The Growth of World Trade[1]

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Abstract

We present a neoclassical two-country dynamic trade model in which moderate reductions in trade costs can generate sizable increases in trade volumes over time. In our setup, a fall in trade costs has two effects on the volume of trade. First, for given factor endowments, it raises the degree of specialization of countries, leading to a larger volume of trade in the short run. Second, it raises (lowers) the factor price of each country's abundant (scarce) production factor, leading to diverging paths of relative factor endowments across countries and a rising degree of specialization. This creates an additional effect on the future volume of trade that adds to the static and dynamic effects of future falls in trade costs. A simulation exercise shows that a fall in trade costs over time produces an exponential increase in the trade share of output much in line with the data.

Keywords: International Trade, Heckscher-Ohlin.

JEL codes: F1, F4.

1 Introduction

One of the most remarkable economic phenomena of the last 40 years is the large growth of the world's trade volume. Since the second half of the 20th century has been a period of worldwide trade liberalization, lower import tariffs seem to be a natural explanation associated to this fact. Figure 1 illustrates this idea by plotting the time paths of worldwide average import tariffs on manufacturing goods (top panel) and of the US manufacturing export share in manufacturing GDP (bottom panel).[1]

As pointed out by Yi [16], however, any standard international trade model attempting to explain the growth of the world's trade volume on the basis of falling trade barriers is challenged by two puzzles concerning the time paths of these variables. (*i*) *The quantitative puzzle*: while worldwide average tariffs on manufactured goods have decreased by just 11 percentage points since the 1960s, the manufacturing export share in GDP has more than trebled. (*ii*) *The qualitative puzzle*: the volume of trade has increased much more rapidly in the second half of the period 1960-2000 than in the first half, whereas the fall of import tariffs in the second half of the period has been (if anything) slower than in the first half.

To address these issues, we present a two-country dynamic trade model with trade costs. Based on time honored models in the areas of international trade (the Heckscher-Ohlin model) and economic growth (the Ramsey model), we show that an exponential increase in the volume of trade in the face of a linear reduction in trade barriers is quite a natural fact once one allows for a dynamic response on the factor accumulation side. In our setup, a fall in trade costs has two effects on the volume of trade. First, for given relative factor endowments, it raises the degree of specialization of countries, leading to a larger volume of trade in the short run. Second, it raises (lowers) the factor price of each country's abundant (scarce) production factor, leading to diverging paths of relative factor endowments across countries and a rising degree of specialization over time. This creates an additional effect on the future volume of trade that adds to the static and dynamic effects of future falls in trade costs. A simulation exercise shows that the observed sequence of reductions in trade costs over time brings about (*i*) a much larger response of the volume of trade than expected from standard static trade models, and (*ii*) an

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[1] The world's manufacturing export share in manufacturing GDP is parallel to that of the US. Figure 1 is based on Figure 1 in Yi [16], who provides details on the construction of these variables. We are grateful to Kei-Mu Yi for kindly sharing his data.

exponential time path for the trade share in output.

Our model also captures an empirical regularity about the relationship between trade liberalization and income per capita divergence: besides being a period of worldwide trade liberalization, the second half of the 20th century exhibits an increase in the cross-country dispersion of income per capita. Figure 2 illustrates the divergence between rich and poor countries by plotting the time path of the median ratio of y_{US}/y_j, where y denotes GDP per capita and j denotes the world (solid line) or non-industrial countries (dotted line line).[2] Slaughter [13] has undertaken a systematic analysis of this issue by comparing convergence patterns among liberalizing countries before and after liberalization with the convergence patterns among randomly chosen control countries. This "difference-in-differences approach," which avoids the pitfalls of before-and-after comparisons, leads him to the conclusion that "much of the evidence suggests that trade liberalization diverges incomes among liberalizers."

Strictly interpreted, the North-South nature of our model makes it a convenient workhorse to understand this issue in the context of trade liberalizations between rich (accumulable-factor abundant) and poor (accumulable-factor scarce) countries. In our setup, trade liberalization implies growing volumes of trade between countries that diverge in both capital-labor ratios and income per capita. In fact, many non-industrial countries have undergone radical processes of trade liberalization over the last 25 years, leading to US trade with industrial countries losing importance relative to trade with non-industrial (non-OPEC) countries, as illustrated in Figure 3.[3] A comparison of the bottom panels of Figures 1 and 3 points to a change in the trend of both the US export share in GDP and the share of US trade with non-industrial countries in the mid-80s. Coincidentally, the mid-80s turns out to be the starting point of a period with increasing income per capita divergence between the US and non-industrial countries (see Figure 2), as our model predicts.

There is a growing literature that attempts to understand the growth of world trade over time. Yi [16] explains the two puzzles mentioned above on the basis of vertical specialization only occurring, hence raising the volume of trade in a nonlinear fashion, after trade costs have reached a critical value. Yi's model, however, falls

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[2] The figure is based on per-capita real GDP for 107 countries, taken from the PWT 6.1 described in Heston, Summers, and Aten [7]. Our common sample starts in 1960 and ends in 2000; we drop all countries for which only shorter time series were available. To identify non-industrial countries (76 observations), we follow the definition provided by the Bureau of Economic Analysis.

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

short of explaining an important share of the growth in the volume of trade. Our model, based on a completely different set of intuitions, may be interpreted as an explanation complementary to his. Bergoeing and Kehoe [2] calibrate a “new trade theory” model in the spirit of Helpman and Krugman [6] and Markusen [9], obtaining mixed results about the ability of the model to match the impressive growth of intra-OECD trade in the second half of the 20th century. In this respect, a reinterpretation of our model with both factors being accumulable may help explain the dynamics of trade between OECD countries.

A sketch of the Heckscher-Ohlin model with many goods and trade costs can be found in Mundell [10]; Dornbusch *et al.* [5] provide an elegant formalization of the continuum of goods; Romalis [11] 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 [14]. Some recent references comparing neoclassical growth under autarky and free trade are Ventura [15] and Cuñat and Maffezzoli [4]. 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. This enables us to uncover some new insights on the effects of trade integration.

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 relative factor endowment divergence. Section 5 discusses the relationship between the fall of trade costs and the growth of the world’s trade volume. Section 6 concludes.

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. 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:

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

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.[4] 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 increasing 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: $P_j Y_j = r_j K_j + w_j L_j$. 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 [12]. We can think of trade costs 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

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[4] In general, we denote aggregate variables with capital letters. κ is just used for normalization purposes and plays no major role in the model.

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 $w_N/r_N > w_S/r_S$.[5] Romalis [11] examines the model's predictions on the pattern of trade using bilateral trade data for the US. They turn out to receive strong support from the data: countries that are abundant in capital and skilled labor capture larger market shares in industries that use those factors intensively.

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 $p_S(z)\, y_S(z) = P_N Y_N + P_S Y_S$.

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 $p_j(z)\, y_j(z) = P_j Y_j$.

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 $p_N(z) y_N(z) = P_N Y_N + P_S Y_S$, and $y_S(z) = 0$.

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

1. Factor market clearing conditions:[6]

$$\begin{aligned} \int_0^1 \frac{\partial b\left(z, \phi_j, r_j, w_j\right)}{\partial w} y_j(z)\, dz &= L_j, \quad (4) \\ \int_0^1 \frac{\partial b\left(z, \phi_j, r_j, w_j\right)}{\partial r} y_j(z)\, dz &= K_j. \quad (5) \end{aligned}$$

2. Marginal commodity conditions:

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

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[5] See Romalis [11].

[6] By Walras Law, one of these conditions is redundant.

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 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 $z \in (0,1)$:

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

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

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. For simplicity, we assume that the labor endowment does not respond to changes in factor prices. The representative households' preferences over consumption streams can be summarized by the following intertemporal utility function:

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

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 equation (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 $\alpha\left(z\right)=z$ 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,

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

It is easy to see that $\frac{z_N^2-z_S^2+2(z_S-1)}{z_S-z_N} < 0$. 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.[7] Since we want to depart from the autarky-vs-free trade thought experiment, let us impose enough structure so as to have an initial

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[7] 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.

steady state with some trade. Assume $\phi_N > \phi_S$. Then $\tilde{r}_N = \tilde{r}_S$ if

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

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 equations (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 $K'_j = \left[\tilde{w}_j L_j + (1 - \delta + \tilde{r}_j) K_j - C_j (K_N, K_S)\right]$, 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 [8].

Following Cooley and Prescott [3], we set $\beta = 0.96$ 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 $\kappa = 0.175$, which implies an autarky steady-state world capital stock $\bar{K} = 2$ when $\phi_j = 1$, and $\tau_0 =$

1.14. 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 $\phi_N = 1.10$ 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 Factor Accumulation

To study the effects of a reduction in trade costs, we assume the world is in the steady state described above, and let τ fall to $\tau_1 = 1.13$ suddenly and permanently. Figure 4 displays the time paths of real per-capita income, consumption, investment, and capital for both countries, as percentage deviations from the original steady state. (The first ten years correspond to the original steady state.) On impact, income per capita increases by 0.08 percentage points in the North and by 0.11 points in the South.[8] This effect is due to the static gains from trade integration, which reduces the price wedge between countries. Countries can now exploit their comparative advantages better for given factor endowments. That is, both North and South find it optimal to reduce the range of goods they produce 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.

The static effect is quite small in comparison with the long-run effect: the dynamics leads to a remarkable process of long-run divergence in capital-labor ratios (and income per capita). 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 5. 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).[9]

Why do interest rates react as they do after a fall in τ? Country N, for example, ceases to produce the most labor-intensive goods it used to produce, since they

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[8] The static effect is so small that it cannot be read off Figure 4.

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

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.[10] Figure 6 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. In fact, the dynamic response of the two countries' trade volumes is much larger than the static one.

It is worth noting that both countries gain from trade integration in terms of welfare. A comparison of their utility levels[11] 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.

Finally, notice that the result on long-run income and consumption divergence depends on the assumption that one of the two factors is not accumulable. A similar model with two accumulable factors would predict relative factor endowments diverging faster, and volumes of trade growing at an even higher speed, but not necessarily cross-country income per capita divergence.

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[10] 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 some factor price convergence on impact. Still, the fall in the trade cost will raise (reduce) the reward to accumulating capital in the North (South).

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

5 The Growth of World Trade

Yi [16] 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. The discussion in the previous section suggests that an exponential increase in the volume of trade in the face of a linear reduction in trade barriers is quite a natural fact once one takes into account the dynamic response on the factor accumulation side. 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. We perform a simulation exercise with our dynamic trade model to illustrate this argument.

In order to compare with the evidence in Yi [16], we feed the time path of the import tariffs he reports into our model, and compare the predicted time paths for the North's export share in GDP with that of the US. For this purpose, however, we first have to decide whether the fall in the trade cost over time is unexpected or anticipated. This is a matter of relevance, given that permanent changes in the trade cost lead to changes in steady states. We assume that trade liberalization is a decision about the future path of τ, which is taken at time 0 and is known by economic agents. The process that determines the time path of τ after trade liberalization is agreed is assumed to be

$$\tau_{t+1} = \theta\bar{\tau} + (1-\theta)\,\tau_t + e_{t+1}, \tag{28}$$

where $\bar{\tau}$ denotes the long-run value for τ, and e is an error term.[12] Given the observed time path for τ, we use nonlinear least squares to estimate θ ($\hat{\theta} = 0.096$), τ_0 ($\hat{\tau}_0 = 1.14$), and $\bar{\tau}$ ($\bar{\tau} = 1.033$). The model fits remarkably well: all coefficients are highly significant, and the overall R^2 is 0.99. These estimates and equation (28) enable us to obtain the "expected" time path $\hat{\tau}$. Any differences between the expected and observed time paths are treated as unexpected changes in the trade cost.

We assume that the world is in the steady state associated with $\tau_0 = 1.14$ and $\left(\bar{K}_N/L_N\right) / \left(\bar{K}_S/L_S\right) = 3$, and that at time 0 a trade liberalization agreement is reached, whereby the future time path of τ is determined according to equation

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[12] A gradual fall in τ seems to correspond to historical experience better. Governments tend to liberalize slowly over time, due probably to political reasons.

(28). Figure 7 plots the actual and predicted US export share in GDP against τ.[13] Notice that although there is an implicit time line from right to left, the time scale is not uniform in this case. (Compare with the time path of import tariffs in Figure 1.) From a qualitative perspective, our simulation seems to approximate the actual time path for the US share of exports in GDP quite well: in general, the predicted series reproduces both the trend and the nonlinearities of the observed series.

The trend of the predicted export share rises over time. This is due to both the change in the long-run value $\bar{\tau}$ and to the variation in τ_t. The fall in $\bar{\tau}$ implies a change in the steady states of countries as in the previous section, and therefore triggers a process of long-run relative factor endowment divergence. The successive reductions in τ_t cause a sequence of increases in the export share (through both the static and dynamic mechanisms discussed in the previous section) that build on the effect generated by the change in steady states. The kink that takes place at $\tau = 1.05$ is due to the fact that we plot the share of exports in GDP against τ rather than time. $\tau = 1.05$ remains constant for almost 10 years. (Compare with Figure 1.) During this period, the volume of trade rises in spite of τ being constant; this is due to the divergence in relative factor endowments triggered by the liberalization process.

To show the extent to which the export share in GDP is responding to the dynamics triggered by trade integration, in Figure 8 we compare the predicted export share in GDP when we allow for capital accumulation (dotted line) and when we keep factor endowments constant at their initial levels (dash-dotted line). In the latter case, the response of the export share to the fall in the trade cost is much lower and linear. We also compare the predicted export share in GDP obtained above with the one we obtain when the whole time path of τ is unexpected (dashed line), *i.e.* when $\theta = 0$ in equation (28). The qualitative behavior of both series is quite similar: the predicted time path of the export share generated with $\theta = 0$ also displays an increasing trend. The mechanism here is less powerful than above, given that the full reduction in $\bar{\tau}$ is only learnt slowly by agents. However, the cumulative effect of the successive reductions in τ_t still applies.

Trade liberalization and North-South divergence As we mentioned above, the long-run increase in the volume of trade due to the divergence in relative factor endowments triggered by trade liberalization also works with both factors being accumulable. In this case, we can think of an "East-West" model that explains the

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[13] This figure is comparable with those reported by Yi [16].

growth of intra-OECD trade without generating a sizable cross-country income per capita divergence. A practical problem with this approach, however, might be that other mechanisms unrelated to comparative advantage may have also played a role here: "New Trade" theory features (scale economies, intra-industry trade) may also underlie the boom in within-OECD trade.[14]

Disentangling the workings of scale economies and comparative advantage in the "East-West" scenario is a major project in itself, and we deem it beyond the scope of this paper. Let us focus instead on the "North-South" context, where (*i*) inter-industry trade is relatively more important and New Trade theory features are therefore less relevant, and (*ii*) there is a rather clear distinction between accumulable factor abundant countries and accumulable factor scarce countries. This is also of interest, given the fact that many non-industrial countries have undergone important policy reforms towards free trade, the increasing importance of these countries in US trade, and Slaughter's evidence on the relationship between trade liberalization and cross-country income per capita divergence.

Figure 9 plots the time paths of the share of the volume of trade between the US and non-industrial countries in the US total trade volume (top-left panel), and the median ratios y_{US}/y_j (top-right), is_{US}/is_j (bottom-left), k_{US}/k_j (bottom-right), where y, is, and k denote GDP per worker, the investment share in GDP, and the capital-labor ratio, respectively, and j denotes non-industrial countries.[15] Notice that the increase in trade coincides with a rise in divergence. Figure 10 shows the divergence generated by our model on y_N/y_S with $\theta = 0.096$ (solid line) and $\theta = 0$ (dotted line). Trade liberalization leads to income per capita divergence through diverging relative factor endowments. Notice that under the assumption that the reductions in τ are unexpected, income divergence only becomes relevant well after the start of trade integration.

Concerning the effects of trade integration on the capital abundant country's production structure, Bernard *et al.* [1], based on a comprehensive set of US manufacturing plants for the period 1977-1997, find that the major effect of import competition from low wage countries has been to accelerate the reallocation of resources towards more capital- and skill-intensive industries within the US manufacturing sector. They also find that, within manufacturing industries, the most capital- and

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[14] See Helpman and Krugman [6], Markusen [9], and Romalis [11] for theoretical discussions, and Bergoeing and Kehoe [2] for a related calibration exercise.

[15] Capital stocks are constructed with the perpetual inventory method with data on investment from the Penn-World Tables. We use the same the same depreciation rate for all countries.

skill-intensive plants are the least likely to shut down when competition from low wage countries rises. These facts are also consistent with the mechanism highlighted in our model: notice that the time path of z_N reported in Figure 6 implies a reallocation of production factors in the North from labor-intensive to capital-intensive sectors.

6 Concluding Remarks

This paper highlights the importance of a dynamic approach to the analysis of trade liberalization. A dynamic treatment of an otherwise standard trade model renders the latter much more powerful in its implications: small reductions in trade costs can have large effects on trade volumes by making countries more different in their relative factor endowments.

For convenience, we have ignored a number of issues that might be worth pursuing in future work. First, we have neglected the other important force in the world markets, capital mobility, as a source of convergence or divergence in relative factor endowments. A first thought suggests that in our model capital mobility may even reinforce the process of divergence following a fall in trade costs, since trade integration produces a positive differential in the return to capital between North and South.

Second, the model might be modified to have accumulation of both factors. This would be quite useful if one has intra-OECD trade in mind. Trade liberalization, the growth of intra-OECD trade, and income per capita convergence within industrial countries have been quite remarkable in the last 50 years. At the same time, the US has become more and more human capital abundant, whereas Europe and Japan seem to have become relatively abundant in physical capital.

Finally, a many-factor, many-country extension of the model has the potential to explain the unequal experience of non-industrial countries in the current "trade liberalization" era: while many countries that were initially abundant in non-accumulable factors (natural resources and unskilled labor) have remained poor, some natural resource-scarce countries have undergone remarkable processes of factor accumulation and economic growth.

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7 Appendix

Following Judd [8], 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:

$$\widehat{c}_j \left(K_N, K_S; \mathbf{a}_j\right) = \sum_{z=0}^{d} \sum_{q=0}^{d} a_{zq}^j \psi_{zq} \left(K_N, K_S\right) \tag{29}$$

where:

$$\psi_{zq} \left(K_N, K_S\right) \equiv T_z \left(2 \frac{K_N - \underline{k}}{\overline{k} - \underline{k}} - 1\right) T_q \left(2 \frac{K_S - \underline{k}}{\overline{k} - \underline{k}} - 1\right) \tag{30}$$

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:

$$R_j \left(k_N, k_S; \mathbf{a}_j\right) \equiv \beta \hat{c}_j \left(k_N, k_S; \mathbf{a}_j\right) \left(\tilde{r}_j' + 1 - \delta\right) - \hat{c}_j \left(k_N', k_S'; \mathbf{a}_j\right) \tag{31}$$

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 (31) at some

	North	South
Avg.	2.43e-9	1.25e-8
Med.	2.34e-9	1.29e-8
Std.	2.88e-9	1.42e-8
Max.	6.00e-9	2.82e-8

Table 1: Euler equation residuals

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:

$$R_j\left(k_{zN}, k_{qS}; \mathbf{a}_j\right) = 0, \quad z, q = 1, 2, ..., d+1 \tag{32}$$

that can be solved with any robust numerical solver.[16] To minimize the approximation error, we optimally chose the collocation nodes among the zeros of Chebyshev polynomials: given the m zeros of $T_m\left[2\left(x-\underline{k}\right)/\left(\overline{k}-\underline{k}\right)-1\right]$ 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 $\left|R_j\left(k_N, k_S, \mathbf{a}_j\right)\right|$, 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 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.

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

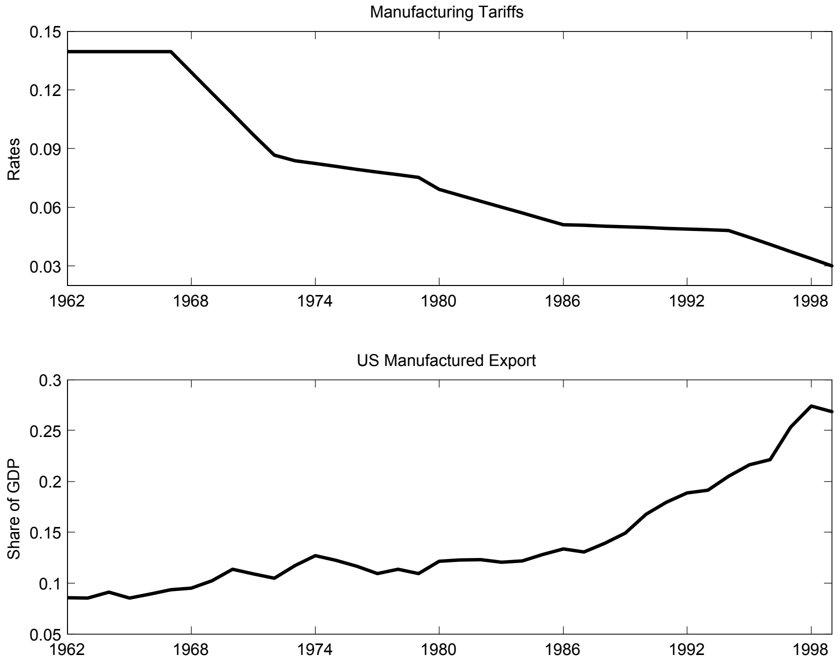

Figure 1: Import tariffs and US exports.

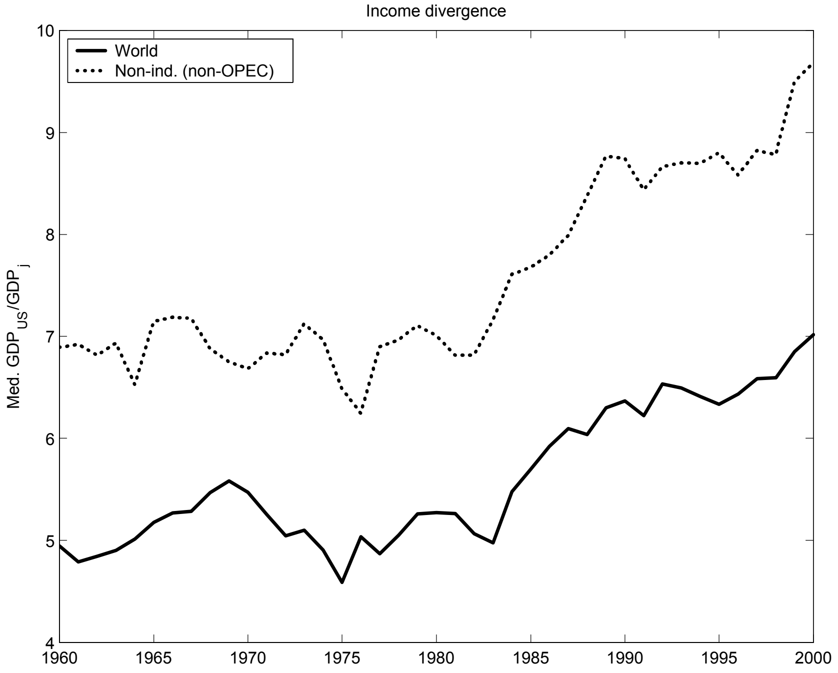

Figure 2: Income divergence in the world.

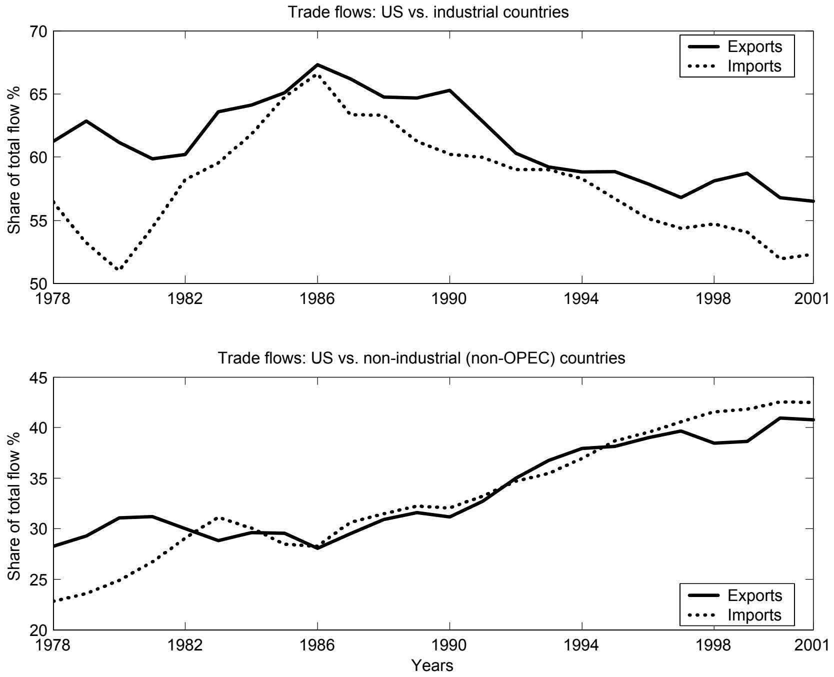

Figure 3: The structure of US trade

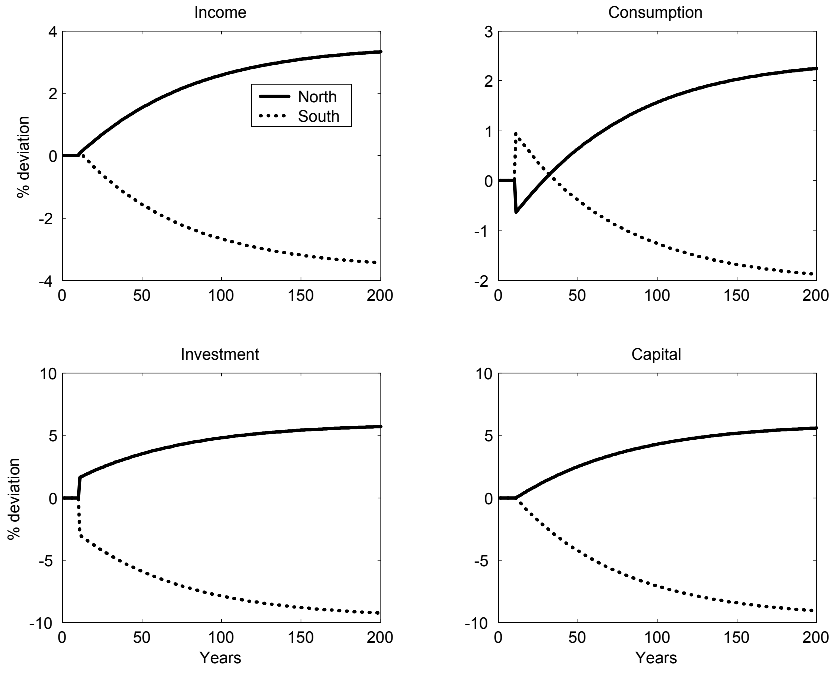

Figure 4: Income, consumption, investment, and capital.

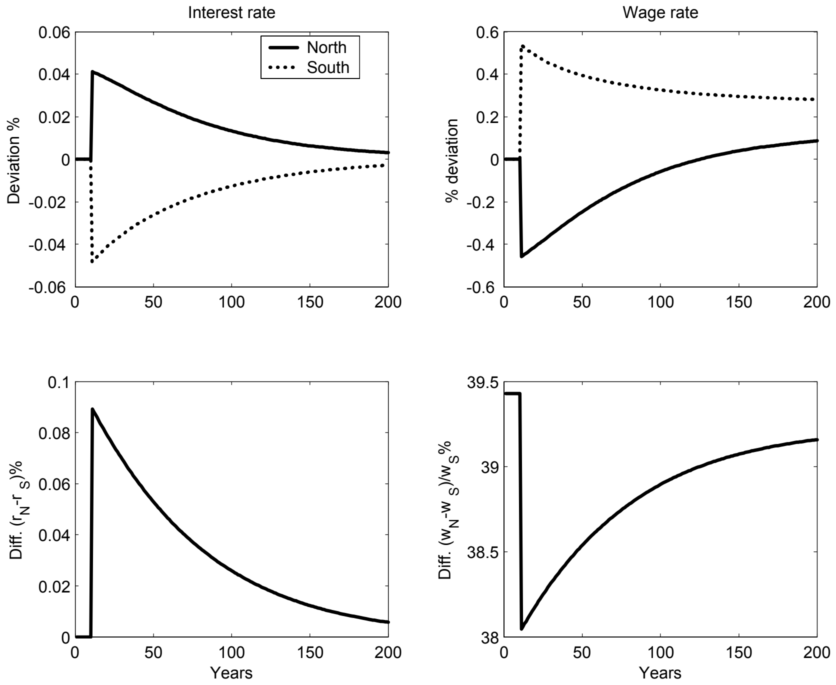

Figure 5: Factor prices (deviations and differentials).

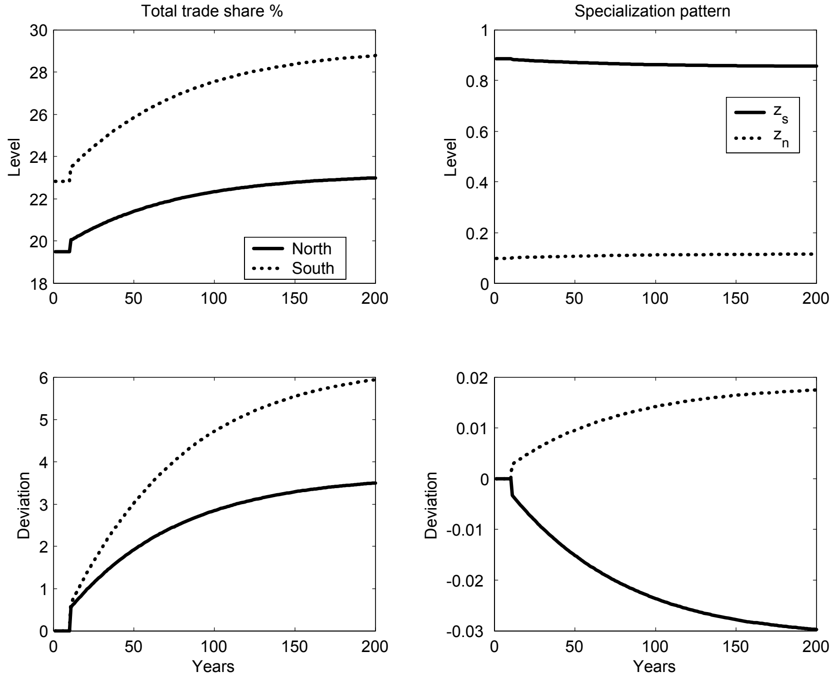

Figure 6: Trade shares and specialization (levels and deviations).

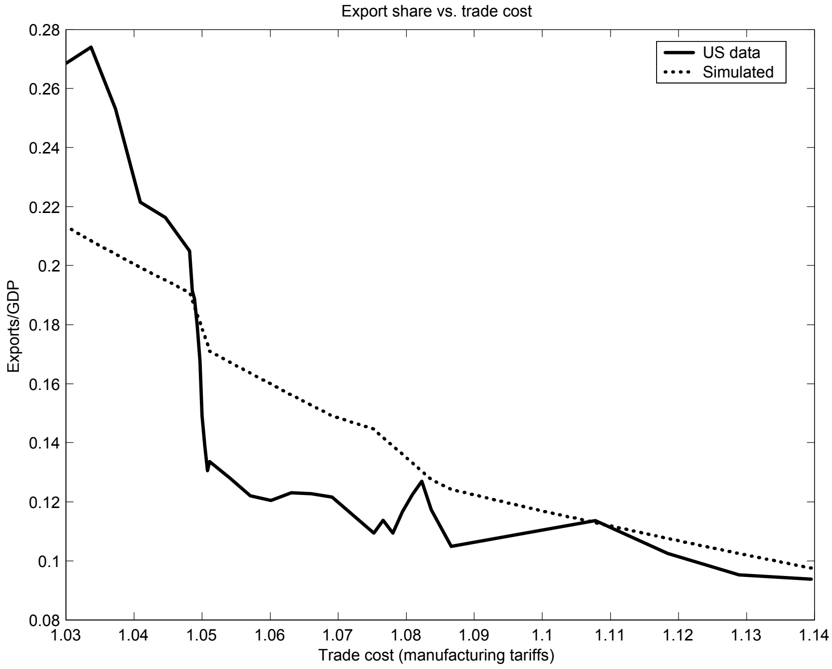

Figure 7: Trade integration and the US export share.

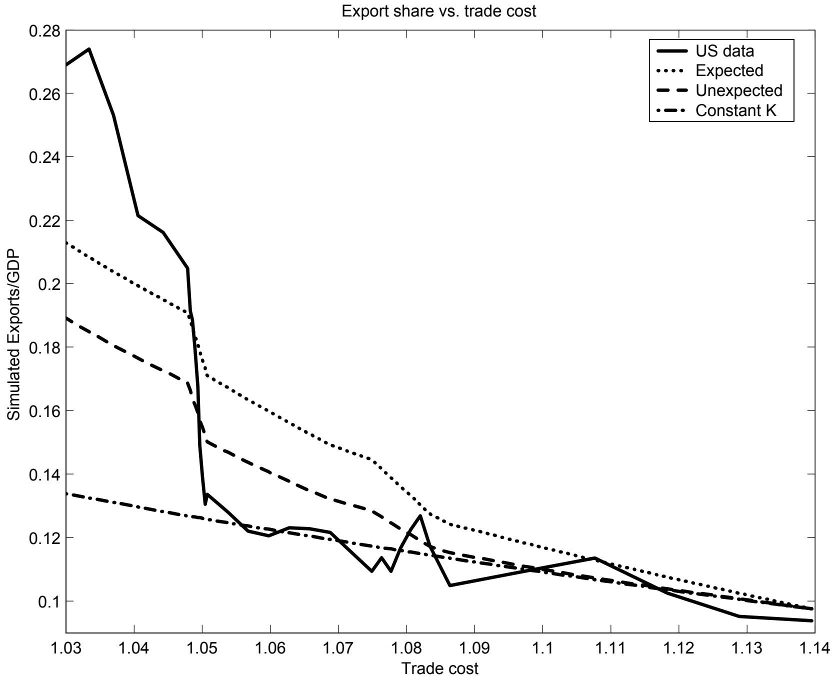

Figure 8: The role of expectations and capital accumulation.

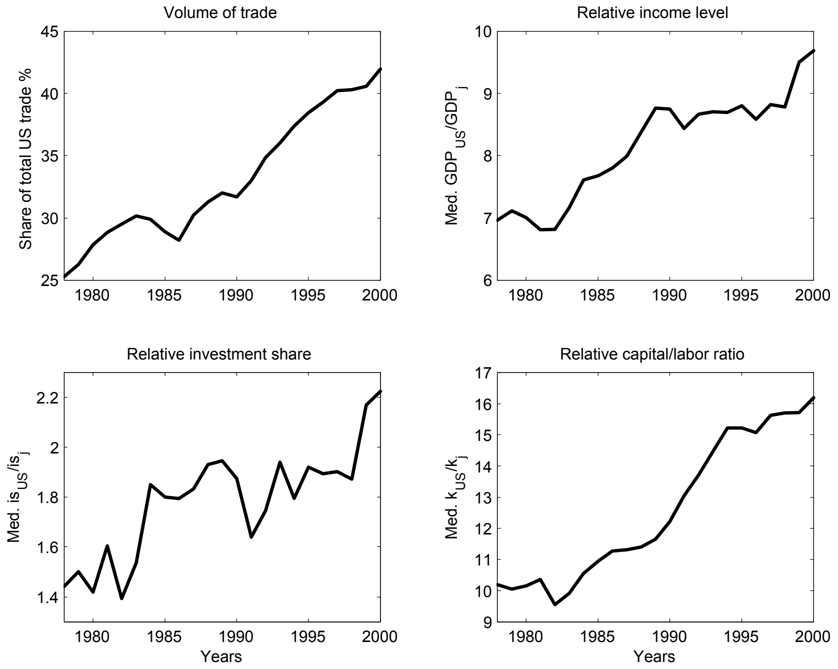

Figure 9: North-South trade and divergence

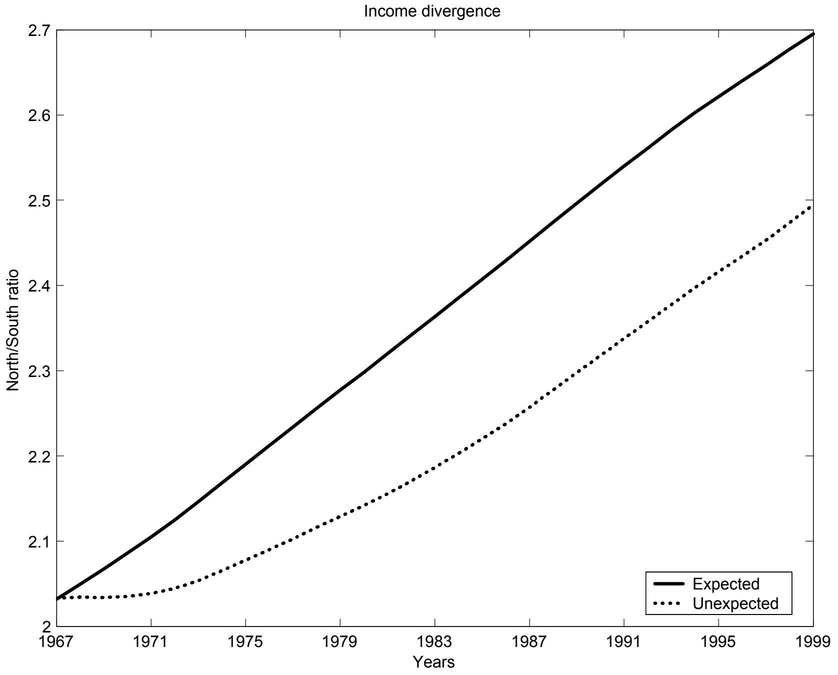

Figure 10: North-South divergence