TEL-AVIV

WP 3-97

THE SACKLER INSTITUTE
for Economic Studies

TEL AVIV UNIVERSITY
The Eitan Berglas School of Economics

מכון סאקלר לכלכלה

הפקולטה למדעי החברה ע"ש גרשון גורדון אוניברסיטת תל-אביב

The Sackler Institute for Economic Studies

Founded by Raymond R. Sackler, M,D, and Mortimer D. Sackler, M.D.

The Sackler Institute promotes theoretical and applied research in economics, in a wide of areas such as game theory, industrial organization, public finance, international trade, monetary economics, and more. The Institute's research staff is made up of members of The Eitan Berglas School of Economics at The Tel Aviv University.

KNOWLEDGE DISSEMINATION, CAPITAL ACCUMULATION, TRADE, AND ENDOGENOUS GROWTH

by

Dan Ben-David[1] and Michael B.Loewy[2]

Working Paper No.3-97

February, 1997

[1] The Eitan Berglas School of Economics, Tel-Aviv University, Ramat Aviv, Tel-Aviv 69978 and CEPR e-mail: BenDavid@econ.tau.ac.il.
[2] University of Houston

THE SACKLER INSTITUTE FOR ECONOMIC STUDIES
The Gershon H.Gordon Faculty of Social Sciences
Tel-Aviv University, Ramat Aviv, Israel.

ABSTRACT

This paper preserves many of the primary features of the standard neoclassical framework while introducing some modifications that transform it into an open economy endogenous growth model with knowledge accumulation. The accumulation of knowledge is determined in part by the extent of knowledge spillovers from abroad which, in turn, are affected by commercial policy that regulates the extent of trade between countries. The model predicts that trade liberalization (even if it is unilateral) will increase steady-state output growth in all countries while benefitting the liberalizing country (or countries) the most in terms of relative income levels.

1. INTRODUCTION

This paper examines the impact of unilateral trade policy on output levels and growth rates in the steady state. The objective is to formulate an open economy endogenous growth model based upon the standard neoclassical growth model of Solow (1956), Cass (1965), and Koopmans (1965). That model, which is essentially a closed economy model, is characterized by exogenous technological growth. We show how the technology variable, specified here as knowledge and which would grow at a fixed rate were the economy to be closed (à la Solow-Cass-Koopmans), instead grows at a rate that is endogenous when the economy is open. Thus, in the context of this modified model, a country's trade policy may influence both the rate of growth of its economy and its steady-state level of income vis-à-vis the other countries.

Why do we return to the Solow-Cass-Koopmans model when there have been so many recent developments in growth theory that endogenize the growth process in other ways?[1] The primary reason is that the standard neoclassical growth model appears to be consistent with a considerable number of empirical observations such as income convergence between U.S. states and regions (Ben-David, 1990; Barro and Sala-i-Martin, 1991; and Loewy and Papell, 1996), conditional convergence among countries (Barro, 1991; and Mankiw, Romer and Weil, 1992), as well as unconditional income convergence among developed countries (Baumol, 1986). Furthermore, as Mankiw, Romer and Weil (1992) note, the model correctly predicts the directions of the effects of saving and population growth. Yet, as Mankiw, Romer and Weil also point out, "all is not right for the Solow model." By virtue of its being dependent on an exogenous growth rate, the standard model is unable to account for the substantial postwar increases in growth among developed countries that have coincided with trade liberalization in those countries. Hence, the focus in this paper is on the impact of trade on the growth process.

Maddison (1982) calculates the average productivity growth rates of the leading countries — that is, countries with the highest output per hour worked — over a span of nearly three centuries and shows

[1] Within the trade-growth context, see, for example, Rivera-Batiz and Romer (1991a,b) and Grossman and Helpman (1991).

that they moved from virtual stagnation in the 1700s to annual growth of over 2% in the 1900s. Ben-David and Papell (1995) search for a structural trend break in the long-run growth paths of real per capita output in 16 OECD countries since 1870. In their calculation of steady-state growth rates along the pre- and postbreak paths, they find that countries grew along their new, postbreak, paths at steady-state rates that were, on average, over twice as high as their prebreak steady-state growth rates.

Table 1 illustrates the long-term behavior of trade and growth by providing some postwar-prewar comparisons for the 16 OECD countries in the Maddison (1991) sample. Each country exhibited increases in their average postwar growth rates (in comparison with their average prewar growth rates). These ranged from a 38% increase for the United States to increases exceeding 200% for five other countries. At the same time, average ratios of exports to output were higher during the postwar for all but one of the countries.[2]

Can the growth increases depicted in Table 1 actually be tied to a greater openness among these countries? Ben-David (1993 and 1996) examines subsets of these countries that are formed on the basis of trade ties and finds substantial evidence that movement towards trade liberalization led to heightened trade flows and was accompanied by significant convergence in per capita output among the trading countries.[3] Hence, increased openness does appear to affect output. Furthermore, when these trade-related convergence findings are combined with Ben-David and Papell's (1995) findings of faster growth, the evidence appears to suggest that the convergence did not come at the expense of the wealthier trading countries, but rather that all of the trading countries experienced faster growth — with the poorer traders benefitting the most. This is consistent with the findings in Sachs and Warner (1995) who find that trade liberalization is related to faster growth. The model developed in this paper represents an attempt at

---

[2] The lone country not experiencing an increase in its export-output ratio is Australia. While this ratio remained relatively unchanged following World War II, Australia experienced a massive population inflow that provided many of the same benefits that trade in goods provide in lieu of such migration flows.

[3] Ben-David (1993) examines the evolutionary periods of the European Economic Community (EEC), the European Free Trade Association (EFTA), and the US-Canada trade pacts within the framework of the GATT Kennedy Round Agreements while Ben-David (1996) focuses on the general relationship between trade and convergence.

explaining these stylized facts within a theoretical framework that tries to maintain the spirit of the standard neoclassical growth model.

The standard model is modified here with the addition of knowledge as a factor of production along with physical capital and labor. While preserving the standard growth model's assumption that each country produces one good, it is assumed further here that these goods are distinct and that consumers derive utility from the consumption of all goods.

The assumption that each country's knowledge stock accumulates at a fixed rate in a closed economy preserves the exogenous growth aspect of the standard model. However, given our form of consumer preferences, the countries in this model will be open. Since each country's good is exposed to competition (both domestically and abroad) from other countries' goods, there is an impetus to learn and obtain foreign knowledge. This pressure increases as the extent of exposure to foreign goods increases. As in Grossman and Helpman (1991), it is assumed here that trade in goods facilitates the diffusion of knowledge. The premise here, as in Grossman and Helpman, is that knowledge is non-rivalrous and is also non-excludable in many respects. Under these conditions, a country's commercial policy leads to dynamic terms of trade effects that can have an impact not only on its level of income, but more importantly on its steady-state growth rate which now becomes endogenous. Moreover, the impact of unilateral trade liberalization improves the steady-state growth rate of per capita output for each of the country's trade partners.

The next section details a two-country version of the model while Section 3 describes the equilibrium. Section 4 extends the model to a multi-country world and simulates the model within a three-country setting. Section 5 concludes.

2. THE MODEL

Following Dollar, Wolff, and Baumol (1988), Rivera-Batiz and Romer (1991a, b), Grossman and Helpman (1991, 1994), and others, the primary thesis of this paper is that trade serves as a conduit for flows of knowledge. To the extent that increased knowledge acts to raise the productivities of physical capital and labor, it follows that heightened trade has the potential to increase the growth rate of per capita income. In Ben-David and Loewy (1996), we show that a simplified version of the model presented below is consistent with the observation that higher ratios of exports to output tend to coincide with faster growth. However, inasmuch as no physical capital is included in that model, it is not possible to consider the effects of trade on the link between the marginal product of capital and the process of knowledge accumulation.

The world economy is assumed to be comprised of two countries. For each country $i = 1, 2$, let good i be the distinct output of country i. As a justification for trade, agents in each country are assumed to derive utility from the consumption of both goods and the marginal utility of consumption of each good satisfies the usual Inada conditions. In order to concentrate on the growth and level effects of commercial policy, in what follows we assume that both countries are identical save for their distinct outputs, their initial conditions, and a possible difference in their tariff rates.

Let n be the population growth rate in each country. For simplicity, the time t population size and labor force in country i are assumed to be equal and are denoted by $L_i(t)$. Define real per capita consumption in country i of good j at time t as $c_{ij}(t)$. Then the preferences of each agent in country i are given by

$$\int_0^\infty e^{-(\rho-n)t}\left[\ln c_{i1}(t) + \ln c_{i2}(t)\right]dt \tag{1}$$

where ρ is the common rate of time preference and the initial population in both countries has been normalized to one.

Each good i is produced using the physical capital, labor, and knowledge available in country i. Assuming that the production function is linear homogeneous in capital and labor, we write this relationship in per capita terms as

$$y_i(t) = Ak_i(t)^{\beta}H_i(t)^{\varepsilon} \tag{2}$$

where $y_i(t)$, $k_i(t)$, and $H_i(t)$ are per capita output and capital, and the aggregate stock of knowledge in country i at time t. It is assumed that $0 < \beta < 1$ and $\varepsilon > 0$.

Given that the only use for good j in country i is in private consumption, any output from country j allocated to "net foreign lending" is, from the standpoint of country i, equivalent to an import.[4] Consequently, we can, with no loss of generality, assume that there does not exist an asset market. Hence, per capita expenditures in country i are simply the sum of per capita consumption of each good plus domestic investment. These expenditures are financed out of per capita income which we define as the sum of per capita net output plus per capita government tariff revenue, $g_i(t)$, an amount which is transferred back to private agents lump sum. Let $p_i(t)$ be the price of good i with good 1 being the numeraire and let τ_{ij} be country i's tariff on imports from country j ($\tau_{ii} = 0$ by definition). Tariffs are assumed to be determined exogenously and are constant over time. Given these definitions, country i's budget constraint is given by

$$c_{ii}(t) + \frac{p_j(t)\cdot(1+\tau_{ij})}{p_i(t)}c_{ij}(t) + \dot{k}_i(t) + nk_i(t) \leq Ak_i(t)^{\beta}H_i(t)^{\varepsilon} + g_i(t) \tag{3}$$

where the rate of depreciation of capital has been set to zero and

$$g_i(t) = \frac{p_j(t)\tau_{ij}c_{ij}(t)}{p_i(t)} . \tag{4}$$

[4]Furthermore, since we show in Section 3 that in steady-state equilibrium the marginal product of capital in countries 1 and 2 are equal, it follows that "net foreign lending" would equal zero in such a case.

Following Lucas (1988), per capita growth is obtained by supposing that the technology of knowledge accumulation in country i is constant returns to scale in the level of knowledge of country i. However, in order to provide a means for knowledge dissemination to affect growth, it is assumed further here that this technology is also constant returns to scale in the level of knowledge present in other countries.[5] Furthermore, the share of country j's knowledge that affects country i's rate of knowledge accumulation depends upon i's degree of openness towards j and on country i's ability to absorb and utilize country j's stock of knowledge.

The general idea behind the openness variable, which we denote as v_{ij}, is that countries must absorb foreign knowledge in order to compete successfully against foreign goods, both domestically and abroad. In our definition of v_{ij} below we make the simplifying assumption that knowledge spillovers derive solely from exports rather than from total trade volume as Grossman and Helpman (1991) suggest. While the inclusion of imports in v_{ij} would be quite intuitive as well (because of knowledge gained by reverse-engineering, for example), we make our modelling choice for two reasons. First, by defining v_{ij} in this way, it follows that each country's problem dichotomizes into a static allocation problem and a dynamic accumulation problem. This substantially simplifies the analysis without affecting the qualitative behavior of the model.[6] Second, suppose that the numerator of v_{ij} is defined either as imports or adds imports to exports. Then a reduction in τ_{ij} would increase c_{ij}, and also lead to an increase in v_{ij}. Hence, by excluding imports from the numerator of v_{ij}, we remove from the model an obvious positive effect of trade liberalization on per capita growth. Indeed, since we show below that the overall growth

---

[5] Lucas (1993) suggest a related technology of knowledge accumulation. In his model the level of knowledge in other countries affects knowledge accumulation in country i through the average level of knowledge worldwide.

[6] This is shown in Ben-David and Loewy (1996) which considers a simpler version of this model.

effects of a unilateral liberalization are positive, this effect would only be further enhanced by the substitution or inclusion of imports in v_{ij}.[7]

In line with the preceding discussion, we define $v_{ij}(t)$, $j \neq i$, as country i's total exports to country j divided by country i's aggregate output. Hence,

$$v_{ij}(t) = \frac{L_j(t)c_{ji}(t)}{L_i(t)y_i(t)} \quad . \tag{5}$$

while the accumulation of country i's stock of knowledge is defined as

$$\dot{H}_i(t) = \phi\left[a_{ij}\, v_{ij}(t)H_j(t) \; + H_i(t)\right] \quad , \tag{6}$$

where ϕ represents a cross-country productivity parameter and a_{ij} is a constant representing the share of country j's knowledge that is applicable for use in production in country i.[8] In some respects, a_{ij} captures Abramovitz's (1986) notion of "social capability," or the ability of a country to utilize existing technologies. Henceforth, we set $a_{ij} = 1$ to conserve on notation.

Equation (6) implies that if no country were to trade (an outcome that is ruled out by the form of the utility function), then each country's growth rate of knowledge would simply be ϕ. This rate corresponds to the exogenous growth rate of technology found in a closed economy Solow-Cass-Koopmans model. In the present model, however, ϕ represents the lower bound on the growth rate of knowledge. To the extent that countries do trade and are able to absorb each others' knowledge, then each country's stock of knowledge grows at a rate that exceeds ϕ. As will be shown below, in steady state this growth rate is common to both countries.

---

[7]Admittedly, in a two-country world the assumption of trade balance renders the choice of exports versus imports innocuous. This distinction only becomes meaningful in economies with three or more countries in which multilateral trade balance is assumed. In such a case, a reduction in a single tariff raises the steady-state value of certain v_{ij}'s and lowers others. See Section 4 below.

[8] The assumption that the a_{ij}'s are constant is made for simplification purposes only.

3. EQUILIBRIUM

This section begins with a definition of an equilibrium for the representative economy. It is followed by a series of propositions regarding these equilibria which provide the paper's main results. First, the existence of a unique steady-state equilibrium is established. In particular, it is shown that such an equilibrium is characterized by the knowledge stocks in each country growing at a common rate that is a decreasing function of each of the two tariffs. Given the assumption of identical economies (save for tariff rates and initial conditions), it follows that output and consumption of the two goods all grow at a common rate as well. Next, it is shown that in addition to its growth effects, a unilateral change in tariffs also produces the expected level effects. Finally, under the analytically useful assumption of equal tariff rates, it is shown that the steady-state equilibrium is locally stable.

As a first step towards defining an equilibrium, briefly consider the problem being solved in each country. Fixing attention on country 1, agents solve the following problem:

Problem **C1**: Choose $\{H_1(t), k_1(t)\}_{t>0}^{\infty}$ and $\{c_{11}(t), c_{12}(t)\}_{t\geq 0}^{\infty}$ to maximize Equation (1) subject to Equations (3), (5) and (6) given $\{c_{21}(t), H_2(t), p_2(t)\}_{t\geq 0}^{\infty}$.

Defining Problem **C2** in a symmetric fashion, an *equilibrium* for this economy is defined by time paths for all of the endogenous variables such that Problems **C1** and **C2** are solved and commodity markets clear. Placing the last condition within the context of good 1, this entails that

$$c_{11}(t) + \frac{L_2(t)}{L_1(t)} c_{21}(t) + \dot{k}_1(t) = y_1(t) \quad . \tag{7}$$

Note that market clearing, together with the private and government budget constraints, implies that trade is balanced. In other words, Equations (7), (3), and (4) imply that

$$L_1(t)p_2(t)c_{12}(t) = L_2(t)c_{21}(t) \quad . \tag{8}$$

The definition of an equilibrium now follows immediately:

Definition 1: Given $H_i(0)$ and $k_i(0)$ for $i = 1, 2$, an equilibrium consists of time paths $\{H_i(t), k_i(t)\}_{t>0}^{\infty}$ and $\{c_{ij}(t), p_2(t)\}_{t\geq 0}^{\infty}$ for $i, j = 1, 2$ such that Problems **C1** and **C2** are solved and Equation (7) holds for all $t \geq 0$.

A. Existence

In what follows, we concentrate solely on steady-state equilibria. Consider first then the implications of Problem **C1**. Let $z_1 = y_1/k_1$ and $\chi_{11} = c_{11}/k_1$ where the time argument is dropped both here and below to simplify the notation. In the Appendix, we show that the Euler equations for H_1 and k_1, the transversality conditions, and the first-order condition for c_{11} imply that in a steady state

$$\gamma_{c_{11}}^{*} = \beta z_1^{*}\left(1 - \frac{\varepsilon(\gamma_{H_1}^{*} - \phi)}{\rho - n + (1 + \varepsilon)(\gamma_{H_1}^{*} - \phi)}\right) - \rho \tag{9}$$

where * denotes steady state and γ_x denotes the growth rate of x. By the definition of a steady state, it follows that z_1^* equals a constant. Hence, $\gamma_{y_1}^{*} = \gamma_{k_1}^{*}$ and by Equation (2), these in turn equal $\varepsilon\, \gamma_{H_1}^{*}/(1 - \beta)$. Next, after substituting Equation (4) into Equation (3), dividing both sides by k_1, making use of the first-order conditions for consumption, and rearranging, one obtains

$$\gamma_{k_1} = z_1 - n - \left[2 - \frac{\tau_{12}}{1 + \tau_{12}}\right]\chi_{11} \quad . \tag{10}$$

Since this expression holds for all t, and z_1^* and $\gamma_{k_1}^*$ are constant in steady state, it follows that χ_{11}^* is constant. Hence, $\gamma_{c_{11}}^* = \gamma_{k_1}^*$ which in turn implies that the left-hand side of Equation (9) may be written as $\varepsilon\gamma_{H_1}^*/(1-\beta)$.

Using the trade balance condition and first-order conditions for consumption, one can write $\nu_{12} = \chi_{11}/[z_1(1 + \tau_{12})]$. Substituting this expression into Equation (6) implies that in a steady state

$$\gamma_{H_1}^* = \phi\left[\frac{\chi_{11}^*}{z_1^*(1+\tau_{12})}\frac{H_2^*}{H_1^*} + 1\right] . \qquad (11)$$

This in turn implies that H_2^*/H_1^* equals a constant. Thus, the steady-state growth rates of the two knowledge stocks must be the same. As this implies that the left-hand side of the two versions of Equation (9) are equal, it follows that $z_1^* = z_2^* = z^*$. Hence, the steady-state marginal products of capital, βz_i^*, are the same in both countries and are constant over time.

Next, solve for H_2^*/H_1^* by eliminating γ_H^* between Equation (11) and its counterpart for country 2. Using Equation (10) to substitute for the two $\chi_{ii}^*/[z^*(1 + \tau_{ij})]$ terms which appear in the expression for H_2^*/H_1^* and then substituting back into Equation (11) implies that this expression reduces to

$$\gamma_H^* = \phi\left[\left(1 - \frac{\varepsilon\gamma_H^*(1-\beta)^{-1} + n}{z^*}\right)T + 1\right] , \qquad (12)$$

where $T = [(2 + \tau_{12})(2 + \tau_{21})]^{-0.5}$.[9]

Equation (12) provides one equation in γ_H^* and z^*. To obtain a second equation, substitute $\varepsilon\gamma_H^*/(1-\beta)$ for $\gamma_{c_{11}}^*$ and γ_H^* for $\gamma_{H_1}^*$ in Equation (9), an expression which for completeness is repeated as Equation (13):

---

[9]Note that the term inside the parentheses on the right-hand side of Equation (12) is simply one minus the common steady-state savings rate, $(\dot{k}_i^* + nk_i^*)/y_i^*$, for $i = 1, 2$.

$$\frac{\varepsilon\gamma_H^*}{1-\beta} = \beta z^* \left(1 - \frac{\varepsilon(\gamma_H^* - \phi)}{\rho - n + (1+\varepsilon)(\gamma_H^* - \phi)}\right) - \rho \quad . \tag{13}$$

Using these two equations, we can prove the following:

Proposition 1: There exists a unique steady-state equilibrium. Furthermore, $\gamma_H^* \in (\phi, \phi(T+1))$.[10]

Proof: Solving Equations (12) and (13) for z as a function of γ_H and denoting the resulting functions as $G(\gamma_H)$ and $E(\gamma_H)$ (for the *growth* rate of H_i and the *Euler* equation for k_i), one obtains

$$G(\gamma_H) = \frac{T\phi[\varepsilon\gamma_H + n(1-\beta)]}{(1-\beta)[\phi(T+1) - \gamma_H]} \tag{14}$$

and

$$E(\gamma_H) = \left[\frac{\varepsilon\gamma_H + \rho(1-\beta)}{(1-\beta)\beta}\right]\left[1 + \frac{(\gamma_H - \phi)\varepsilon}{(\rho - n + \gamma_H - \phi)}\right] \quad . \tag{15}$$

To prove existence and the restriction on γ_H^*, it suffices to show that $\exists\ \gamma_H \in (\phi, \phi(T+1))$ such that Equations (14) and (15) hold simultaneously. To see that this is indeed the case, note that these expressions imply that $G(\phi) = \varepsilon\phi/(1-\beta) + n < [\varepsilon\phi/(1-\beta) + \rho]/\beta = E(\phi)$, $\lim_{\gamma_H \to \phi(T+1)^-} G(\gamma_H) = \infty$, and $E(\phi(T+1)) < \infty$. Since $\gamma_H^* = \phi$ when trade yields no spillovers, the continuity of $G(\cdot)$ and $E(\cdot)$ establishes these results.

To prove uniqueness, note first that $\partial G/\partial\gamma$, $\partial E/\partial\gamma$, $\partial^2 G/\partial\gamma^2 > 0\ \forall\ \gamma_H \in [\phi, \phi(T+1))$ (see Appendix). Since $\lim_{\gamma_H \to \infty} E(\gamma_H) = \infty$, the result follows directly by continuity if $\partial^2 E/\partial\gamma^2 \leq 0$. As

[10] Given our choice of utility function, the restrictions on parameters such that Proposition 1 holds are quite weak: $0 < \beta < 1$, $\varepsilon > 0$, $\rho > n$ by the transversality conditions, and $\tau_{ij} \geq 0$ which is necessary given the absence of any source of government revenue other than tariffs.

shown in the Appendix, this inequality holds $\forall\ \gamma_H \in [\phi, \phi(T + 1))$ if $\varepsilon(\phi + n - \rho) + \rho(1 - \beta) \geq 0$. Should $\varepsilon(\phi + n - \rho) + \rho(1 - \beta) < 0$ so that $\partial^2 E/\partial\gamma^2 > 0$ over the relevant domain, then continuity, the limiting behavior of $E(\cdot)$, and $\partial^3 G/\partial\gamma^3 > 0 > \partial^3 E/\partial\gamma^3$ (see Appendix) imply the result. ■

To gain some further insight into the determination of γ_H^*, note that γ_H^* corresponds to the maximum eigenvalue of the 2×2 system defined by Equation (6) when all of the endogenous variables are evaluated at their steady-state levels, namely,

$$\gamma_H^* = \phi\left[1 + \left(\nu_{12}^*\nu_{21}^*\right)^{0.5}\right] \quad , \tag{16}$$

which shows that the steady-state growth rate is an increasing function of the ν_{ij}^*'s. Since each of the ν_{ij}^*'s is itself a function of γ_H^* (because χ_{ii}^* and z_i^* are), Equations (14) and (15) effectively solve a particular fixed point problem. By the same token, the steady-state *relative* level of the stocks of knowledge corresponds to the ratio of the elements of the eigenvector associated with γ_H^*, namely $H_2^*/H_1^* = (\nu_{21}/\nu_{12})^{0.5}$.

B. Productivity, Growth and Level Effects of Trade Liberalization

The emphasis now shifts to a description of the effects of trade liberalization on the steady-state magnitudes of the marginal product of capital, the growth rate of output, and relative levels of output across countries. The following proposition addresses the question of the effects of changes in tariffs on productivity and output growth. Specifically, we show that a unilateral reduction of a single tariff raises the steady-state marginal product of capital and the rate of growth of knowledge. The latter in turn implies that the steady-state growth rate of output rises. Since the steady-state growth rates of consumption and capital are also so affected, it follows that the growth effects of even a unilateral tariff reduction are widespread.

Proposition 2: $\partial z^*/\partial \tau_{ij} < 0$ and $\partial \gamma_H^*/\partial \tau_{ij} < 0$.

Proof: Recall that $T = [(2 + \tau_{12})(2 + \tau_{21})]^{-0.5}$. Hence, without loss of generality, it suffices to show that $\partial z^*/\partial T > 0$ and $\partial \gamma_H^*/\partial T > 0$. Totally differentiating Equations (14) and (15), applying Cramer's Rule, and noting that $G'(\gamma_H^*) > E'(\gamma_H^*)$, the results follow. ■

The next proposition shows that the level effects of a tariff reduction coincide with the growth effects just established. Hence, the liberalizing country experiences an increase in its steady-state level of output relative to that of its trade partner. This occurs not just because the level of knowledge in the liberalizing country rises relative to that of its trade partner, but because the same also holds for the relative level of capital. Therefore, during the transition to the steady state it is possible for an initial income gap to be increased, eliminated or reversed depending upon the pre-liberalization and post-liberalization relative magnitude of the tariffs.

Proposition 3: $\partial(y_i^*/y_j^*)/\partial \tau_{ij} < 0$.

Proof: $z_1^* = z_2^*$ implies that $y_2^*/y_1^* = (H_2^*/H_1^*)^{\varepsilon/(1-\beta)}$. Since Equations (10) and (11) imply that $H_2^*/H_1^* = [(2 + \tau_{12})/(2 + \tau_{21})]^{0.5}$, the result follows. ■

Proposition 3 and Equation (13) provide some insight into the question posed by Lucas (1990) on why capital doesn't flow from rich countries to poor countries. To the extent that countries differ from one another in their commercial policies, Proposition 3 implies that the country with the higher tariffs will be the poorer of the two.[11] However, while the two countries may be at different stages of development, Equation (13) implies that their steady-state returns to capital, βz_i^*, will be the same.

[11]This outcome is consistent with evidence reported by Easterly and Rebelo (1993).

Finally, since the real wage for a given level of knowledge is $(1-\beta)y$, it follows that labor will seek to migrate from the poor to the rich country.

C. Stability

As the discussion following Proposition 1 suggests, the dynamics of the economy are described by Equations (6). However, because in the transition to the steady-state these equations represent a pair of differential equations with *time varying* coefficients, it is not possible to describe the transition path of the economy.[12] Despite this analytical limitation, it is possible to study the local stability of the steady state. While the usual means for doing so entails writing down and then linearizing the laws of motion for the endogenous variables used to solve for the economy's steady-state, such an approach does not work well here since one of these variables, γ_H, is itself a growth rate. Hence, it is necessary to alter the choice of variables used in Subsection *A* and choose instead a set of variables whose laws of motion can be described as functions of themselves. Our choice of variables is $z_i = y_i/k_i$, $\chi_{ii} = c_{ii}/k_i$, for $i =$ 1, 2, and $\xi = H_2/H_1$.

Using Equations (9), (10), and (11), it is possible to write down the steady-state laws of motion for each of these five variables (see Appendix). Linearizing these expressions around their steady-state values yields the following system of equations:

$$\begin{bmatrix} \gamma_{z_1} \\ \gamma_{\chi_{11}} \\ \gamma_{z_2} \\ \gamma_{\chi_{22}} \\ \gamma_{\xi} \end{bmatrix} = \begin{bmatrix} z_1 z_1 & z_1\chi_{11} & 0 & 0 & z_1\xi \\ \chi_{11}z_1 & \chi_{11}\chi_{11} & 0 & 0 & \chi_{11}\xi \\ 0 & 0 & z_2 z_2 & z_2\chi_{22} & z_2\xi \\ 0 & 0 & \chi_{22}z_2 & \chi_{22}\chi_{22} & \chi_{22}\xi \\ \xi z_1 & \xi\chi_{11} & \xi z_2 & \xi\chi_{22} & \xi\xi \end{bmatrix} \begin{bmatrix} z_1 - z_1^* \\ \chi_{11} - \chi_{11}^* \\ z_2 - z_2^* \\ \chi_{22} - \chi_{22}^* \\ \xi - \xi^* \end{bmatrix} \tag{17}$$

[12]Such a description is possible in Ben-David and Loewy (1996) since in that paper the absence of physical capital implies that the coefficients of the dynamic system are constant.

where the terms *wx* correspond to the partial derivatives of γ_w with respect to the variable x evaluated at the steady-state.

Unfortunately, one cannot usually say much about the roots of the characteristic equation of a 5×5 system without the aid of some simplifying assumptions. In the present case, it is sufficient to assume that $\tau_{12} = \tau_{21} = \tau$. While this assumption effectively implies that both countries are parametrically identical, doing so has the useful effect of reducing the number of distinct non-zero elements in the Jacobian which in turn permits the characteristic equation to be factored and therefore analyzed.

Proposition 4: Given that $\tau_{12} = \tau_{21} = \tau$, the economy is locally stable.

Proof: Under the assumption of equal tariffs, it follows that $z_1^* = z_2^*$, $\chi_{11}^* = \chi_{22}^*$, and $\xi^* = 1$. Therefore, $z_1z_1 = z_2z_2$, $z_1\chi_{11} = z_2\chi_{22}$, $z_1\xi = -z_2\xi$, $\chi_{11}z_1 = \chi_{22}z_2$, $\chi_{11}\chi_{11} = \chi_{22}\chi_{22}$, $\chi_{11}\xi = -\chi_{22}\xi$, $\xi z_1 = -\xi z_2$, $\xi\chi_{11} = -\xi\chi_{22}$, and $\xi\xi < 0$. These results imply that the characteristic equation of Equation (17) can be factored into the product of a quadratic defined by the 2×2 system in the upper left-hand corner and a third-order polynomial defined by the rest of the matrix.[13] It is sufficient to show that one of the roots of the quadratic is a negative real. Direct calculation shows that this is the case if $(z_1\chi_{11})(\chi_{11}z_1) > (z_1z_1)(\chi_{11}\chi_{11})$. Since algebraic manipulation of this inequality shows that it is equivalent to $G'(\gamma_H^*) > E'(\gamma_H^*)$, the result is established. ■

While the above proof implies that the stable manifold is one dimensional, numerical simulations suggest that in practice it is likely to be three dimensional. In particular, the third-order polynomial referred to above typically possesses two negative real roots and one positive real root. These values

---

[13]Copies of this factorization and of the expressions for the elements of the Jacobian matrix are available from the authors upon request.

roughly correspond to the same two roots as above plus $\xi\xi$ which is known to be negative. Finally, while a stability proof for the case where $\tau_{12} \neq \tau_{21}$ is not possible, continuity and Proposition 4 imply that such a case will also exhibit local stability as long as the two tariff rates do not differ too much. As for cases where the tariff rates differ a great deal, the numerical simulation below shows that the system is again locally stable.

D. Example

Let $(\varepsilon, \beta, \phi, \tau_{12}, \tau_{21}, \rho, n) = (0.3, 0.4, 0.05, 0.75, 0.75, 0.04, 0.02)$. Then the unique steady-state equilibrium is $\gamma_H^* = 0.064$, $z^* = 0.201$, $\chi_{11}^* = \chi_{22}^* = 0.095$, $v_{12}^* = v_{21}^* = 0.270$, and $y_1^*/y_2^* = 1$. In this case the eigenvalues of the Jacobian of the linearized system are 1.030, 1.029, -0.541, -0.540, and -0.027. Hence, the stable manifold is three dimensional as suggested above.

To illustrate Propositions 1-4, suppose that country 1 unilaterally liberalizes trade setting $\tau_{12} = 0$ while all other parameters remain unchanged. The associated steady-state equilibrium is $\gamma_H^* = 0.066$, $z^* = 0.207$, $\chi_{11}^* = 0.077$, $\chi_{22}^* = 0.098$, $v_{12}^* = 0.372$, $v_{21}^* = 0.271$, and $y_1^*/y_2^* = 1.083$. Hence, the rate of growth of output and productivity of capital both increase while country 1 opens up an income gap of 8.3% with country 2. The eigenvalues of the linearized system are now 1.403, 1.400, -0.517, -0.501, and -0.041.

4. The General Case

In the above numerical example, a reduction in either or both of the tariff rates leads to an increase in both of the v's, and from Equation (16), to a subsequent increase in the steady-state growth rate of both countries. However, when the number of countries in the model increases beyond two, then the outcomes become a bit less straightforward. In particular, unilateral liberalization leads to dynamic terms of trade effects and the resultant changes in relative prices cause some of the v's to rise and others to fall. Hence, the overall impact of trade liberalization on steady-state growth is not immediately obvious.

Furthermore, a model of a world with many countries enables an analysis of the impact of a regional trade agreement by a subset of countries on the growth rates of the signatory and non-signatory countries as well as on the change in the income gap between the two groups of countries. Thus, the goal of this section is to briefly present the general multi-country version of the model and examine its implications.

Consider then, a J-country world of nonidentical economies. While Equations (2) and (5) are unchanged, the analogues of Equations (1), (3), (4), and (6) are

$$\int_0^\infty e^{-(\rho_i - n_i)t} L_i(0) \sum_{j=1}^{J} \alpha_{ij} \ln c_{ij}(t)\, dt \tag{18}$$

where $\sum_{j=1}^{J} \alpha_{ij} = 1$,

$$\sum_{j=1}^{J} \frac{p_j(t)\cdot(1+\tau_{ij})}{p_i(t)} c_{ij}(t) + \dot{k}_i(t) + n_i k_i(t) \le A k_i(t)^{\beta_i} H_i(t)^{\varepsilon_i} + g_i(t) \quad ; \tag{19}$$

$$g_i(t) = \sum_{j \ne i} \frac{p_j(t)\tau_{ij} c_{ij}(t)}{p_i(t)} \quad ; \tag{20}$$

and

$$\dot{H}_i(t) = \phi_i \left[\sum_{j \ne i} a_{ij} v_{ij}(t) H_j(t) + H_i(t) \right] \quad . \tag{21}$$

After optimizing and making use of these expressions and market clearing,

$$c_{ii}(t) + \sum_{j \ne i} \frac{L_j}{L_i} c_{ji}(t) + \dot{k}(t) = y_i(t) \quad , \tag{22}$$

one obtains a distinct version of Equation (9) for each country plus the following analogues to Equations (10) and (11):

$$\gamma_{k_i} = z_i - n_i - \left[J - \sum_{j \neq i} \frac{\tau_{ij}}{1 + \tau_{ij}} \right] \chi_{ii} \quad ; \tag{23}$$

$$\gamma^*_{H_i} = \phi_i \left[\sum_{j \neq i} \frac{\pi_j (1 - \psi^*_i)}{\pi_i (1 - \psi^*_j)} \frac{\chi_{ij}}{z_j (1 + \tau_{ji})} \frac{H^*_j}{H^*_i} + 1 \right] \quad ; \tag{24}$$

where $\psi^*_i = (\gamma^*_{k_i} + n_i)/z^*_i$ is the steady-state savings rate in country i and market clearing implies that $\pi_1 = 1$ while the remaining J - 1 scalars π_i are functions of the $J(J - 1)$ terms $\alpha_{ij} Q_i/(1 + \tau_{ij})$, $i \neq j$, with

$$Q_i = \frac{\prod_{j \neq i} (1 + \tau_{ij})}{1 + \sum_{j \neq i} (1 - \alpha_{ij}) \tau_{ij} + \sum_{j \neq i,k} \sum_{k \neq i,j} [1 - (\alpha_{ij} + \alpha_{ik})] \tau_{ij} \tau_{ik} + \ldots + (1 - \sum_{j \neq i} \alpha_{ij}) \prod_{j \neq i} \tau_{ij}} \quad .$$

By the definition of a steady state, it is immediate from Equation (24) that the steady-state equilibrium will again exhibit a common growth rate of knowledge. After substituting $\varepsilon_i \gamma^*_H/(1 - \beta_i)$ for $\gamma^*_{c_{ii}}$ in each of the J country-specific versions of Equations (9), for $\gamma^*_{k_i}$ in each of the J steady-state versions of Equation (23), and for the π_i and ψ^*_i terms in the J versions of Equation (24), then these three sets of equations yield $3J$ equations in the $3J$ unknowns $\{\gamma^*_H, z^*_i, \chi^*_{ii}, H^*_j/H^*_1\}$, $i = 1, \ldots, J; j = 2, \ldots, J$. As in Section 3, it is again the case that the steady-state growth rate of knowledge corresponds to the maximum eigenvalue of the $J \times J$ system defined by Equation (21) evaluated at the steady-state and the H^*_j/H^*_i to the ratio of elements of the associated eigenvector. While the existence of this growth rate typically cannot be established analytically, it can be solved for numerically.

To get a sense of the terms of trade dynamics — and the subsequent growth and level effects — that result from trade liberalization, consider a three-country world and suppose that country 1 reduces its tariffs on imports from country 2 (i.e., τ_{12} is reduced). In this case, since the gross of tariff price of good 2 in country 1 falls, country 1's imports from country 2 rise while its imports from country 3 fall due to import substitution. These two effects imply that v_{21}^* rises while v_{31}^* falls.[14] The increase in the demand for country 2's good causes its price to rise. This improvement in country 2's terms of trade implies that it imports more of both good 1 and good 3. Therefore, both v_{12}^* and v_{32}^* increase. On the other hand, the rise in the price of good 2 causes country 3's imports of good 2 to fall resulting in a fall in v_{23}^*. Finally, note that Equation (21) implies that the increase in v_{12}^* causes an increase in H_1^*, ceteris paribus. This in turn causes an increase in the supply of good 1 and a fall in its relative price. The decline in the price of good 1 causes an increase in the import of good 1 by country 3 thereby causing an increase in v_{13}^*. Of course this effect only strengthens the growth in the supply of good 1 and the rise in country 2's imports of good 1. With four v_{ij}^*'s increasing and two falling, it is not possible to determine the effect of the reduction in τ_{12} on γ_H^* without the aid of a numerical simulation.

Therefore, consider a three-country analogue of the example in Section 3D, namely, $(\varepsilon, \beta, \phi, \rho, n) = (0.3, 0.4, 0.05, 0.04, 0.02)$, $\alpha_{ij} = 0.33$ for $i, j = 1, 2, 3$, and τ_{ij} equal 0.75 for $i \neq j$. Then the unique steady-state equilibrium is $\gamma_H^* = 0.070$, $z^* = 0.215$, and $\chi_{ii}^* = 0.075$ for all i, and $v_{ij}^* = 0.198$ and $y_i^*/y_j^* = 1$ for all i, j, $i \neq j$. Now, to simulate the unilateral tariff reduction by country 1 on imports from country 2, let τ_{12} fall to 0, with all other parameters being unchanged. The directions that the individual v_{ij}'s take as a result of the reduction in τ_{12} are as noted above, with $v_{12}^* = 0.248$, $v_{13}^* = 0.207$, $v_{21}^* = 0.231$, $v_{23}^* = 0.165$, $v_{31}^* = 0.159$, $v_{32}^* = 0.238$. The resultant impact on steady-state growth is positive with γ_H^* rising to 0.071 and z^* to 0.217 while $\chi_{11}^* = 0.063$, and $\chi_{22}^* = \chi_{33}^* = 0.075$. Furthermore, relative gaps in income levels are created. The liberalizing country, while raising the steady-state growth rates of all three countries, benefits the most in terms of level effects. The ratio of its per capita income to that of the other two countries rises to $y_1^*/y_2^* = 1.044$ and $y_1^*/y_3^* = 1.049$. Country

---

[14] Recall that the v_{ij}^* are functions of exports. Hence, an increase in c_{12}^* raises v_{21}^*.

2, the beneficiary of the unilateral liberalization by Country 1, sees its income rise relative to Country 3 with $y_2^*/y_3^* = 1.006$.

As Easterly and Rebelo (1993) show, developing countries tend to tax trade more than do developed countries. This is consistent with the predictions of the model. Thus, suppose that the initial tariff policies of the individual countries in the simulation had been different — with the resultant negative relationship between tariff rates and the levels of development of the three countries. Then a free trade agreement between the top two countries that coincides with the imposition of an equal external tariff by both countries on the third country (where the external tariff now equals the minimum of the tariffs previously levied by the two on the third country) will lead to an outcome of faster growth for all three countries, a result which is consistent with the long-run increases in growth rates reported by Maddison (1982) and Ben-David and Papell (1995). The faster growth by all will be accompanied by income convergence among the top two countries and a persistent, and possibly larger, gap between the two leaders and the third country. The latter outcome, that of non-convergence, or even of temporary divergence between the leading countries and those that are less developed, is one of the empirical regularities that has characterized the postwar world.[15]

5. Conclusion

This paper considers a variant of the neoclassical growth model in which technological change is assumed to be endogenous and directly linked to the extent of openness of an economy. Specifically, technological change is modeled as the accumulation of knowledge. This accumulation process is assumed to be driven by the degree to which each country is able to apply the knowledge spillovers coming from its trading partners to its own knowledge stock. As Grossman and Helpman (1991) suggest,

[15] For examples of countries where liberalization brings about income convergence and increased growth, see Ben-David (1993) and Sachs and Warner (1995). For evidence of non-convergence between developed and less developed countries, see Baumol (1986) and Ben-David (1995).

knowledge spillovers are taken to be directly related to the degree of openness among countries. The model provides an analysis of the impact of trade liberalization on the steady-state marginal product of capital, the rate of growth of output, and the relative levels of income.

Assuming that economies possess similar technologies, it is shown that rates of return to capital are the same in all countries, regardless of their level of development. Returns to labor on the other hand, vary among countries — with the highest rates of return appearing in the most developed, and hence, wealthiest countries. Countries that tax trade heavily will be poorer in the steady state than countries adopting more liberal trade policies.

Commercial policy emphasizing trade liberalization should have a positive affect on knowledge accumulation and as a result, on economic growth as well. The model's implications are consistent with: (1) the increases in economic growth seen during the postwar period among countries that have actively sought to liberalize trade (even after adjusting for the slowdown in growth along the path to steady state); (2) the income convergence among countries that engaged in extensive trade liberalization with one another; and (3) a non-decreasing income gap between those leading countries that liberalized trade with one another and the less developed countries that did not attain the same degree of liberalization with either the leading countries or with each other.

APPENDIX

Derivation of Equation (9)

Letting $\theta_1(t)$ and $\lambda_1(t)$ be the co-state variables for physical capital and knowledge, the Euler equations of Problem C1 are (after dropping the time argument)

$$\dot{\theta}_1 = \theta_1[\rho - \beta_1 z_1] + \lambda_1(\beta_1/k_1)\phi v_{12}H_2 \quad ; \qquad \textbf{(A1)}$$

$$\dot{\lambda}_1 = \lambda_1[\rho - n - \phi(1 - \varepsilon v_{12}H_2/H_1)] - \theta_1 \varepsilon y_1/H_1 \quad . \tag{A2}$$

Using Equation (6) to eliminate $v_{12}H_2/H_1$ and the first-order condition for c_{11} to eliminate θ_{11} in Equation (A2), this expression may be written as

$$\dot{\lambda}_1 = \lambda_1\left[\rho - n - \phi + (\gamma_{H_1} - \phi)\varepsilon\right] - \varepsilon z_1/(H_1 \chi_{11}) \quad . \tag{A3}$$

Solving this differential equation and imposing the transversality condition $\rho > n$ implies that in the steady state

$$\lambda_1^* H_1^* = \frac{\varepsilon z_1^*}{\chi_{11}^*[\rho - n + (\gamma_H^* - \phi)(1 + \varepsilon)]} \quad . \tag{A4}$$

Next, multiply and divide the second term on the right-hand side of Equation (A1) by H_1 and again make use of Equation (6) to eliminate the resulting term in $v_{12}H_2/H_1$. Imposing the steady state and substituting Equation (A4) for $\lambda_1^* H_1^*$ and the first-order condition for c_{11} for θ_{11} yields Equation (9).

Derivatives of $G(\cdot)$ and $E(\cdot)$

Taking derivatives of Equations (14) and (15) yields

$$\frac{\partial G}{\partial \gamma_H} = \frac{\phi T[\varepsilon\phi(T + 1) + n(1 - \beta)]}{(1 - \beta)[\phi(T + 1) - \gamma_H]^2} \quad ; \tag{A5}$$

$$\frac{\partial^2 G}{\partial \gamma_H^2} = \frac{2\phi T[\varepsilon\phi(T + 1) + n(1 - \beta)]}{(1 - \beta)[\phi(T + 1) - \gamma_H]^3} \quad ; \tag{A6}$$

$$\frac{\partial E}{\partial \gamma_H} = \frac{\varepsilon}{\beta(1-\beta)(\rho - n + \gamma_H - \phi)}\left(\frac{[\varepsilon\gamma_H + \rho(1-\beta)](\rho - n)}{\rho - n + \gamma_H - \phi} + \rho - n + (\gamma_H - \phi)(1+\varepsilon)\right) \quad ; \text{(A7)}$$

$$\frac{\partial^2 E}{\partial \gamma_H^2} = -\frac{2\varepsilon(\rho - n)[\varepsilon(\phi + n - \rho) + \rho(1-\beta)]}{\beta(1-\beta)(\rho - n + \gamma_H - \phi)} \quad . \qquad \text{(A8)}$$

Inspection shows that the first three expressions are strictly positive $\forall\ \gamma_H \in [\phi, \phi(T+1)$ whereas the sgn $\partial^2 E/\partial\gamma_H^2 = -$ sgn $\varepsilon(\phi + n - \rho) + \rho(1-\beta)$. The signs of the third derivatives follow immediately.

Derivation of Equation (17)

Using Equations (9)-(11) and the definitions of z_i, χ_{ii}, and ξ, we have for $i = 1, 2$ and $j \neq i$ that

$$\gamma^*_{z_i} = \frac{\varepsilon\phi}{(1-\beta)}\left[\frac{\chi^*_{ii}\Xi_i}{z_i^*(1+\tau_{ij})} + 1\right] - \left[z_i^* - n - \left(2 - \frac{\tau_{ij}}{1+\tau_{ij}}\right)\chi^*_{ii}\right] \quad ; \qquad \text{(A9)}$$

$$\gamma^*_{\chi_{ii}} = \beta z_i^*\left[1 - \frac{\varepsilon\phi\chi^*_{ii}\Xi_i/[z_i^*(1+\tau_{ij})]}{\rho - n + (1+\varepsilon)\phi\chi^*_{ii}\Xi_i/[z_i^*(1+\tau_{ij})]}\right] - \rho - \left[z_i^* - n - \left(2 - \frac{\tau_{ij}}{1+\tau_{ij}}\right)\chi^*_{ii}\right] \quad ; \text{(A10)}$$

$$\gamma^*_{\xi} = \phi\left[\frac{\chi^*_{22}}{z_2^*\xi^*(1+\tau_{21})} - \frac{\chi^*_{11}\xi^*}{z_1^*(1+\tau_{12})}\right] \quad ; \qquad \text{(A11)}$$

where $\Xi_i = \begin{cases} \xi^* & \text{if } i = 1 \\ \xi^{*-1} & \text{if } i = 2 \end{cases}$. Linearizing these three expressions around the steady state for the case where $\tau_{12} = \tau_{21} = \tau$, one obtains Equation (17) above.

REFERENCES

Abramovitz, Moses (1986), "Catching Up, Forging Ahead, and Falling Behind," *Journal of Economic History*, *46*, 385-406.

Barro, Robert J. (1991), "Economic Growth in a Cross-Section of Countries," *Quarterly Journal of Economics*, *106*, 407-443.

Barro, Robert J. and Xavier Sala-i-Martin (1991), "Convergence Across States and Regions," *Brookings Papers on Economic Activity*, 107-82.

Baumol, William J. (1986), "Productivity Growth, Convergence, and Welfare: What the Long-Run Data Show," *American Economic Review*, *76*, 1072-85.

Ben-David, Dan (1996), "Trade and Convergence Among Countries," *Journal of International Economics*, *40*, 279-298.

Ben-David, Dan (1995), "Convergence Clubs and Diverging Economies," Foerder Institute working paper 40-95.

Ben-David, Dan (1993), "Equalizing Exchange: Trade Liberalization and Income Convergence," *Quarterly Journal of Economics*, *108*, 653-79.

Ben-David, Dan (1990), "From Liberalization to Equalization: Some Evidence on the Impact of Freer Trade on Income Differentials," unpublished University of Chicago Ph.D. dissertation.

Ben-David, Dan and Michael B. Loewy (1996), "Free Trade and Long-Run Growth," Foerder Institute working paper 32-96.

Ben-David, Dan and David H. Papell (1995), "The Great Wars, the Great Crash, and Steady State Growth: Some New Evidence About an Old Stylized Fact," *Journal of Monetary Economics*, *36*, 453-75.

Cass, David (1965), "Optimum Growth in an Aggregative Model of Capital Accumulation," *Review of Economic Studies*, *32*, 233-40.

Dollar, David, Edward N. Wolff, and William J. Baumol (1988), "The Factor-Price Equalization Model and Industry Labor Productivity: An Empirical Test across Countries," in *Empirical Methods for International Trade*, Robert C. Feenstra (ed.), Cambridge, MA: MIT Press, 23-47.

Easterly, William, and Sergio Rebelo (1993), "Fiscal Policy and Economic Growth: An Empirical Investigation," *Journal of Monetary Economics*, *32*, 417-58.

Grossman, Gene M. and Elhanan Helpman (1994), "Technology and Trade," NBER Working Paper No. 4926.

Grossman, Gene M. and Elhanan Helpman (1991), *Innovation and Growth in the Global Economy*, Cambridge, MA: MIT Press.

Koopmans, Tjalling C. (1965), "On the Concept of Optimal Economic Growth," in *The Econometric Approach to Development Planning*, Pontificia Academia Scientiarum, Amsterdam: North-Holland Publishing Co.

Loewy, Michael B. and David H. Papell (1996), "Are U.S. Regional Incomes Converging? Some Further Evidence," *Journal of Monetary Economics*, *38*, forthcoming.

Lucas, Robert E. Jr. (1993), "Making a Miracle," *Econometrica*, *61*, 251-272.

Lucas, Robert E., Jr. (1990), "Why Doesn't Capital Flow from Rich to Poor Countries?," *American Economic Review*, *80*, 92-96.

Lucas, Robert E. Jr. (1988), "On the Mechanics of Economic Development," *Journal of Monetary Economics*, *22*, 3-42.

Maddison, Angus (1991), *Dynamic Forces in Capitalist Development: A Long-Run Comparative View*, Oxford: Oxford University Press.

Maddison, Angus (1982), *Phases of Capitalist Development*, Oxford: Oxford University Press.

Mankiw, N. Gregory, David Romer and David N. Weil (1992), "A Contribution to the Empirics of Economic Growth," *Quarterly Journal of Economics*, *107*, 407-37.

Rivera-Batiz, Luis A. and Paul M. Romer (1991a), "International Trade with Endogenous Technological Change," *European Economic Review*, *35*, 971-1004.

Rivera-Batiz, Luis A. and Paul M. Romer (1991b), "Economic Integration and Endogenous Growth," *Quarterly Journal of Economics*, *106*, 531-555.

Sachs, Jeffrey D. and Andrew Warner (1995), "Economic Reform and the Process of Global Integration," in Brainard, William C. and George L. Perry (eds.), *Brookings Papers on Economic Activity*, 1-95.

Solow, Robert M. (1956), "A Contribution to the Theory of Economic Growth," *Quarterly Journal of Economics, 70*, Reprinted in *Readings in the Modern Theory of Economic Growth*, Joseph E. Stiglitz and Hirofumi Uzawa (eds.), Cambridge, MA: MIT Press, 58-87.

Table 1

Changes in Rates of Growth and Changes in Export-GDP Ratio for 16 OECD Countries

Postwar (1950-1989) versus Prewar (1870-1939)

Country	Ratio of Postwar Average to Prewar Average	
	Growth Rates	EX/Y
Australia	3.75	0.96
Austria	3.38	2.37
Belgium	3.12	2.63
Canada	1.74	1.24
Denmark	1.62	2.02
Finland	2.26	1.31
France	2.44	2.15
Germany	2.09	1.16
Italy	3.51	2.34
Japan	3.14	3.15
Netherlands	2.38	2.21
Norway	2.00	1.97
Sweden	1.64	1.94
Switzerland	1.66	1.48
U.K.	2.55	1.03
U.S.	1.38	1.31
Average	2.42	1.83

THE FOERDER INSTITUTE FOR ECONOMIC RESEARCH and THE SACKLER INSTITUTE FOR ECONOMIC STUDIES

The Eitan Berglas School of Economics
Tel-Aviv University

List of Recent Working Papers

44-95 (Foerder)	Elhanan Helpman Gene M.Grossman	Technological Determinants of Trade
45-95 (Sackler)	Chaim Fershtman Aart de Zeeuw	Tradeable Emission Permits in Oligopoly
1-96 (Foerder)	Eyal Sulganik Itzhak Zilcha	The Value of Information: The Case of Signal-Dependent Opportunity Sets
2-96 (Foerder)	Gene M.Grossman Elhanan Helpman	Intergenerational Redistribution with Short-Lived Governments
3-96 (Sackler)	Jacob Glazer Ariel Rubinstein	What Motives should Guide Referees? On the Design of Mechanisms to Elicit Opinions
4-96 (Foerder)	Dan Ben-David Atiqur Rahman	Technological Convergence and International Trade
5-96 (Foerder)	Dan Ben-David David H.Papell	Some Evidence on the Continuity of the Growth Processes Among the G7 Countries
6-96 (Sackler)	Jeffrey Church Neil Gandal	Systems Competition, Vertical Merger and Foreclosure
7-96 (Foerder)	Lee A.Lillard Yoram Weiss	Uncertain Health and Survival: Effects on End-of-Life Consumption
8-96 (Foerder)	Graciela L.Kaminsky Leonardo Leiderman	High Real Interest Rates in the Aftermath of Disinflation: Is it a Lack of Credibility?
9-96 (Sackler)	Dan Ben-David David H.Papell	Slowdowns and Meltdowns: Post-War Growth - Evidence from 74 Countries
10-96 (Foerder)	Gene M.Grossman Elhanan Helpman	Electoral Competition with Policy Compromise
11-96 (Foerder)	Avinash Dixit Gene M.Grossman Elhanan Helpman	Common Agency and Coordination: General Theory and Application to Tax Policy

---

Copies of the working papers or a complete working paper list of the two Institutes can be obtained from: Mrs.Stella Padeh, The Foerder Institute for Economic Research, Tel-Aviv University, Tel-Aviv, 69978 Israel. Fax: 972-3-640-9908. e-mail: foerder@econ.tau.ac.il

12-96 (Sackler)	Neil Gandal Oz Shy	Standardization Policy and International Trade
13-96 (Foerder)	Oded Galor Daniel Tsiddon	Technological Progress, Mobility and Economic Growth
14-96 (Foerder)	Tamim Bayoumi David T.Coe Elhanan Helpman	R&D Spillovers and Global Growth
15-96 (Sackler)	Chaim Fershtman Arthur Fishman Avi Simhon	Relative Price Variability, Repeat Sales and the Welfare Cost of Inflation
16-96 (Foerder)	Leonardo Leiderman Gil Bufman	Searching for Nominal Anchors in Shock-Prone Economies in the 1990s: Inflation Targets and Exchange Rate Bands
17-96 (Foerder)	Chaim Fershtman Yoram Weiss	Social Rewards, Externalities and Stable Preferences
18-96 (Sackler)	Oded Galor Daniel Tsiddon	The Distribution of Human Capital and Economic Growth
19-96 (Foerder)	Bent E.Sorensen Oved Yosha	Income and Consumption Smoothing Among U.S. States: Regions or Clubs?
20-96 (Foerder)	Peter B.Morgan Oz Shy	Undercut-Proof Equilibria
21-96 (Sackler)	Chaim Fershtman Yoram Weiss	Why Do We Care What Others Think About Us?
22-96 (Foerder)	Momi Dahan Zvi Hercowitz	Fiscal Policy and Saving Under Distortionary Taxation
23-96 (Foerder)	David M. Frankel	The (Retail) Price of Inequality
24-96 (Sackler)	Elhanan Helpman Manuel Trajtenberg	Diffusion of General Purpose Technologies
25-96 (Foerder)	Timothy F.Bresnahan Scott Stern Manuel Trajtenberg	Market Segmentation and the Sources of Rents from Innovation: Personal Computers in the late 1980s
26-96 (Foerder)	Hedva Ber Yishay Yafeh Oved Yosha	The Post-Issue Performance of IPO Firms When Banking is Concentrated and Universal
27-96 (Sackler)	Itzhak Zilcha	Intergenerational Transfers, Economic Growth and Income Distribution
28-96 (Foerder)	Robert M. Sauer	Job Mobility and the Market for Lawyers
29-96 (Foerder)	Elazar Berkovitch Ronen Israel Yossef Spiegel	Managerial Compensation and Capital Structure
30-96 (Sackler)	Omri Ben-Shahar	Scientific Information and Products Liability: An Economic Analysis

31-96 (Foerder)	Lucian Arye Bebchuk Omri Ben-Shahar	Pre-Contractual Reliance
32-96 (Foerder)	Dan Ben-David Michael B.Loewy	Free Trade and Long-Run Growth
33-96 (Sackler)	Dan Ben-David Robin L.Lumsdaine David H.Papell	Unit Roots, Postwar Slowdowns and Long-Run Growth: Evidence from Two Structural Breaks
34-96 (Foerder)	Yosi Hadar David Pines	Are Large Cities Too Large? A Contribution to the Debate
35-96 (Foerder)	Assaf Razin Efraim Sadka	Tax Burden and Migration: A Political Economy Perspective
36-96 (Sackler)	Alex Cukierman	The Economics of Central Banking
37-96 (Foerder)	Alex Cukierman	Targeting Monetary Aggregates and Inflation in Europe
38-96 (Foerder)	Assaf Razin Prakash Loungani Chi-Wa Yuen	Capital Mobility and the Output-Inflation Tradeoff
39-96 (Sackler)	Michele Piccione Ariel Rubinstein	The Absent Minded Driver's Paradox: Synthesis and Responses
40-96 (Foerder)	Bent E.Sϕrensen Oved Yosha	International Risk Sharing and European Monetary Unification
41-96 (Foerder)	Dan Ben-David David H.Papell	Structural Change and International Trade
42-96 (Sackler)	Momi Dahan Daniel Tsiddon	Demographic Transition, Income Distribution, and Economic Growth
43-96 (Foerder)	Chaim Fershtman Uri Gneezy	Strategic Delegation: An Experiment
44-96 (Foerder)	Todd R.Kaplan David Wettstein	Cost Sharing: Efficiency and Implementation
45-96 (Sackler)	Bhaskar Chakravorti Yossef Spiegel	A Posnerian Model of Entry into Regulated Markets
1-97 (Foerder)	Michael Kaganovich Itzhak Zilcha	Education, Social Security and Growth
2-97 (Foerder)	David Pines	Specialization and Trade: The Perspective of Club and Local Public Good Theories
3-97 (Sackler)	Dan Ben-David Michael B.Loewy	Knowledge Dissemination, Capital Accumulation, Trade, and Endogenous Growth