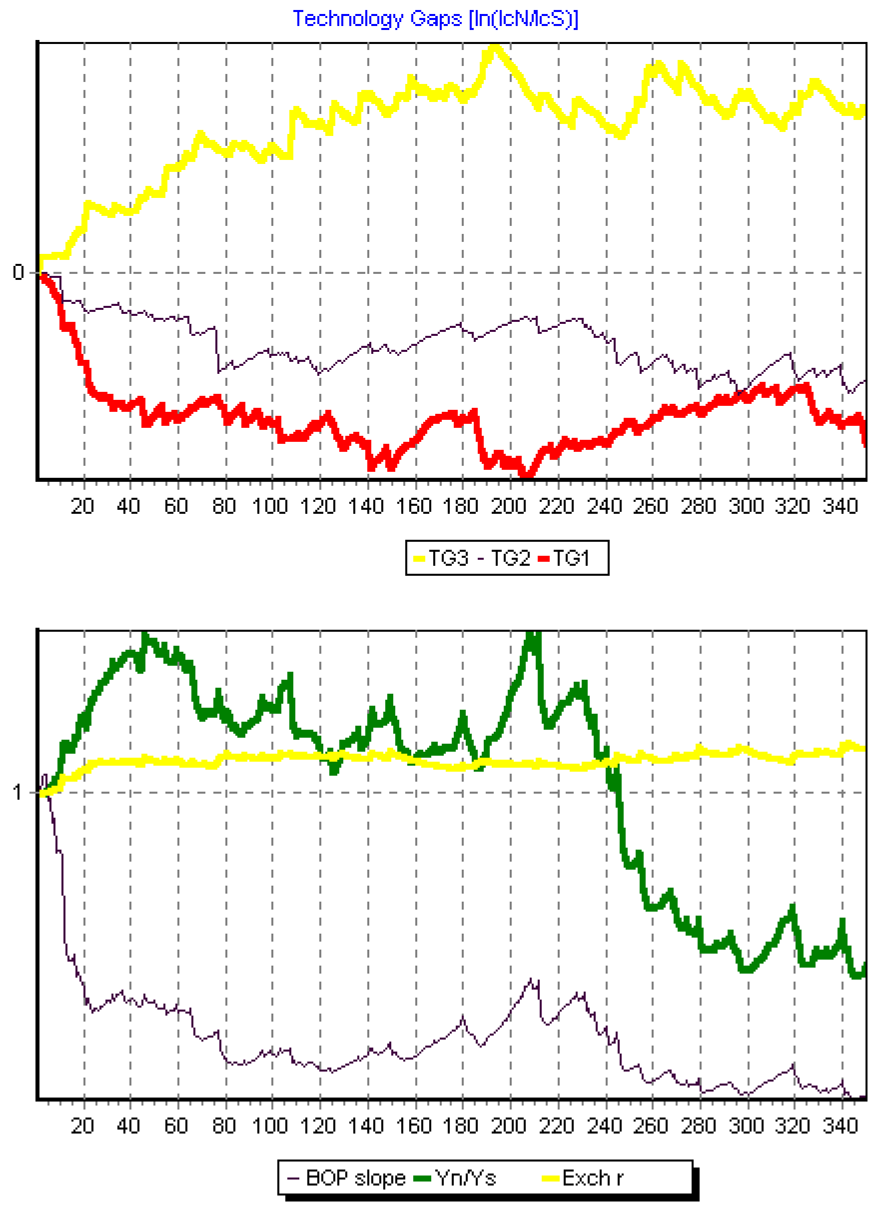
Which of the two second-order effects dominates depends on a number of parameters and variables, of which the sensitivity of market shares to price changes is an important one. However, also the trade structure with respect to the intermediate inputs required for its production matters. The bottom line of this simple comparative statics analysis is that it is impossible to tell in advance which effect will dominate, and hence what the ultimate effect of an innovation on relative growth rates will be.

In order to get an insight into the behavior of the model, we resort to simulation analysis. While one would ideally like to investigate the complete parameter space by varying each parameter in turn while keeping the other parameters constant, this is obviously a too large task given the number of parameters of the model. We therefore concentrate on the set of parameters related to the sectoral arrival rates of innovation (λ). We leave other parameters for future research.

Before we present the results of repeated simulations for parameter variations, we first illustrate the basic behavior of the model by looking at a single simulation run. The parameter values for this run are given in the appendix. The run is set up in such a way that sector 2 is the key to the results in the figure. This sector is initially small (in terms of its consumption share), but has a tendency to grow (to 45% of total consumption) when real income grows. Sector 2 is also the sector with the lowest rate of technical progress: the arrival rate of innovations in this sector is half the rate attained in the other sectors. Sector 1 is initially large, but its share declines (also to 45%). Sector 3 is a small sector for which the consumption share stays constant.

At the start of the simulation, productivity is equal in all sectors and countries. Due to random innovation, one country will gain an advantage in each of the sectors, and market shares will react to this. As it turns out in the run in Figure 4 (top panel), North becomes the technological leader in sectors 1 and 2.[18] South leads in sector 3. Because sector 1 is large, this (random but persistent) pattern enables North to start as the macro productivity leader (bottom panel, top line, *Y* indicates aggregate labor productivity in terms of real value added over physical labor input).

Figure 4. Simulation results



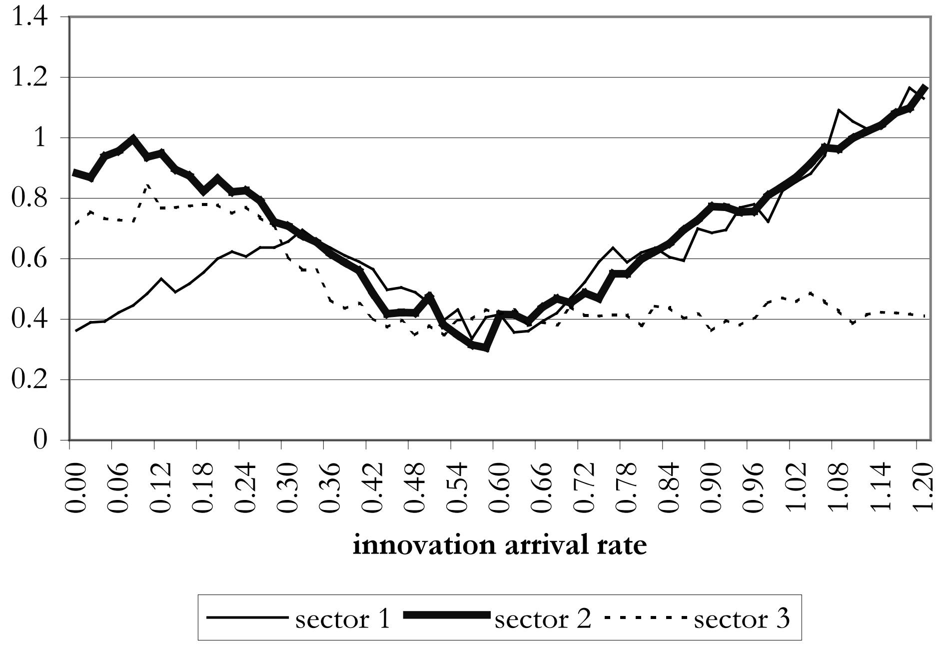
The Northern leadership in sectors 1 and 2, by nature of the specification of catch-up and technological change, will persist in the long run. But this does not mean that North remains the overall productivity leader. As sector 2 increases its share in consumption, the sector becomes more and more important for the macro leadership. Because technical change is slow in sector 2, specialization in this sector retards macro productivity, at an increasing rate when the sector

[18] Note that the vertical axis of Figure 4's top panel represents the logarithm of the ratio of labor requirements per unit of gross output. A negative value therefore indicates lower requirements for North and its technological leadership.

becomes larger. Random innovation in this sector causes fluctuations in the specialization pattern. Around period 180, sector 2 has become so large that this effect starts to play a dominant role. The increase of the Northern macro productivity lead (bottom panel, top line) that starts shortly after period 180 is the result of increasing specialization of South in sector 2. However, around period 240, due to random innovation in North as well as price dynamics, South becomes de-specialized in sector 2, and, accordingly, North becomes specialized in this sector. This leads to the takeover of macro productivity leadership by South (bottom panel Figure 4).

Note that because of the growing consumption share of sector 2 as a function of (growing) total consumption, one may indeed say that the fall in productivity leadership of North is an endogenous event. In a way, the Northern leadership is self-destructive, because it invokes a larger share of sector 2 in consumption, and this, given the positive specialization of North and the slow rate of technical progress in this sector, leads to slower growth in the North. Obviously, this process is similar to Baumol's disease, but the context of international productivity differences adds an interesting dimension to the closed economy context in which this phenomenon is often analyzed.

Figure 5. Productivity differences for varying values of the innovation arrival rate



The run thus illustrates that consumption share dynamics play an important role in (macroeconomic) productivity leadership. We now turn to a set of simulation experiments that will underline this effect in a more systematic way. The setting is almost identical to the one in the above experiment, with the exception of the arrival rates of innovations in each of the sectors. We perform three experiments. In each of them, the arrival rate of innovations is fixed to

0.6 in two of the three sectors, while the arrival rate in the other sector grows from zero to 1.2. We examine the variations of macroeconomic productivity differences between North and South with these differing values of the arrival rate.

Figure 5 displays the results from the three experiments. The vertical axis gives the mean productivity level difference between North and South over the last 250 periods in a 350 period run. These values are taken as the mean over 20 runs with identical parameter values (but different draws of the random numbers), and can thus be conceived as an average outcome more or less independent of stochastic fluctuations. The horizontal axis displays the value of the arrival rate of innovations in a sector. The arrival rate is fixed at 0.6 in the two other sectors, which implies that at 0.6 on the horizontal axis, the (expected) rate of technical progress is equal among the three sectors.

It turns out that the point 0.6 on the horizontal axis indeed plays a crucial role. Focusing on sector 2 to start, we see a V-shaped pattern around this point. Remember that to the left of the point 0.6, sector 2 is the lagging sector in productivity difference, hence we would expect that at some point of time, the negative effect of specialization in this sector will dominate the macroeconomic pattern (as in Figure 4). The more sector 2 lags in terms of productivity, the more scope there is for this effect to become large, and set in earlier. Hence, for values on the left of Figure 5, we find relatively high values of macroeconomic inequality (this is the left top of the V). With an increasing arrival rate in sector 2, the effect vanishes, and the process converges to a lower value of inequality. Hence the curve for sector falls over the range 0 to 0.6.

To the right of the point 0.6, the scope for large productivity differences increases again, but now in a way that is opposite to the case in Figure 4. Now specialization in sector 2 leads to an increasing probability of macroeconomic leadership, because the share of sector increases over time, while technical progress is relatively rapid. Hence we see an increasing line for macroeconomic inequality to the right of 0.6.

Switching the attention to sector 1 (large initially, but declining), we note that in principal, one would expect a similar pattern to that for sector 2. To the left of the point 0.6, sector 1 has slow technical progress, and hence specialization in this sector will slow down growth. But over time, this disadvantage becomes smaller because sector 1 declines in terms of its consumption share (whereas in the case of sector 2, the disadvantage became larger over time). The same line of reasoning as in the case of sector 2 would then lead to the expectation of a falling line for sector 1 to the left of the point 0.6.

Figure 5 shows, however, that this is only the case for the range 0.35-0.6 (roughly). Left of this point, the line is upward sloping. The reason for this lies in a subtle aspect of the consumption share dynamics: consumption shares increase or decrease as a function of real income. The slow growth associated with specialization in sector 1 may thus lead to relatively slow adaptation of the consumption shares. In this way, the world economy may enter in a low-growth trap due to the initially large consumption share of sector 1. While in this 'trap', the scope for large inequality due to specialization in sector 1 is low. Although we have no clear explanation for the exact point at which this process becomes to dominate the results, it is obvious from looking at the simulation results on consumption shares (not documented here) that this causes the relatively low levels of inequality on the very left of the line for sector 1.

In a certain sense, this low-growth trap is the mirror image of the self-destructing productivity leadership that was noted in the discussion of Figure 4. Thus we note that the international version of Baumol's disease that we associated with that self-destructing tendency is only one of several manifestations of the unexpected effects of consumption share dynamics on international productivity growth rate differentials.

Sector 3 shows a pattern quite different from the (partly) V-shaped pattern of sectors 1 and 2. The reason for this is that sector 3 is quite small. Thus, when technical progress in this sector is slow, this only has a minor effect on macroeconomic productivity differences. For very low rates of technical progress in sector 3, the effect is noticeable, but the line levels off after (roughly) 0.45. From this point onwards, the differences in the arrival rate of innovations between the sectors are too small to cause any major differences in productivity, given the size of sector 3 (if we would extend the figure to the right, one would expect that at one stage the line would rise again).

5. Concluding Remarks

The model that was presented in this paper shows that an exclusive focus on either supply (i.e., technology) or demand factors may lead to a biased view on convergence or divergence of productivity levels. Even though our model greatly simplifies the dynamics found in the real economy, we find that the long-run impact of an innovation on (in)equality of productivity levels is hard to predict. This impact depends on the parameter values of the model (which, in principle could be obtained from econometric exercises), as well as on the state of the economy (i.e., the endogenous variables in the model).

To illustrate the latter point, we may summarize the result obtained in the simulation analyses associated to a situation that is traditionally described as Baumol's disease. In this case, productivity growth (technical change) is relatively low in a sector that increases its share in production over the long run (in our case, as a result of increasing real income). In such a case, a country specializing in the slow-growing but consumption-increasing sector may take macroeconomic leadership during a phase when the share of the sector is still low. Subsequently, growth of real income leads to an increasing share of the slow-growth sector and this retards growth. Eventually, macroeconomic leadership will be overtaken by a country specialized in the more dynamic sectors. Thus, under these circumstances, we see that macroeconomic productivity leadership is self-destructing. In mathematical terms, such a take-over of leadership may be interpreted as a bifurcation of our model.

We have also shown that a reverse situation may occur when technical change is rapid in the sector that sees its share in consumption increase. In such a case, specialization in this sector when it is still small may provide prospects for rapid productivity increases and associated macroeconomic productivity leadership in the future (when the sector becomes larger). But the present situation of dependence on the large slow-growing sectors may retard growth, and hence the shift towards the more dynamic sector. In this case, the economy may reside in a situation of relatively slow growth for a long time (low-growth trap).

Concluding, one may say that the introduction of both technological change and consumption share dynamics in a model of international growth rate differentials enriches the analysis greatly. Non-linearities and bifurcations in the model open up prospects for interesting dynamics, partly corresponding to previous analysis of closed economies (Baumol's disease). We are, however, just at the first stage of the analysis of our model, and the full richness of the potential results thus still remains somewhat obscured in the clouds of future research.

References

Aghion, Ph. and P. Howitt (1992), "A Model of Growth through Creative Destruction", *Econometrica*, vol. 60, pp. 323-351.

Baumol, W.J. (1967), "Macroeconomics of Unbalanced Growth: The Anatomy of Urban Crisis", *American Economic Review*, vol. 57, pp. 415-426.

Baumol, W.J. (1986), "Productivity Growth, Convergence, and Welfare: What the Long-Run Data Show", *American Economic Review*, vol. 76, pp. 1072-1085.

Dietzenbacher, E., A.R. Hoen and B. Los (2000), "Labor Productivity in Western Europe 1975-1985: An Intercountry, Interindustry Analysis", *Journal of Regional Science*, vol. 40, forthcoming.

Fagerberg, J. (1988), "International Competitiveness", Economic Journal, vol. 98, pp. 355-374.

Gerschenkron, A. (1962), *Economic Backwardness in Historical Perspective*, Harvard University Press, Cambridge MA.

Leontief, W. and F. Duchin (1986), *The Future Impact of Automation on Workers*, Oxford University Press, New York.

Los, B. (1999), *The Impact of Research & Development on Economic Growth and Structural Change*, PhD Thesis, University of Twente, Enschede, The Netherlands.

Los, B. (2000), "Endogenous Growth and Structural Change in a Dynamic Input-Output Model", Working Paper, University of Groningen.

Los, B. and B. Verspagen (2000), "Technology Spillovers in an Interindustry Growth Model with North-South Trade", Working Paper, University of Groningen/Eindhoven University of Technology.

Lucas, R.E. (1988), "On the Mechanisms of Economic Development", *Journal of Monetary Economics*, vol. 22, pp. 3-42.

Luptacik, M. and B. Böhm (1999), "A Consistent Formulation of the Leontief Pollution Model", *Economic Systems Research*, vol. 11, pp. 263-275.

McCombie, J.S.L. (1993), "Economic Growth, Trade Interlinkages, and the Balance-of-Payments Constraint", *Journal of Post Keynesian Economics*, vol. 15, pp. 471-505.

McCombie, J.S.L. and A.P. Thirlwall (1994), *Economic Growth and the Balance-of-Payments Constraint*, Macmillan, London.

Miller, R.E. and P.D. Blair (1985), *Input-Output Analysis: Foundations and Extensions*, Prentice-Hall, Englewood Cliffs NJ.

Oosterhaven, J. and J.A. Van der Linden (1997), "European Technology, Trade and Income Changes for 1975-1985: An Intercountry Input-Output Decomposition", *Economic Systems Research*, vol. 9, pp. 393-412.

Pasinetti, L.L. (1981), *Structural Change and Economic Growth*, Cambridge University Press, Cambridge UK.
Romer, P.M. (1986), "Increasing Returns and Long-Run Growth", *Journal of Political Economy*, vol. 94, pp. 1002-1037.
Silverberg, G. and B. Verspagen (1994), "Collective Learning, Innovation and Growth in a Boundedly Rational, Evolutionary World", *Journal of Evolutionary Economics*, vol. 4, pp. 207-226.
Solow, R.M. (1956), "A Contribution the Theory of Economic Growth", *Quarterly Journal of Economics*, vol. 70, pp. 65-94.
Thirlwall, A.P (1979), "The Balance of Payments Constraint as an Explanation of International Growth Rate Differences", *Banca Nazionale del Lavoro Quarterly Review*, vol. 32, pp. 45-53.
Verspagen, B. (1993), *Uneven Growth between Interdependent Economies*, Avebury, Aldershot UK.
Verspagen, B. (1999), "Evolutionary Macroeconomics; What Schumpeterians Can Learn from Kaldor(ians)", Working Paper, Eindhoven University of Technology.

Appendix: Parameter and initial variable configuration in reference simulation run

```
1234567          Random seed
180.0            lmaxn (initial maximum labor supply North)
180.0            lmaxs (initial maximum labor supply South)
0.8              etax (exchange rate adjustment parameter)
0.0              nun (population growth rate North)
0.0              nus (population growth rate South)

Astar (intermediate input requirements)
0.300000  0.150000  0.150000  0.300000  0.150000  0.150000
0.150000  0.300000  0.050000  0.150000  0.300000  0.050000
0.050000  0.050000  0.300000  0.050000  0.050000  0.300000

Ta (initial trade shares for intermediate inputs)
0.666667  0.500000  0.500000  0.333333  0.500000  0.500000
0.666667  0.500000  0.500000  0.333333  0.500000  0.500000
1.000000  1.000000  1.000000  0.000000  0.000000  0.000000
0.333333  0.500000  0.500000  0.666667  0.500000  0.500000
0.333333  0.500000  0.500000  0.666667  0.500000  0.500000
0.000000  0.000000  0.000000  1.000000  1.000000  1.000000

0.8  0.8  bf (initial consumption shares)
0.1  0.1
0.1  0.1

0.45  0.45  bfstar ('asymptotic' consumption shares)
0.45  0.45
0.10  0.10

Tau (consumption share adjustment parameters)
0.000000  0.001000  0.001000  0.000000  0.001000  0.001000
0.001000  0.000000  0.001000  0.001000  0.000000  0.001000
0.001000  0.001000  0.000000  0.001000  0.001000  0.000000

0.727273  0.272727  tf (initial trade shares for consumption goods)
0.500000  0.500000
1.000000  0.000000
0.272727  0.727273
0.500000  0.500000
0.000000  1.000000
```

```
0.50                lcn (initial labor requirements in North)
0.50
0.50
0.50                lcs (initial labor requirements in South)
0.50
0.50

0.02                alfa (speed of catch-up parameters)
0.02
0.02

0.05 0.05           phiF (trade share adjustment parameters)
0.05 0.05
0.05 0.05
0.05 0.05           phiA
0.05 0.05
0.05 0.05
0.00 0.00           epsilonF (trade share adjustment parameters)
0.00 0.00
0.00 0.00
0.00 0.00           epsilonA
0.00 0.00
0.00 0.00
0.50                eta (trade share adjustment parameter)

0.6                 lambda (sectoral innovation arrival rates)
0.3
0.6

0.02                rho (sectoral average size of innovations)
0.02
0.02

200.0               qn (initial gross output levels in North)
100.0
100.0
200.0               qs (initial gross output levels in South)
100.0
100.0
```