Trade Integration and Growth[1]

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Abstract

Recent empirical evidence suggests a negative relationship between trade integration and income per capita convergence. We show that moderate reductions in trade costs can generate sizable increases in income per capita divergence in a neoclassical two-country model of trade and growth. The welfare of both countries, however, rises with trade integration due to changes in their consumption time paths. Our setup sheds light on the striking nonlinear growth in the trade share of output since World War II: a linear fall in trade costs over time produces an exponential increase in the trade share of GDP. Concerning the empirical relationship between openness and technological progress, we perform an exercise that cautions against the use of aggregate production functions to obtain Solow residuals: two countries that reduce their trade costs and experience no technological progress are measured to have positive TFP growth rates if an aggregate production function is used for that purpose.

Keywords: International Trade, Heckscher-Ohlin, Economic Growth.

JEL codes: F1, F4, O4.

1 Introduction

One of the most interesting questions in the globalization context is whether trade integration raises or reduces the distance between rich and poor countries. Historical evidence suggests a negative relationship between trade integration and income per capita convergence. O'Rourke and Williamson [21] argue that the 19th century marks the beginning of commodity price convergence across countries, whereas Pritchett [22] shows that the income per capita gap between rich and poor countries has been growing at least since 1870: according to his estimates, the cross-country standard deviation of the natural log of income per capita doubled from 1870 to 1990. The second half of the 20th century, a period of worldwide trade liberalization, also exhibits an increase in the cross-country dispersion of income per capita, as illustrated in Figure 1.[1]

The experience of particular groups of countries also seems to suggest a positive relationship between trade integration and income divergence: Rodríguez and Rodrik [24] report that the relatively open East Asian economies have steadily diverged since the 1960s, while the relatively closed South American economies show a steady decrease in income per capita dispersion during the period of import substitution. More strikingly, they also report that dispersion jumped upwards after Latin America started to liberalize its trade. Finally, Slaughter [27], who has analyzed the link between trade liberalization and convergence systematically, argues that "much of the evidence suggests that trade liberalization diverges incomes among liberalizers."[2]

This paper presents a two-country model that analyses the link between trade integration and income per capita divergence. Our framework relies entirely on neoclassical assumptions: based on time honored models in the areas of international trade (the Heckscher-Ohlin model) and economic growth (the Ramsey model), it shows that moderate reductions in trade costs can generate sizable increases in income per capita divergence. The mechanism underlying our results could not be simpler: in a Heckscher-Ohlin model with capital and labor, a fall in trade costs leads to an interest rate increase in the capital-abundant country, and an interest rate fall in the labor-abundant country. This changes the countries' rewards to accumulating capital in opposite directions, leading to an increasing gap in income per capita

[1] The figure is based on logged per-capita real GDP for 113 countries, taken from the PWT 6.0 described in Heston, Summers, and Aten [14]. Our common sample starts in 1961 and ends in 1996; we drop all countries for which only shorter time series were available.

[2] Work by Ben-David [2],[3] and Sachs and Warner [26] seems to suggest the opposite. See Rodríguez and Rodrik [24] and Slaughter [27] for the limitations of previous empirical evidence.

levels. From a normative perspective, trade integration is welfare improving for all countries despite leading to divergence. A fall in trade costs changes the countries' time paths of consumption: initial gains in the poor country's consumption level turn out to compensate future consumption losses. The rich country experiences instead an initial fall in consumption, which is compensated by future gains.

The dynamic effect of trade integration through factor prices and factor accumulation has been discussed previously in a more or less informal way, e.g. Smith [28] and Slaughter [27]. To the best of our knowledge, however, ours is the first two-country dynamic Heckscher-Ohlin model to address the effects of a fall in transport costs explicitly, and obtain the time paths of income, consumption and capital. This enables us to assess the quantitative importance of a fall in trade costs for income per capita divergence.

Our setup also sheds light on the striking nonlinear growth of the trade share in output since World War II, which is hard to explain by static trade models with linearly decreasing tariff barriers. (See Yi [31].) In our model, a fall in trade costs has two effects: it raises the volume of trade and changes factor prices, leading to diverging paths of relative factor endowments. This creates an additional effect on the future volume of trade that adds to the static effect of future falls in trade costs. A simple simulation exercise shows that a linear fall in trade costs over time produces an exponential increase in the trade share of output much in line with the data.[3]

In a second application of our framework, we address the empirical relationship between openness and technological progress. Empirical work in this area tends to find a positive relationship between different indicators of openness and total factor productivity (TFP) growth. Controversies in this area usually focus on the measures of openness.[4] We point out instead a measurement problem on the TFP growth side, due to the use of Solow residuals from aggregate production functions. Countries that reduce their trade costs are subject to relevant changes in their production structures according to their comparative advantages, and to have their prices determined in a trade equilibrium, as opposed to the autarky scenario. This implies that the use of an invariant aggregate production function can be misleading when measuring TFP growth. We perform an exercise in which two countries that

[3] Yi [31] explains this phenomenon on the basis of vertical specialization. We see his and our explanations as complementary.

[4] E.g., see Edwards [8] and Rodríguez and Rodrik [24]. For theoretical references on the relationship between openness and long-run growth see, among others, Lucas [19], Grossman and Helpman [9],[10],[11], and Rivera-Batiz and Romer [23].

reduce their trade costs and experience no technological progress are measured to have positive TFP growth rates if an aggregate production function is used for that purpose.

A sketch of the Heckscher-Ohlin model with many goods and trade costs can be found in Mundell [20]; Dornbusch *et al.* [7] provide an elegant formalization of the continuum of goods; Romalis [25] introduces trade costs into the model, and provides empirical support for the hypothesis that factor proportions are an important determinant of the structure of international trade. There is a vast number of dynamic Heckscher-Ohlin models in the literature, starting with Stiglitz [29]. Some recent references comparing neoclassical growth under autarky and free trade are Ventura [30] and Cuñat and Maffezzoli [6]. In comparison with these models, we depart from the rather unrealistic autarky/free trade dichotomy by introducing a trade cost that can change over time.

Like Baldwin [1], who shows that trade liberalization can have important dynamic welfare effects in case the social and private returns to capital differ, our model focuses on steady-state changes due to trade integration, but we are able to also study the implied transition dynamics. The endogenous growth literature has also studied how trade integration can affect the long-run growth rates of countries.[5] The new economic geography is another strand of the literature that has addressed similar issues: Krugman and Venables [18] show that in a model with cost and demand linkages between firms a fall in transport costs may lead to income divergence or convergence, depending on the level of transport costs. In comparison with these references, it is worth noting that our divergence result is obtained in a purely competitive neoclassical model.

The rest of the paper is structured as follows: Sections 2 and 3 present our analytical setup, which is used in Section 4 to analyze the link between trade integration and income divergence. Section 5 discusses the relationship between the fall of trade costs and the growth of the world's trade volume. Section 6 shows that trade integration can lead to the measurement of higher TFP growth rates. Section 7 concludes.

[5] See references above.

2 The Model

This section presents the dynamic trade model we use for studying the long-run effects of trade integration. We first model international trade in a Heckscher-Ohlin framework. The presence of transport costs forces us to briefly study the autarky case, so as to establish sufficient conditions that grant international trade in equilibrium. We do so due to our interest in studying situations with more or less trade, as opposed to the autarky/free trade dichotomy. We then integrate the static trade model into a Ramsey framework.

2.1 International Trade with Trade Costs

Assume the world has two countries, North and South, denoted by $j = N, S$. There are two internationally immobile factors, capital and labor. All markets are competitive. Each country produces a nontraded final good, which is used for both consumption and investment. The final good is produced with a continuum of intermediates $z \in [0, 1]$, with the following Cobb-Douglas production function:[6]

$$Y_j = \kappa \exp \left[\int_0^1 \ln x_j (z) \, dz \right], \tag{1}$$

where $x_j (z)$ denotes the quantity of intermediate good z used in the production of the final good Y_j in country j, and κ is a positive constant. Demand for intermediate goods is given by $x_j (z) = \frac{P_j Y_j}{p_j(z)}$, where P_j is the aggregate price index

$$P_j = \kappa^{-1} \exp \left[\int_0^1 \ln p_j (z) \, dz \right]. \tag{2}$$

Intermediate goods are produced using capital and labor with the following Cobb-Douglas technologies:

$$y_j (z) = \phi_j k_j (z)^{\alpha(z)} \, l_j (z)^{1-\alpha(z)}, \tag{3}$$

where $y_j (z)$ denotes the quantity of intermediate good z produced in country j; ϕ_j denotes country-specific factor efficiency levels; and $k_j (z)$ and $l_j (z)$ denote, respectively, the capital and labor allocated to the production of intermediate good z in country j. Capital-labor intensities vary across industries: we rank intermediate goods according to their capital-labor intensities by assuming that $\alpha (z)$ is increas-

[6]We denote aggregate variables with capital letters.

ing in z. Technologies are identical across countries, but for the exogenous factor augmenting coefficients ϕ_j. We are more specific about ϕ_j below, when we discuss the dynamic model's steady state.

In contrast with the final good, intermediate goods can be traded. For simplicity, we assume balanced trade: $P_jY_j = r_jK_j + w_jL_j$. Trade in intermediates is assumed not to be frictionless: $\tau > 1$ units of a good must be shipped from the country of origin for one unit to arrive in the country of destination ($\tau = 1$ corresponds to free trade.) This is the classical "iceberg" assumption, due to Samuelson. We can think of τ as both transport costs and barriers to trade. Concerning the latter interpretation, we abstract from any revenue they might produce.

2.1.1 Trade Equilibrium

Let us assume $K_N/L_N > K_S/L_S$, so that country N (country S) has a comparative advantage in capital-intensive (labor-intensive) goods. In general, the model's equilibrium is characterized by a range of very capital-intensive goods and a range of very labor-intensive goods produced exclusively by country N and country S, respectively; a range of nontraded goods produced by both countries; and factor prices such that $w_N/r_N > w_S/r_S$.[7] We choose $p_S(0) = 1$ as the numeraire. Given ϕ_j, K_j, L_j, $\alpha(z)$, and τ, the unknowns of the model are w_j, r_j, P_j, and z_j. The two cut-off values z_N, z_S, $0 \leq z_N < z_S \leq 1$, divide the range $[0, 1]$ in the three ranges mentioned above:

1. For $z \in [0, z_N)$, z is produced exclusively by S, and exported to N. Therefore $p_N(z) = \tau p_S(z)$, and $p_S(z) = b(z, \phi_S, r_S, w_S)$, where $b(z, \phi_j, r_j, w_j)$ denotes sector z's unit cost function in country j. Market clearing implies $y_N(z) = 0$, and $p_S(z)\, y_S(z) = P_NY_N + P_SY_S$.

2. For $z \in [z_N, z_S]$, z is produced in both N and S, and nontraded. Therefore $p_j(z) = b\left(z, \phi_j, r_j, w_j\right)$. Market clearing implies $p_j(z)\, y_j(z) = P_jY_j$.

3. For $z \in (z_S, 1]$, z is produced exclusively by N, and exported to S. Therefore $p_N(z) = b(z, \phi_N, r_N, w_N)$, and $p_S(z) = \tau p_N(z)$. Market clearing implies $p_N(z)y_N(z) = P_NY_N + P_SY_S$, and $y_S(z) = 0$.

We can solve for the unknowns from the definition of P_j and the following system of equations:

[7] See Romalis [25].

1. Factor market clearing conditions:[8]

$$\int_0^1 \frac{\partial b\left(z,\phi_j,r_j,w_j\right)}{\partial w} y_j(z)\,dz = L_j, \tag{4}$$

$$\int_0^1 \frac{\partial b\left(z,\phi_j,r_j,w_j\right)}{\partial r} y_j(z)\,dz = K_j. \tag{5}$$

2. Marginal commodity conditions:

$$b\left(z_j,\phi_j,r_j,w_j\right) = \tau b\left(z_j,\phi_{-j},r_{-j},w_{-j}\right). \tag{6}$$

3. Numeraire:

$$p_S(0) = 1 = b(0,\phi_S,r_S,w_S). \tag{7}$$

Given factor prices, the marginal commodity conditions imply there is a range of commodities that are not worth shipping from one country to another despite comparative advantage. This is due to the price wedge between countries introduced by the trade cost.

2.1.2 Autarky Equilibrium

If $(K_N/L_N)/(K_S/L_S)$ is 'too small' relative to the trade cost τ, countries will not trade and the equilibrium will be like under autarky, with $z_N = 0$ and $z_S = 1$. From the factor and good market clearing conditions,

$$\frac{w_j^a}{r_j^a} = \frac{\int_0^1 [1-\alpha(z)]\,dz}{\int_0^1 \alpha(z)\,dz}\frac{K_j}{L_j}, \tag{8}$$

where the index a distinguishes autarky equilibrium prices from trade equilibrium prices. For the autarky equilibrium to be sustainable, it must be true that at autarky prices transport costs make it pointless to ship goods across countries. That is, the marginal commodity conditions implied by Equation (6) must not hold for $z \in (0,1)$:

$$b(1,\phi_S,r_S^a,w_S^a) \leq \tau b(1,\phi_N,r_N^a,w_N^a), \tag{9}$$

$$b(0,\phi_N,r_N^a,w_N^a) \leq \tau b(0,\phi_S,r_S^a,w_S^a). \tag{10}$$

[8] By Walras Law, one of these market clearing conditions is redundant.

2.2 Consumption and Capital Accumulation

Each country is populated by a *continuum* of identical and infinitely lived households, each of measure zero. Being identical, they can be aggregated into a single country-level representative household. The nontraded final good can be used for both consumption and investment. The representative households' preferences over consumption streams can be summarized by the following intertemporal utility function:

$$U_{jt} = \sum_{s=t}^{\infty} \beta^{s-t} \ln \left(C_{js} \right), \tag{11}$$

where β is the subjective intertemporal discount factor, and C_{jt} the per-capita consumption level in country j at date t. The representative households maximize (11) subject to the following intratemporal budget constraint:

$$P_{jt} \left(C_{jt} + I_{jt} \right) = w_{jt} L_{jt} + r_{jt} K_{jt}. \tag{12}$$

Factor prices are taken as given by the representative household. The capital stocks evolve according to the following accumulation equation:

$$K_{jt+1} = \left(1 - \delta \right) K_{jt} + I_{jt}. \tag{13}$$

Denote factor prices in terms of the final good with $\tilde{w}_{jt} \equiv w_{jt}/P_{jt}$ and $\tilde{r}_{jt} \equiv r_{jt}/P_{jt}$. The first order conditions

$$\beta C_{jt} (\tilde{r}_{jt+1} + 1 - \delta) = C_{jt+1}, \tag{14}$$

$$K_{jt+1} = \tilde{w}_{jt} L_j + \left(\tilde{r}_{jt} + 1 - \delta \right) K_{jt} - C_{jt}, \tag{15}$$

and the usual transversality conditions are necessary and sufficient for the representative household's problem. A recursive competitive equilibrium for this economy is characterized by equations (14)-(15) and the equations that characterize the static trade equilibrium.

3 Solution Procedure and Parameterization

3.1 Trade Equilibrium

Let us assume $\alpha(z) = z$ for simplicity. In that case, the trade equilibrium's conditions can be reduced to the following system:

$$w_S = \phi_S, \tag{16}$$

$$w_N = \tau^{\frac{z_N+z_S}{z_S-z_N}} \phi_N, \tag{17}$$

$$r_N = \tau^{\frac{z_N+z_S-2}{z_S-z_N}} \frac{\phi_N}{\phi_S} r_S, \tag{18}$$

$$w_N L_N + \phi_S L_S = r_N K_N + r_S K_S, \tag{19}$$

$$P_N Y_N z_N = P_S Y_S (1 - z_S), \tag{20}$$

$$P_N Y_N z_N^2 + P_S Y_S z_S^2 = 2 r_S K_S, \tag{21}$$

$$P_N = \frac{\exp\left(\frac{1}{2}\right)}{\kappa} \tau^{\frac{z_N+z_S-z_N^2-1}{z_S-z_N}} \sqrt{\frac{r_S}{\phi_S}}, \tag{22}$$

$$P_S = \frac{\exp\left(\frac{1}{2}\right)}{\kappa} \tau^{\frac{2z_S-z_S^2-1}{z_S-z_N}} \sqrt{\frac{r_S}{\phi_S}}. \tag{23}$$

The system has no analytical solution, and needs to be solved numerically.

With $\alpha(z) = z$, Equations (9) and (10) become, respectively, $\phi_S^{-1} r_S^a \leq \tau \phi_N^{-1} r_N^a$ and $\phi_N^{-1} w_N^a \leq \tau \phi_S^{-1} w_S^a$. Thus, if $(w_N^a / r_N^a) / (w_S^a / r_S^a) = (K_N/L_N) / (K_S/L_S) \leq \tau^2$, autarky will take place. If, on the other hand, $(K_N/L_N) / (K_S/L_S) > \tau^2$, autarky will not be sustainable and countries will trade.

3.2 Steady State

Given the assumption that β and δ are equal across countries, the steady state is characterized by the same interest rate for both of them: $\tilde{r}_j = \tilde{r} \equiv \frac{1}{\beta} - 1 + \delta$. In the trade equilibrium,

$$\frac{\tilde{r}_N}{\tilde{r}_S} = \frac{\phi_N}{\phi_S} \tau^{\frac{(z_N-z_S)(z_N+z_S)+2(z_S-1)}{z_S-z_N}}. \tag{24}$$

It is easy to see that $\frac{(z_N-z_S)(z_N+z_S)+2(z_S-1)}{z_S-z_N} < 0$. Thus, for $K_N/L_N > K_S/L_S$ and $\phi_N = \phi_S$, $\tilde{r}_N < \tilde{r}_S$. Hence, the trade equilibrium *cannot* yield a steady state if technologies are identical across countries.[9] Since we want to depart from the autarky-vs-free trade thought experiment, let us impose enough structure so as to have an initial steady state with some trade. Assume $\phi_N > \phi_S$. Then $\tilde{r}_N = \tilde{r}_S$ if

$$\tau^{\frac{(z_N - z_S)(z_N + z_S) + 2(z_S - 1)}{z_S - z_N}} = \frac{\phi_S}{\phi_N}. \tag{25}$$

Thus, provided $\phi_N > \phi_S$, we *may* find a steady state in the trading equilibrium. If the ϕ_j's are different enough to rule out autarky in steady state, r_S has to satisfy the following equation:

$$r_S = \tilde{r} P_S = \frac{\exp(1)}{\phi_S} \left(\frac{\tilde{r}}{\kappa} \tau^{\frac{2z_S - z_S^2 - 1}{z_S - z_N}} \right)^2. \tag{26}$$

The remaining factor prices are obtained from (16)-(18). The system (19)-(21) and the condition $\tilde{r}_N = \tilde{r}_S$ can be solved numerically for K_N, K_S, z_N, and z_S. A similar procedure enables us to solve for the ϕ_j's that generate a particular steady-state distribution of capital stocks such that $K_N/L_N > \tau^2 K_S/L_S$. Numerical explorations suggest that both of these procedures are remarkably robust and generate unique results.

3.3 Solution Procedure

The recursive structure of our problem guarantees that the solution can be represented as a couple of time-invariant policy functions expressing the optimal level of consumption in each region as a function of the two state variables, K_N and K_S. These policy functions have to satisfy the following functional equations:

$$\beta C_j \left(K_N', K_S' \right) \left(\tilde{r}_j' + 1 - \delta \right) = C_j \left(K_N, K_S \right), \tag{27}$$

where $K_j' = [\tilde{w}_j L_j + (1 - \delta + \tilde{r}_j) K_j - C_j (K_N, K_S)]$, and the factor prices $\tilde{w}_j$ and $\tilde{r}_j$ are obtained by numerically solving the appropriate equilibrium conditions. The policy functions have to generate stationary time series in order to satisfy the transversality conditions. To solve equation (27) numerically, we apply the Orthogonal Collocation projection method described in Judd [16].

[9] If the countries' initial capital-labor ratios are different enough, trade will occur during the transition towards the steady state even if the ϕ_j's are identical. However, as soon as countries become sufficiently similar in their capital-labor ratios, they cease to trade and the final part of the transition takes place under autarky.

Following Cooley and Prescott [5], we set $\beta = 0.949$ and $\delta = 0.048$, standard values in the quantitative macroeconomics literature, which implicitly assume that the unit time period is a year. We assume that $L \equiv L_N + L_S = 2$, $L_N = L/(1+\sqrt{3}) = 0.73$, and $L_S = (L\sqrt{3})/(1+\sqrt{3}) = 1.27$. We choose $\kappa = 0.1$, which implies an autarky steady-state world capital stock $\bar{K} = 2$ when $\phi_j = 1$. We assume an initial trade cost $\tau_0 = 1.16$. We numerically solve the steady-state equations for the ϕ_j's that imply (i) $\left(\bar{K}_N/L_N\right)/\left(\bar{K}_S/L_S\right) = 3$; (ii) $\bar{K}_N = (\bar{K}\sqrt{3})/(1+\sqrt{3}) = 1.27$ and $\bar{K}_S = \bar{K}/(1+\sqrt{3}) = 0.73$. The resulting coefficients are $\phi_N = 1.11$ and $\phi_S = 0.93$. Notice that the initial distribution of factor endowments is symmetric across countries, and that $\left(\bar{K}_N/L_N\right)/\left(\bar{K}_S/L_S\right) = 3 > \tau_0^2$, so that international trade takes place in steady state.

4 Trade Integration and Growth

To study the effects of a reduction in trade costs, we assume the world is in the steady state described above, and let the trade cost fall to $\tau_1 = 1.15$ suddenly and permanently. Figures 2 and 3 display the time paths of real per-capita income, consumption, investment, and capital for both countries.[10] Let us start by pointing out that (i) the "static" gains from trade are positive (income increases on impact by 0.07 percentage points in the North and by 0.10 points in the South), but quantitatively small; and that (ii) the dynamic effects lead instead to a remarkable process of long-run divergence in all income components.[11]

To understand the mechanics of the exercise, let us look at the time path of factor prices in terms of the final good in Figure 4. Notice that right after the fall in τ interest rates diverge, rising in country N and falling in country S. This raises the incentive to delay consumption and accumulate capital in country N, whereas the opposite happens in country S. This is what causes the initial upward (downward) jump of investment, and the initial downward (upward) jump of consumption in country N (country S).[12]

[10] In the figures, the first ten years correspond to the original steady state. The top panel in each figure displays the corresponding variable's time path. The bottom panel displays the corresponding percentage deviation from the original steady state.

[11] The speed of transition towards the steady state is admittedly low. This is due to the set of assumptions we imposed to keep the structure of the model as simple as possible. In particular, the assumption on the shape of $\alpha(z)$ implies very high aggregate capital shares in income, and hence slow adjustment dynamics.

[12] The cross-country interest rate differential is actually very small, being no grater than 0.1 percentage points: the presence of even moderate transaction costs would be enough to prevent

Why do interest rates react as they do after a fall in τ? Trade integration reduces the price wedge between countries. This implies that specialization increases: goods that were previously nontraded become now exclusively produced by one country. Country N, for example, ceases to produce the most labor-intensive goods it was producing, since they become cheaper to import from country S. This implies capital and labor need to be reallocated from labor-intensive towards capital-intensive goods. In this case, full employment requires the use of lower capital-labor intensities, which imply a higher marginal productivity of capital, and thus a higher r_N. A symmetric argument leads to a lower r_S.[13] Figure 5 shows that the range of non-traded goods shrinks immediately after the fall in τ: z_S falls, *i.e.* country S ceases to produce its most capital-intensive goods, and z_N rises, *i.e.* country N stops producing its most labor-intensive goods. Notice that both countries' shares of trade in income, $V_N = 2z_N$ and $V_S = 2(1 - z_S)$, increase.

The different reaction of interest rates implies that investment increases in country N and decreases in country S. Country N (country S) needs to raise (reduce) its capital-labor ratio to drive the interest rate back to its steady state level. This leads to an increasing difference in their capital-labor ratios, and reinforces their respective patterns of comparative advantage, reducing the range of nontraded goods even more, and raising the share of trade in GDP. Divergence in relative factor endowments also implies divergence in income and consumption.

It is worth noting that both countries gain from trade integration in terms of welfare. A comparison of their utility levels[14] with and without the fall in the trade cost shows that both countries achieve a higher level of utility in the new scenario. Although the long-run income per capita level of country S falls, the fact that it can attain a higher level of consumption in the first periods after the change in τ compensates for the discounted long-run losses in consumption. On the other hand, country N experiences an initial fall in consumption, but is more than compensated by the discounted future gains.

Due to the amplifying function of factor accumulation, the steady-state effect of trade integration on income is much larger than the initial impact. To assess the

international capital flows.

[13] In our exercise, the rental rates diverge on impact after a reduction in the trade cost. This is due to the fact that both countries are initially in steady state. If the trade cost falls while countries are still converging towards their steady states, and the South is further away than the North, we may observe factor price convergence on impact. Still, the trade cost will raise (reduce) the reward to accumulating capital in the North (South).

[14] The welfare levels are calculated as the discounted sum of the intratemporal utility function over 2,000 years.

quantitative importance of this long-run effect, we perform a second exercise in which we compare steady-state income divergence for different degrees of trade integration. Denote with $\lambda_i \equiv (\bar{Y}_N/L_N)_i - (\bar{Y}_S/L_S)_i$ the difference in steady-state income per capita between countries N and S associated with trade cost τ_i, holding everything else constant. Denote with $\Lambda_i \equiv (\lambda_i - \lambda_0)/\lambda_0$ the percentage difference between λ_i and λ_0. Figure 6 plots Λ_i against $(\tau_0 - \tau_i)$, $\tau_i = \tau_0 - 0.01 \cdot i$, $i \geq 0$. Notice that when τ falls from $\tau_0 = 1.21$ (autarky) down to $\tau_{20} = 1.01$, λ nearly quadruples. Figure 6 also plots the same measure of divergence for capital per capita and consumption per capita: notice that the steady-state difference $(\bar{K}_N/L_N)_i - (\bar{K}_S/L_S)_i$ becomes more than six times larger after the trade cost falls from $\tau_0 = 1.21$ to $\tau_{20} = 1.01$.

5 The Growth of World Trade

One of the most important developments in the global economy since World War II is the spectacular growth in the trade share of output. Yi [31] convincingly argues that the nonlinear growth of the trade share in GDP is hard to explain by standard static trade models on the basis of falling trade barriers, since these have just decreased linearly (and not that much) over the same time period. He proposes an explanation based on vertical specialization only occurring, and hence raising the volume of trade in a nonlinear fashion, after trade costs have reached a critical value.

The discussion in the previous section suggests a complementary explanation. In our model, a fall in trade costs raises the volume of trade immediately, but also leads to diverging paths of relative factor endowments through its effect on factor prices. This creates an additional effect on the future volume of trade, that adds to the static effect of subsequent reductions in trade costs. To check whether this argument has some quantitative bite, we perform the following simulation with our dynamic trade model: given the same initial factor endowments and parameter values assumed above, we let τ decrease linearly from $\tau_1 = 1.15$ to $\tau_{40} = 1.04$ over a 40-year span. This roughly reproduces the time path of US tariffs from 1962 to the present.

In order to compare with the evidence reported in Yi [31], in the top panel of Figure 7 we plot country N's predicted share of exports in GDP z_N against the trade cost. (Recall that the horizontal axis now has an implicit time line from right to left.) The model seems to approximate the actual path for the US share of exports in GDP quite well. The bottom panel of Figure 7 plots the predicted elasticity of the share of exports in GDP with respect to the trade cost against the trade cost itself: it is apparent that the elasticity rises as the trade cost falls over time, as reported by Yi [31]. To understand how much of this effect is caused by the dynamics triggered by trade integration, in the two panels of Figure 7 we also report the predicted share of exports in GDP when the factor endowments remain constant at their initial levels: in this case, the response of the export share to the fall in the trade cost is almost perfectly linear.

As is well known, countries trade not only for comparative advantage reasons, but also due to scale economies. Each motive for trade has different implications about the types of countries trading with each other: international trade driven by comparative advantage takes place between countries that are different enough, whereas scale economies tend to foster trade between similar countries.[15] Figure 8a shows that the percentage of US trade (imports plus exports) to non-industrial countries (excluding OPEC members) as a total of US trade has increased at least since 1978.[16] This fact is consistent with the mechanism highlighted in this section, in which countries trade more because they become more different over time. Figure 8b plots the average degree of bilateral σ-divergence, *i.e.* the standard deviation of the natural log of real GDP per capita, between the US and the non-industrial countries in our sample.[17] Note that the speed of income divergence increases sharply at the beginning of the 80's, and that in the subsequent years both income divergence and trade with the US increase substantially. This is of course nothing more than casual evidence, but still a suggestive one, and broadly compatible with our model's predictions.

6 Openness and Productivity Growth

Empirical work on the relationship between openness and technological progress tends to find a positive relationship between different indicators of openness and TFP growth, e.g. Edwards [8].[18] These results are usually interpreted as evidence

[15] See Helpman and Krugman [13].

[16] The source for the data is the Bureau of Economic Analysis, which does not report data on the structure of US trade before 1978.

[17] Our calculations are based on data for 87 non-industrial (non-OPEC) countries taken from the PWT 6.0 described in Heston, Summers, and Aten [14]. For comparability reasons, to identify non-industrial countries we follow the definition provided by the Bureau of Economic Analysis.

[18] More generally, cross-country studies of TFP growth or TFP levels tend to be based on the existence of an aggregate production function identical across countries but for the TFP level. See, among others, Klenow and Rodríguez-Clare [17], Hall and Jones [12], and Bernanke and Gurkaynak

suggesting that openness has a positive effect on technological progress. Econometric sophistication in this area usually focuses on the measurement and endogeneity problems of any openness indicator, giving the impression that there are no problems on the TFP growth side. This is kind of paradoxical, given that TFP growth is usually measured as the Solow residual from a Cobb-Douglas aggregate production function:

$$Y_{jt} = A_{jt} K_{jt}^{\alpha_{jt}} L_{jt}^{1-\alpha_{jt}}. \tag{28}$$

Under the usual set of assumptions, the log of the TFP level corresponds to the Solow residual:

$$\ln A_{jt}^{P} = \ln Y_{jt} - s_{K,jt} \ln K_{jt} - (1 - s_{K,jt}) \ln L_{jt}, \tag{29}$$

where $s_{K,jt} \equiv (r_{jt} K_{jt}) / Y_{jt} = \alpha_{jt}$ is either calibrated from information on aggregate capital shares or estimated, but in any case held constant over the time period of study ($s_{K,jt} = s_{K,j}$), and often even across countries ($s_{K,jt} = s_K$).

Regarding our model, computing the Solow residual with such an aggregate production function would be no problem in the autarky case: it is easy to show that when $z_N = 0$ and $z_S = 1$, countries behave as if they were just producing a final good with aggregate production function

$$Y_{jt}\big|_{[z_N=0, z_S=1]} = A_j^a K_{jt}^{1/2} L_{jt}^{1/2}, \tag{30}$$

where $A_j^a \equiv \exp\left(-\frac{1}{2}\right) 2\kappa\phi_j$. Hence, the Solow residual under autarky equals $\ln A_j^a \equiv -1/2 + \ln 2 + \ln \kappa + \ln \phi_j$, which is assumed to be constant over time. For future reference, recall one can also compute TFP with the so-called dual approach:[19] the unit cost function associated to the production function in equation (28) is $P_{jt} = \frac{r_{jt}^{\alpha} w_{jt}^{1-\alpha}}{A_{jt} a}$, where $a \equiv \alpha^{\alpha} (1-\alpha)^{1-\alpha}$. Thus, TFP can be computed also as

$$\ln A_{jt}^{D} = s_{K,jt} \ln r_{jt} + (1 - s_{K,jt}) \ln w_{jt} - \ln a - \ln P_{jt}. \tag{31}$$

Again, in terms of our model, provided that countries have the production structure implied by $z_N = 0$ and $z_S = 1$, equations (29) and (31) give exactly the same (and correct) measure of a country's TFP: $\ln A_{jt}^P = \ln A_{jt}^D = \ln A_j^a$.

However, countries that are open to trade (or reduce their trade costs) are likely

[4].

[19] See Hsieh [15] for a recent application of the dual approach.

to have different production structures (or experience relevant changes in their production structures) according to their comparative advantages. This implies that the use of an invariant aggregate production function can be misleading when measuring TFP growth. Let us elaborate on this issue by retaking our first exercise above: we let the trade cost fall from $\tau_0 = 1.16$ to $\tau_1 = 1.15$, and take the time paths of the variables simulated with our dynamic trade model as "data." Based on this information, we compute the TFP growth rates of countries N and S as Solow residuals from equation (29). Figure 9 plots the time path of the Solow residual under the assumption that $s_{K,jt} = s_K = 0.5$, the cross-country average of each country's average aggregate capital share.[20] The Solow residual yields positive growth rates for TFP despite the fact that the parameters ϕ_j and κ are held constant in our simulations. Note also that country S, which is the country that suffers more important changes in its production structure, is the one measured to have a higher TFP growth rate.[21]

To understand the intuition underlying these results, recall that when the trade cost falls, countries can exploit their comparative advantages better for given factor endowments. That is, both countries find it optimal to reduce the range of goods they are producing and exchange a wider range of commodities. This enables both of them to "consume" more intermediate goods and thus produce more of the final good. Hence, the static gains from trade are immediately translated into a sudden increase in the Solow residuals that has nothing to do with technological progress. During the transition towards the new steady state, the capital stocks diverge across countries, while the labor endowments remain constant. Note that $\gamma^A_{jt} = \gamma^Y_{jt} - 1/2\gamma^K_{jt}$, where $\gamma^x_{jt} \equiv \ln(x_{jt}/x_{jt-1})$. The dynamics of factor prices under trade implies that $\left|\gamma^Y_{jt}\right| > \left|\gamma^K_{jt}\right|/2$; this generates further increases in the Solow residual over time. Hence, the dynamics depicted in figure 9 is due to fact that countries are open to trade and their prices are therefore determined in a trade equilibrium, rather than by the marginal productivity from an aggregate production function.

Figure 10 compares the trade equilibrium's factor prices in terms of the final good with the marginal productivities of a hypothetical aggregate Cobb-Douglas production function. Notice that assuming an aggregate production function is extremely misleading: country N's (country S's) return to capital predicted by the

[20] Qualitatively similar results are obtained when we use each country's average aggregate capital share to compute their Solow residuals, or when we use the aggregate production function's dual for the same purpose.

[21] Countries N and S produce goods in the ranges $[z_N, 1]$ and $[0, z_S]$, respectively. Figure 5 shows that after the fall in the trade cost, z_S falls over time, while z_N rises. Notice that the change in z_S is quantitatively more important than the change in z_N.

trade model is always higher (lower) than its initial value, whereas the wage displays roughly the opposite time path. Recall that the North (South) is accumulating (decumulating) capital. In the trade model this implies that the time path of capital reinforces the effect of factor prices on income per capita: the time paths of factor prices reward each country's factor abundance. In the aggregate production function case, instead, the return to capital falls (rises) in the North (South), whereas the wage rate rises (falls) in the North (South). The same factor endowments predict a lower growth rate of income in the aggregate production function case than in the trade model because of their different predictions on factor prices: the prediction error is captured by the Solow residual as an improvement in TFP.

To better understand this result, let us consider the measure of TFP one obtains with the dual.[22] Equations (16)-(18), (22), (23), and (31), and the assumption that $s_{K,jt} = s_K = 0.5$ yield the following expressions:

$$\ln A^D_{Nt} = \ln A^a_N + \frac{z^2_{Nt}}{z_{St} - z_{Nt}} \ln \tau, \tag{32}$$

$$\ln A^D_{St} = \ln A^a_S + \frac{(1 - z_{St})^2}{z_{St} - z_{Nt}} \ln \tau. \tag{33}$$

The dynamic components in equations (32) and (33) depend exclusively on z_N and z_S, *i.e.* on the evolution over time of the countries' specialization pattern. After the initial reaction due to the reduction in τ, the dynamics of the specialization pattern depends exclusively on capital accumulation. Recall that z_N grows over time, whereas z_{St} falls over time. This implies that the second term in the right hand side of both equations (32) and (33) grows over time.

7 Concluding Remarks

Our results stress the importance of both a dynamic approach to understand how world trade evolves after trade liberalization, and an open economy approach to understand the time path of income per capita. Small reductions in trade costs lead to volumes of trade larger than predicted by static models due to their dynamic effects on the comparative advantage of countries. At the same time, small initial differences in ϕ_j can lead to remarkable degrees of income divergence through mod-

[22]We focus here on the dual for convenience. Being the assumption of an aggregate production function invalid under trade, there is no reason to expect that $A^P_{jt} = A^D_{jt}$. The time paths of these two measures are qualitatively similar, though.

erate improvements in trade integration. This does not imply, however, that trade liberalization is bad: in our model, both countries gain from integration in terms of welfare, despite the poor country ending up poorer.

For convenience, we have ignored the other important force in the world markets, capital mobility, as a source of convergence or divergence. A first thought suggests that capital mobility may reinforce the process of divergence following a fall in trade costs, since trade integration produces a positive differential in the return to capital between the rich North and the poor South.

Finally, the paper cautions against the use of Solow residuals obtained from aggregate production functions in a context (openness, trade liberalization) in which countries are likely to undergo important changes in their production structures. In this respect, we favor the use of sector- or plant-level TFP growth studies.

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8 Appendix

Following Judd [16], we approximate the policy functions for consumption over a rectangle $D \equiv [\underline{k}, \overline{k}] \times [\underline{k}, \overline{k}] \in R_+^2$ with a linear combination of multidimensional orthogonal basis functions taken from a *2*-fold tensor product of Chebyshev polynomials. In other words, we approximate the policy function for country $j \in \{N, S\}$ with:

$$\widehat{c}_j (K_N, K_S; \mathbf{a}_j) = \sum_{z=0}^{d} \sum_{q=0}^{d} a_{zq}^j \psi_{zq} (K_N, K_S) \tag{34}$$

where:

$$\psi_{zq} (K_N, K_S) \equiv T_z \left(2 \frac{K_N - \underline{k}}{\overline{k} - \underline{k}} - 1 \right) T_q \left(2 \frac{K_S - \underline{k}}{\overline{k} - \underline{k}} - 1 \right) \tag{35}$$

and $\{K_N, K_S\} \in D$. Each T_n represents an n-order Chebyshev polynomial, defined over $[-1, 1]$ as $T_n (x) = \cos (n \arccos x)$, while d denotes the higher polynomial order used in our approximation. In our case, it turns out that $d = 4$ is a good compromise between speed and accuracy.

We defined the residual functions as:

$$R_j (k_N, k_S; \mathbf{a}_j) \equiv \beta \hat{c}_j (k_N, k_S; \mathbf{a}_j) \left(\tilde{r}'_j + 1 - \delta \right) - \hat{c}_j (k'_N, k'_S; \mathbf{a}_j) \tag{36}$$

where $k'_j = \tilde{w}_j + (1 - \delta + \tilde{r}_j) k_j - \hat{c}_j (k_N, k_S; \mathbf{a}_j)$; the factor prices in terms of the final goods are determined by numerically solving the appropriate equilibrium conditions.

To pin down the vectors $\mathbf{a}_j$ we use the simplest projection method: orthogonal collocation. This method identifies the $2m^2$ coefficients, where $m = d+1$, by making the approximating polynomials exactly solve the functional equations (36) at some m^2 distinct points in D, known as collocation nodes. In other words, the functional equations are transformed into a system of $2m^2$ non-linear equations:

$$R_j (k_{zN}, k_{qS}; \mathbf{a}_j) = 0, \quad z, q = 1, 2, ..., d + 1 \tag{37}$$

that can be solved with any robust numerical solver.[23] To minimize the approximation error, we optimally chose the collocation nodes among the zeros of Chebyshev polynomials: given the m zeros of $T_m \left[2 (x - \underline{k}) / \left(\overline{k} - \underline{k} \right) - 1 \right]$ in $\left[\underline{k}, \overline{k} \right]$, we organize them into two (identical) vectors $\{k_{N,i}\}_{i=1}^{m}$and $\{k_{S,i}\}_{i=1}^{m}$ and take their Cartesian product $\{k_{N,i}\} \times \{k_{S,i}\}$ as the set of our collocation nodes.

Table 1 summarizes the empirical distribution of the Euler equation residuals in absolute terms, i.e. the values of $|R_j (k_N, k_S, \mathbf{a}_j)|$, over 100 *equally spaced* points in D that do obviously not coincide with the collocation nodes. As we can see, the size of the residuals is extremely small, and this confirms that orthogonal collocation is

[23] We use Broyden's variant of the standard Newton method and follow a continuation approach to obtain the initial conditions.

	North	South
Avg.	2.55e-9	1.15e-8
Med.	2.39e-9	1.17e-8
Std.	3.01e-9	1.30e-8
Max.	6.20e-9	2.51e-8

Table 1: Euler equation residuals

not only simple but also surprisingly efficient and accurate. The functional equation residuals are of course only an indirect measure of the quality of our approximation, but still a very informative one. Another informative test of the approximation accuracy is the long-run stability of the solution: the approximated system remains in steady state even if the simulation horizon is extended to $10,000$ years.

Once the approximated policy functions are available, we choose the initial conditions and simulate the system recursively to generate the artificial time series for all variables of interest by using the appropriate set of policy functions.

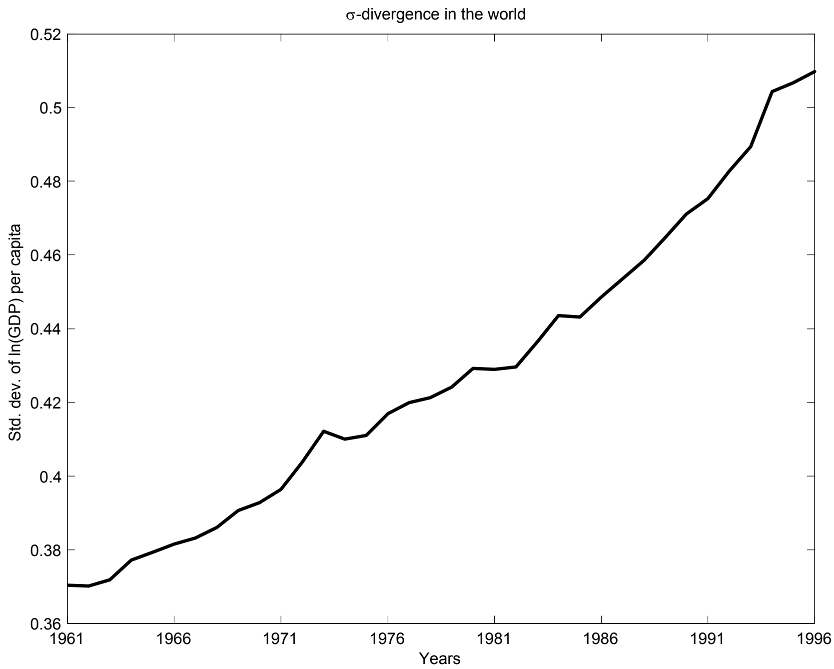

Figure 1: Income divergence in the world.

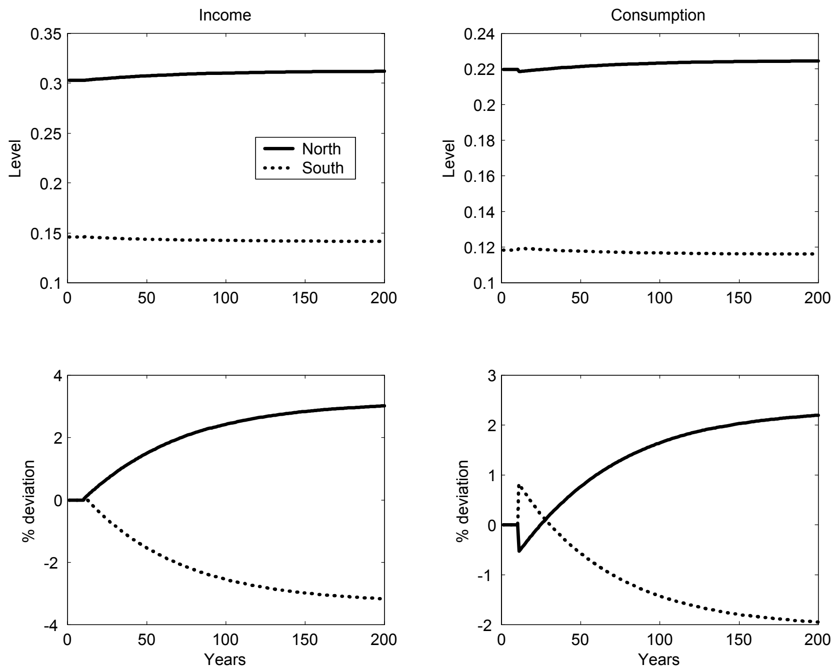

Figure 2: Income and consumption (levels and deviations).

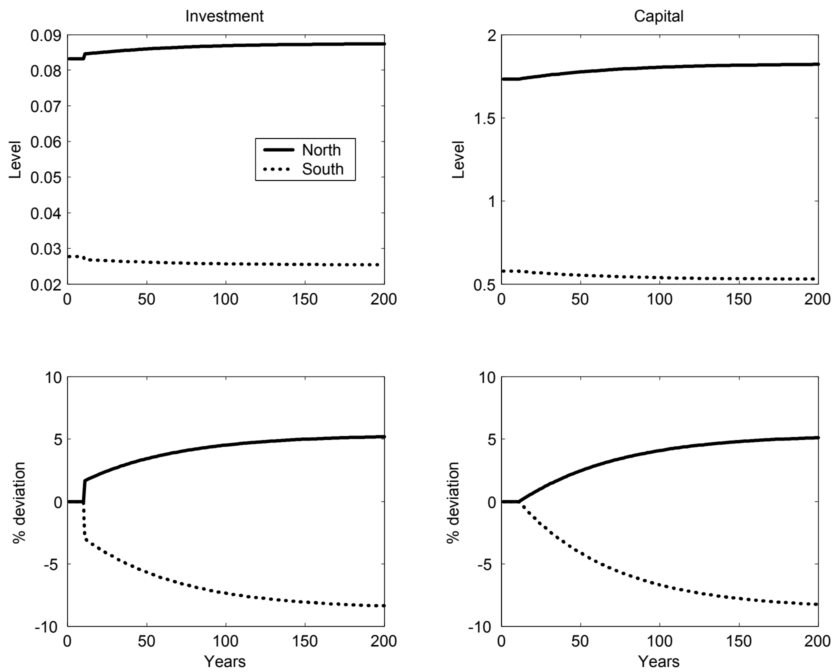

Figure 3: Investment and capital (levels and deviations).

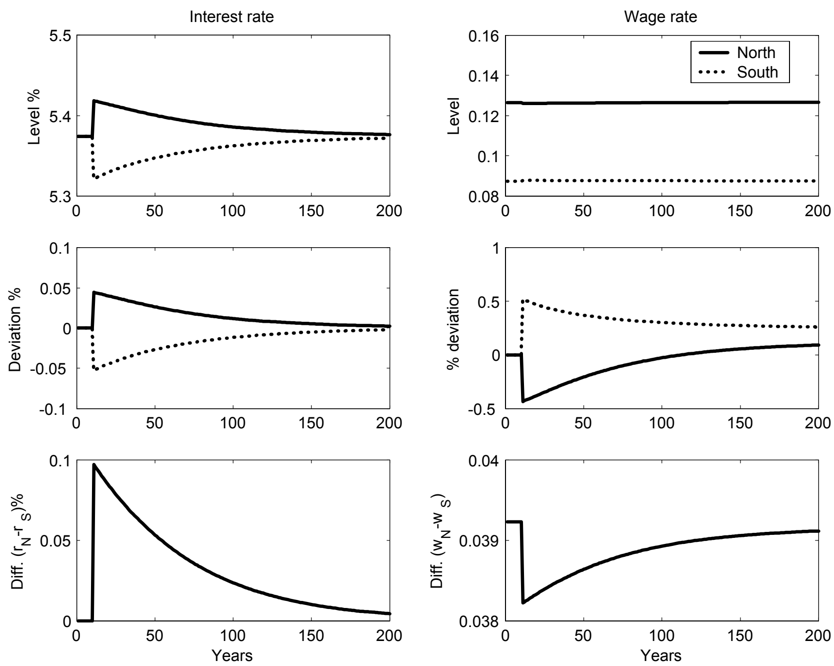

Figure 4: Factor prices (levels, deviations, and differentials).

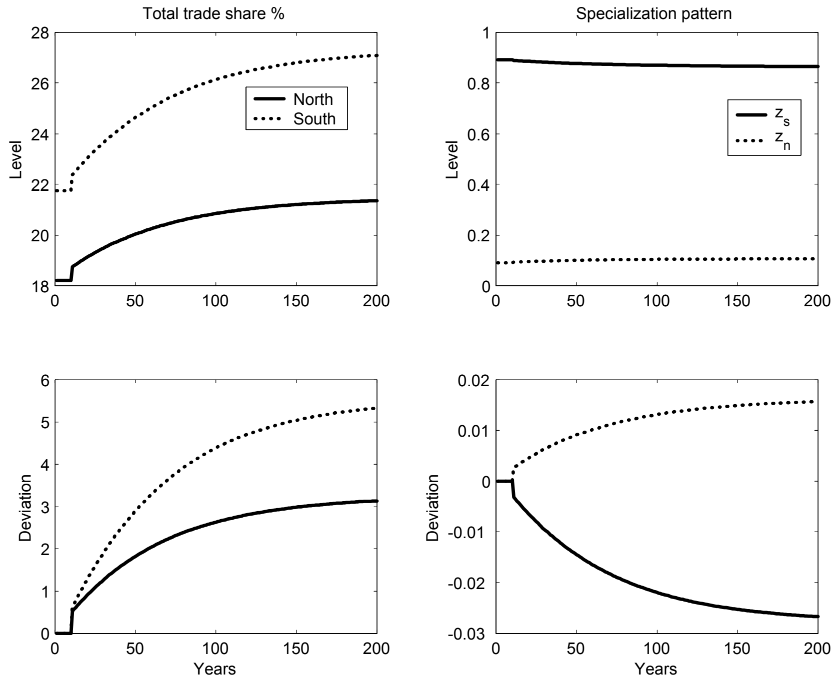

Figure 5: Openness and specialization (levels and deviations).

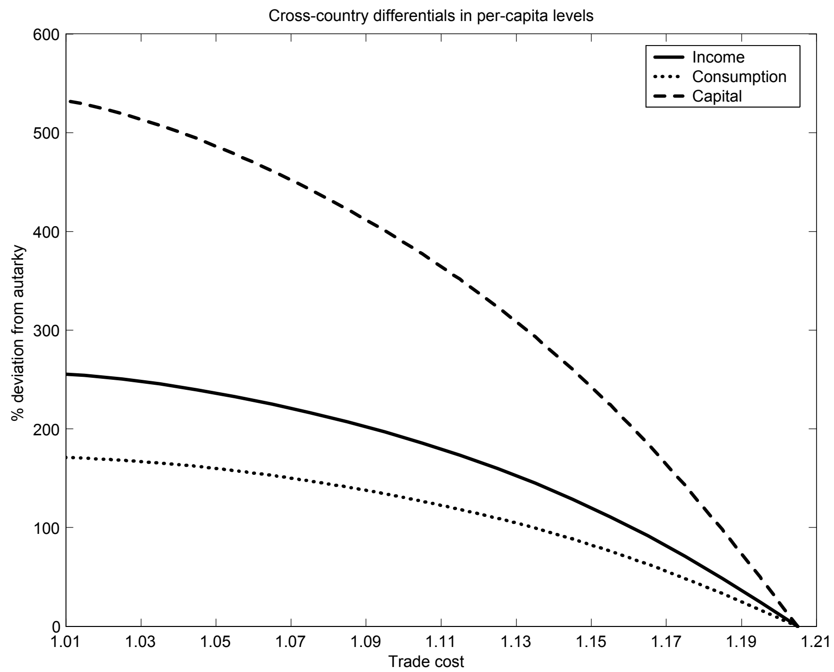

Figure 6: Trade integration and steady-state differentials.

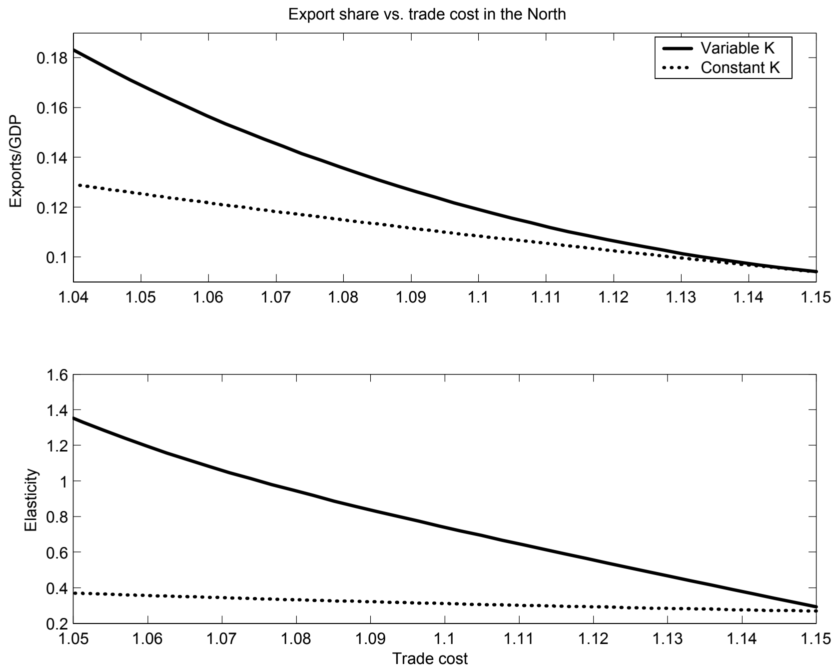

Figure 7: Trade integration and the export share.

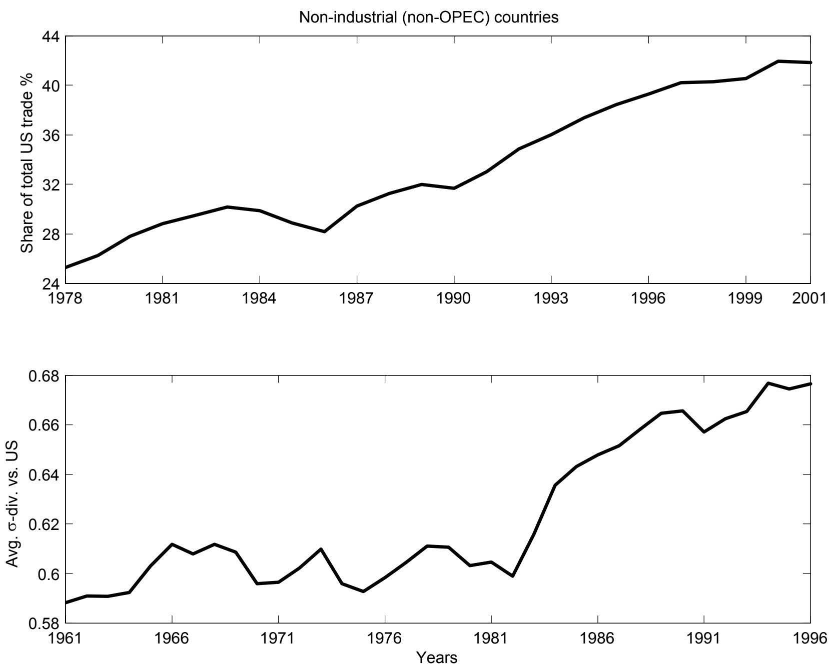

Figure 8: Trade and divergence: US vs. non-industrial countries.

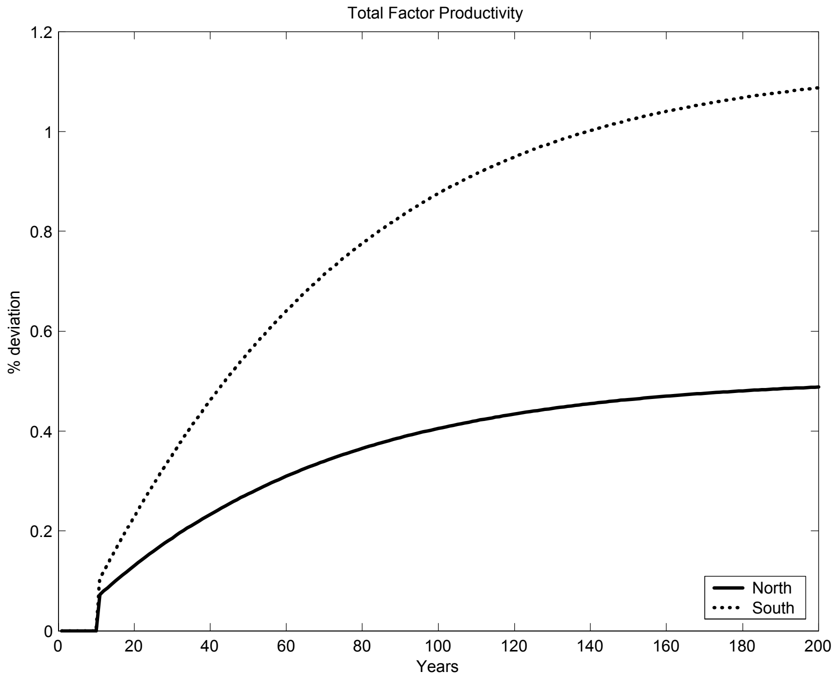

Figure 9: Trade integration and TFP

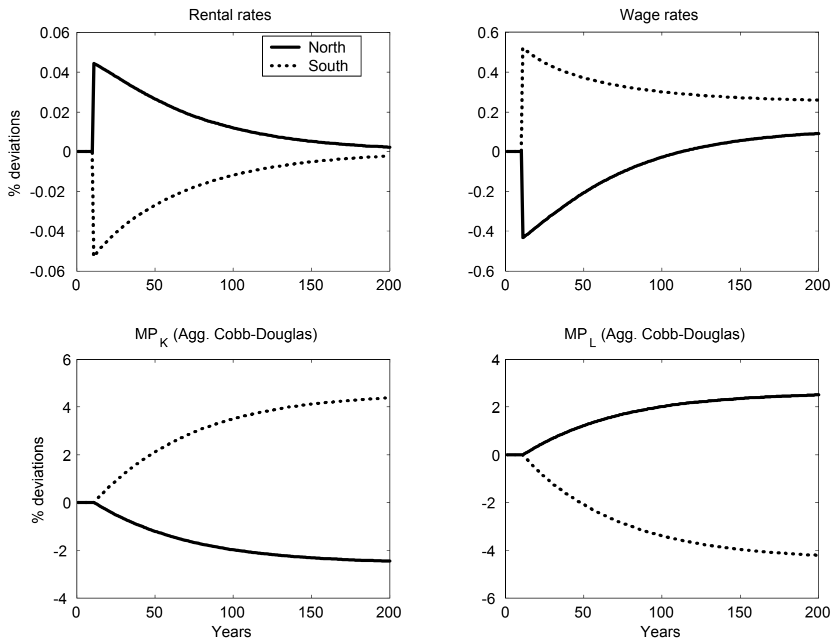

Figure 10: