

# On the Output Effects of Barriers to Trade

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## Abstract

We study the macroeconomic effects of international trade policy by integrating a Heckscher-Ohlin trade model into an optimal-growth framework. The model predicts that a more open economy will have higher factor productivity. Furthermore, there is a “selective development trap” to which countries may or may not converge, depending on policy. Income at the development trap falls as trade barriers increase. Hence, cross-country differences in barriers to trade may help explain the dispersion of per-capita income observed across countries. The effects are quantified and we show that protectionism can explain a relevant fraction of TFP and long-run income differentials across countries.

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# 1 Introduction

We study the effects of international trade policy on output. To do so, we analyze a standard neoclassical growth model, where countries can trade intermediate goods. The markets of these goods are structured as in the also-standard Heckscher-Ohlin trade model. Thus, trade happens due to comparative advantage, which emerges from differences in factor endowments across countries.<sup>2</sup>

We focus on the case of a small, price-taking economy. One can solve for equilibrium sequentially: first, each period's output and trade can be treated as a static problem, and its solution can be summarized by a mapping from capital and labor to the output of the final good. Then, using that endogenous mapping as if it were an exogenous production function, one can solve the intertemporal decisions of agents in the economy. In that way, a potentially complex dynamic trade problem is avoided. It turns out that the equilibrium mapping linking inputs and final output is affected by tariffs, as the gains

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<sup>2</sup>Most previous efforts to explain the link between trade and macroeconomic performance emphasize other motives for trade, not comparative advantage. For instance, in Rivera-Batiz and Romer (1991) or Grossman and Helpman (1991), trade happens due to increasing returns. Other papers study linkages –Rodriguez-Clare (1996), learning by doing –Young (1991), or the absorption of foreign technology –Holmes and Schmitz (1995). Corden (1971), Trejos (1992) and Ventura (1997) are exceptions to this, and also use a factor-endowments framework to introduce trade in a macro model. We use a factor-endowment approach because it can better explain trade in developing countries, and while those nations, due to the size of their economies, account for a small fraction of overall international trade, they are the center of the puzzle regarding TFP differentials and convergence.

from trade impact not only welfare but also the availability and price of intermediate inputs, and hence productivity. Furthermore, while the technologies for the intermediate and final goods are homogeneous of degree one and strictly concave, this equilibrium mapping is not globally concave, due to the distortion created by barriers to trade. Hence, there is not one, but two, asymptotically stable steady states. We find that the economy may converge to the lower steady state, under certain initial conditions, parameters and, notably, policy choices. Then, in equilibrium, countries can fall into a development trap, but not all poor countries end up there. The higher the barriers to trade, the lower the level of capital and output in the development trap.

Consequently, the model makes two predictions that may be empirically relevant. First, tariffs and other trade barriers will be negatively correlated to total factor productivity. Second, poor countries with protectionist policies will have lower levels of capital and output, and may fail to converge to the income of developed countries in the long run. There is empirical evidence supporting these results. Regarding the first, on the link between trade policy and measured productivity, Frankel and Romer (1999) find a relationship between openness and per capita income levels, which Irwin and Terzio (2000) show to be robust across different historical periods. Hall and Jones (1999) find that an open trade policy (namely, low tariffs and low incidence of quotas and other non-tariff trade barriers) increases income per-capita, both by enhancing capital accumulation and, notably, by expanding productivity. Finally, Alcalá and Ciccone (2001) find highly significant effects of trade on average productivity, controlling for

institutional quality and geographic factors.

Regarding the second result, on the link between trade policy and convergence, Ben-David (1993) finds a strong relationship between the removal of trade barriers and the decrease in income disparity across countries in the European Economic Community. Papageorgiou (2002) shows with data-sorting methods that openness is a key variable to identify middle-income countries into high- and low-growth groups. Sachs and Warner (1995) show that among countries that are open to trade, one cannot statistically reject convergence, while the same is not true in a broader sample of countries. Along similar lines, Dollar and Kraay (2004) find that developing economies that have experienced large increases in trade and significant declines in tariffs are catching up to the rich nations, while other developing countries are not. Finally, O'Rourke and Williamson (2000) show that in the late 19<sup>th</sup> century, along with an increase in trade, there was significant convergence among the main Atlantic economies, and that this pattern was reversed with protectionism after World War I. All these findings suggest that countries that choose isolationist trade policies can stagnate around relatively low incomes, even though not all poor nations do.<sup>3</sup>

To assess the magnitude of the two predictions mentioned above, we calibrate the model and find that the predicted effects from trade barriers can be significant. Re-

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<sup>3</sup>There is a broader literature regarding the link between international trade and other aspects of macroeconomic performance, using a variety of data and techniques. See, for instance, Dollar (1992), Harrison (1996), Lee (1996), Taylor (1996), Krueger (1997), Edwards (1998), Rodriguez and Rodrik (2000) and Wacziarg and Welch (2003).

garding productivity, we find that for a country with 1/3 of the US capital/labor ratio, the difference between having tariffs of 10% and having tariffs of 100% implies a loss of TFP equivalent to 7.1% of output, all other things being equal. From the data of some countries, over 1/4 of their unexplained TFP residual could be attributed to trade policy. As for long-run output, we find that with a sustained generalized tariff of 75%, output at the lower steady state is 1/3 of the output at the higher steady state. We illustrate that the growth performance of several countries across the 20<sup>th</sup> century is explained by their choice of trade policy, in the manner that the model suggests.

Section 2 presents the model and Section 3 derives the theoretical results. Calibration and quantification of the results are performed in Section 4. Section 5 concludes.

## 2 The economy

Time is discrete and unbounded, and there is a continuum of identical, infinitely-lived individuals. There are three goods. Two of these, called  $A$  and  $B$ , are non-storable intermediate products, used only as inputs to make the third, a final good called  $Y$ . There are two factors of production: labor  $L$  and capital  $K$ . The endowment of labor, measured in efficiency units, grows at an exogenous rate  $\mu$ . We will denote  $k = K/L$  and  $y = Y/L$ .

There are many small, price-taking countries, and one large country. The latter holds a very high fraction of the world market, so from its perspective trade is negligible, and

its autarkic prices are the international prices for all tradable goods. We will assume that this large country has already converged to its long-run steady-state capital labor ratio, denoted  $k^*$ , and focus our study instead on one of the small countries.

Physical capital and labor are used in the production of the intermediate goods  $A$  and  $B$ , with constant returns Cobb-Douglas technologies:

$$A = K_A^{\alpha_a} L_A^{1-\alpha_a} \tag{1}$$

$$B = K_B^{\alpha_b} L_B^{1-\alpha_b}.$$

Without loss of generality, we assume that  $A$  is the labor-intensive good, so  $\alpha_a < \alpha_b$ . Calling  $a$  and  $b$  the amounts of intermediate products that are used in the production of the final good (notice that, because of trade,  $a$  and  $b$  may differ from  $A$  and  $B$ ), total output of  $Y$  is given by:<sup>4</sup>

$$Y = a^\gamma b^{1-\gamma}. \tag{2}$$

Final goods can be used in either consumption or investment, so capital follows the usual law of motion:

$$K' = (1 - \delta)K + Y - C. \tag{3}$$

The representative consumer owns the capital, and faces the standard intertemporal maximization problem, with instantaneous log utility and discount rate denoted  $\beta$ .

There is an international market for the intermediate goods  $A$  and  $B$ , but it is phys-

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<sup>4</sup>Assuming  $K$  and  $L$  are also used in the production of the final good, so (2) becomes  $Y = (a^\gamma b^{1-\gamma})^\sigma (K_Y^{\alpha_y} L_Y^{1-\alpha_y})^{1-\sigma}$ , would complicate the exposition, without altering the main results.

ically impossible to trade final output  $Y$  across countries.<sup>5</sup> It is also impossible to trade internationally the factors  $K$  and  $L$ , or any form of financial asset or obligation. All markets that do exist, domestic or international, are assumed to be perfectly competitive. The international relative price of  $A$  in terms of  $B$  is denoted  $p$ . As  $k^*$  is given, and prices are set in the large economy, the international price  $p$  is constant. Governments may impose barriers to international trade, which here will be represented by a flat, ad-valorem tariff  $\tau$  on imports, the proceeds of which are transferred back to households. Because of these tariffs, the domestic relative price of  $A$  in terms of  $B$  may differ from  $p$ , and is denoted  $q$ . The domestic prices of  $K$ ,  $L$  and  $Y$  (again in terms of  $B$ ) are denoted  $r$ ,  $w$  and  $\pi$ .

The market-clearing conditions for both factors are given by

$$K \geq K_a + K_b \tag{4}$$

$$L \geq L_a + L_b,$$

and since there is no trade in financial assets or obligations, the current account has to be in balance, so

$$pA + B = pa + b. \tag{5}$$

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<sup>5</sup>This may appear counterfactual, as international trade includes the exchange of seemingly finished goods. However, recall that even goods that are ready for use need to be domestically transported, stored, retailed, insured, etc., after they are produced or traded, and the value-added through these local activities is large. One can interpret the production process of  $Y$  as the addition of these services to the products  $A$  and  $B$ , after they are produced or imported.

### 3 Equilibrium

#### 3.1 Static equilibrium

The model is designed so that the potentially complicated dynamic trade problem can be solved sequentially, using the following procedure to obtain equilibria. First, we derive the allocation of  $K$  and  $L$  between the production of  $A$  and  $B$ , the quantities  $a$  and  $b$  used domestically, and final output  $Y$ . Because  $A$  and  $B$  are not storable, and  $Y$  is not tradable, this is a static problem. Once solved, one can derive an implicit mapping

$$Y = F(K, L)$$

that relates final output with factor endowments. Second, because factors are not tradable, we can simply take  $F$  as if it were an exogenously given technology, and use it to solve the standard dynamic problem.

A period's static-equilibrium allocation is a combination of  $K_i, L_i, a, b, \pi, q, w, r$  under which

1. Producers of intermediate goods and final output choose  $K_i, L_i, a, b$  in order to maximize the period's profits

$$K_A, L_A = \arg \max_{K_A, L_A} qK_A^{\alpha_a} L_A^{1-\alpha_a} - wL_A - rK_A \quad (6)$$

$$K_B, L_B = \arg \max_{K_B, L_B} K_B^{\alpha_b} L_B^{1-\alpha_b} - wL_B - rK_B$$

$$a, b = \arg \max_{a, b} \pi a^\gamma b^{1-\gamma} - qa - b \quad (7)$$



2. Firms make zero profits

$$\pi a^\gamma b^{1-\gamma} - qa - b = 0$$

$$qA - wL_A - rK_A \leq 0, = 0 \text{ if } A > 0$$

$$B - wL_B - rK_B \leq 0, = 0 \text{ if } B > 0$$

3. Local prices of tradable goods satisfy an after-tariff law of one price:

$$q = \begin{cases} p/(1 + \tau) & \text{if } a < A \\ p(1 + \tau) & \text{if } b < B \end{cases}. \quad (8)$$

and

4. Markets clear, satisfying (4) and (5).

From these conditions, one can solve for the value of  $Y$  as a function of parameters, international prices and factor endowments, and thus derive the equilibrium relationship  $Y = F(K, L)$ .

It will be useful to start by solving for  $F(K, L)$  for the case of an economy that does not trade. This is equivalent to solving the problem for the large country, where trade is negligible. Defining  $k_A = \frac{K_A}{L_A}$ ,  $k_B = \frac{K_B}{L_B}$  and  $\lambda = L_A/L$ , one can obtain from (4) and from the first-order conditions for (6) and (7) that

$$\frac{(1 - \alpha_a)}{\alpha_a} k_A = \frac{(1 - \alpha_b)}{\alpha_b} k_B \quad (9)$$

$$q(1 - \alpha_a)k_A^{\alpha_a} = (1 - \alpha_b)k_B^{\alpha_b} \quad (10)$$

$$\frac{\gamma}{(1 - \gamma)} = \frac{qa}{b} \quad (11)$$

$$\lambda k_A + (1 - \lambda) k_B = k. \quad (12)$$

Defining  $\bar{\alpha} = \gamma\alpha_a + (1 - \gamma)\alpha_b$ , it follows that

$$\begin{aligned} k_A &= \frac{\alpha_a}{(1 - \alpha_a)} \frac{1 - \bar{\alpha}}{\bar{\alpha}} k \\ k_B &= \frac{\alpha_b}{(1 - \alpha_b)} \frac{1 - \bar{\alpha}}{\bar{\alpha}} k. \end{aligned} \tag{13}$$

Additionally, if there is no trade,  $A > 0$ ,  $B > 0$ ,  $a = A$ ,  $b = B$ , and  $Y = A^\gamma B^{1-\gamma}$  so, by virtue of (13), one can derive

$$Y = \Omega_4 K^{\bar{\alpha}} L^{1-\bar{\alpha}} \tag{14}$$

for a constant  $\Omega_4$ . The intermediate steps in the previous analysis, plus the formula for  $\Omega_4$ , are obtained in the Appendix.

If an economy is not trading, by (10) and (13), the value of  $q$ , the internal relative price of  $A$ , is a function of  $k$ , which we denote  $\theta(k)$ , where

$$\theta(k) = \frac{\alpha_b^{\alpha_b} (1 - \alpha_b)^{1-\alpha_b}}{\alpha_a^{\alpha_a} (1 - \alpha_a)^{1-\alpha_a}} \left[ \frac{1 - \bar{\alpha}}{\bar{\alpha}} k \right]^{\alpha_b - \alpha_a}. \tag{15}$$

Clearly,  $p = \theta(k^*)$ , as the international relative price of the tradable goods is going to be determined in the large economy, which is already in steady state.

Return now to our small, price-taking economy. Is  $Y$  also pinned down by (14)? The answer is yes if, in equilibrium, the small economy does not trade. This will happen if it is unprofitable to import either good, because the local autarkic prices are so similar to the international prices, that the difference is not enough to pay for the tariff. In other words, there will be no trade if and only if

$$(1 + \tau)\theta(k^*) \geq \theta(k) \geq \theta(k^*)/(1 + \tau), \tag{16}$$

since when the local economy does not trade, the local autarkic price is also pinned down by  $q = \theta(k)$ . Condition (16) will hold if  $k \in (x_1, x_2)$ , where  $x_1$  is defined by  $\theta(x_1) \equiv p/(1 + \tau)$  (that is,  $x_1$  is the capital labor ratio for which the domestic price of  $B$  is identical to the after-tariff price of imported  $B$ ); and  $x_2$  by  $\theta(x_2) \equiv p(1 + \tau)$ . The expressions for  $x_1$  and  $x_2$  are derived in the Appendix. Obviously,  $k^* \in (x_1, x_2)$ .

What happens if  $k \notin (x_1, x_2)$ ? Take for example the case where  $k < x_1$ , meaning – because  $\theta(k) > 0$  – that  $\theta(k) < p/(1 + \tau)$ . In that case, it will be profitable to import at least some  $B$  and export at least some  $A$ , and it will no longer be the case that the local price will be given by the function  $\theta$ , but rather, according to (8), by  $q = p/(1 + \tau)$ . Solving for  $k_B$  in (9), and substituting into (10), one can derive two values  $s_1$  and  $s_2$ , where  $s_1 < x_1 < s_2$ , such that the capital labor ratios in both intermediate industries are independent of  $k$ , and given by  $k_A = s_1$  and  $k_B = s_2$  whenever  $k \in [s_1, x_1]$ . By (4) and (12)

$$L_A = \frac{s_2 L - K}{s_2 - s_1} \quad L_B = \frac{K - s_1 L}{s_2 - s_1} \quad . \quad (17)$$

$$K_A = s_1 \frac{s_2 L - K}{s_2 - s_1} \quad K_B = s_2 \frac{K - s_1 L}{s_2 - s_1}$$

and (17) implies that the equilibrium output of the final good  $Y$  is linear in the endowment of inputs, or

$$Y = \Omega_2 K + \Omega_3 L \quad (18)$$

The derivation of (18), and the values of  $s_1$ ,  $s_2$ ,  $\Omega_2$  and  $\Omega_3$  are shown in the Appendix.

The fact that  $Y$  is linear in  $K$  and  $L$  is just a corollary of the Factor Price Equalization Theorem that holds in the Heckscher-Ohlin model. According to that theorem, under diversification and trade  $k_A$  and  $k_B$  are independent of  $k$ , the interest rate and wages are constant, and hence the production function (18) is linear. But this only holds if the economy is diversified, which requires that  $k > s_1$ ; otherwise, the values of  $L_B$  and  $K_B$  implied by (17) are negative.

What happens, then, if  $k < s_1$ ? In this case, the economy is no longer diversified, but rather specializes in producing only the labor-intensive good  $A$ , importing all of its use of the capital-intensive good  $B$ . In that case,  $L_B = K_B = B = 0$ ,  $K_A = K$ ,  $L_A = L$ , and therefore, by (11),

$$Y = \Omega_1 K^{\alpha_a} L^{1-\alpha_a} \quad (19)$$

where again  $\Omega_1$  is derived in the Appendix.

By similar arguments, if we had considered the cases where  $k > x_2$ , we would also have found that there is an interval where the economy is diversified and an exporter of  $B$ , the capital labor ratios of both industries are fixed (but now given by different values, say,  $z_1$  and  $z_2$ ), and the production function is linear, and given by

$$Y = \Omega_5 K + \Omega_6 L \quad (20)$$

Again, we would find that if  $k > z_2$ , for reasons similar to those above, the economy would be completely specialized in producing the capital-intensive good  $B$ , and output

would be

$$Y = \Omega_7 K^{\alpha_b} L^{1-\alpha_b}, \quad (21)$$

where again the values of  $\Omega_5$ ,  $\Omega_6$ ,  $\Omega_7$ ,  $z_1$  and  $z_2$  are derived in the Appendix.

Hence, the equilibrium relationship from  $K$  and  $L$  to  $Y$  takes the form

$$F(K, L) = \begin{cases} \Omega_1 K^{\alpha_a} L^{1-\alpha_a} & \text{if } K/L < s_1 \\ \Omega_2 K + \Omega_3 L & \text{if } K/L \in [s_1, x_1] \\ \Omega_4 K^{\bar{\alpha}} L^{1-\bar{\alpha}} & \text{if } K/L \in [x_1, x_2] \\ \Omega_5 K + \Omega_6 L & \text{if } K/L \in [x_2, z_2] \\ \Omega_7 K^{\alpha_b} L^{1-\alpha_b} & \text{if } K/L > z_2 \end{cases} \quad (22)$$

where the values  $\Omega_i$ ,  $x_i$ ,  $s_i$ ,  $z_i$  are functions of parameters, and *are* affected by  $p$  and  $\tau$ .

For all values of  $p$  and  $\tau$ ,  $F$  is homogeneous of degree one in  $K$  and  $L$ . Hence, we can rewrite it as  $y = f(k)$ . It is straightforward to show that  $f$  is continuous.

Summing up what is important: first, a country with very little capital per labor will specialize and only produce good  $A$ , trading some of it in the international market to acquire all the  $B$  that its  $Y$  producers need. In that case, the value of this output in the international market is proportional to the amount of  $A$  produced, and hence  $F$  will also be a Cobb-Douglas with a capital share  $\alpha_a$ . Second, a country with more capital per labor will diversify its production between  $A$  and  $B$ , but still be an  $A$ -exporter. In this circumstance, and for reasons that relate to the Factor Price Equalization Theorem,  $F$  is linear in  $K$  and  $L$ . Third, if the capital per labor is even higher, so that it is close

enough to  $k^*$ , there will be no international trade, because the difference between the local autarkic prices and the international prices is not enough to compensate the cost of the tariff. In that case,  $F$  happens to be a Cobb-Douglas function, with a capital share that is an average of  $\alpha_a$  and  $\alpha_b$ . Even higher capital-output ratios will yield a linear  $F$  for a diversified  $B$ -exporting country, and very high ratios will imply that the country only produces and exports  $B$ , again with a Cobb-Douglas technology with share  $\alpha_b$ .

The function  $f$  is decreasing in  $\tau$  (strictly decreasing if  $k \notin [x_1, x_2]$ ), as the gains from trade in this economy are reflected in the quantity and mix of inputs that go into  $a^\gamma b^{1-\gamma}$ , and tariffs unambiguously reduce the gains from trade in the Heckscher-Ohlin model. It is also increasing in  $p$  if  $k < x_1$ , and decreasing in  $p$  if  $k > x_2$ , as improvements in terms of trade enhance the gains from trade.

The fact that  $\partial f / \partial \tau < 0$  implies that a protectionist trade policy carries as a consequence a loss in output, given inputs, and therefore a loss in measured productivity. This is consistent with the empirical findings mentioned in the introduction. The effect of  $\tau$  on  $f$  is not because tariffs appear directly in any of the production functions, but rather because tariffs change  $q$  in a way that distorts the decisions of producers. There are two reasons why this is so. First, a distorted  $q$  introduces an inefficiency in the allocation of  $K$  and  $L$  between  $A$  and  $B$ , thus reducing the value of national product at international prices. Second, the same price distortion causes an inefficiency in the choice of  $a$  and  $b$  by  $Y$ -producers.

One should point out that the effect of tariffs on output is not uniform. As a fraction

of output, trade is more important for a country with  $k$  very different from  $k^*$ . This is because world prices  $p$  are pinned down by  $k^*$ ; a country with very low  $k$  will have very low  $p$  if in autarky, and large potential benefits from exploiting its comparative advantage by specializing in  $A$ . Hence, for a wealthy country with its  $k$  close to  $k^*$ , even the static gains from trade are not very important, but the opposite is true for a country where capital is scarce, and where much can be lost due to barriers to trade.

The effects of tariffs on output are illustrated in Figure 1, where  $f$  is drawn for  $\tau = 0$  and  $\tau > 0$ . Notice that, given  $k$ , the more open economy unambiguously obtains more output as  $f(k|\tau > 0)$  is everywhere below  $f(k|\tau = 0)$ .

<< INSERT FIGURE 1 >>

Generically,  $f$  is locally concave and continuously differentiable, although, if  $\tau > 0$ , these properties do not hold globally. In particular,  $f'(k)$  is not well defined and has discrete variations at the critical values  $x_i$ ,  $s_1$  and  $z_2$ , so  $f$  is not globally continuously differentiable. Furthermore, at  $x_1$  and  $x_2$ ,  $f'(k)$  discretely jumps *up*, and thus  $f(k)$  is not globally concave either. This is proven in the Appendix and illustrated in Figure 2.

<< INSERT FIGURE 2 >>

### 3.2 Dynamic equilibrium

Taking  $F$  as if it were an exogenously given (albeit peculiar) production function, consider the macroeconomics of an intertemporal model with that aggregate technology. Recall that barriers to trade, in this model, affect not only the level of output but also the marginal productivity per worker,  $f'(k)$ . This means that the long-run differences in output caused by tariffs are larger than the static losses mentioned above, as the capital/labor ratio in steady state is also affected by  $\tau$ . Furthermore, even the global concavity of  $f(k)$  is lost when  $\tau > 0$ . Therefore, as we shall see, the qualitative properties of the set of steady states may also change. This can occur even though all the production functions in the model are concave and homogeneous of degree one. These results are generated by policy distortions, as they change the equilibrium production choices.

Usual derivations, assuming log utility, lead to the Euler equation

$$\frac{f(k') + (1 - \delta)k' - (1 + \mu)k''}{f(k) + (1 - \delta)k - (1 + \mu)k'} = \frac{\beta}{1 + \mu} [f'(k) + 1 - \delta],$$

which characterizes the law of motion of  $k$ . We know that any asymptotically stable steady state in  $k$  will be characterized by a capital labor ratio  $\tilde{k}$  that satisfies

$$\Gamma < f'(\tilde{k}_-) \tag{23}$$

$$\Gamma > f'(\tilde{k}_+)$$

where  $\tilde{k}_-$  and  $\tilde{k}_+$  are the limits as  $k \rightarrow \tilde{k}$  from below and above, and where  $\Gamma \equiv \frac{1+\mu}{\beta} + \delta - 1$ .

Notice that (23) is written in this way rather than in a single equation, since the global



concavity of  $f$  is not guaranteed, and at some steady state candidates  $f'(k)$  may not be well defined.

**Proposition 1** *For all  $\tau > 0$ , there are two asymptotically stable steady-state levels of  $k$ . The higher steady state is given by  $k = k^*$ . The lower steady state is given by  $k = s_1$ .*

**Proof.** It is easy to verify that  $s_1$  is decreasing in  $\tau$  and therefore that  $f'(s_1^-)$  is increasing in  $\tau$ . Furthermore, one can show that  $f(s_1) = \Gamma$  when  $\tau = 0$ . Hence, for all  $\tau > 0$ , there is no  $k \in [0, s_1)$  that satisfies (23). This also establishes that  $\Gamma < f'(s_1^-)$ . Also, as it is shown in the Appendix, one can show that  $\partial\Omega_2/\partial\tau < 0$  and again, since  $\Omega_2 = \Gamma$  when  $\tau = 0$ , this implies that there are no  $k \in (s_1, x_1)$  for any  $\tau > 0$  that satisfy (23). This also establishes that  $\Gamma > f'(s_1^+)$ , which completes the proof that  $k = s_1$  satisfies (23).

We know that  $f(k)$  is continuous and strictly decreasing in  $k$ , and invariant in  $\tau$ , when  $k \in (x_1, x_2)$ , so that interval contains at most one  $k$  that satisfies (23) and, by construction, we know it to be  $k^*$ .

Notice now that one can also show  $\partial\Omega_5/\partial\tau < 0$  and, since  $\Omega_5 = \Omega_2$  under  $\tau = 0$ , it follows that there is no  $k \in (x_2, z_2)$  which satisfies (23). As is shown in the Appendix,  $f'(z_2^-) > f'(z_2^+)$ , and  $f'(k) < 0$  for  $k > z_2$ , so the same happens in  $[z_2, \infty)$ .

In conclusion, we have now proven that  $k \in \{s_1, k^*\}$  satisfy (23), and no other level of  $k$  does. Hence, those two are the only asymptotically stable steady-state equilibria.

■

The proposition implies that there is a lower steady state to which a country may converge if it starts poor enough. That lower steady state is a “selective development trap”: if two countries start with the same initial capital/labor ratio, but different  $\tau$ , it is possible that only one of them will fall in the trap and converge to  $k = s_1$ , while the other one catches up to the large economy and converges to  $k = k^*$ .<sup>6</sup>

The existence of the lower steady state, specially since, as  $\tau$  increases,  $s_1$  decreases, is consistent with the finding that one cannot statistically reject convergence among countries with low barriers to trade, while countries with high barriers fail to converge and tend to stagnate at lower levels of capital and output. This is also consistent with the finding that trade barriers can be used to identify middle-income countries into high- and low-growth groups (that is, into groups converging to high or low income levels).<sup>7</sup>

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<sup>6</sup>Ironically, a country may avoid the trap altogether by applying a very high tariff early on, since any country with an initial capital stock  $k_0 < x_1$  will converge to  $s_1$ , and  $x_1 \rightarrow 0$ , as  $\tau \rightarrow \infty$ . However, this policy will clearly be suboptimal; welfare (statically and in the long run) will be higher under a policy of free trade, even if the country ends up, as a consequence, converging to the low steady state. In fact, it is often mentioned that while open trade policy is key for catching up in today’s developing economies, some of those developed nations that have been wealthy for a longer time were once very closed to trade.

<sup>7</sup>Interestingly, if one allowed for countries to differ in parameters other than trade policy, one would find that when  $\Gamma$  is higher in the small country than in the large one, the small country may avoid the development trap altogether. This is because, in that case, there is a value  $\tau_o$  such that, if  $\tau < \tau_o$ , then there is no steady state at  $k = s_1$ .

## 4 Quantification

In this section we quantify the size of the results found above. We interpret the large economy in steady state to be the US; hence, we will replicate the standard calibration of the American economy in closed RBC models using  $f(k) = \Omega_4 k^{\bar{\alpha}}$ . Along those lines, we choose  $\delta = 0.06$ ,  $\mu = 0.04$  and  $\beta = 0.9802$  so that, in steady state, there is 6.1% net return on capital, 2% per-capita annual growth, and a 2.75 capital/output ratio.

Following NIPA figures for capital's share in national income, we also match  $\bar{\alpha} = 1/3$  (although we discuss at the end of this section the effect of considering different values). This pins down the average  $\bar{\alpha}$ , but leaves freedom in choosing  $\gamma$ ,  $\alpha_a$  and  $\alpha_b$ . These parameters are particularly important, as the quantitative effects of all trade-related phenomena, for low  $k$ , are bound to be larger with a big spread  $\alpha_b - \alpha_a$ , and with a lower  $\gamma$ , given  $\bar{\alpha}$ . If both industries require very different capital labor ratios, there is much to be gained from trade, as each country can specialize strongly on the industry whose demand is closest to their endowment. For instance, there is no trade at all if  $\alpha_a = \alpha_b$ . At the other extreme, Ventura (1993) finds very large permanent effects from trade, in the case where  $\alpha_a = 0$  and  $\alpha_b = 1$ . Also, for a poor country, the fraction of output that will be exported will decrease with  $\gamma$ .

We choose  $\alpha_a$ ,  $\alpha_b$  and  $\gamma$  so that exports cannot amount to more than half of output, and so that, for any one of the 20 richest countries in the world in 1985, the total gains from trade (the difference between  $\tau = \infty$  and  $\tau = 0$ ) are at most 1% of total output. This leads to  $\gamma = 1/2$ ,  $\alpha_a = 0.258$  and  $\alpha_b = 0.408$ . Despite the fact that the effects

of trade are small (in volume and productivity gains) for the wealthier countries, the model predicts larger effects as  $k$  falls. For instance, with  $k/k^*$  equal to Mexico's capital labor ratio as a fraction of the US, the whole difference between autarky and free trade is about 5.7% of GDP.<sup>8</sup>

One could evaluate the choices for  $\alpha_a$  and  $\alpha_b$  by measuring whether they imply an implausibly large volume of trade. We measure the fraction of the output of the labor-intensive good  $A$  that gets to be exported rather than consumed locally and find that with our parameters, for Brazil's level of  $k$  and  $\tau$ , the exported fraction of the output of  $A$  is 32%. For a poorer country like Kenya, even at 60% tariffs, exports would represent 22% of the output of the labor-intensive good. These numbers seem to be in line with the data. In no case does the model predict an export's share of output in excess of  $1/2$ .

Using this calibration, consider first the static effect of tariffs on measured productivity. Figure 3 shows proportionately how much higher productivity would be with  $\tau = 5\%$  than with  $\tau = 75\%$ , as a function of  $k/k^*$ . Such contrasting differences in tariffs are not unusual in the developing world. In fact, while a few countries have

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<sup>8</sup>In the survey by Kehoe and Kehoe (1994) it is argued that most estimates of the effect of NAFTA reflect negligible impact for the US and Canada, and only 2.2 percent of GDP for Mexico, in a static, applied general-equilibrium model. Considering that NAFTA does not imply a change from autarky to unrestricted free trade, but rather a much smaller change in effective protection, our calibration is conservative even according to their results. It also yields negligible effects of trade for the richest countries.

aggressively pursued export-led growth for decades, protectionism for many developing nations between the 1960's and 1980's was very high, frequently with average tariffs well over 100%.

<< INSERT FIGURE 3 >>

While for rich-enough countries the difference is negligible, for the world's poorest countries these two policies yield productivity levels that differ by as much as 29%.

The calibration predicts important static effects in productivity for the many Latin American countries that have undertaken trade liberalization in the last few years. This matches several empirical findings. For instance, Ferreira and Rossi (2003) report that industry measures of Brazilian TFP soared in the 1990's, and that Brazil took average nominal tariffs from 112% to 13% in that period. According to our model, that change in tariffs would imply a jump in productivity of 8% through efficiencies in international trade alone.

While the lost productivity from trade barriers can be large, so are the TFP differences that a variety of studies have found across countries. For instance, Klenow and Rodriguez (1997) estimate TFP levels for Brazil and Costa Rica that are 77%, and 64%, of those in the US. We do not do a complete levels- accounting exercise in this paper. It is illustrative to see, however, that if one applies our function  $f(k)$  to the values for  $k$  that Klenow and Rodriguez use, and the pre-liberalization tariffs for those countries

measured by Gonzalez-Vega and Monge(1995) and by Ferreira and Rossi (2003), one finds that, according to our model, trade barriers could explain nearly 27% of the productivity shortcomings of both countries. This suggests that further work regarding a complete levels-accounting exercise using our model could help understand at least part of the puzzle of TFP differences across countries.

We now study the magnitude of the effect of falling into the lower steady state. What we ask is how big the differences  $Y/L$  are between the two steady states (that is, between an economy that has fallen in the trap and one that has converged to the higher balanced-growth path), and the sensitivity of those differences to  $\tau$ .

We find that for low tariffs the gap is actually fairly small. At  $\tau = 0$ , income at the lower steady state is 90% of income at the higher steady state. As  $\tau$  increases, the gap widens, as both  $s_1$  and productivity fall. At  $\tau = 40\%$ , income is just half in the trap compared to the high steady state; at  $\tau = 100\%$ , it is one quarter. This is illustrated in Figure 4.

<< INSERT FIGURE 4 >>

As it turns out, the numbers in Figure 4 are somewhat sensitive to the calibration of  $\bar{\alpha}$ , on which there has been extensive discussion in the literature around the issue of intangible capital. One can show that as  $\bar{\alpha}$  increases, output at the lower steady state,

as a fraction of output in the higher steady state, decreases significantly. In particular, as we move from  $\bar{\alpha} = 1/3$  to  $\bar{\alpha} = 2/3$ ,  $f(s_1)/f(k^*)$  falls from 0.89 to 0.81 at  $\tau = 0$ ; from 0.5 to 0.29, at  $\tau = 40\%$ ; from 0.258 to 0.051 at  $\tau = 100\%$ . The long-run output gap that can be explained with the model is larger if one believes in a bigger capital share.

The model is useful to explain the evolution of income in specific countries. For instance, using the data in Maddison (2001), consider the cases for Argentina and Canada, two countries with similar natural endowments that enjoyed periods of relatively high income throughout the last century. In particular, both Canada's and Argentina's GDPs were, in per-capita terms, between 70 and 80% of the US GDP in the first decades of the century. Argentina went from being very open to trade before the Great Depression, to very protectionist for a long time during and after WWII. Predictably, output fell, from being stable at about 75% of US income before the protectionist period to being stable at about 45% of US levels afterwards. Our model, under the benchmark calibration, predicts that it takes tariffs to jump from 7% to 70% for the income at the development trap to vary at these amounts, a prediction that is in line with the tariff data for this country in that period. In contrast, Canada's per-capita GDP remained at around 80% of US levels during most of the 20<sup>th</sup> century, while trade policy remained very open. Likewise, Australia started last century as one of the richest countries in the world and has remained as such until today. As opposed to Argentina, there was never any relevant barrier to trade in Australia.

A similar observation can be made about countries that caught up significantly fol-

lowing trade liberalization after long periods of relative stagnation. A case in point is Singapore. In 1960, when it seceded from Malaysia, Singapore had a very closed economy, with tariffs in excess of 100%, and adopted a nearly free-trade policy soon after. According to the Penn-World Tables (PWT), version 6.1, output per worker, relative to the U.S., jumped from around 20% in 1960 to 80% in 2000, and seems like it is still catching up. Our model would predict this growth in income as a consequence of a tariff reduction from  $\tau = 129\%$  to  $\tau \sim 0$ , which is in line with the data. Qualitatively and quantitatively, the predictions of our model are consistent with Singapore's performance.

## 5 Conclusion

In this paper, we have studied a model that integrates a simple Heckscher-Ohlin trade structure into a dynamic optimal-growth setup. The main theoretical results are that barriers to international trade reduce total factor productivity and can cause the existence of a development trap, or low-income steady state. We then calibrate the model to get an idea of the possible order of magnitude of the effects of trade policy on macroeconomic performance. We find that the aggregate effects of trade barriers can be large in productivity and in long-run output levels.

Exploiting comparative advantage generated by factor endowments is not the motive for most international trade, but it is the main motive of international trade for most



poor countries. We seem to understand better the static welfare effects of this kind of trade than what it does to productivity, capital accumulation and long-run output. Because intermediate goods in our model are traded, the gains from trade show up in production, not only in welfare. Hence, even within a Heckscher Ohlin framework, trade can have aggregate implications.

Following Parente and Prescott (1994), many researchers have attempted to explain cross-country income disparities as the differences in steady-state income emerging from measurable differences in parameters, within the neoclassical model. The motivation for this research is that many poor countries behave as if in a balanced-growth path, with a very stable relationship between their income and that of the wealthiest countries, (see Figure 5). It does not seem as if these countries are catching up, but rather that they have converged. The problem is that by applying reasonable differences in parameters across countries, one can explain only a small portion of their poverty.

Something needs to be added to the neoclassical model to solve the puzzle. Isolation from international trade is one possible reason why so many nations stagnate at such poor relative-income levels. One feature that countries stuck at very low incomes seem to share is a high level of protectionism. Our model relates these two features.

<< INSERT FIGURE 5 >>

Our model predicts that there may be more than one balanced-growth path to which an economy may converge. It shall be stressed that this does not come from assuming

non-convexities in the technologies or preferences in the economy, as every production function is concave and CRS. The multiplicity of steady states, comes instead, from the nature of the equilibrium relationships in a trading economy, under the distortion of import taxes. This multiplicity allows parameter differences across countries a double explanatory effect: not only do they generate income disparities *within* a steady state, but also *across* them. If one can interpret rich countries as being in the high steady state, and at least some poor countries as being in the low steady state, the income disparities that can be explained with a given difference in fundamentals can be much larger.

It is important to note that the “development traps” in our model depend on policy. Not all countries that start out very poor will end up being very poor. Two nations with similar initial conditions but different policies will converge to different output levels, even if they both fall in the trap. We illustrate this by comparing the income performance over the 20<sup>th</sup> century of Argentina, Singapore and Canada.

As O’Rourke and Williamson (2000) note, the forces that are enhancing trade across countries are not necessarily permanent, as similar events before (the expansion of trade due to the decrease in communication and transportation costs in the late 19<sup>th</sup> century) have been reversed by protectionism and policy-imposed trade barriers. Whether or not we see world convergence in the long run may depend on this.

## A Appendix

To derive the autarkic production function (14), notice first that the first-order conditions for (6) and (7) are

$$\begin{aligned}
 q\alpha_a \left(\frac{K_A}{L_A}\right)^{\alpha_a-1} &= \alpha_b \left(\frac{K_B}{L_B}\right)^{\alpha_b-1} = r & (24) \\
 q(1-\alpha_a) \left(\frac{K_A}{L_A}\right)^{\alpha_a} &= (1-\alpha_b) \left(\frac{K_B}{L_B}\right)^{\alpha_b} = w \\
 \pi\gamma \left(\frac{a}{b}\right)^{\gamma-1} &= q \\
 \pi(1-\gamma) \left(\frac{a}{b}\right)^{\gamma} &= 1
 \end{aligned}$$

Which upon some manipulation, and using (4) and (5), translate into equations (9)-(12). Equation (11) can be rewritten as

$$\frac{\gamma}{(1-\gamma)} = q \frac{\lambda}{1-\lambda} \frac{k_A^{\alpha_a}}{k_B^{\alpha_b}}, \quad (25)$$

and using (10) and (25), we get

$$\frac{\gamma}{(1-\gamma)} = \frac{\lambda}{1-\lambda} \frac{1-\alpha_b}{1-\alpha_a},$$

and therefore,

$$\lambda = \frac{\gamma(1-\alpha_a)}{1-\gamma\alpha_a - (1-\gamma)\alpha_b}. \quad (26)$$

From (9) and (12), it follows that

$$\begin{aligned}
 k_A &= \frac{\alpha_a(1-\alpha_b)}{\lambda\alpha_a(1-\alpha_b) + (1-\lambda)(1-\alpha_a)\alpha_b} \\
 k_B &= \frac{(1-\alpha_a)\alpha_b}{\lambda\alpha_a(1-\alpha_b) + (1-\lambda)(1-\alpha_a)\alpha_b}.
 \end{aligned}$$

which applying (26), yields equations (13) in the text. Substituting from (13) into (2), one can obtain (14), and it is cumbersome but straightforward to obtain that

$$\Omega_4 \equiv \frac{\gamma^\gamma (1-\gamma)^{1-\gamma} [\alpha_a^{\alpha_a} (1-\alpha_a)^{1-\alpha_a}]^\gamma [\alpha_b^{\alpha_b} (1-\alpha_b)^{1-\alpha_b}]^{1-\gamma}}{\bar{\alpha}^{\bar{\alpha}} [1-\bar{\alpha}]^{1-\bar{\alpha}}}.$$

Recall that  $x_1$ , the minimal capital level for the small economy not to trade in equilibrium, is defined by  $\theta(x_1) \equiv p/(1+\tau)$ , and  $x_2$  by  $\theta(x_2) \equiv p(1+\tau)$ . Hence, from (15):

$$\begin{aligned} x_1 &= \frac{\bar{\alpha}}{1-\bar{\alpha}} \left[ \left( \frac{p}{1+\tau} \right) \frac{\alpha_a^{\alpha_a} (1-\alpha_a)^{1-\alpha_a}}{\alpha_b^{\alpha_b} (1-\alpha_b)^{1-\alpha_b}} \right]^{\frac{1}{\alpha_b-\alpha_a}} \\ x_2 &= \frac{\bar{\alpha}}{1-\bar{\alpha}} \left[ p(1+\tau) \frac{\alpha_a^{\alpha_a} (1-\alpha_a)^{1-\alpha_a}}{\alpha_b^{\alpha_b} (1-\alpha_b)^{1-\alpha_b}} \right]^{\frac{1}{\alpha_b-\alpha_a}}. \end{aligned} \quad (27)$$

When  $k < x_1$ , one can derive from (10) and (11) that

$$\begin{aligned} s_1 &= \left[ \frac{p}{1+\tau} \left( \frac{\alpha_a}{\alpha_b} \right)^{\alpha_b} \left( \frac{1-\alpha_a}{1-\alpha_b} \right)^{1-\alpha_b} \right]^{\frac{1}{\alpha_b-\alpha_a}} \\ s_2 &= \left[ \frac{p}{1+\tau} \left( \frac{\alpha_a}{\alpha_b} \right)^{\alpha_a} \left( \frac{1-\alpha_a}{1-\alpha_b} \right)^{1-\alpha_a} \right]^{\frac{1}{\alpha_b-\alpha_a}}. \end{aligned} \quad (28)$$

From here and (17) it is easy to derive  $A$  and  $B$  through (1), and then one can rewrite (5) as

$$pa + b = L \frac{ps_1^{\alpha_a} s_2 - s_2^{\alpha_b} s_1}{s_2 - s_1} + K \frac{s_2^{\alpha_b} - ps_1^{\alpha_a}}{s_2 - s_1} \quad (29)$$

By (11) and (29), one can obtain values for  $a$  and  $b$ , which substituting into (2) yield that  $Y$  is a linear function of  $K$  and  $L$ , given by (18) where

$$\begin{aligned} \Omega_2 &= \gamma^\gamma (1-\gamma)^{1-\gamma} p^{-\gamma} \frac{(1+\tau)^\gamma}{1+\gamma\tau} \frac{s_2^{\alpha_b} - ps_1^{\alpha_a}}{s_2 - s_1} \\ \Omega_3 &= \gamma^\gamma (1-\gamma)^{1-\gamma} p^{-\gamma} \frac{(1+\tau)^\gamma}{1+\gamma\tau} \frac{ps_1^{\alpha_a} s_2 - s_2^{\alpha_b} s_1}{s_2 - s_1} \end{aligned} \quad (30)$$

Notice now that  $K_B, L_B < 0$  are negative when  $k < s_1$ . In that case, (18) does not describe equilibrium output, as it holds that  $K_A = K$  and  $L_A = L$ . Again by virtue of (11) and (29)

$$\Omega_1 = \gamma^\gamma (1 - \gamma)^{1-\gamma} p^{1-\gamma} \frac{(1 + \tau)^\gamma}{1 + \gamma\tau}.$$

By derivations analogous to those above, one can obtain values  $z_1$  and  $z_2$

$$z_1 = \left[ p(1 + \tau) \left( \frac{\alpha_a}{\alpha_b} \right)^{\alpha_b} \left( \frac{1 - \alpha_a}{1 - \alpha_b} \right)^{1-\alpha_b} \right]^{\frac{1}{\alpha_b - \alpha_a}}$$

$$z_2 = \left[ p(1 + \tau) \left( \frac{\alpha_a}{\alpha_b} \right)^{\alpha_a} \left( \frac{1 - \alpha_a}{1 - \alpha_b} \right)^{1-\alpha_a} \right]^{\frac{1}{\alpha_b - \alpha_a}}$$

such that if  $k < z_2$ , then  $k_A = z_1$  and  $k_B = z_2$ , and in that case output will be pinned

down by (20), and

$$\Omega_5 = \gamma^\gamma (1 - \gamma)^{1-\gamma} p^{-\gamma} \frac{(1 + \tau)^{1-\gamma}}{(1 + (1 - \gamma)\tau)} \frac{z_2^{\alpha_b} - pz_1^{\alpha_a}}{z_2 - z_1} \quad (31)$$

$$\Omega_6 = \gamma^\gamma (1 - \gamma)^{1-\gamma} p^{-\gamma} \frac{(1 + \tau)^{1-\gamma}}{(1 + (1 - \gamma)\tau)} \frac{pz_1^{\alpha_a} z_2 - z_2^{\alpha_b} z_1}{z_2 - z_1}. \quad (32)$$

Similarly, the derivation of (21) is analogous to that of (19), and

$$\Omega_7 = \gamma^\gamma (1 - \gamma)^{1-\gamma} p^{-\gamma} \frac{(1 + \tau)^{1-\gamma}}{1 + (1 - \gamma)\tau}.$$

Notice that  $F$  is continuous, as the curves defined by (19) and (18) intersect precisely at  $k = s_1$ , (18) and (14) intersect at  $k = x_1$ , (14) and (20) at  $k = x_2$ , and (20) and (21) at  $k = z_2$ . One can also show that  $F$  is locally concave at  $s_1$ , by demonstrating that

$$\Omega_1 \alpha_a s_1^{\alpha_a - 1} \geq \Omega_2.$$

This inequality can be simplified to

$$p\alpha_a\left(\frac{s_2}{s_1} - 1\right) \geq s_1^{-\alpha_a} s_2^{\alpha_b} - p$$

which in turn becomes

$$p\alpha_a\left(\frac{\alpha_b(1 - \alpha_a)}{\alpha_a(1 - \alpha_b)} - 1\right) \geq \frac{p(1 - \alpha_a)}{(1 + \tau)(1 - \alpha_b)} - p.$$

Collecting terms, we obtain

$$1 - \alpha_a > \frac{(1 - \alpha_a)}{(1 - \alpha_b)} \left[ \frac{1}{(1 + \tau)} - \alpha_b \right],$$

which is true for  $\tau \geq 0$ , and holds with equality at  $\tau = 0$ . The procedure to prove that  $F$  is locally concave at  $z_2$ , by showing that  $\Omega_7\alpha_b z_2^{\alpha_b-1} \leq \Omega_5$ , is very similar.

It is important to show that  $\Omega_2 < \Gamma$  if  $\tau > 0$ , which is key to the proof of the proposition. From (23) we can get  $k^*$  and, substituting into  $k^*$  into (15) for  $p$  and, in turn  $p$  into (30) for  $\Omega_2$ , after substituting  $s_1$  and  $s_2$  from (28), it is easy to get that.

$$\Omega_2 = (1 + \tau) \frac{1 - \bar{\alpha}}{\alpha_b - \alpha_a} \frac{[\alpha_b - \alpha_a - \tau(1 - \alpha_b)]}{(\alpha_b - \alpha_a)(1 + \gamma\tau)} \Gamma.$$

Hence, the derivative we are looking for can be turned into

$$(1 - \bar{\alpha})\Omega_2 \left[ \frac{1}{(\alpha_b - \alpha_a)(1 + \tau)} - \frac{1}{(1 + \gamma\tau)[\alpha_b - \alpha_a - \tau(1 - \alpha_b)]} \right]$$

which has the same sign as

$$-(1 - \gamma)\tau(\alpha_b - \alpha_a) - \tau(1 + \gamma\tau)(1 - \alpha_b) < 0.$$

Finally, we are left to show that, if  $\tau > 0$ ,  $F$  is *not* locally concave at  $x_1$ , the key result that yields the development trap, as  $F_K(x_1^-) < F_K(x_1^+)$ . This is equivalent to showing that

$$\Omega_2 < \Omega_4 \bar{\alpha} x_1^{\bar{\alpha}-1}$$

which means

$$\frac{s_2^{\alpha_b} - p s_1^{\alpha_a}}{1 + \gamma\tau} > (\alpha_b - \alpha_a) \left( \frac{p}{1 + \tau} \right)^{\frac{\alpha_b}{\alpha_b - \alpha_a}} \left[ \left( \frac{\alpha_a}{\alpha_b} \right)^{\alpha_a \alpha_b} (1 - \alpha_a)^{\alpha_a(1-\alpha_b)} (1 - \alpha_b)^{-\alpha_b(1-\alpha_a)} \right]^{1/(\alpha_b - \alpha_a)}.$$

Substituting and collecting terms

$$(\alpha_b - \alpha_a) + \tau \alpha_b > (1 + \gamma\tau)(\alpha_b - \alpha_a)$$

which holds if  $\tau \bar{\alpha} > 0$ . The proof that  $F$  is not locally concave at  $x_2$  either, and which requires showing that  $\Omega_5 > \Omega_4 \bar{\alpha} x_2^{\bar{\alpha}-1}$ , is very similar.

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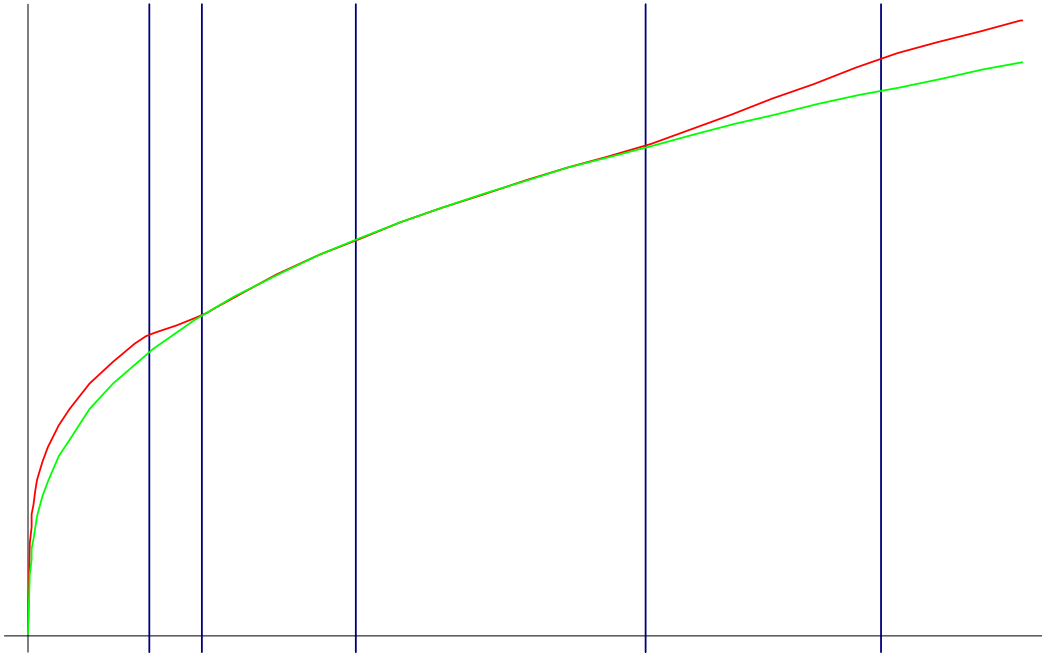


Figure 1:  $f(k|\tau > 0)$  and  $f(k|\tau = 0)$

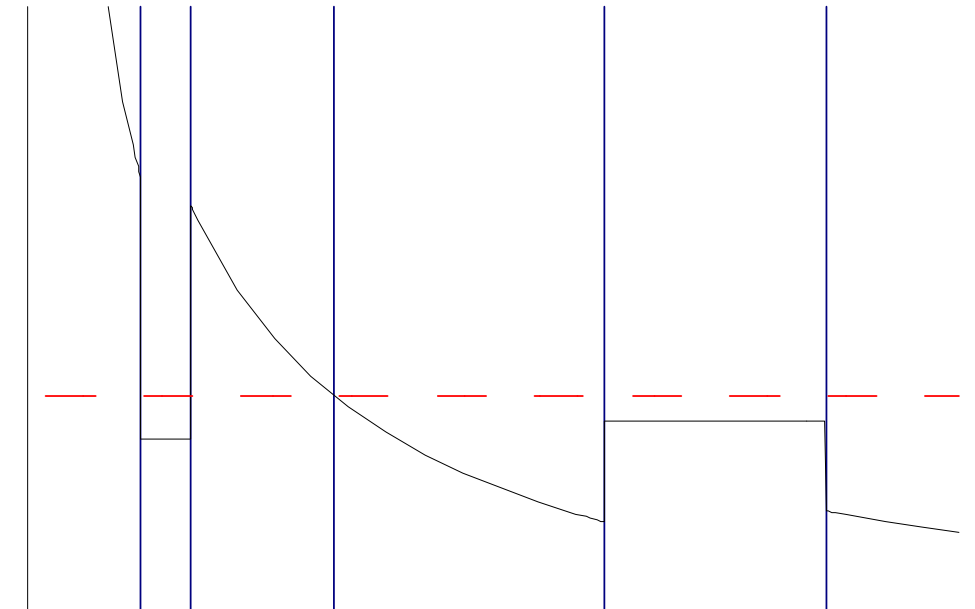


Figure 2:  $f'(k|\tau > 0)$

Figure 3: lost productivity from  $\tau = 75\%$  instead of  $\tau = 5\%$ , as a function of  $k/k^*$

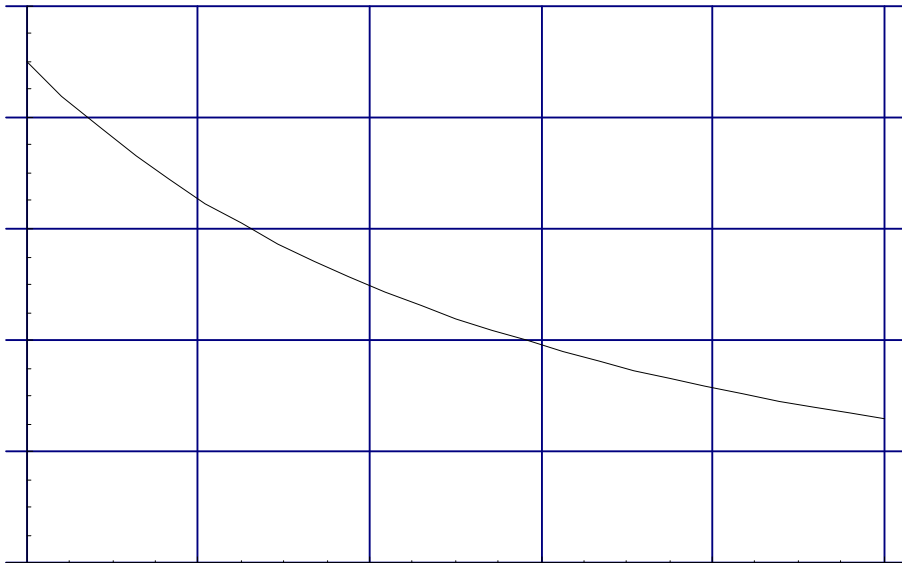


Figure 4:  $f(s_1)/f(k^*)$ , as a function of  $\tau$

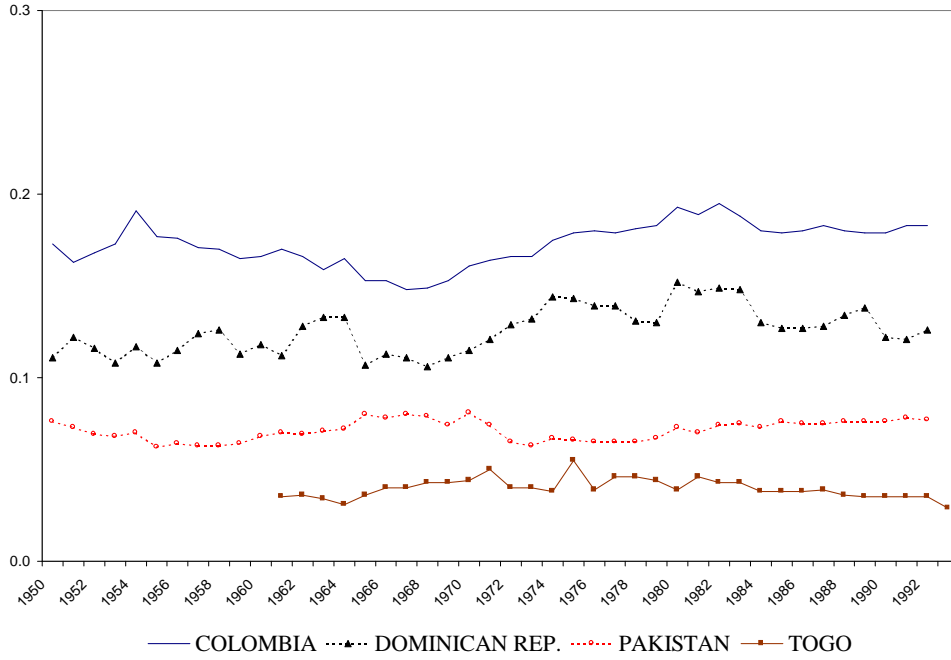


Figure 5: Income per capita relative to the US