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CATCH-UP, TRADE, AND TECHNOLOGICAL DIFFUSION*

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ABSTRACT

This paper provides a trade-related formalization of the catch-up hypothesis and an empirical examination of the relationship between international trade and technological convergence among countries. In the model, trade is assumed to act as a conduit for knowledge spillovers among countries, while investment in education is needed for utilization of these spillovers. Trade-related dissemination of knowledge is shown to lead to convergence in technologies and incomes among the traders. The empirical implications of the hypothesis are examined in the second part of the paper. Countries that trade extensively with one another tend to exhibit a high incidence of significant convergence in technologies. Furthermore, it is shown that – as the catch-up hypothesis suggests – the size of the initial technological gap is related to the speed of the subsequent technological convergence that occurs among the heavy traders.

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I. INTRODUCTION

The notion that countries should exhibit income convergence over time is not a new one. The catch-up hypothesis – which evolved over the decades through the contributions of Veblen (1915), Gerschenkron (1952), Abramovitz (1979, 1986), and others – suggests one possible avenue through which this process might occur. The idea is that relatively under-developed economies have the potential to adopt existing technologies and catch-up to the technological leaders. The less developed an economy, the more growth potential it possesses – though, as Abramovitz points out, there exists some minimum level of development below which a country is not capable of absorbing new technologies. As a country catches up to the leader, the stock of unabsorbed knowledge is reduced and, in lieu of technological shocks, existing technological gaps should decline and eventually disappear over time.

The catch-up hypothesis suggests that the convergence process operates in a manner that is akin to a spring – the more you pull one end way from the other, the faster the two ends will move back together. In other words, the speed of convergence is negatively related to the extent of a country's backwardness. Or, to borrow terminology from the field of physics, the greater a country's displacement, the greater should be its velocity towards the lead country.

But, as Romer (1986) and Lucas (1988) observed in their seminal papers, income gaps between most countries in the world show little evidence of falling over time. If anything, the opposite seems to be the case. While there is some evidence of convergence among OECD countries (see, for example: Baumol, 1986; and Dowrick and Nguyen, 1989), this in itself is not a particularly robust outcome. In fact, a random sub-grouping of relatively developed countries exhibits significant income convergence in only about half of the draws. What then, might lie behind the convergence between some countries that distinguishes them from the non-convergence between the rest?

One potential thread that ties countries together is international trade. Ben-David (1993, 1994) shows that formal trade liberalization agreements and their implementation leads to income convergence (that had not previously existed) among liberalizing countries. Sachs and Warner (1995) find that more open countries exhibit stronger convergence tendencies than do closed countries – and Rassekh (1992) and Ben-David (1996) show that per capita income convergence is evident when countries trade extensively with one another.

What might be the mechanism through which international trade might lead to income convergence? One theoretical framework that has been associated with the equalization of incomes is the Heckscher-Ohlin theory, and in particular, the factor-price equalization proposition (Samuelson, 1948; Helpman and Krugman, 1985) which postulates that, when certain restrictions apply, free trade should bring about an equalization of commodity and factor prices. But, as Rassekh and Thompson (1996) and Slaughter (1997) show, this does not necessarily translate into an equalization of per capita incomes since there is no requirement that capital-labor ratios converge as well.

Alternatively, the neoclassical growth model (Solow, 1956; Cass, 1965; Koopmans, 1965) explains convergence in per capita incomes – but without any reference to international trade. Under the assumption of identical and exogenous technological progress across nations, unhindered capital flows from rich to poor countries facilitate the convergence process by bringing about an equalization of capital-labor ratios, and subsequently, of incomes as well. As Lucas (1990) points out however, the international flow of capital is much smaller than the theory predicts.

Slaughter (1997) concludes that, while there appears to be empirical evidence linking international trade to income convergence, there remains a need to understand the mechanisms underlying the role that trade plays in the convergence process. That issue is the focus of this paper – first, within an open economy theoretical framework where educational attainment and the accumulation of knowledge and physical capital contribute to per capita output growth; and second, with an empirical examination of the model's predictions.

The goal of section two is to provide a trade-related formalization of the Veblen-Gerschenkron-Abramovitz catch-up hypothesis. As Baumol, Blackman, and Wolff (1989) state, the knowledge dissemination underlying the catch-up process is facilitated by pressures induced through competition in the international marketplace. Hence, international trade in the model acts as a conduit of ideas between countries. The resultant knowledge spillovers in turn lead to faster knowledge accumulation and output growth in the poorer countries – and subsequently, to a convergence in levels and growth rates between trading countries.

It should be noted that, while trade may be a conduit for knowledge spillovers, it is obviously not the only route. If such spillovers are dependent on interaction between people, then there are clearly many additional avenues through which such interaction takes place – for example via foreign investments, electronic communications channels, migration and travel. The emphasis here is not on ruling out other conduits for knowledge dissemination, but rather on focusing on one of the major determinants that induces and facilitates such dissemination.

Section three provides an empirical examination of two main questions: do countries that trade extensively with one another exhibit technological convergence; and, is the size of the technology gap related to the speed of the subsequent convergence in technologies? This paper shows that, in general, the answer to both questions is positive. Section four concludes.

II. THE MODEL

In some of the more recent growth literature, which endogenizes the growth process, trade facilitates the diffusion of knowledge. This conclusion is supported by the empirical findings of knowledge spillovers between trade partners in Coe, Helpman, and Hoffmaister (1997), Keller (1995), and Weinhold (1995), as well as Helliwell's (1992) finding of a positive relationship between trade and technological progress. The model developed below incorporates this empirical evidence with the intuition of Baumol, Blackman and Wolff (1989), Grossman and Helpman (1991, 1995) and others – that trade regulates the extent of spillovers – by modifying and extending the Solow-Cass-Koopmans model into an open-economy multi-country model that accounts for the contribution of both knowledge accumulation and educational attainment in the production process.[1]

In the model that follows, it is assumed that knowledge is non-rivalrous and, to a certain extent, non-excludable. The non-rivalrousness assumption implies that the stock of knowledge within a country can be used by all individuals concurrently. The non-excludability assumption is used here in the broad sense to permit knowledge spillovers among countries. It is not meant to imply that patent and copyright protections do not exist, but rather to invoke the concept of knowledge in the broader sense. For example, at the turn of the last century, learning about the existence of assembly lines in the manufacture of automobiles facilitated a modification of the concept into other areas of manufacturing. Hence, it is the general notion of concepts and ideas that is behind the term "knowledge" that is used here.

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[1] Ben-David (1997) also accounts for knowledge accumulation and educational attainment in the growth process, but within a different setting that does not include physical capital, as is the case here. The focus there is on the growth and level effects of income taxes and tariffs.

II.A. Setup of the Model

Assume that each of J countries produces a unique good, with country i producing good i. Output in country i is produced using physical capital together with labor supplemented by human capital.

Human capital in this model comprises two components: a stock variable, knowledge; and a flow variable, education. The first component, knowledge, reflects the accumulation of ideas over time. Each country i starts off with an initial stock of knowledge, $H_i(0)$. As people interact, new ideas ensue. These new ideas enlarge the knowledge stock and provide a richer source of building blocks upon which new ideas are developed. Hence, the extent of the change in $H_i(t)$ depends on the size of $H_i(t)$ and a constant productivity parameter ϕ that is common to all countries. In autarky, this relationship may be described by $\dot{H}_i(t) = \phi H_i(t)$ which implies that the stock of knowledge in country i grows at the constant and exogenous rate ϕ.

When countries open up to trade with one another, the need to compete with foreign goods, both at home and abroad, leads domestic residents to assimilate foreign ideas – and the domestic knowledge stock is affected accordingly. Following Grossman and Helpman (1991), the intuition here is that the volume of trade between any two countries i and j acts as a spigot that determines the extent of knowledge spillovers between the two. Let $v_{ij}(t)$ equal the endogenously determined ratio of i's bilateral trade with j to country i's output, or

$$v_{ij}(t) = \frac{L_i(t)p_j(t)c_{ij}(t) + L_j(t)p_i(t)c_{ji}(t)}{L_i(t)p_i(t)y_i(t)} \quad , \qquad i \neq j \tag{1}$$

where $y_i(t)$ is the level of output per capita in country i, $c_{ij}(t)$ represents country i's real per capita consumption of country j's goods, $p_i(t)$ is the price of good i (good 1 is the numeraire good) and $L_i(t)$ is the population size in country i at time t (no distinction is made here between the size of the labor force and the size of the population). It is assumed that $L_i(t)$ grows at the constant rate, n.

Since not all of the stock of knowledge in country j is necessarily relevant or applicable for country i, let a_{ij} reflect the proportion of each $H_j(t)$ that is useful for country i.[2] Thus, the contribution of country j's applicable knowledge stock, $a_{ij}H_j$, to the increase in i's knowledge stock – which is regulated by the extent of openness, v_{ij} – is given by $v_{ij}a_{ij}H_j$. In a world with J countries, knowledge in country i accumulates according to

$$\dot{H}_i(t) = \phi\left[H_i(t) + \sum_{j \neq i} v_{ij}(t)\, a_{ij} H_j(t)\right] \quad . \qquad \textbf{(2)}$$

Thus, domestic knowledge accumulation is dependent not only on the stock of domestic knowledge, but also on the relevant stock of knowledge in the country's trade partners, as well as on the extent of trade that exists between the countries. In contrast with Lucas (1993), knowledge spillovers in this model are not complete and the extent of trade, which regulates the degree of knowledge dissemination, is determined within the model.

But while trading countries may have access to foreign knowledge, how capable are they of absorbing and utilizing that knowledge? In large part, this capability depends on the level of education that each of the (identical) individuals in the country possesses. In contrast with ideas, which can be accumulated and preserved over time,[3] education is something that each individual must attain for him or herself and is not something that passes automatically through the womb

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[2] To simplify the analysis that follows, these a_{ij}'s are assumed to be constant.

[3] Inclusion of a variable to account for the depreciation of ideas, while realistic, contributes little additional insight and clutters the notation, hence this possibility is not considered here.

from one generation to the next. Therefore, education must be provided each period in order to allow newly-born individuals to receive an education.

Both time and physical resources are needed to produce education. Individuals divide their time between production of the physical good and the attainment of education, with u_i representing the proportion of time spent producing good i and $(1-u_i)$ representing the amount of time spent in school. In addition to deciding how to allocate their time, individuals must also decide how much physical capital, $K_i(t)$, to allocate toward the production of education and how much toward the production of good i. The proportion ψ_i of physical capital is used in the production of good i and the proportion $(1-\psi_i)$ is used in the production of education. Thus, the level of education, $E_i(t)$, is produced according to

$$E_i(t) = \delta\left[\left(1 - \psi_i(t)\right)K_i(t)\right]^{\eta}\left[\left(1-u_i(t)\right)L_i(t)\right]^{1-\eta} \quad \textbf{(3)}$$

where δ is a productivity parameter common to all countries.

The level of education per person, $e_i(t)$, determines how much of the available knowledge stock, $H_i(t)$, can be utilized by the representative worker. The resultant level of human capital per person, e_iH_i, is multiplied by u_iL_i, the size of the workforce engaged in the production of the country's output, $Y_i(t)$, to yield $L_i^e(t)$, the effective labor force. Output production is a constant returns to scale function in effective labor and physical capital,

$$Y_i(t) = A\left[\psi_i(t)K_i(t)\right]^{\beta}\left[e_i(t)H_i(t)u_i(t)L_i(t)\right]^{1-\beta} \quad \textbf{(4)}$$

where A is a constant output productivity parameter common across countries.

The budget constraint, in per capita terms, is

$$\sum_{j=1}^{J}\frac{p_j(t)}{p_i(t)}c_{ij}(t) + \dot{k}_i(t) + nk_i(t) = y_i(t) \quad \textbf{(5)}$$

where $k_i(t)$ is the levels of capital per person in country i at time t. Market clearing,

$$c_{ii} + \sum_{j \neq i} \frac{L_j}{L_i} c_{ji} + \dot{k}_i + n k_i = y_i \quad , \tag{6}$$

together with the budget constraint, implies that each country's overall trade must be balanced, *i.e.*

$$L_i(t) \sum_{j \neq i} p_j(t)\, c_{ij}(t) = \sum_{j \neq i} p_i(t)\, L_j(t)\, c_{ji}(t) \qquad \forall\ i \tag{7}$$

though its bilateral trade need not be balanced.

Finally, consumer preferences in country i are given by

$$\int_0^{\infty} e^{-(\rho - n)t}\ L_i(0) \sum_{j=1}^{J} \alpha_{ij} \ln c_{ij}(t)\, dt \tag{8}$$

where ρ is the rate of time preference and $0<\alpha_{ij}<1$ ensures trade in the model ($\sum_{j=1}^{J} \alpha_{ij} = 1$). Initial population levels in each country are normalized to equal unity.

II.B. Solution of the Model

To find the equilibrium time path for this economy, the current value Hamiltonian is maximized for country i. Letting $\theta_i(t)$ and $\lambda_i(t)$ be the costate variables for physical capital and knowledge in country i, then, after dropping the time argument, the current value Hamiltonian is

$$H\left(\{c_{ij}\}_{j=1}^{J}, u_i, \psi_i, k_i, H_i, \theta_i, \lambda_i, t\right) = \sum_{j=1}^{J} \alpha_{ij} \ln c_{ij} + \theta_i \left(y_i - \sum_{j=1}^{J} \frac{p_j}{p_i} c_{ij} - n k_i \right) + \lambda_i \phi \left(H_i + \sum_{j \neq i} v_{ij} a_{ij} H_j \right) \quad .$$

The first-order conditions for an interior solution to this problem are:

$$\frac{\alpha_{ii}}{c_{ii}} = \theta_i \quad ; \tag{9}$$

$$\frac{\alpha_{ij}}{c_{ij}} = \frac{p_j}{p_i}\theta_i \quad , \qquad j \neq i \quad ; \tag{10}$$

$$u_i = \frac{1}{2-\eta} \quad ; \tag{11}$$

and

$$\psi_i = \frac{\beta}{\beta + (1-\beta)\,\eta} \quad ; \tag{12}$$

while changes in the costate variables are given by the Euler equations:

$$\dot{\theta}_i = \theta_i(\rho - n) - \theta_i\left[\left(\beta + \eta(1-\beta)\right)\frac{y_i}{k_i} - n\right] \quad ; \tag{13}$$

and

$$\dot{\lambda}_i = \lambda_i(\rho - n) - \theta_i(1-\beta)\frac{y_i}{H_i} - \lambda_i\phi \quad . \tag{14}$$

Substitution of Equations (11) and (12) into the per capita version of education equation (3) yields

$$e_i = \delta\left[\frac{(1-\beta)\,\eta}{\beta + (1-\beta)\,\eta}\right]^{\eta}\left[\frac{1-\eta}{2-\eta}\right]^{1-\eta} k_i^{\eta} \tag{15}$$

which indicates that countries with less capital per person will also have a lower level of education per person. Is the positive relationship between e_i and k_i suggested by Equation (15) borne out empirically?

Combining real aggregate capital stock data from the World Bank (which is described in Nehru and Dhareshwar, 1993) with real output per worker data from Summers and Heston (1995), it is possible to calculate capital-labor ratios that are comparable across countries. Since the capital stock data is denoted in constant domestic currency, it is converted here into internationally comparable capital per worker (k) by multiplying the aggregate capital stocks of each country by the ratio of real GDP per worker from Summers and Heston to real aggregate GDP denoted in constant domestic currency from the World Bank (1994).[4]

Barro and Lee (1993) provide data on educational attainment. Letting the average number of school years per person proxy for e_i, Figure 1 provides a plot of the (log e_i, log k_i) pairs for each of 71 countries in 1985. A correlation coefficient of 0.84 between the two variables suggests that a positive relationship does indeed exist between the two variables.

From Equations (9) and (13), the steady state growth rate for c_{ii} is

$$\gamma^*_{c_{ii}} = \rho - [\beta + \eta(1-\beta)]\frac{y_i^*}{k_i^*} \tag{16}$$

where γ will be used to denote growth rates and the (*) to designate steady state values. Since c_{ii} must be growing at a constant rate in the steady state, the implication from (16) is that the capital-output ratio must be constant as well in the steady state. This, together with Equations (4) and (15) yields $\gamma^*_{y_i} = \gamma^*_{k_i} = \frac{1}{1-\eta}\gamma^*_{H_i}$.

Let s_i be the savings rate, where

$$s_i = \frac{\dot{k}_i + nk_i}{y_i} \quad . \tag{17}$$

Dividing both the numerator and the denominator by k_i yields $s_i^* = (\gamma^*_{k_i} + n)/(y_i^*/k_i^*)$.

[4] Summers and Heston (1995) also provide data on capital stocks, but they covers less countries and less years (which is an important consideration for the analysis in the next section) than the World Bank dataset. In any event, the two datasets are quite correlated when matched for the countries and years of overlap, so the World Bank capital stock data is used here.

Since $\gamma^*_{k_i}$ and y_i^*/k_i^* , are both constant in the steady state, then the savings rate, s_i^*, will also constant.

The consumption equations

$$c_{ii} = \alpha_{ii}(1 - s_i)y_i \tag{18}$$

and

$$c_{ij} = \alpha_{ij}\frac{p_i}{p_j}(1 - s_i)y_i \tag{19}$$

are found by combining the market clearing equation (6) with the savings rate expression (17) and first order conditions (9) and (10). Thus, the steady state growth rates of own consumption, capital and output,

$$\gamma^*_{c_{ii}} = \gamma^*_{k_i} = \gamma^*_{y_i} = \frac{1}{1-\eta}\gamma^*_{H_i} \tag{20}$$

are determined by the growth rate of knowledge. The solution to this latter growth rate is found by solving the system of differential equations (2) that determine the rate of knowledge accumulation in each country. But to solve this system, it is first necessary to show that the trade ratios, v_{ij}, are constant in the steady state.

Insertion of (18) and (19) back into the market clearing equation yields the market clearing prices

$$p_i^* = \pi_i \frac{L_1(1 - s_1^*)y_1^*}{L_i(1 - s_i^*)y_i^*} \quad , \tag{21}$$

where π_i is a function of the α_{ij}'s and is therefore constant. The bilateral openness variable, v_{ij}^*, is found by substituting the price and consumption equations into Equation (1), *i.e.*

$$v_{ij}^{*} = \left(\alpha_{ij} + \alpha_{ji}\frac{\pi_j}{\pi_i}\right)\left(1 - s_i^{*}\right) \quad . \qquad \textbf{(22)}$$

Hence, v_{ij}^{*}, is constant in the steady state.

Turning now to the solution for $\gamma_{H_i}^{*}$, the system of differential equations (2) for countries $i = 1, ..., J$ is solved by determining the eigenvalues (μ_1,...,μ_J) and their associated eigenvectors. This solution is

$$H_i(t) = \sum_{j=1}^{J} x_{ij}\, \xi_j e^{\mu_j t} \qquad \textbf{(23)}$$

where x_{ij} is the ith component in the eigenvector associated with the eigenvalue μ_j while the ξ_j are constants determined by the initial conditions $H_1(0)$, ..., $H_J(0)$ and the eigenvectors.

Suppose that μ_z (where $1 \leq z \leq J$) is the largest eigenvalue. Since each of the v_{ij}'s is positive, and assuming that at least one of the a_{ij}'s is also positive for each i, then it must be true that μ_z is greater than ϕ, the autarky growth rate of knowledge. Furthermore, since the largest eigenvalue will dominate the other eigenvalues in the steady state, it follows that the H_i^{*} in each country will grow at the same rate, thus

$$\gamma_{H_1}^{*} = \ldots = \gamma_{H_J}^{*} = \gamma_{H}^{*} = \mu_z \ . \qquad \textbf{(24)}$$

From Equations (23) and (24) it is possible to determine the relative levels of knowledge in any two countries i and j. This ratio is simply the ratio of the relevant components in the eigenvector associated with eigenvalue μ_z, or

$$\frac{H_i^{*}}{H_j^{*}} = \frac{x_{iz}}{x_{jz}} \quad . \qquad \textbf{(25)}$$

In a two country world, it is straightforward to show analytically that this ratio has to equal unity (and that γ_H^* equals a constant greater than ϕ). In other words, $H_1^* = H_2^*$. Numerical solutions indicate that this is also the case when there are more than two countries.

Alternatively, it is also possible to show that equal H^*'s are the solution in a J-country world using the system of equations given by (2) and applying Equation (24). Define $\boldsymbol{R}_{ji}^*$ as the ratio H_j^*/H_i^* and divide each country i's Equation (2) by that country's H_i. This gives the steady state growth rates (which are equal) on the left-hand side of each equation, which in turn gives a system of $J-1$ equations $\sum_{k \neq j} v_{jk}^* \boldsymbol{R}_{kj}^* = \sum_{j \neq i} v_{ij}^* \boldsymbol{R}_{ji}^*$ in $J-1$ unknowns. The steady state solution $\boldsymbol{R}_{kj}^* = \boldsymbol{R}_{ji}^* = \ldots = 1$, or

$$H_1^* = H_2^* = \ldots = H_J^*,$$

solves this system.

So, in a world in which countries are allowed to trade freely with one another, the model predicts that the levels of knowledge in each of the countries should converge to the same growth path. What are the implications of this as far as income convergence is concerned?

As noted earlier, in Equation (16), constant consumption growth in the steady state implies that the capital-output ratio should also be constant in the steady state. Combining Equations (20) and (24) further implies that these ratios will be equal across countries.[5] Therefore, since the knowledge stocks and capital-output ratios are equalized in the steady state, the implication is that output per worker, capital-labor ratios, and education levels should become equalized as well, *i.e.*

[5] This, incidently, implies that the marginal products of physical capital should also be equal across countries.

$$y_1^* = y_2^* = \ldots = y_J^*$$
$$k_1^* = k_2^* = \ldots = k_J^*$$

and

$$\boldsymbol{e}_1^* = \boldsymbol{e}_2^* = \ldots = \boldsymbol{e}_J^* \quad .$$

The next section examines how well this prediction holds when confronted with the data.

III. EMPIRICAL EVIDENCE

From an empirical perspective, Linder (1961) suggests that similar countries trade more, hence it might be that increased convergence leads to heightened trade relationships rather than the other way around. The issue of causality between trade and income convergence is addressed in Ben-David (1993, 1994). In these studies, implementation of formal trade agreements with specified timetables for the removal of trade barriers are treated as exogenous events. This allows for a convergence analysis of the countries prior to, during, and after the specified period of liberalization.

The studies show that countries whose income differentials had remained more or less constant for over half a century began to exhibit convergence just as they began to liberalize trade (with different periods of liberalization for different groups of countries). At the end of each of the liberalization processes, income differentials continued to remain at their new, low, levels for the remaining decades of the sample. The studies also show that these episodes of convergence were not evident in benchmark comparisons of non-liberalizing countries.[6] Hence, it would appear that the movement towards free trade led to the income convergence – which was not otherwise evident – rather than the other way around as suggested by the Linder hypothesis.

One of the by-products of the Ben-David (1993, 1994) research is the finding that trade liberalization is conducive to income convergence only if the trade reform is being carried out by major trade partners. In a generalization of this outcome – where formal trade liberalization is no longer the criteria for grouping countries – Ben-David (1996) shows substantial evidence of convergence in income levels between countries that trade extensively with one another.

While these studies established that there exists a link between trade and income convergence, they do not address two important points. First, the model developed here suggests that convergence in levels of knowledge facilitated by trade underlies convergence in incomes, and that capital-labor ratios and education levels should exhibit convergence as well. Do these three components of income converge, and is there a role played by international trade in this context as well?

The second point involves the empirical applicability of the intuition underlying the catch-up hypothesis. Specifically, does there exist a relationship between the size of the knowledge gap and a subsequent speed of reduction in this gap – and what role, if any does international trade play in enhancing this relationship?

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[6] These results are similar to those of Sachs and Warner (1995), who provide an extensive review of postwar trade policy reforms and find that income convergence is related to the extent of openness among countries.

III.A. Setup of the Empirical Analysis

A natural experiment of the model's predictions would be among countries that trade extensively with one another. Since most trade is between relatively developed countries, then one would expect that these should exhibit convergence in income levels. As noted in the introduction, such convergence has indeed been found among OECD countries. To avoid the problems raised by De Long (1988) in his criticism of the sample selection by Baumol (1986) — who chose countries that were developed at the end of the sample period rather than at its beginning, thereby biasing the results towards convergence — the definition of "developed", for the purpose of this exercise, will be a level of at least 33% of the United States' output per worker in 1960, the first year of the sample period.[7] These countries will be referred to as "source" countries and they include only non-Communist and non-primary-oil producing countries. There are 24 countries that meet this criteria.

The next step is to determine who the primary trade partners are for each of the source countries. IMF Direction of Trade statistics are used for this purpose. To the extent that it might make a difference (in the convergence analysis that follows) whether the partners are chosen on the basis of exports or imports, each source country will have one group that is created on the basis of export data and one group that is created on the basis of import data. Choosing an ad hoc cutoff point of 10%, or even 5%, of total exports or imports yields only one trade partner — if even that much — for many of the source countries. Lowering the cutoff point to 3% of total exports or imports yields a very large number of trade partners in many instances. Thus, a cutoff point of at least 4% of total exports, or 4% of total imports, is used to determine each source

[7] *Data source:* Summers and Heston (1995)

country's primary trade partners. This yields export and import-based groups that range in size from 3 to 9 countries.

The combined selection criteria of source and partner countries produces a list of 27 countries that, together, form a fairly self-contained web of major trade relationships. This list includes the 24 source countries and only 3 additional non-source countries.[8]

In the case of exports, there are two instances (three in the case of the imports) in which the export-based group of one source country is identical to the export-based group of another source country. When this occurs, the redundant group is omitted from the analysis. Hence, there are 22 export-based groups of countries and 21 import-based groups of countries.

The common method for determining convergence is to calculate each country's average growth rates over a period and to then regress these on the respective country's initial levels of income as well as on additional variables that one wishes to control for. These cross-country convergence regressions have been criticized by Quah (1993) and Friedman (1992) for regression to the mean problems that bias the results. Quah shows that this bias is similar to Galton's fallacy. In any event, the relatively small number of countries in each group precludes the use of cross-country regressions to determine intra-group convergence here since the number of observations would be extremely small.

Friedman advocates Hotelling's (1933) view that convergence is indicated by a diminution of the income variance among countries over time. This approach for determining convergence is adopted here. Namely, annual standard deviations of the logs of the variable of interest ($\sigma_{x,t}$ for any variable x) are calculated and these are regressed on trend. A negative trend coefficient

[8] The membership of each source country's export and import-based groups is detailed in the appendix table.

indicates a reduction in income differentials over time, or convergence. Divergence is indicated by a positive trend coefficient.

In general, how does the behavior over time of the overall income gap for this web of 27 countries – that are the sources and recipients of most of the world's trade – compare with the behavior of the gap between the remaining 97 countries in the Summers and Heston sample? The initial gap within the group of 97 is nearly twice as large as the initial gap within the group of 27, thus for the sake of clarity in the visual exposition in Figure 2, the plot is of the ratio of each group's $\sigma_{y,t}$ to its initial σ_y in 1960 rather than the actual $\sigma_{y,t}$'s. The average income gap between the 97 countries rose steadily through the late 70's until appearing to level off in the early 80's and even declining somewhat to a gap that was about 16% higher than the 1960 gap. By comparison, the gap within the web of 27 countries chosen here fell substantially until the early 80's before returning to a level that was nonetheless about 8% below the 1960 gap.

The comparison between the two groups provides an interesting example regarding the broad applicability of the catch-up hypothesis's prediction that the size of the initial gap is related to the speed of the subsequent convergence. Not only is the group with the larger gap not converging faster here, it is not converging at all. However, it is also a group bound by relatively few trade ties (compared to the group of 27) and handicapped by relatively low levels of education (as is illustrated in Figure 1) which limit the ability of the countries to garner the knowledge spillovers that nonetheless do come their way. An analysis of the individual trade groups will sharpen the analysis pertaining to the relationship between trade and underlying determinants of the income convergence since it takes the web of 27 traders and focuses directly on its subsets of major trade partners.

III.B. Convergence in Education Levels, Capital Stocks and Technologies

While data exists for education levels, output and capital per worker, it does not exist for knowledge stocks, H_i. However, output equation (4) suggests that one way to proxy for knowledge stocks is to calculate the total factor productivities (TFP) of each country, $y_i/(k_i^{\beta} e_i^{1-\beta})$, since (4) may be rewritten as

$$H_i = \kappa \left(\frac{y_i}{k_i^{\beta} e_i^{1-\beta}} \right)^{\frac{1}{1-\beta}} \qquad \textbf{(26)}$$

where κ comprises the constant parameters

$$\kappa = \left[\left(\frac{A}{(2-\eta)^{1-\beta}} \right) \left(\frac{\beta}{\beta + (1-\beta)\,\eta} \right)^{\beta} \right]^{\frac{1}{1-\beta}}$$

after substitution of the first order conditions (11) and (12) for u_i and ψ_i. Following Mankiw, Romer, and Weil (1992), who note that capital's share of income is roughly one-third, the β used here will be one-third. Construction of the k_i's was described earlier while the e_i's come from World Bank data on the average number of school years per person.[9]

Do countries with high capital-labor ratios and high TFPs also have higher output per worker? If not, then findings of convergence in the *k*'s and in the TFP's might not be reflective of a convergence in the *y*'s. For the countries and years of the sample in question however, the correlation coefficient between *y* and *k* is approximately 0.9, *i.e.* countries that have relatively high capital-labor ratios tend to be those that produce more per worker. The correlation

[9] The World Bank data, which is positively correlated with the Barro and Lee (1993) data, has the advantage of being annual data rather than just every 5 years as is the case with the Barro-Lee dataset.

coefficients between the *y*'s and the TFPs are also positive and are approximately 0.9 as well. There is a similarly strong positive relationship between education levels and output.

So are the three components of *y* converging over time? The focus will first be on education levels, then on capital-labor ratios, and finally on TFPs. In the case of each of these components, random groupings of countries from the larger web of 27 countries will first be examined to provide a benchmark for the subsequent analysis of the individual trade groups. 1000 such randomly-chosen groups containing 6 countries – the average trade group size – are formed and the degree of disparity within each, σ_t, is regressed on trend for the period 1960–87.[10]

Out of 1000 randomly created groups, education levels exhibited significant convergence (at the 10% level) in 98% of the groups and significant divergence in just 1% of the groups. The results from the trade-based groups appear in Table 1. The export-based groups are in the left panel, while the import-based groups are in the right panel. The source countries of each group are listed in the left column of each panel. The column to the right of the source countries lists the number of countries in each group. The next column to the right provides the results of the trend estimations.

The trade based groups exhibited an 86% incidence of significant convergence (in exports and in imports), a 14% incidence of significant divergence among the export-based groups, and a 10% incidence of significant divergence among the import-based groups. Thus, in the case of education levels, convergence seems to be the common denominator among nearly all of the countries in the 27 country web. Stronger trade ties do not affect this relationship.

[10] The problem of serial correlation, when it exists, is addressed and corrected in the reported estimations.

A similar story also appears to hold true for capital-labor ratios. Random groupings produce significant convergence 73% of the time and significant divergence in 19% of the groups. As is evident from Table 2, the incidence of significant *k* convergence is 95% in both the export-based groups and the import-based groups versus no cases of significant *k* divergence in either group.

It is in the TFP convergence where the strong trade relationships appear to matter the most. In the random groupings, 49% of the outcomes indicate significant convergence while 31% indicate significant divergence – a 1.6 ratio of convergence to divergence outcomes. Among the trade-based groups, the results of which are reported in Table 3, TFP convergence appears to be quite a bit more prevalent. 71% of the import-based groups converged while 19% diverged, a convergence-divergence ratio of 3.8. In the case of the export-based groups, 82% converged while just 9% diverged, yielding a convergence-divergence ratio of 9.0.

III.C. Gap Size and Speed of Convergence

Did groups with large initial technology gaps ($\sigma_{TFP,1960}$) exhibit the fastest subsequent convergence, as suggested by the catch-up hypothesis? Figure 3 depicts the relationship between the initial gaps and the estimated trend coefficients for each of the trade-based groups. The trade groups are identified by their source countries and these names are preceded by either the letter "X" (for export-based groups) or "M" (for import-based groups). When the composition of a source country's export-based group is identical to that of its import-based group, then this group appears only once and is not preceded by either an "X or an "M" (this occurred in two cases: the United States and Canada).

The correlation coefficient between the gap size and rate of convergence is -0.83 for the export groups and -0.60 for the import groups. Exclusion of Argentina's import-based group, which appears to be somewhat of an outlier in the figure, drops the correlation coefficient to -0.82 for imports as well. Thus, there does appear to be a fairly strong negative relationship between the size of the technology gap and the extent of the subsequent technological convergence among countries that trade extensively with one another.

Finally, the speed of the TFP convergence appears to be fairly closely related to the speed of income convergence. Groups that exhibit faster rates of TFP convergence tend to exhibit faster rates of convergence in output per worker as well. Correlation coefficients between the estimated trend coefficients for σ_{TFP} and σ_y range from 0.68 for the import-based groups to 0.77 for the export-based groups.

IV. CONCLUSION

This paper addresses the gap between the empirical evidence of trade-related income convergence among countries and the explanations provided by traditional trade theory and traditional growth theory. An open-economy growth model is used to formalize a trade-related variant of the catch-up hypothesis – which conjectures that knowledge flows between nations underlie the convergence process. In the model, it is assumed that international trade facilitates the dissemination of knowledge across countries. It predicts that the trade-induced knowledge spillovers will lead to a convergence in levels of knowledge across countries. This, in turn, should lead to a convergence in levels of output, capital and education. These predictions of the model are then examined empirically.

A group of 27 countries is formed that comprises various sub-groups of countries created on the basis of extensive trade ties. This larger group, which is similar to a web, is characterized by a high incidence of convergence in education levels and in capital-labor ratios, but not in total factor productivities – which are used here to proxy for levels of technology. However, when the focus shifts to the trade-based subgroups, it turns out that a large majority of these do exhibit significant convergence in TFPs. In addition, as suggested by the catch-up hypothesis, it is shown here that the size of the initial technology gap is negatively related to the speed of the subsequent technological convergence.

In summary, the model described in this paper provides one mechanism through which the oft-cited catch-up process might operate. Empirical evidence on the prevalence of trade-related technology and income convergence would appear to support the model's prediction that an important channel through which trade leads to this income convergence is via the technology route.

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Table 1:

Convergence in Levels of Education‡

(trade groups sorted by *t*-statistics)

	Export-Based Groups			
	Source Country	Size	Trend Coeff.	*t*-stat
1	URUG	6	-0.00982	-190.77 ***
2	NZ	5	-0.00542	-94.07 ***
3	CHIL	8	-0.00786	-70.44 ***
4	ARGN	5	-0.00931	-56.47 ***
5	SPA	7	-0.00303	-48.93 ***
6	AUSTL	4	-0.00619	-46.21 ***
7	US	6	-0.00684	-43.26 ***
8	MEX	4	-0.00813	-28.89 ***
9	UK	8	-0.00367	-26.58 ***
10	ISRA	6	-0.01579	-20.07 ***
11	ICE	5	-0.00245	-19.38 ***
12	IRE	7	-0.00497	-15.44 ***
13	CAN	3	-0.00158	-8.11 ***
14	FIN	7	-0.00216	-7.64 ***
15	GERM	9	-0.00036	-5.25 ***
16	FRA	8	-0.00028	-4.06 ***
17	ITAL	6	-0.00033	-3.89 ***
18	AUSTR	6	-0.00037	-3.89 ***
19	NETH	7	-0.00063	-3.86 ***
20	DEN	7	0.00032	3.40 ***
21	SWED	9	0.00151	6.04 ***
22	NOR	7	0.00082	16.75 ***

‡ Significant at the 1% (***) level.

	Import-Based Groups			
	Source Country	Size	Trend Coeff.	t-stat
1	URUG	5	-0.00991	-254.57 ***
2	SPA	7	-0.00686	-108.96 ***
3	AUSTL	6	-0.00450	-103.37 ***
4	CHIL	5	-0.00962	-59.40 ***
5	US	6	-0.00684	-43.26 ***
6	ARGN	8	-0.01131	-29.85 ***
7	MEX	3	-0.01011	-29.27 ***
8	ISRA	8	-0.01239	-18.48 ***
9	IRE	5	-0.00630	-17.01 ***
10	GERM	8	-0.00064	-15.02 ***
11	AUSTR	4	-0.00461	-11.62 ***
12	UK	9	-0.00044	-9.85 ***
13	ICE	9	-0.00109	-9.70 ***
14	CAN	3	-0.00158	-8.11 ***
15	SWIS	8	-0.00027	-4.42 ***
16	FRA	7	-0.00063	-3.86 ***
17	ITAL	6	-0.00063	-3.40 ***
18	SWED	9	-0.00041	-2.79 ***
19	FIN	6	-0.00012	-0.44
20	NETH	6	0.00056	6.21 ***
21	DEN	9	0.00046	9.06 ***

Table 2: **Convergence in Capital-Labor Ratios**‡

(trade groups sorted by *t*-statistics)

	Export-Based Groups			
	Source Country	Size	Trend Coeff.	*t*-stat
1	IRE	7	-0.00894	-54.53 ***
2	UK	8	-0.00828	-51.57 ***
3	ARGN	5	-0.01976	-25.82 ***
4	AUSTL	4	-0.03396	-23.84 ***
5	ICE	5	-0.02473	-23.11 ***
6	CAN	3	-0.03998	-23.06 ***
7	NZ	5	-0.02821	-22.03 ***
8	MEX	4	-0.02659	-19.97 ***
9	ISRA	6	-0.00671	-19.86 ***
10	US	6	-0.02179	-18.87 ***
11	SPA	7	-0.01139	-17.85 ***
12	FRA	8	-0.00717	-17.36 ***
13	ITAL	6	-0.00743	-13.90 ***
14	NOR	7	-0.00646	-12.30 ***
15	SWED	9	-0.00583	-11.29 ***
16	URUG	6	-0.00557	-10.05 ***
17	DEN	7	-0.00690	-9.76 ***
18	FIN	7	-0.00565	-9.48 ***
19	CHIL	8	-0.00756	-8.86 ***
20	NETH	7	-0.00297	-4.24 ***
21	GERM	9	-0.00148	-2.41 ***
22	AUSTR	6	-0.00035	-0.42

‡ Significant at the 1% (***) level.

	Import-Based Groups			
	Source Country	Size	Trend Coeff.	t-stat
1	IRE	5	-0.01134	-37.65 ***
2	GERM	8	-0.01893	-25.80 ***
3	FIN	6	-0.02332	-23.09 ***
4	CAN	3	-0.03998	-23.06 ***
5	AUSTL	6	-0.02489	-22.04 ***
6	UK	9	-0.01790	-21.09 ***
7	NETH	6	-0.00867	-20.33 ***
8	MEX	3	-0.03228	-20.21 ***
9	ICE	9	-0.01706	-20.09 ***
10	DEN	9	-0.01781	-19.55 ***
11	US	6	-0.02179	-18.87 ***
12	SWED	9	-0.01785	-18.02 ***
13	SPA	7	-0.00971	-17.54 ***
14	AUSTR	4	-0.00649	-16.18 ***
15	ARGN	8	-0.00988	-13.30 ***
16	ISRA	8	-0.00517	-12.21 ***
17	URUG	5	-0.00631	-10.30 ***
18	CHIL	5	-0.01191	-10.26 ***
19	ITAL	6	-0.00426	-6.50 ***
20	FRA	7	-0.00297	-4.24 ***
21	SWIS	8	-0.00075	-1.00

Table 3:

Convergence in Total Factor Productivities‡

(trade groups sorted by *t*-statistics)

Export-Based Groups

	Source Country	Size	Trend Coeff.	*t*-stat
1	MEX	4	-0.00827	-15.56 ***
2	NZ	5	-0.00812	-13.82 ***
3	AUSTL	4	-0.00902	-10.80 ***
4	DEN	7	-0.00165	-8.62 ***
5	GERM	9	-0.00303	-8.61 ***
6	UK	8	-0.00476	-8.17 ***
7	IRE	7	-0.00559	-7.87 ***
8	AUSTR	6	-0.00354	-7.02 ***
9	ISRA	6	-0.00513	-6.85 ***
10	CAN	3	-0.00607	-6.41 ***
11	US	6	-0.00598	-6.25 ***
12	FRA	8	-0.00239	-4.88 ***
13	NOR	7	-0.00137	-4.85 ***
14	ITAL	6	-0.00285	-4.83 ***
15	FIN	7	-0.00209	-4.66 ***
16	ICE	5	-0.00319	-3.19 ***
17	ARGN	5	-0.00381	-3.02 ***
18	SWED	9	-0.00085	-2.93 ***
19	CHIL	8	0.00027	0.21
20	SPA	7	0.00015	0.48
21	NETH	7	0.00053	2.15 **
22	URUG	6	0.00450	4.20 ***

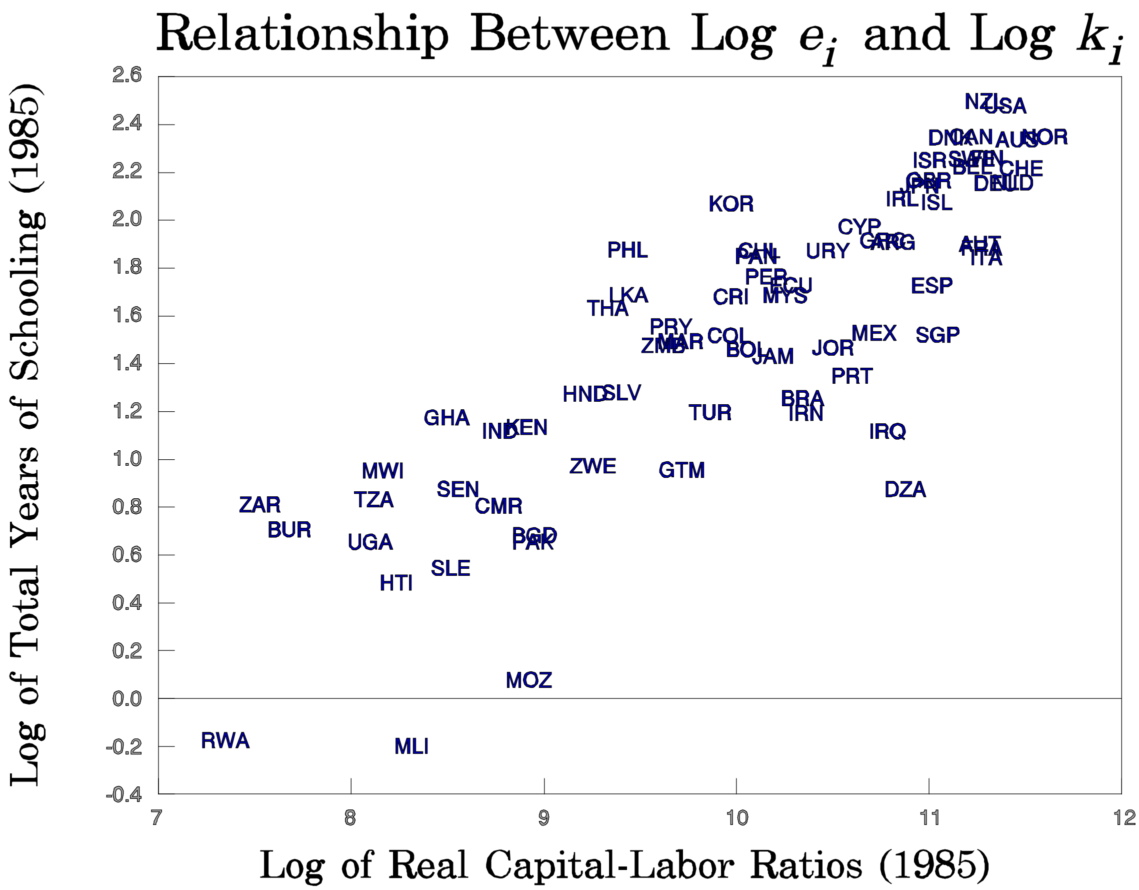
‡ Significant at the 1% (***) and 5% (**) levels.

Import-Based Groups

	Source Country	Size	Trend Coeff.	t-stat
1	MEX	3	-0.01065	-18.01 ***
2	AUSTL	6	-0.00693	-11.83 ***
3	UK	9	-0.00217	-8.35 ***
4	IRE	5	-0.00683	-7.83 ***
5	CAN	3	-0.00607	-6.41 ***
6	ISRA	8	-0.00514	-6.38 ***
7	US	6	-0.00598	-6.25 ***
8	AUSTR	4	-0.00591	-5.81 ***
9	SWED	9	-0.00323	-5.75 ***
10	ICE	9	-0.00339	-5.53 ***
11	DEN	9	-0.00334	-5.13 ***
12	FIN	6	-0.00342	-4.33 ***
13	SPA	7	-0.00337	-3.80 ***
14	GERM	8	-0.00242	-3.08 ***
15	SWIS	8	-0.00184	-3.07 ***
16	CHIL	5	-0.00079	-0.43
17	NETH	6	0.00018	0.62
18	FRA	7	0.00053	2.15 **
19	ITAL	6	0.00059	2.30 ***
20	URUG	5	0.00517	4.27 ***
21	ARGN	8	0.00804	5.82 ***

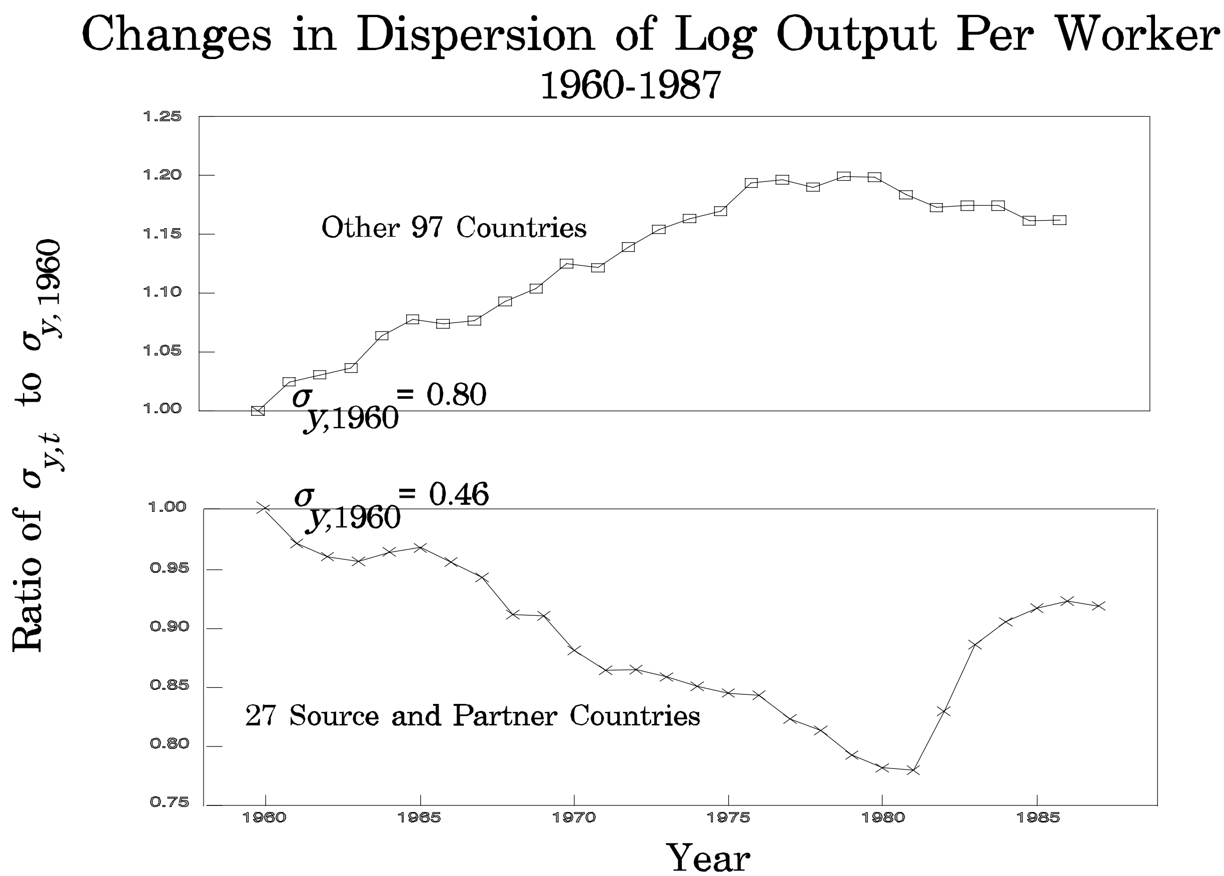
Appendix Table: List of Countries in Trade Groups

	Source Country	Countries in Group							
Export-Based Groups									
1	Canada	Japan	U.S.A.						
2	New Zealand	Australia	Japan	U.K.	U.S.A.				
3	Australia	Japan	New Zealand	U.S.A.					
4	Iceland	Germany	Japan	U.K.	U.S.A.				
5	Germany	Austria	Belgium-Lux	France	Italy	Netherlands	Switzerland	U.K.	U.S.A.
6	Spain	France	Germany	Italy	Netherlands	U.K.	U.S.A.		
7	France	Belgium-Lux	Germany	Italy	Netherlands	Switzerland	U.K.	U.S.A.	
8	Austria	Germany	Italy	Switzerland	U.K.	U.S.A.			
9	Italy	France	Germany	Switzerland	U.K.	U.S.A.			
10	Israel	France	Germany	U.S.A.	Netherlands	U.K.			
11	Netherlands	Belgium-Lux	France	Germany	Italy	U.K.	U.S.A.		
12	U.S.A.	Canada	Germany	Japan	Mexico	U.K.			
13	Chile	Austria	Brazil	Germany	Italy	Japan	U.K.	U.S.A.	
14	U.K.	Belgium-Lux	France	Germany	Ireland	Italy	Netherlands	U.S.A.	
15	Sweden	Denmark	Finland	France	Germany	Netherlands	Norway	U.K.	U.S.A.
16	Argentina	Brazil	Japan	Netherlands	U.S.A.				
17	Finland	Denmark	Germany	Norway	Sweden	U.K.	U.S.A.		
18	Ireland	Belgium-Lux	France	Germany	Netherlands	U.K.	U.S.A.		
19	Mexico	Japan	Spain	U.S.A.					
20	Denmark	France	Germany	Norway	Sweden	U.K.	U.S.A.		
21	Norway	France	Germany	Netherlands	Sweden	U.K.	U.S.A.		
22	Uruguay	Argentina	Brazil	Germany	U.K.	U.S.A.			
Import-Based Groups									
1	Canada	Japan	U.S.A.						
2	Denmark	France	Germany	Japan	Netherlands	Norway	Sweden	U.K.	U.S.A.
3	Finland	Germany	Japan	Sweden	U.K.	U.S.A.			
4	Germany	Belgium-Lux	France	Italy	Japan	Netherlands	U.K.	U.S.A.	
5	Sweden	Denmark	Finland	France	Germany	Japan	Norway	U.K.	U.S.A.
6	Australia	Germany	Japan	New Zealand	U.K.	U.S.A.			
7	U.K.	Belgium-Lux	France	Germany	Italy	Japan	Netherlands	Norway	U.S.A.
8	Iceland	Denmark	Germany	Japan	Netherlands	Norway	Sweden	U.K.	U.S.A.
9	Austria	Germany	Italy	Switzerland					
10	Switzerland	Belgium-Lux	France	Germany	Italy	Netherlands	U.K.	U.S.A.	
11	France	Belgium-Lux	Germany	Italy	Netherlands	U.K.	U.S.A.		
12	Italy	France	Germany	Netherlands	U.K.	U.S.A.			
13	Netherlands	Belgium-Lux	France	Germany	U.K.	U.S.A.			
14	Israel	France	Germany	Italy	U.K.	U.S.A.	Belgium-Lux	Switzerland	
15	U.S.A.	Canada	Germany	Japan	Mexico	U.K.			
16	Spain	France	Germany	Italy	Mexico	U.K.	U.S.A.		
17	Ireland	France	Germany	U.K.	U.S.A.				
18	Mexico	Japan	U.S.A.						
19	Uruguay	Argentina	Brazil	Germany	U.S.A.				
20	Chile	Brazil	Germany	Japan	U.S.A.				
21	Argentina	Bolivia	Brazil	France	Germany	Italy	Japan	U.S.A.	



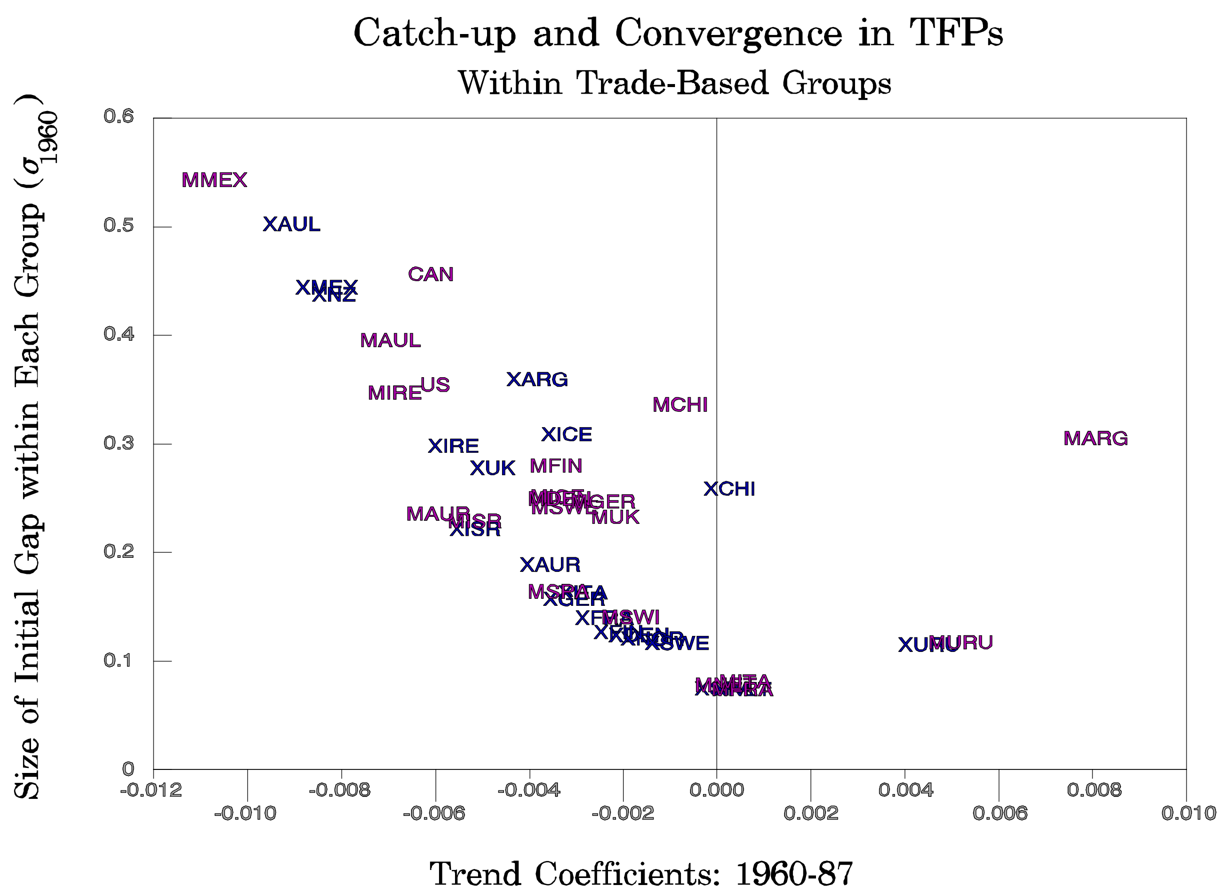
Relationship Between Log e_i and Log k_i
Log of Total Years of Schooling (1985)
Log of Real Capital-Labor Ratios (1985)
2.6
2.4
2.2
2.0
1.8
1.6
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
-0.2
-0.4
7
8
9
10
11
12
USA
NOR
AUS
CAN
ISR
CHE
IRL
ISL
KOR
CYP
PHL
URY
ESP
LKA
THA
CRI
MYS
PRY
COL
MEX
SGP
BOL
JAM
JOR
PRT
HND
SLV
TUR
BRA
IRN
IRQ
GHA
KEN
ZWE
GTM
MWI
DZA
SEN
ZAR
TZA
CMR
BUR
UGA
PAK
SLE
HTI
MOZ
RWA
MLI
ITA

Figure 1



Changes in Dispersion of Log Output Per Worker
1960-1987
Other 97 Countries
σ y,1960 = 0.80
σ y,1960 = 0.46
27 Source and Partner Countries
Ratio of σ y,t to σ y, 1960
Year
1.25
1.20
1.15
1.10
1.05
1.00
0.95
0.90
0.85
0.80
0.75
1960
1965
1970
1975
1980
1985

Figure 2



Catch-up and Convergence in TFPs
Within Trade-Based Groups
Size of Initial Gap within Each Group (σ_{1960})
Trend Coefficients: 1960-87
0.6
0.5
0.4
0.3
0.2
0.1
0
-0.012
-0.010
-0.008
-0.006
-0.004
-0.002
0.000
0.002
0.004
0.006
0.008
0.010
MMEX
XAUL
CAN
XMEX
XNZ
MAUL
XARG
MIRE
US
MCHI
XICE
MARG
XIRE
XUK
MFIN
XCHI
MGER
MUK
MAUR
XISR
XAUR
XGER
XSWE
XURU
MURU

Figure 3