Inappropriate Technology*

Ana Fernandes **Krishna B. Kumar**

January 2003

Abstract

In this paper, we investigate incentives other than altruism that developed countries have in improving technologies specific to developing countries. We propose a simple model of international trade between two regions, in which all individuals have similar preferences over an inferior good and a luxury good. The poor region has a comparative advantage in the production of the inferior good, and the rich in the luxury good. Even when costly adaptation of the technology to the poor region's characteristics is required – which makes the technology inappropriate for local use – we show that there are parameter configurations for which the rich region has an incentive to incur this cost. By raising the efficiency of the productive process of the developing region, the developed region can redirect its own productive resources toward the luxury good; it can also gain access to a more diversified set of consumption choices. Indeed, there are cases where the rich region would prefer to improve the poor region's technology for producing the inferior good rather than its own. Such technology transfers can increase the welfare of both regions. We apply our model to the Green Revolution and provide a quantitative assessment of its welfare effects.

Keywords: Technology improvements, Dynamic trade models, Welfare analysis
JEL Classification: O33, F11, F41

*Fernandes: CEMFI, Madrid, Spain; ana.fernandes@cemfi.es. Kumar: USC Marshall School of Business, Los Angeles, CA; kbkumar@usc.edu. We benefitted from useful discussions and comments from V. V. Chari, Alejandro Cuñat, Larry Kotlikoff, Robert Lucas, John Matsusaka, Victor Rios-Rull, Jim Robinson, Manuel Santos, Martin Schneider, Kei-Mu Yi, and participants at the 2001 SED meeting at Stockholm, Sweden, the 2002 Minnesota Workshop in Macroeconomic Theory, the 2003 winter meetings of the Econometric Society at Washington, D.C., and workshops at Boston University, USC, the University of Toulouse and *MadMac* (Madrid Macroeconomics Seminar). We especially thank Doug Gollin for generously sharing data on the Green Revolution with us and Doug Joines for his comments and support. Financial support from the US Department of Education and USC's CIBEAR is gratefully acknowledged.

1 Introduction

Calls are made, often on humanitarian grounds, for the developed countries to become actively involved in solving economic problems particular to developing countries. For instance, Jeffrey Sachs (1999) makes the plea: "Research and development of new technologies are overwhelmingly directed at rich-country problems. To the extent that the poor face distinctive challenges, science and technology must be directed purposefully towards them," and goes on to argue that the rich countries should fund research into malaria and AIDS vaccines for the poor countries.[1] Referring to the "Green Revolution", an international effort directed toward developing high-yield plant breeds to address the food needs of the developing world, Evenson and Gollin (2001) assert: "Literally millions of people are alive today who would have otherwise died from hunger or from diseases related to inadequate nutrition."

The benefits to poor countries from improved seed varieties and vaccines might seem obvious; however, for the rich countries, is altruism the only motivation to spend resources to invent or improve technologies for the poor? Under what circumstances would the industrialized world find that developing and donating technological innovations to the developing region is also in its own economic self-interest, even if such technologies were inappropriate for its own use? How is its welfare affected by improvements in the poor region's technologies or by an increase in its labor force, say through an increase in life expectancy? These are a few of the questions we address in this paper.

Consider, for example, the Green Revolution. The establishment of the Consultative Group on International Agricultural Research (CGIAR) in 1971 solidified the international efforts in this regard that had begun as early as the 1940s. The achievements of this revolution in increasing food production and decreasing prices have been nothing less than staggering.[2] Clearly, increased use of inputs, improvements in irrigation, mechanization, and better education of farmers played important roles in this process; nevertheless, the introduction of new seed varieties by the international community played a pivotal role.[3] The cost of such research, while not insignificant, was not particularly high. Evenson and Gollin (2000) report that the funding for the CGIAR has been about 5 billion US dollars

[1] McArthur and Sachs (2001) provide some evidence that variables such as the incidence of malaria affect the per capita GNP. Gallup and Sachs (2000) go further, and argue that intensive malaria negatively affects growth.

[2] The real price of food in international markets is less than half its level of 50 years ago. The FAO's index of food production per capita for developing countries shows a 50% increase from 1969-71 to 1998-2000. The yield of rice for all developing countries soared from 1,756 kilograms/hectare in 1961 to 3,798 kilograms/hectare in 2000. See Evenson and Gollin (2001) for a comprehensive and fascinating summary.

[3] Evenson and Rosegrant (2001) estimate that if the developing countries had not availed themselves of crop genetic improvements, prices would have been 35 to 66 percent higher and production would have been 8 to 12 percent lower for all food crops.

since 1971, and its budget for 1998 was $340 million.

The benefits to the poor countries of international efforts such as the Green Revolution have been catalogued in detail; but little has been said about the economic incentives the developed countries have for researching technologies inappropriate for their own use. An improvement in the technology or the health of poor countries could allow the rich countries to shift resources away from the goods typically produced by poor countries and allow them to focus on more advanced goods wherein their advantage lies. The expansion of the market for its good is particularly beneficial to the rich countries if the goods they produce are mostly luxury goods and services, while those produced by the poor countries are inferior goods such as food crops.

In order to study these issues, we develop a non-altruistic model of the world, which has two regions that trade with each other. Preferences are identical, and defined over an inferior ("agricultural") good and a luxury ("non-agricultural" or "manufacturing") good. We conduct a preliminary static analysis to argue that the rich region benefits from an improvement in the poor region's technology for producing the labor-intensive, inferior good, and is hurt by an improvement in the capital-intensive, luxury good. If the labor force of the poor region is sufficiently large, the rich region prefers to improve the poor region's agricultural technology to its own. Furthermore, it prefers an improvement in the poor region's production technology to an increase in the life expectancy of the citizens of that region.

We use these outcomes to specify a simplified production structure for the dynamic model, which allows us to conduct steady-state and transitional analysis. Now, the developing region produces only the inferior good using labor as the sole input, and the developed region produces this, as well as a luxury good, which requires both capital and labor. We further assume that technology is specific to a region and that the developing countries are unable to commit to future payments in return for technological assistance; consequently, technology transfers must take the form of donations.[4] Initially, we abstract from the costs of technology improvements and focus on comparative statics that highlight the basic forces at work.[5] In a steady state in which the rich region produces both goods, an improvement in the poor region's technology induces reallocation of the rich region's labor force toward the luxury good and increases its income; there is no improvement in its terms of trade. The poor region's income experiences a direct increase. However, when the rich region is specialized

[4] A case for this assumption can be made on the basis of empirical relevance. More important for us is the conservative nature of this assumption; if it can be shown that the rich countries have an incentive to provide technologies specific to poor countries for free, it will be all the more likely they would do so when paid for these technologies.

[5] Given the evidence on low costs of improvements presented earlier, this exercise is not empirically irrelevant.

in producing only the luxury good, an improvement in the poor region's technology makes the terms of trade more favorable for the rich and increases its income; there is no factor reallocation effect. The poor benefit from increased output, but are hurt by the terms of trade effect. In this case, there are parameter configurations in which the net effect from better technology is also beneficial to the poor.

We then incorporate the cost of technology improvements explicitly, via a quadratic cost function. While these costs might not be quantitatively important, explicitly modeling them allows us to analyze the technological investment choices individual regions face, and to compare individual investments to that of a world social planner.[6] Given the non-rival nature of technology and the resulting scale effect, if the poor country has a large enough workforce, the benefits for the rich from researching inappropriate technology could outweigh those from appropriate improvements. Therefore, the rich would prefer to research their trading partner's agricultural sector rather than their own. While individual countries perceive the benefits of better technology only on their own income and terms of trade, the social planner would evaluate the impact on both regions. Therefore, in the non-specialized case where both countries experience an increase in income, the planner's investment in improving the poor regions' technology exceeds that of the rich country acting on its own self-interest. When specialization prevails, however, the redistributive effects induced by the terms of trade hurt the poor at the expense of the rich. In this case, the rich overinvest relative to the efficient outcome.

We analyze the transition from a low level of technology in the poor region to a higher one; the dichotomy mentioned earlier between increased production versus improved terms of trade becomes less stark when transition is also considered. For instance, when the rich region is not specialized, there is a terms of trade improvement during the transition, even if there is none in the steady state.

Though the model allows us to address issues of broader interest, the Green Revolution appears to be a natural application for it. The above-mentioned dynamic analysis sets the stage for providing a quantitative assessment of the Green Revolution using numerical simulations. We find positive welfare benefits for both the poor and the rich regions in most cases, with the relative magnitudes of the gains mirroring the theoretical analysis summarized above.

Given the likelihood of Pareto improvement, why are such international "interventions" rare? We have considered regions and ignored the individual countries that form a region. The free riding problems inherent in technology improvement are likely to be a major disincentive for a given rich country to improve the poor region's technology on its own: countries that do not share the cost of research will also benefit. The issues of how sovereign entities

[6] The planner's problem could be seen as a version of the world in which the markets for technology production and sales or licensing by the rich region are complete.

form consortia to ensure the provision of this "public" technology, and why certain provisions such as improved crop seeds met with better success than the currently debated provision of lifesaving drugs, are interesting in their own right and are the subject of ongoing research.[7] However, in this paper we abstract from such considerations and assume that rich countries effectively coordinate their actions and can be treated as a region. We focus instead on the first step of theoretically and quantitatively assessing the benefits, if any, of such a provision, and on the mechanics of trade and the transition that ensues.[8]

The effect of a donation of goods on the welfare of the recipient country is often discussed in textbooks of international economics, and the result typically hinges on differential income elasticities of the donor and recipient country for the donated good. We focus on the less frequently encountered topic of technology development by the rich for the poor, and the resulting increase in welfare. Moreover, our results do not hinge on differences in preferences. There is also an extensive literature on how a country can increase the terms of trade in its favor by levying a tariff on the imported good; it can balance the consumer distortion arising from such a tariff with increases in producer surplus and revenues, and arrive at an optimal tariff. However, unlike technology improvements, optimal tariffs will hurt the poor region. And as is often pointed out, the optimal tariff is an interesting theoretical possibility but one that is difficult to implement in practice, given the possibility of retaliation and the inefficiencies involved in disbursing the collected tariffs. Nevertheless, we briefly consider tariffs in our setup in Section 7.

Romer and Rivera-Batiz (1991) are also interested in the effects of economic integration and technological progress. However, they focus on the pure scale effects of integration and "do not consider the general case of trade between countries with different endowments and technologies," as we do. Matsuyama (2000) develops a Ricardian model of two regions in which "North" specializes in higher income elasticity goods and "South" in lower elasticity goods. North cannot lose from an improvement its own productivity, while South may lose from an improvement in its productivity; it specializes in goods whose demand does not increase with income and is thus forced to reallocate labor toward industries in which it does

[7] In the next section we present a preliminary analysis on why the rich region might prefer an improvement in the crop technology of the poor country to an increase in the life expectancy of that country's citizens.

[8] We also abstract from the exact mechanism by which the developed regions raise funds for developing the poor region's technology without thwarting the incentives of the private sector that produces the technology in the first place. The following quote from the *Economist* dated February 22, 2001, is relevant in this regard: "The case for much more generous provision of life-saving drugs to the developing countries is irresistible both morally and as a matter of economics. But it is naive, wrong and in the long run counter-productive, to expect the cost of this aid to be met out of drug-company profits. Instead, rich-world taxpayers should pay. It would be much better to spend aid money on drugs for developing countries than it is to waste it in the usual ways."

Also see Sachs, Kremer, and Hamoudi (2001) on this matter.

not have a comparative advantage. The good structure is much simpler in our model, and the difference in income elasticities is not necessary for our results; it merely amplifies the incentive the rich region has in improving the poor region's technology. The non-specialized and specialized regimes we study provide a useful dichotomy in understanding the roles of increased production and improved terms of trade in expanding the value of the rich region's overseas markets; our analysis thus provides an additional perspective on the issue of market expansion analyzed by Matsuyama. We are also concerned with the identity of the technology producer and the potential cost of its production, which makes our goal different from his.

Acemoglu and Zilibotti (2001) are interested in quantifying the international differences in productivity and output arising from a mismatch of the technologies developed for rich countries and the low skills of workers in the poor countries where these technologies are used. Their frame of reference for *in*appropriateness is the poor country; ours is the rich country. The mismatch that they document further justifies the need for directed development of technologies suitable for poor countries.

The rest of the paper is structured as follows. In Section 2, we do preliminary analysis on a static model to set the stage for the dynamic model to follow. In Section 3, we present this dynamic model and characterize steady state outcomes when the developed region produces both goods as well as when it specializes in the luxury good. In Section 4, we conduct the steady state welfare analysis when technology improvement is costly. We characterize the transitional dynamics that follow technology improvements in Section 5. In Section 6, we present a quantitative assessment of the welfare effects by interpreting the Green Revolution in light of our model, and in Section 7, we present a brief discussion on tariffs. Section 8 concludes.

2 A Preliminary Analysis

Our aim is to argue that there are incentives for the rich region to develop technologies that might be *in*appropriate for itself but are of use to the poor countries; these incentives may even lead the rich to forgo technological improvements more appropriate to its own domestic sectors. In this section, we highlight these incentives using a static framework. We will later use the lessons learned from this static analysis to motivate a simplified production structure on which dynamic analysis can be conducted.

We consider a world formed of two regions – developing, or poor, subscripted by P, and developed, or rich, subscripted by R – whose citizens value consumption of two goods, denoted by superscripts 1 and 2. The instantaneous utility is given by:

$$\theta \log \left(c_i^1 - m_i\right) + (1-\theta) \log \left(c_i^2\right),$$

for region $i = P, R$. The constant $m_i > 0$ is the minimum amount of good 1 that must be consumed by region i. This good can be thought of as a necessity; it is straightforward to show that the income elasticity of demand is smaller than one for good 1, and greater than one for good 2. The degree of inferiority is increasing in m_i.[9] The weight of good 1 in the overall utility is denoted by θ. As mentioned in the introduction, it is not strictly correct to think of a "region" as an individual "country"; however, for simplicity, we will use the two terms interchangeably.[10]

The production of good 1 in region i is given by, $Y_i^1 = A_i^1 \left(K_i^1\right)^\alpha \left(L_i^1\right)^{1-\alpha}$, and that of good 2 is given by $Y_i^2 = A_i^2 \left(K_i - K_i^1\right)^\beta \left(L_i - L_i^1\right)^{1-\beta}$. Here K_i, L_i, are factor endowments of region i. We assume $\beta > \alpha$, so that good 2 is the capital intensive good. The labor intensive good is thus the inferior one. This fairly general production structure becomes analytically intractable rather quickly, so we start by analyzing the welfare effects of technology improvements in the special case of $\alpha = 0$ and $\beta = 1$. We thus have $Y_i^1 = A_i^1 L_i$ and $Y_i^2 = A_i^2 K_i$. This allows us to abstract from factor allocation decisions within the country and focus on the income and price effects induced by technology changes, and arrive at intuitive and tractable conditions. The forces outlined below will also be present in the general case of $\alpha, \beta \in (0, 1)$, where the GNP of a region will be additionally affected by changes in factor allocations.

Optimization of each country's problem, together with the market clearing conditions allow us to solve for relevant equilibrium quantities:[11]

$$\begin{aligned} p &= p\left(\overset{+}{A_P^1}, \overset{+}{A_R^1}, \overset{-}{A_P^2}\right), \\ I_P &\equiv Y_P^1 + pY_P^2 = I_P\left(\overset{+}{A_P^1}, \overset{+}{A_R^1}, \overset{+}{A_P^2}\right), \\ I_R &\equiv Y_R^1 + pY_R^2 = I_R\left(\overset{+}{A_P^1}, \overset{+}{A_R^1}, \overset{-}{A_P^2}\right), \end{aligned} \tag{1}$$

where p is the price of good 2 relative to the numeraire (good 1), and I_P and I_R are the GNPs of the poor and rich countries. The GNP of individual countries can be directly

[9] The minimum consumption is indexed by i to allow for the possibility that the norms for a mimum, say as defined by the poverty level, can change with the level of development. See Chatterjee and Ravikumar (1999) for an exposition on minimum consumption in a macroeconomic context.

[10] In the presence of a minimum consumption requirement, the representative agent construct needs to be interpreted with caution; Engel curves have intercepts different from zero. If one derived the aggregate demand curve for good 1 by adding up individual demand curves for which the minimum consumption is satisfied, it will be satisfied in the aggregate as well. If, instead, the economy's aggregate income were given to a representative agent, the satisfaction of the minimum consumption requirement in the aggregate does not necessarily mean it will be satisfied for every individual. We abstract from this possibility.

Throughout the paper, we interpret the minimum consumption requirements m_i as aggregate requirements proportional to population size. Given this, we use the aggregate agent's utility for analysis instead of multiplying individual utility by the number of agents. This is done for ease of exposition and nothing crucial, including the scale effect, depends on this.

[11] Appendix A.1 provides the complete expressions.

affected by a change in the technological coefficients and / or by a change in the price p; the above expressions for I_j capture the reduced form relationship between income and the parameters of interest, once the expression for the price has been substituted. The indirect utility function of country i, excluding constants, is:

$$V_i = \log\left(Y_i^1 + pY_i^2 - m_i\right) - (1-\theta)\log(p). \tag{2}$$

Increased production exerts a positive effect on a region's welfare; absent factor allocation, such an increase can happen when there is technology improvement. When the relative price, p, increases, there is a positive effect on welfare due to an increase in GNP and a negative effect due to an increase in the cost of consumption; one can view the positive effect as an "income" or a "production" effect and the negative effect as a "substitution" or "consumption" effect. Which of these two effects dominates will depend on technological parameters and factor endowments.

Absent altruism, the rich country's stance toward improvement of a technology can be evaluated in terms of the effect on its own welfare, V_R. In what follows, we use this criterion to evaluate the following questions which seem interesting *a priori*: 1) Does the rich country benefit more from an improvement in the poor country's technology for producing the labor intensive good or in the capital intensive good? 2) When does the benefit to the rich country of an improvement in the poor country's technology exceed the benefit of an improvement in its own technology? 3) Does the rich country benefit more from an improvement in a specific technology of the poor country, say crop seeds, or by a general improvement in the poor country's condition, say by an increase in life expectancy? 4) What role does the inferiority of the labor-intensive good play? Recall that the immediate aim is to identify the incentives for the rich country and motivate a simple production structure for the dynamic model, rather than derive categorical claims.

1. **Which poor country good to target?** As seen from (1), an increase in the poor country's technology for good 1, A_P^1, increases the relative price, p, while an increase in the poor country's technology for good 2, A_P^2, decreases this price. As argued above, a price change had an ambiguous effect on welfare in general. However, if the poor country is abundant in labor, and the rich country is abundant in capital, the production effect of a price increase dominates the consumption effect in welfare considerations of the rich country; the rich country would, therefore, prefer a price increase to a decrease. In particular, simple algebra for the $\alpha = 0$, $\beta = 1$ case shows that:

$$\frac{A_R^1 L_R - m_R}{A_P^1 L_P - m_P} < \frac{A_R^2 K_R}{A_P^2 K_P} \Leftrightarrow \frac{\partial V_R}{\partial A_P^1} > 0,\ \frac{\partial V_R}{\partial A_P^2} < 0. \tag{3}$$

   If the rich country has a comparative advantage in good 2, its welfare increases when the poor country technology for producing good 1 is improved, but decreases when the poor country's technology for producing good 2 is improved. As Dixit and Norman (1980; p.139) say, "...the foreign country is bound to benefit from technical progress in the home country's export industry." The rich region would prefer to improve the technology of the poor country's export good, which we have assumed, in an empirically consistent way, is labor intensive. The terms of trade for the rich country, which is a net exporter of good 2 given the above pattern of comparative advantage, improves. We also verify that $\partial V_P / \partial A_P^1 > 0$, so that there is no "immiserization" and the poor region has an incentive to accept the new technology.

2. **Improve own technology or the poor country's technology?** If the poor country's technology for good 1, A_P^1, is improved, the rich country benefits only through an increase in the relative price p. If, on the other hand, the rich country's own technology for good 1, A_R^1, is improved, it directly benefits from an increase in its output, Y_R^1, as well as a higher relative price p. However, given that the poor country is abundant in labor, it is conceivable that the intensity of the price effect from an improvement in the "inappropriate" technology is strong enough for the rich country to prefer an improvement in A_P^1, to an improvement in its own technology. The effect of an improvement in A_P^1 is magnified by the size of the poor country's labor force. If this labor force is large enough, improving A_P^1 might be a more effective way of generating a terms of trade improvement for the rich country than improving A_R^1. Indeed, one can show that condition (3) can ensure $\frac{\partial V_R}{\partial A_P^1} > \frac{\partial V_R}{\partial A_R^1}$, provided $A_R^2 K_R > A_P^2 K_P$ and $L_P > L_R$ are also satisfied.[12]

   Therefore, for the rich country to prefer an improvement in the inappropriate technology, conditions stronger than the comparative advantage condition, (3), are needed; the rich country needs to be a large enough producer of good 2, and the poor country amply endowed with labor to be a large enough producer of good 1.[13]

3. **Improve technology or life expectancy?** We have captured an increase in the poor country's technology, say through an improvement of crop seeds, by an increase in the technological coefficient A_P^1. Likewise, it seems reasonable to capture an increase in the life expectancy of the country's citizens, say through the development of malarial drugs, by an increase in the labor force L_P. For the $\alpha = 0$, $\beta = 1$ case, it is easy to see that the rich region treats increases in both parameters symmetrically, as there is no labor allocation decision involved. In the more general case, where labor can be used to produce good 1 or good 2, the poor region might have an incentive to allocate some

[12] The actual condition is: $\frac{A_R^1 L_R - m_R}{A_P^1 L_P - m_P} < \frac{A_R^2 K_R + A_P^1 K_P \frac{L_R}{L_P - L_R}}{A_P^2 K_P + A_P^2 K_P \frac{L_R}{L_P - L_R}}$. When $A_R^2 K_R > A_P^2 K_P$ and $L_P > L_R$, the right hand side is smaller than $\frac{A_R^2 K_R}{A_P^2 K_P}$, retrieving condition (3).

[13] When factor endowments and minimum consumption levels are identical across countries, ($L_P = L_R = L$, $K_P = K_R = K$, $m_P = m_R = m$), it is straighforward to show that the rich country will never benefit more from a marginal increment in A_P^1 when compared to a similar change in A_R^1. That is, $\partial V_R / \partial A_P^1 < \partial V_R / \partial A_R^1$.

of the increase in labor to producing good 2 and "compete" with the rich country, thus numbing the impact on the terms of trade. We consider the case of $\alpha = 0$, $\beta < 1$, to illustrate this effect; labor is used to produce both goods, while capital is used to produce only good 2. In this case, one can show $\partial Y_P^2/\partial L_P > 0$, as conjectured above.

Both A_P^1 and L_P affect V_R only through p, and one can show that the rich country prefers the option that increases this relative price the most. An increase in A_P^1 (technology improvement), induces an increase in the allocation of the poor country's labor to the production of good 1 in addition to a direct effect on output; this translates into a greater increase in the price of good 2 than the one caused by an increase in L_P (health improvement). Therefore, if the poor country is endowed with abundant labor, L_P, relative to technology, A_P^1, which is the empirically plausible case, it follows that $\partial V_R/\partial A_P^1 > \partial V_R/\partial L_P$.

Evidently, the rich region would prefer to donate directed technologies, such as seeds specific to the poor region's climate, rather than "general purpose" technologies, such as drugs to cure tropical diseases, which can effectively cause the developing region to compete in the rich region's export good sector.[14]

4. **What role does inferiority play?** We answer this question by reverting to the $\alpha = 0$, $\beta = 1$ case and examining how $\partial V_R/\partial A_P^1$ varies with the minimum consumption level. For simplicity, we now set $m_P = m_R = m$. First, note that the strength of the price response increases with the inferiority of good 1. That is, $d \ln p/d \ln A_P^1$ increases with m. For this reason, one might first expect the cross partial $\partial^2 V_R/\left(\partial A_P^1 \partial m\right)$ to be positive; but it cannot be unambiguously signed even if (3) holds, since an increase in m affects the strength of *both* the income and the substitution effects in $\partial V_R/\partial A_P^1$. The condition for $\partial^2 V_R/\left(\partial A_P^1 \partial m\right) > 0$ is more stringent and is satisfied for low enough $A_P^2 K_P$ and high enough $A_R^2 K_R$; in other words, the rich country's production advantage in good 2 has to be strong enough for the income effect to outweigh the substitution effect.[15] For instance, values of $A_R^2 K_R = 10$, $A_1^2 K_P = 0.2$, $A_R^1 L_R - m_R = 2$, $A_P^1 L_P - m_P = 1$, would ensure that the benefit to the rich country of raising A_P^1 increases with the inferiority of good 1; even if one conservatively assumes $A_R^2 = A_P^2$, and $A_R^1 = 4A_P^1$, these numbers imply that the cross partial is positive if the

[14] This conclusion is robust to our interpretation that the minimum consumption requirements are effectively aggregate magnitudes. A larger population raises the aggregate subsistence consumption levels of good 1; therefore, the increase in p is muted, causing the rich to prefer technology improvement to health improvement for the poor.

[15] The actual condition is

$$\frac{(3-2\theta)\left(A_R^2 K_R\right)^2 + \left(A_P^2 K_P\right)\left(A_R^2 K_R\right)}{\left(A_R^2 K_R\right)^2 + 3\left(A_P^2 K_P\right)\left(A_R^2 K_R\right) + 2\theta\left(A_P^2 K_P\right)^2} > \left(\frac{A_R^1 L_R - m_R}{A_P^1 L_P - m_P}\right)^2.$$

rich-poor capital ratio is 20, and the rich-poor labor force ratio is 0.5, both of which are empirically reasonable.

To summarize, the lessons we learn from this analysis are that the rich country benefits most from an improvement in the poor country's technology for the good: 1) in which the rich country does not have a comparative advantage, 2) which is produced in large quantities in the poor country, 3) whose technological development cannot spill over to other goods, i.e. is directed, and 4) which is inferior.

In the more general case where $\alpha, \beta \in (0,1)$, changes in both the factor allocation and the terms of trade arising from an improvement in the poor country's technology would affect the rich country's GNP, but welfare will continue to be evaluated using equation (2) and its counterpart for V_P. The relative strengths of the income and substitution effects, which in turn would depend on the actual values of these coefficients, would continue to determine the welfare effects of technological change.[16]

In the following section, we introduce our dynamic model. The poor country produces only the inferior good, while the rich country is capable of producing this good as well as a luxury good. As we show below, the rich country will find itself in one of two regimes. If the poor country is not too efficient in producing its good, the rich country produces both goods (the non-specialization regime). Otherwise, the rich country will become fully specialized in the production of the luxury good (the specialization regime).[17] We find this dichotomy useful in illustrating the two effects of an increase in the poor country's technology on the rich country's GNP. In the non-specialization regime, the rich country benefits in the steady state only by reallocating labor toward the good in which it has a comparative advantage, the luxury good; there is no improvement in its terms of trade. In the specialization regime, the rich country benefits in the steady state only by an improvement in the terms of trade; there is obviously no factor reallocation effect. The real world would correspond, of course, to a convex combination of the two scenarios in our model; as we will see, this is especially true when the transition is considered.

[16] Higher A_P^1, for example, will lead the rich country to reallocate capital and labor to sector 2, raising its output in this sector while reducing it in sector 1. In turn, higher output in sector 2 dampens the initial upward impact on the price p of a higher A_P^1. For the poor country, given higher A_P^1 and higher p, at this level of generality the net effect on resource reallocation is not clear. However, given earlier assumptions on labor abundance and labor intensity of good 1 similar results should continue to obtain.

As an aside, in Matsuyama (2000), where there is satiation and a strict ordering of goods in terms of their income elasticities, poor countries redirect resources to industries where they have a comparative disadvantage, which, in our case, would correspond to the poor country raising its output in sector 2 or the rich in sector 1.

[17] Except for the fact the poor country does not produce good 2, the specialized environment is very similar to the $\alpha = 0$, $\beta < 1$ model discussed above.

3 The Dynamic Model

The notation for the regions and the goods as well as the preference specification were introduced in the previous section. We now present a simplified production structure, based on the lessons learned from the previous analysis.

The poor region can produce only the inferior good. Its total production of good 1, Y_P, is given by:

$$Y_P = A_P L_P,$$

where L_P is the total labor force of this country and A_P is a productivity measure.[18]

The rich country produces both goods. Its production of good 1 is given by:

$$Y_R^1 = A_R^1 L_R^1,$$

where $A_R^1 \geqslant A_P$ and the amount of labor used in the production of good 1, $L_R^1 \leqslant L_R$, the total labor force. Production of the luxury good, labeled 2, requires both capital and labor and is given by:

$$Y_R^2 = A_R^2 K_R^\beta \left(L_R - L_R^1\right)^{1-\beta},$$

where $A_R^2 > 0$ is the efficiency parameter characterizing sector 2, L_R is the total labor force, and K_R the stock of physical capital of the rich country.[19] As in the previous section, sector 1 can be thought of as representing agriculture, and sector 2, manufacturing ("non-agricultural" in general). Capital evolves according to $\dot{K}_R = i_R - \delta K_R$, where i_R denotes gross investment by the rich country. The developed region decides how to allocate its labor between the two sectors and how much to invest in physical capital. We make the realistic assumption that the manufacturing good alone is used for accumulating capital.

The poor country's efficiency parameter, A_P, is of fundamental importance for our analysis. Indeed, one of our purposes is to argue that the rich country could benefit from making the poor country more efficient, and describe forces relevant to this outcome. We also wish to compare the benefits from increasing A_P to those associated with increasing A_R^1. Therefore, we will solve for and highlight the dependence of the main variables (prices, quantities, welfare) on A_P and A_R^1 as we proceed.[20]

[18] We have suppressed the superscript, since the poor countries produce only one good. We have assumed that all poor countries can be lumped into a region and the same technology is appropriate for all. Given that a vast majority of the developing countries are in the arid or semi-arid tropics, agricultural and health concerns are likely to be very similar for them.

[19] Our main results should go through when capital is used in both sectors provided the technology for good 1 is less capital intensive than the technology for good 2.

[20] We assume that the parameters of the model satisfy the following inequality:

$$A_P L_P > m_P + \frac{1}{1-2\theta} m_R. \tag{4}$$

If p denotes the relative price of good 2 in units of good 1, as before, the problem of the poor country is:

$$\max_{c_P^1, c_P^2} \int_0^\infty e^{-\rho t} \left[\theta \log\left(c_P^1 - m_P\right) + (1-\theta) \log c_P^2\right] dt,$$

subject to the constraint:

$$c_P^1 + p c_P^2 \leq A_P L_P.$$

Since this country has no dynamic choices to make, the solution to its optimization problem is trivially given by:

$$c_P^1 = \theta Y_P + (1-\theta) m_P \tag{5}$$

$$c_P^2 = (1-\theta) \frac{Y_P - m_P}{p}. \tag{6}$$

The problem of the rich country is:

$$\max_{c_R^1, c_R^2, i_R, L_R^1} \int_0^\infty e^{-\rho t} \left[\theta \ln\left(c_R^1 - m_R\right) + (1-\theta) \ln c_R^2\right] dt,$$

subject to the constraints:

$$c_R^1 + p c_R^2 + p i_R \leqslant A_R^1 L_R^1 + p A_R^2 (K_R)^\beta \left(L_R - L_R^1\right)^{1-\beta} \tag{7}$$

$$\dot{K}_R = i_R - \delta K_R. \tag{8}$$

We form the current value Hamiltonian of this problem, $\mathcal{H}$, and write the the first-order conditions as:

$$\left[c_R^1\right] : \frac{\theta}{c_R^1 - m_R} = \lambda_1 \tag{9}$$

$$\left[c_R^2\right] : \frac{1-\theta}{c_R^2} = p\lambda_1 \tag{10}$$

$$[i_R] : \lambda_1 p = \lambda \tag{11}$$

$$\left[L_R^1\right] : A_R^1 - (1-\beta) p A_R^2 (K_R)^\beta \left(L_R - L_R^1\right)^{-\beta} \leq 0 \ \left(\text{w.e.i } L_R^1 > 0\right) \tag{12}$$

$$\left[\dot{\lambda} - \rho\lambda = -\mathcal{H}_{K_R}\right] : \dot{\lambda} - \rho\lambda = -\left[\lambda_1 \beta p A_R^2 (K_R)^{\beta-1} \left(L_R - L_R^1\right)^{1-\beta} - \lambda\delta\right], \tag{13}$$

as well as the budget constraint and the law of motion for capital. Here λ_1 and λ are the multipliers on the budget constraint and the law of motion, respectively.

Using (9) and (10) in the budget constraint, we get:

$$c_R^1 = \theta\left(Y_R^1 + p\left(Y_R^2 - i_R\right)\right) + (1-\theta) m_R \tag{14}$$

$$c_R^2 = (1-\theta) \frac{\left(Y_R^1 + p\left(Y_R^2 - i_R\right) - m_R\right)}{p}. \tag{15}$$

This assumption guarantees that, if good 1 is only produced by the poor country, the output will be enough to satisfy both countries' aggregate minimal consumption requirements. It also ensures the empirically plausible outcome of the rich country consuming more of good 2 than the poor country.

If condition (12) holds with equality, both goods are produced by the rich country. This equality implies a sectoral capital-to-labor ratio of:

$$\frac{K_R}{L_R - L_R^1} = \left(\frac{1}{(1-\beta)\, p} \frac{A_R^1}{A_R^2} \right)^{1/\beta}. \tag{16}$$

However, if (12) is a strict inequality even when $L_R^1 = 0$, the rich country specializes in good 2 and good 1 is produced only by the poor country. In what follows, we analyze the specialized and non-specialized cases separately.

3.1 Equilibrium

An equilibrium is simply defined as both regions optimizing according to the problems given above, and the following market clearing condition being satisfied:

$$c_P^1 + c_R^1 = Y_P + Y_R^1.$$

Using the first order conditions for consumption in the two regions in the above equilibrium condition, we can get the following alternative equilibrium condition, which we find more useful:[21]

$$\theta p \left(Y_R^2 - i_R\right) = (1-\theta) \left[Y_P + Y_R^1 - (m_P + m_R)\right]. \tag{17}$$

The value of the world consumption of good 2 is equated to the value of total consumption of good 1 in excess of the minimum requirements, up to a factor of the utility weights.

3.2 Steady State: Non-Specialization

We first examine the steady-state outcomes; transition analysis is conducted in Section 5. We highlight the impact of A_P on the rich country's welfare when the cost of improving this technology is negligible; in section 4, we assume a plausible cost function for such improvements to study the net effect on welfare. For notational simplicity, we omit the asterisk notation that is commonly used for steady state quantities; however, it is to be understood that all quantities are evaluated at the steady state.

We analyze the steady state when the rich region produces both goods to substantiate the following claim.

Claim 1 *When A_R^1 is large enough relative to A_P, L_R is not too small relative to L_P, and the minimum consumption requirements are sufficiently large, the rich country produces both goods. An increase in the technology of the poor country, A_P:*

1. *Has no effect on the steady state terms of trade.*

[21] By using the rich region's budget constraint with the market clearing condition for good 1 one can obtain the usual balance of trade condition as an alternate equilibrium condition: $p\left(Y_R^2 - c_R^2 - i_R\right) = Y_P - c_P^1$.

2. *Increases the rich country's capital stock, its production of good 2, its income, and welfare, in the steady state. These effects are magnified by the size of the poor country's labor force and, in the case of welfare, by the degree of inferiority of good 1.*

3. *Increases the output and the welfare of the poor country.*

4. *Is preferred by the rich country to an increase in its own technology for the corresponding good if the labor force in the poor country is large enough.*

(1) Imposing the steady-state conditions $\dot{\lambda} = \dot{K}_R = 0$ and rearranging (13), we get:

$$\frac{K_R}{L_R - L_R^1} = \left(\frac{\beta A_R^2}{\rho + \delta}\right)^{\frac{1}{1-\beta}}. \tag{18}$$

This condition pins down the capital-to-labor ratio in sector 2 in terms of the developed world's technological and preference parameters alone. At the steady state, $i_R = \delta K_R$, as usual.

Combining (18) with (16), we get:

$$p = \frac{A_R^1}{(1-\beta)\left(\frac{\beta}{\rho+\delta}\right)^{\frac{\beta}{1-\beta}} \left(A_R^2\right)^{\frac{1}{1-\beta}}}. \tag{19}$$

In this case, the long-run relative price is determined solely by the parameters of the rich country. The dynamic condition (18) equates the marginal product of capital to the cost of investment thereby pinning down the steady state capital-to-labor ratio in sector 2 purely in terms of the rich country's parameters. The static condition (16) equates the marginal product of labor across the two sectors and pins down the steady state price in terms of the previously derived capital-to-labor ratio. Thus the steady state relative price is unaffected by any change in the technology of the poor country. As we will see later, there will be a relative price effect in *transition* when A_P increases.[22]

(2, 3) Using (18) in the production function for good 2, we can express the total output of good 2 as:

$$Y_R^2 = A_R^2 \left(L_R - L_R^1\right) \left(\frac{\beta A_R^2}{\rho + \delta}\right)^{\frac{\beta}{1-\beta}},$$

which is a decreasing, linear function of L_R^1.

The equilibrium choice of L_R^1 can be shown, from (17) and (19), to be:

$$L_R^1 = aL_R - b\frac{A_P L_P - (m_P + m_R)}{A_R^1}, \tag{20}$$

[22] These implications would obtain even if only good 1 were used as the investment good or if investment were a composite of the two investment goods, such as $i = B\left(i^1\right)^{\gamma}\left(i^2\right)^{1-\gamma}$.

where a and b are positive constants that depend only on model fundamentals.[23] The rich country's employment in sector 1 will depend positively on its labor force, L_R, and on its efficiency in producing this good, A_R^1, and negatively on the productive efficiency of the poor country, A_P, and on its labor force, L_P. Moreover, by calculating $\partial L_R^1 / \partial A_P$, one can see that the negative impact of A_P on the labor force devoted to agriculture in the rich countries is magnified by the size of the poor country's labor force. This is a scale effect of technology which we will see repeatedly; the larger the labor force of the poor region working with the technology, the greater the effect of improving it.[24]

From (18), one can also see that the steady-state capital stock K_R increases with A_P; an increase in the rich country's production of good 2 results. To summarize, we have:

$$\frac{\partial L_R^1}{\partial A_P} < 0; \; \frac{\partial K_R}{\partial A_P} > 0; \; \frac{\partial Y_R^1}{\partial A_P} < 0; \; \frac{\partial Y_R^2}{\partial A_P} > 0$$

and all these derivatives are magnified by L_P. As noted earlier, the relative price of good 2 is independent of A_P: $\partial p / \partial A_P = 0$.

In order to evaluate the impact of changes in A_P on the steady-state welfare of both countries, we define:

$$I_P \equiv Y_P \text{ and } I_R \equiv Y_R^1 + p\left(Y_R^2 - \delta K_R\right),$$

with I_j denoting country j's income net of depreciation, measured in units of good 1. Since the relative price p does not change across steady-states, from equations (5), (6), (14) and (15) we see that the impact of A_P on consumption (and therefore on welfare) is confined to its impact on a particular country's income, I_j.

For the poor country, a positive relationship between I_P and A_P is immediately apparent. However, for the rich country, higher A_P decreases output in sector 1 but increases it in sector 2. Simple algebra shows that:

$$I_R = cA_R^1 L_R + e\left(A_P L_P - (m_P + m_R)\right), \tag{21}$$

where c and e are again positive constants. Therefore, A_P has a positive effect also on the rich country's income net of depreciation. As with L_R^1, the impact of A_P on I_R is magnified by the size of the poor country's labor force.

The improved efficiency of the poor country enables the rich country to redirect its resources to sector 2, where it has a comparative advantage, thereby increasing I_R. Moreover, it is straightforward to show that the world's output of good 1 also increases even when the poor country alone becomes more efficient. When A_P is higher, the steady state "endowment" of both goods in the world is strictly higher; one can thus think of the improved productive efficiency as increasing both sides of an Edgeworth box.

[23] Appendix A.2 presents the complete expressions relevant to this subsection.

[24] It is important to note that the scale effect is preserved when the problem is formulated in terms of per worker utility, since what is relevant is the *ratio* of labor forces, L_p/L_R.

The positive relationship between I_P and A_P, together with the consumption equations (5) and (6), imply that the poor country's consumption of both goods will also vary positively with A_P. Similarly, the result in (21) together with consumption equations (14) and (15), imply that the rich country also consumes more of both goods when A_P is higher. Therefore, in the non-specialization regime, both regions unambiguously benefit from a more efficient sector 1 in the developing world. Below, we present the indirect utility functions of both countries evaluated at the steady-state (ignoring constants):

$$V_P = \frac{\ln(I_P - m_P) - (1-\theta)\ln p}{\rho} = V_P\left(\overset{+}{A_P}\right), \tag{22}$$

$$V_R = \frac{\ln(I_R - m_R) - (1-\theta)\ln p}{\rho} = V_R\left(\overset{+}{A_P}\right). \tag{23}$$

Assuming for the moment $m_R = m_P = m$, it can be shown that $\partial^2 V_R / (\partial A_P \partial m) > 0$; in other words the welfare effect for the rich country of an increase in A_P is magnified by the inferiority of good 1. In the absence of a terms of trade effect, the effect on steady state welfare is driven only by the GNP net of the minimum consumption. The higher this minimum, the greater is the percentage effect of labor reallocation toward the rich country's production of the luxury good. The increase in I_R outweighs the direct negative effect of m on the rich country's welfare.

Though the steady state consumption of both goods increases for the poor country, it increases by a higher percentage for good 2 given that it is a luxury good. The claim often made in policy discourse that improving the condition of the poor countries can only expand the global market for the goods produced by the rich countries is validated in this case.

(4) Next we briefly sketch the implications of an improvement in the rich country's efficiency in its own sector 1 (higher A_R^1). From (20), we see that L_R^1 depends positively on A_R^1. This implies that the rich country's output in sector 1 will increase with A_R^1; output in sector 2 decreases, however, both through the reduction in the labor assigned to it and through a lower stock of capital (see (18)). Summarizing:

$$\frac{\partial L_R^1}{\partial A_R^1} > 0; \ \frac{\partial K_R}{\partial A_R^1} < 0; \ \frac{\partial Y_R^1}{\partial A_R^1} > 0; \ \frac{\partial Y_R^2}{\partial A_R^1} < 0.$$

Since the relative price of good 2 does depend on the rich country's technological parameters, there will also be a terms of trade effect: $\partial p / \partial A_R^1 > 0$. From (21), it follows that the rich country's steady state income, I_R, will increase; the poor country's income, I_P, is unaffected by changes in A_R^1.

What are the welfare effects of a change in A_R^1? Since I_P does not change, but the terms of trade worsen for the poor country, V_P unambiguously decreases: $V_P = V_P\left(\overset{-}{A_R^1}\right)$. The rich country has essentially become more competitive in the poor country's export industry. For the rich country, however, the relationship is ambiguous since I_R and p both increase and have opposite effects on welfare: $V_R = V_R\left(\overset{+/-}{A_R^1}\right)$. In fact, the condition for welfare to improve for the rich is:

$$\frac{\partial V_R}{\partial A_R^1} > 0 \Longleftrightarrow \frac{\theta}{1-\theta} A_R^1 L_R + m_R > \frac{(1-\theta)\beta\rho}{\rho + \delta(1-\beta)} (A_P L_P - m_P). \tag{24}$$

Clearly, if the poor country is a large producer of the necessity, this condition will not be met and the rich country will actually lose from an improvement of A_R^1; such a change will induce a shift of resources toward a sector of comparative disadvantage.[25] An increase in A_R^1 decreases the incentive to accumulate capital, used only in the production of good 2. Steady-state capital and the economy's production of good 2 decreases; this intensifies the increase in p and the increase in income is not sufficient to outweigh the negative effect of price on welfare.[26]

Even if condition (24) is met and the effect on V_R of added efficiency in domestic agriculture is positive, the following condition is sufficient for the rich country to prefer a marginal increase in A_P to one in A_R^1:

$$\frac{L_P}{L_R} > \underbrace{\frac{\rho + \delta(1-\beta)}{\beta\rho(1-\theta)}}_{>1}. \tag{25}$$

This is another manifestation of the non-rival nature of technology; the rich country prefers an improvement in the technology that can be exploited by the larger force. And as mentioned earlier, it is the *ratio* of labor forces that matters; the scale effect is not an artifact of formulating the problem in aggregate rather than per capita terms.

When does the non-specialization regime obtain? Use (20), to derive a condition for the non-specialized steady state:

$$\left(\frac{\theta}{1-\theta}\right)\left(\frac{\rho + \delta(1-\beta)}{(\rho+\delta)(1-\beta)}\right) A_R^1 L_R > A_P L_P - (m_P + m_R). \tag{26}$$

This assumption is likely to be satisfied when: A_R^1 is large enough relative to A_P, L_R is not too small relative to L_P, the ms are sufficiently large, θ is large enough to make the world consumption needs of good 1 large, and β is high enough to make capital, rather than labor, more important for the production of good 2. In particular, the presence of the ms makes it more likely for the previous condition to be satisfied.

In the next section, we characterize the equilibrium of this two-country world when A_P is large enough so that the non-specialization condition (26) fails to hold, and the rich country specializes in the production of good 2.

---

[25] This is reminiscent of the result in Matsuyama (2000), where the poor may be made worse off by a productivity improvement.

[26] In the static model, the absence of the effect on capital accumulation meant that an increase in A_R^1 always increases the welfare of the rich region, though possibly not as much as the one caused by an increase in A_P. In this sense, dynamic capital accumulation considerations make the possibility of the rich country improving an *in*appropriate technology more likely.

3.3 Steady State: Specialization

We make the following claim about the specialization steady state.

Claim 2 *When (26) fails to hold, the rich country specializes in good 2. An increase in the technology of the poor country,* A_P *:*

1. *Leaves the rich country's steady state capital stock and its production of good 2 unchanged. However, its steady state terms of trade improves and increases its income. The improvement in terms of trade is magnified by the inferiority of good 1.*

2. *Increases the output and the welfare of the poor country if its output is large relative to the minimum consumption levels.*

3. *Increases the steady state welfare of the rich country; this welfare effect is magnified by the degree of inferiority of good 1.*

(1) Since $L_R^1 = 0$, (18) reduces to:

$$K_R = L_R \left(\frac{\beta A_R^2}{\rho + \delta} \right)^{\frac{1}{1-\beta}}. \tag{27}$$

The steady-state capital stock does not depend on A_P. If the rich region is specialized for a given A_P, we can see from (26) that it will continue to be specialized for higher A_Ps; therefore, increases in A_P do not affect output in the rich region. Total output of good 2 net of depreciation (δK_R) in the steady state is also independent of the poor country's technology.

Let $\bar{Y}_R$ denote the rich country's total output of good 2, net of depreciation, at the steady-state. Then:

$$\bar{Y}_R \equiv Y_R^2 - \delta K_R = \left(A_R^2\right)^{\frac{1}{1-\beta}} L_R \left(\frac{\beta}{\rho + \delta} \right)^{\frac{\beta}{1-\beta}} \left(1 - \delta \frac{\beta}{\rho + \delta} \right).$$

The *value* of this output in terms of good 1 can, however, change with A_P. Define $I_R \equiv Y_R^1 + p\left(\bar{Y}_R\right) = p\bar{Y}_R$, since $Y_R^1 = 0$. If the relative price p depends on A_P, so will the value of the rich country's net output.

With specialization, the trade-balance condition simplifies to: $c_R^1 = pc_P^2$. With (6) and (14), this implies:

$$p = \frac{1-\theta}{\theta} \frac{A_P L_P - m_P - m_R}{\bar{Y}_R}. \tag{28}$$

Unlike the non-specialization case, the steady state price now depends (positively) on A_P. An increase in world output of good 1, with no increase in good 2, increases the relative price p.

It can be seen that the elasticity with respect to A_P of the terms of trade for the rich country is:

$$\frac{d \ln p}{d \ln A_P} = \frac{A_P L_P}{A_P L_P - m_P - m_R}. \tag{29}$$

This elasticity increases with the minimum consumption levels. The minimum consumption level thus provides an amplification of incentives for the rich region to improve the technology of the poor region; the higher the relative superiority of good 2, the stronger the terms of trade effect for the rich country.

(2) Inspection of (5) shows that the poor country's consumption of good 1 depends positively on A_P. We combine the price under specialization, equation (28), and (6) to get:

$$c_P^2 = \theta \frac{A_P L_P - m_P}{A_P L_P - m_P - m_R} \bar{Y}_R.$$

Therefore, c_P^2 is a decreasing function of A_P under specialization. Since p increases with A_P, equations (14) and (15) unambiguously show that both c_R^1 and c_R^2 increase with A_P.

Steady-state utilities can be read from equations (22) and (23). Below, we specialize those equations taking advantage of the specific formulas for the price and output associated with the specialization regime. The poor country's steady-state indirect utility function is (excluding constants):

$$V_P(A_P) = \frac{1}{\rho}\left[\ln(I_P - m_P) - (1-\theta)\ln(I_P - m_P - m_R) + (1-\theta)\ln \bar{Y}_R\right]. \tag{30}$$

It can be seen that, if $A_P L_P > m_P + m_R/\theta$, then $\partial V_P/\partial A_P > 0$; this ensures that the income effect for the poor country due to an increase in A_P is stronger than the price effect.[27] If this condition does not hold, a donation of technology can be "immiserizing" for the poor country.[28]

(3) The rich country's welfare is:

$$V_R(A_P) = \frac{1}{\rho}\left[(1-\theta)\ln \bar{Y}_R + \ln\left[(1-\theta)(I_P - m_P) - m_R\right] - (1-\theta)\ln(I_P - m_P - m_R)\right]. \tag{31}$$

For the rich country, it is always the case that $\partial V_R/\partial A_P \geq 0$ and the inequality is strict whenever $m_R > 0$; the welfare effect can never be negative for the developed world.[29]

In (31), I_P is the only determinant of V_R that changes with A_P. When we set $m_R = m_P = m$, we can show $\partial^2 V_R/(\partial I_P \partial m) > 0$; therefore, the welfare effect of an increase in A_P is magnified by the inferiority of good 1 here also. Unlike the non-specialized case, the entire effect is due to a more favorable terms of trade for the rich country; and as seen in (29), the elasticity of the relative price of good 2 with respect to A_P increases with m. This elasticity decreases with L_P which again points to the disincentive the rich country might have in raising the poor country's life expectancy.

---

[27] If $\theta > 1/3$, assumption (4) will automatically imply this condition.

[28] Also see Matsuyama (2000) in this regard.

[29] We also note that the relative price of good 2 is continuous across the specialization and non-specialization regimes, as are the steady-state utility functions, V_P and V_R. However, there is a discontinuity in the derivatives of V_R and V_P with respect to A_P at the critical value of A_P that triggers specialization.

Even though the consumption of good 2 by the poor country, c_P^2, decreases with A_P, its *value*, pc_P^2, increases; the percentage increase of expenditure on good 2 is still higher than on good 1. Therefore, the global market for the good produced by the rich countries increases here too, in value if not in actual units of goods.

Since the rich country does not produce good 1, we do not compare the welfare effects of marginal improvements in A_P and A_R^1.

4 Welfare Experiments with Costly Improvements

In this section, we complement the previous analysis by incorporating the cost of improving A_P. This allows us to compare the optimal investment each country would make in technology improvements to the efficient outcome as given by the solution to a planner's problem. Given our assumption that the poor cannot credibly commit to make payments for R&D, the comparison between the rich country's selfish investment with the efficient outcome is of special interest.

This analysis will allow us to answer questions of the following nature:

1. Suppose, an invention (idea) for improving A_P arrives exogenously – for example, an academic paper on a high-yield seed variety suitable to the tropics, or one on a new possibility for treating malaria. Given costly adoption, how much is each country willing to invest in the invention and create a usable technology out of it – that is, develop a seed or a malarial drug based on the idea?

2. Suppose an idea for improving *both* A_P and A_R^1 arrive exogenously. Given costly adoption, are there any conditions under which the rich country chooses to invest in A_P instead of A_R^1? In other words, are the earlier conclusions about the rich country's preference for improving inappropriate technology robust to the inclusion of costs?

4.1 The Planner's Problem

Suppose γ and $(1-\gamma)$ are the Pareto weights the planner places on the poor and rich countries, respectively. Given the technology and factor endowments of the two countries, the planner solves:

$$\max_{\{c_i^j\}_{i,j=1}^2, L_R^1, i_R} \int_0^\infty e^{-\rho t} \left\{\gamma \left[\theta \ln\left(c_P^1 - m_P\right) + (1-\theta)\ln\left(c_P^2\right)\right] + (1-\gamma)\left[\theta \ln\left(c_R^1 - m_R\right) + (1-\theta)\ln\left(c_R^2\right)\right]\right\} dt,$$

subject to the following constraints:

$$c_P^1 + c_R^1 \leq A_P L_P + A_R^1 L_R^1 \quad (32)$$
$$c_P^2 + c_R^2 + i_R \leq A_R^2 \left(L_R - L_R^1\right)^{1-\beta} K_R^\beta \quad (33)$$
$$\dot{K}_R = i_R - \delta K_R.$$

Since there are no production externalities in this economy, the planner's optimal choice of L_R^1 and i_R coincides with the solution to the decentralized problems in sections 3.2 and 3.3. We define Y^j as the as the worldwide output in sector j, net of depreciation where relevant:

$$Y^1 \equiv Y_P + Y_R^1,\ Y^2 \equiv Y_R^2 - \delta K_R.$$

The allocation of output across countries is given by:

$$\begin{array}{ll} c_P^1 - m_P = \gamma\left(Y^1 - (m_P + m_R)\right) & c_P^2 = \gamma Y^2 \\ c_R^1 - m_R = (1-\gamma)\left(Y^1 - (m_P + m_R)\right) & c_R^2 = (1-\gamma) Y^2 \end{array}$$

and the utility function of the world planner evaluated at the steady-state, V_W, excluding constants, is

$$V_W \equiv \frac{1}{\rho}\left[\theta \ln\left(Y^1 - (m_P + m_R)\right) + (1-\theta)\ln\left(Y^2\right)\right].$$

In order to improve the technology from A_P to A_P', a country has to expend resources. We assume that this cost, incurred in terms of good 2 (the manufacturing good), is given by the following convex specification:

$$c(A_P, A_P') = \begin{cases} \frac{1}{2}\left(A_P' - A_P\right)^2, \text{ if } A_P' \geqslant A_P \\ 0, \text{ if } A_P' < A_P. \end{cases} . \tag{34}$$

In this section, the analysis is confined to steady-state comparisons (see section 5 for analysis of transitions). Steady-state expressions for income and factor allocations are used to evaluate benefits from improvements. To make the cost compatible with this interpretation, we assume that the investment cost is borne in the steady-state in the form of a perpetual payment, $rc\left(A_P, A_P'\right)$, where r is the interest rate.[30]

In order to compute the planner's optimal choice of investment, we must therefore subtract $rc\left(A_P, A_P'\right)$ from the right-hand side of (33)[31]. The planner's first-order condition for investment in A_P is:

$$\frac{\lambda_1^W}{\lambda_2^W}\left[\frac{\partial Y_P}{\partial A_P} + \frac{\partial Y_R^1}{\partial A_P}\right] + \frac{\partial Y_R^2}{\partial A_P} = r\frac{\partial c\left(A_P', A_P\right)}{\partial A_P}, \tag{35}$$

[30] This assumption might seem contradictory given that the economies have been set up originally as closed economies. In the appendix section A.4, we show that even if the interest rate is determined endogenously by the developed world's behavior, an empirically plausible supposition, the results are qualitatively similar.

[31] We ignore the implications that the explicit introduction of costly investment have on the equilibrium quantities derived in sections 3.2 and 3.3. For example, total output of the rich country under non-specialization, $I_R\left(A_p\right)$, would now depend on its expenditure on technology improvement. Since this does not alter the qualitative results below, and the magnitude of this cost is likely to be very small relative to the size of the rich country's GNP, we choose to not consider this explicitly; in other words, we do not derive a new set of equilibrium conditions.

We also find it analytically convenient to consider welfare changes when the technological change leaves the regime for the rich country – non-specialized or specialized – unchanged. We postpone the discussion of a switch in regime to the sections on dynamics and the numerical simulation.

where λ_1^W and λ_2^W represent the Lagrange multipliers associated with constraints (32) and (33), respectively.

Before analyzing equation (35), it is useful to derive the optimal investment rule when countries act on their own accord. We again consider the specialization and non-specialization cases separately.

4.2 Individual Investment Under Non-Specialization

We prove the following claim in this subsection:

Claim 3 *In the non-specialized regime:*

1. *If the same cost function for improving technologies applies to both countries, the poor country will invest more in improving its own technology than the rich country. A social planner would invest more in improving the poor country's technology than either country would.*

2. *If the labor force of the poor country is large enough, the rich country would prefer to improve the poor country's technology rather than its own; that is, it would prefer an investment in the* ***in****appropriate rather than the appropriate technology.*

(1) As we did in the planner's problem, we subtract the cost $rc\,(A_P, A_P')$ from the resource constraint of each country. For example, for the rich country we modify (7) to read:

$$c_R^1 + p\left(c_R^2 + i_R + rc\left(A_P', A_P\right)\right) \leq A_R^1 L_R^1 + pA_R^2\left(L_R - L_R^1\right)^{1-\beta} K_R^\beta = I_R\left(A_P'\right).$$

Recall that an increase in A_P increases the rich country's income, I_R, but has no effect on the terms of trade, p. Therefore, the optimal investment condition will equate the marginal increment in income to the marginal cost of research:

$$\frac{1}{p}\frac{\partial I_R}{\partial A_P} = \frac{1}{p}\frac{\partial Y_R^1}{\partial A_P} + \frac{\partial Y_R^2}{\partial A_P} = r\frac{\partial c\left(A_P', A_P\right)}{\partial A_P}. \tag{36}$$

Since I_R is strictly increasing in A_P and the marginal cost of zero investment is zero, it follows from the above first-order condition that the rich country will always undertake positive investment in A_P.

A similar investment rule emerges for the poor country:

$$\frac{1}{p}\frac{\partial I_P}{\partial A_P} = \frac{1}{p}\frac{\partial Y_P}{\partial A_P} = r\frac{\partial c\left(A_P', A_P\right)}{\partial A_P}. \tag{37}$$

Therefore, *if* the poor country could afford to pay the research cost $rc\,(A_P', A_P)$, it would also undertake strictly positive investment in A_P.

One can evaluate the marginal benefits in (36) and (37) and show that under the plausible conditions of $\delta > \rho$ and $\beta < 2/3$, the poor would invest a greater amount than the rich;

the effect on the income of the poor is more direct, through improved technology, while the effect on the rich is indirect, through labor reallocation.

Next, we compare the optimal investment choices of individual countries with that of the planner, given by (35). It is easy to show that the ratio λ_1^W/λ_2^W coincides with the inverse of the terms of trade $1/p$ obtained in the decentralized environment. Comparing (35) with (36) and (37), we see that the benefit from technology improvement, as seen by the planner, corresponds to the *sum* of the benefits perceived by the individual countries. Consequently, the efficient investment in technology improvement exceeds the investment undertaken by either country acting on its own.

The efficient investment characterized in (35) would result in a decentralized setting if markets exist for the rich country to sell or license technology improvements in A_P to the poor; such markets have been assumed away in our setup. The rich country would then evaluate the impact of R&D in inappropriate technology on the direct increase in the poor country's output in addition to the indirect effect on its own output. Since the rich country imports good 1 from the poor country, its representative agent views the benefits from the poor country's productivity improvement as if it were an improvement in his domestic productivity.

(2) Finally, we address the possibility of appropriate as opposed to inappropriate technology investment by the rich country. If the rich country could improve its own domestic agricultural sector, say by incurring the same quadratic cost function as above, could it be the case that it would still prefer to improve A_P rather than A_R^1? In the appendix (Section A.3), we show that this is indeed possible if L_P is sufficiently large. This should not come as a surprise given our result in Section 3.2 that higher A_R^1 may even be detrimental to the rich. Even if this does not happen, recall that the rich country's incentive to invest in the poor country's technology, A_P, is amplified by the size of its labor force, L_P. The endogenous response of technology improvement to the poor country's labor force (the scale effect) makes it more likely that the rich country would choose to improve the poor country's technology rather than its own, provided this labor force is large enough.

The rich country's preference for improving inappropriate technology at the expense of appropriate technology is therefore robust to the inclusion of costs of improvement.

4.3 Individual Investment under Specialization

In this subsection, we substantiate the following claim:

Claim 4 *In the specialized regime:*

- *If the same cost function for improving technologies applies to both countries, the rich country will invest more in improving the poor country's technology than the poor country would do on its own (provided θ is small enough). A social planner would invest* *more than what the poor country would, and when θ is small enough, less than what the rich country would.*

Under specialization, the benefits to the rich come from the terms of trade effect, only. Simple algebra shows that the first-order condition is now:

$$\frac{\partial p}{\partial A_P} c_P^2 = pr \frac{\partial c\left(A_P', A_P\right)}{\partial A_P}.$$

In words, the net benefit for the rich is the added revenue from exports that the improved terms of trade induce.

For the poor, optimal investment is given by:

$$\frac{\partial Y_P}{\partial A_P} - \frac{\partial p}{\partial A_P}\left(c_P^2 + rc\left(A_P', A_P\right)\right) = pr \frac{\partial c\left(A_P', A_P\right)}{\partial A_P}.$$

The (marginal) positive impact of enhanced efficiency on output net of the added cost of imports (in the form of consumption and technology investment) is equated to the marginal cost. The inequality $\theta < 0.5$ is sufficient to ensure that the investment by the rich exceeds that of the poor.[32]

Under non-specialization, the steady state relative price, p, depends only on the rich region's parameters. In the centralized version, the corresponding multipliers λ_1^W and λ_2^W are pinned down by the allocation of L_R between the two sectors, and do not interact with the planner's preference parameter, γ, which determines the fraction of the world's output that the planner allocates to each country. However, in the decentralized environment under specialization, the trade balance condition determines p as a function of the ratio of the output of the rich relative to that of the poor. The terms of trade in turn govern decentralized consumption. Therefore, in the centralized version, the above-mentioned multipliers depend on γ. In order to make the decentralized and planning investment decisions comparable under specialization, we assume γ is such that the planner's allocation of consumption replicates those in the decentralized environment. Consequently, as in the case of non-specialization, $\lambda_1^W / \lambda_2^W = 1/p$.

The efficient investment is characterized by equation (35), as before; however, recall that higher A_P affects neither Y_R^1 nor Y_R^2. Therefore, this equation simplifies to:

$$\frac{\partial Y_P}{\partial A_P} = \frac{\lambda_2^W}{\lambda_1^W} r \frac{\partial c\left(A_P', A_P\right)}{\partial A_P}. \tag{38}$$

The planner's preference weights are fixed in our formulation. Unlike the poor country, the planner is not concerned with redistributive effects of a change in p. Therefore, a comparison of (38) and the poor country's condition, indicates that the planner would invest more.

[32] The exact condition is $\frac{1-\theta}{\theta} \frac{I_P - m_P}{I_P - m_P - \frac{m_R}{\theta}} > 1$.

The marginal benefit of investing in improvements in A_P for the rich can be shown to be:

$$\frac{\partial p}{\partial A_P} c_P^2 = (1-\theta) \frac{Y_P - m_P}{Y_P - m_P - m_R} L_P,$$

whereas the marginal investment from the planner's point of view is simply $\frac{\partial Y_P}{\partial A_P} = L_P$. Therefore, for small enough θ (that is, the weight on the luxury good in the utility function is high enough) or large enough m_R, the rich country will invest more than the planner. Unlike the planner, the rich country is concerned mainly with the change in its terms of trade, which is high when θ is low and m_R is high.

5 Dynamics

The steady state comparison of the two regimes reveals stark contrasts; in the non-specialization regime, it is the poor country that wants more technology improvement and in the specialized regime it is the rich country that desires greater improvement. As we saw, this is driven by a pure factor reallocation effect in the non-specialized regime and a pure terms of trade effect in the specialized regime. Is the contrast as stark when the transition to the new steady state is included? Are there transitional forces that counteract those seen in steady state comparisons? To answer these questions, to get an insight into the mechanics of the model, and to set the stage for a more realistic quantitative assessment, we study the transitional dynamics in this section.

5.1 Non-specialization

We start by deriving the differential equations that characterize the dynamics in the regime where the rich country does not specialize. We seek these equations in the capital stock K_R, a state variable, and $L_R^2 \equiv L_R - L_R^1$, a jumping variable; this choice of the dynamic system variables happens to be convenient. Note that we can back out the price p in terms of these two dynamic system variables as:

$$p = \frac{A_R^1}{(1-\beta) A_R^2} \left(\frac{L_R^2}{K_R} \right)^{\beta}. \tag{39}$$

In particular, note that, for a given K_R, p increases with L_R^2, which will happen at the instant A_P is increased. Indeed, all other variables can be backed out from these two system variables.

In Appendix A.5, we derive and present the differential equations for K_R and L_R^2; these equations characterize the dynamics and are used to derive the steady state. In Appendix A.6, we use phase diagrams to argue that the transition paths for the labor allocation to good 1, the relative price, and the capital stock are as shown in Figure 1, and prove the following claim:

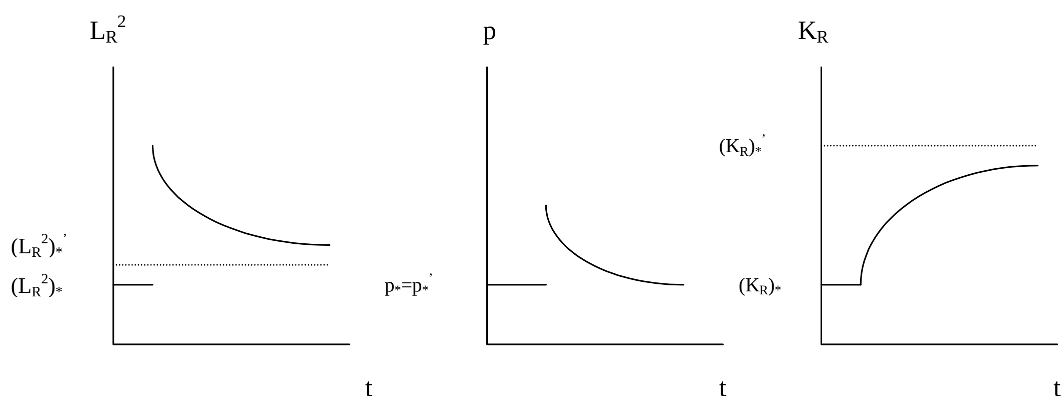
Claim 5 *A sudden increase in A_P, which still obeys the non-specialization condition causes:*

- *The relative price, p, and the labor devoted by the rich country to good 2, L_R^2, to jump to higher levels at the moment of the increase in A_P.*
- *Over transition, this price steadily decreases to the old steady state value; the labor allocated to good 2 decreases to its new, higher steady state value.*
- *Capital increases monotonically from its old steady state value to its new, higher steady state value.*

In the very short run, K_R is fixed; any increase in rich-country labor allocated toward good 2 is not enough to counteract the increase in the poor-country supply of good 1 due to the increase in A_P. The output of good 1 increases relative to that of good 2, and the relative price, p, jumps.[33] But K_R, and thus the supply of good 2, increase over time, which brings the price back to its previous level. Therefore, when the transition to the new steady state is included, there is a terms of trade effect as seen in the steady state consideration of the specialization regime; it is in this sense that the inclusion of dynamics makes the dichotomy between the non-specialized and specialized steady states less stark.

Figure 1

Dynamics without specialization: Transition paths after an increase in A_P



5.2 Specialization

We can no longer use the L_R^2 variable in the specialized regime for obvious reasons; we instead use K_R and p as our dynamic system variables. In the specialized regime, the only first-order condition that does not apply is the $\left[L_R^1\right]$ one; every other condition holds with

[33] The initial jump in L_R^2 could be high enough to cause the rich region to temporarily specialize in good 2.

$L_R^1 = 0$. We derive the differential equations that characterize the dynamic system, and the steady state that follows, in Appendix A.7.

When the rich country is specialized initially, any increase in A_P will only reinforce specialization; see (26). There will be no change in the rich country's steady state capital; the steady state price will increase due to an increase in the production of good 1. The adjustment is instantaneous; therefore, dynamic considerations do not alter the steady state comparisons made earlier.

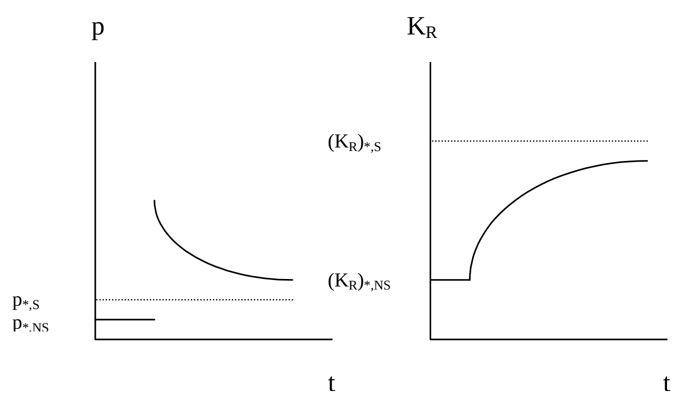
When the rich country is non-specialized initially, the dynamics are more interesting. In Appendix A.8, we provide phase diagrams for both these cases and show that the transition paths for the relative price and capital stock when the rich region is initially non-specialized are as shown in Figure 2, and prove the following claim.

Claim 6 *A sudden increase in A_P:*

- *When the rich country is already in a specialized regime causes the price, p, to increase immediately to its new steady state value. There is no change in the steady state stock of capital.*
- *When the rich country is initially non-specialized, and the increase causes it to become specialized, the stock of capital increases toward its new steady state value monotonically. The price overshoots its final steady state value at the moment of the increase in A_P, and decreases over time to it.*

Figure 2

Dynamics with specialization: After an increase in A_P; non-spl.→spl.



As in the case without specialization, an increase in A_P causes the output of good 1 to increase relative to that of good 2; given the initially fixed nature of the capital stock, p

increases. As the capital stock increases, thereby increasing the output of good 2, this price decreases over time.

In summary, when the transition is included, there is always a terms of trade effect in favor of the rich country.

6 Quantifying the Effects

In this section, we examine the historical episode of the Green Revolution in light of our model. The Green Revolution closely resembles the experiments we describe in Section 4; rich countries undertook research to improve agricultural technology specific to poor countries. We view this as a positive change in the technological coefficient, A_P, of the developing world. We now attempt to quantify the effects of this episode by choosing empirically plausible values for the parameters of our model and simulating it numerically. This allows us to assess the welfare benefits of the Green Revolution including transition. We ignore the costs of technology improvements for this exercise, which, as mentioned in the introduction, are not very high.[34]

We choose $\rho = 0.07$, $\delta = 0.09$, and $\beta = 0.35$ (capital share in rich countries), values typically used in calibrating dynamic models. We set $m_P = m_R = 0.55$, which yield minimum consumption values that are $80 - 85\%$ of the poor region's consumption of good 1.[35] We start by setting $\theta = 0.1$, and later study the dependence of the results on θ.[36] We normalize $L_P = 1$. Based on the ratio of the population in high income countries to that in the rest of the world in 1980, we set $L_R = 0.217$. We normalize $A_P = 1$. Evenson and Gollin (2001) report that rice yields increased by a factor of 2 between 1961 and 2000; gains in other crops

[34] In Fernandes and Kumar (2003), we also attempt to quantify the effects of the Green Revolution by direct recourse to historical data and counterfactual simulations (provided in Evenson and Rosegrant (2001)).

[35] Our choice of m was motivated by the following analysis. Under the interpretation that the minimum consumption requirements are subsistence levels, we first used the \$1 a day standard of the 1990 *World Development Report* of the World Bank (measured in 1985 international PPP prices). This would imply a yearly amount of \$365 for subsistence alone, a number which the data suggested was significantly above the annual per capita consumption of the developing countries. (Our data comes from the United Nations Development Program, the Statistical Annex to the 2000 *Human Development Report.*) As a consequence, we set m to 80% of the per capita food consumption of the poor in the years before the Green Revolution took place. Results, however, are not sensitive to the choice of m. For more retails, see Fernandes and Kumar (2003).

[36] We impute per capita food consumption at the onset of the Green Revolution as the product of the share of food consumption (as a fraction of total household consumption) times per capita disposable income (net of saving). Once we know the value of c_P^1, and given the value of m already established, we use the formula $c_P^1 = \theta I_P + (1 - \theta) m_P$ from our model to solve for the preference parameter θ. The number $\theta = 0.1$ is the simple average between the two magnitudes of θ we obtained for the rich and poor countries, of 0.12 and 0.09, respectively. Again, see Fernandes and Kumar (2003) for further details.

were not as spectacular. We therefore consider a wide range of values for $A_P^{'}$, the post-Green Revolution technology index: 1.3, 1.5, and 2.0. Finally, we set $A_R^1 = A_R^2 = 8.3A_P$ to correspond to the productivity differences between the richest and poorest countries reported by Hall and Jones (1999; p. 92) for the year 1985.

In a stylized model such as ours, it will not be possible to quantitatively account for the tariff schedules adopted by different countries. Moreover if poor countries experience economic growth for reasons beyond an increase in A_P, they could end up as net importers of food; their demand for food can outstrip domestic supply. Trying to match trade flow data would run into difficulties, as there would be a confounding of increases in tariffs and unmodeled increases in economic growth with productivity gains arising from the Green Revolution; this is the primary reason we make contact with the terms of trade data in this section rather than with trade flow data directly. We briefly consider tariffs in the next section.

The rich region is non-specialized before the transfer of technology to the poor region. The pre-Green Revolution steady state equilibrium quantities are:

$$(K_R)_* = 15.57; \ \left(L_R^2\right)_* = 0.18; \ (p)_* = 0.32.$$

In Table 3 we present the post-Green Revolution outcomes under the above-mentioned assumptions on the final productivity index, $A_P^{'}$; outcomes under the new level of technology are denoted by primes.[37]

Table 3 – Simulation Outcomes

				Gain: poor		**Gain: rich**	
Experiment	$(K_R)_*^{'}$	$\left(L_R^2\right)_*^{'}$	$(p)_*^{'}$	SS	$Tran.$	SS	$Tran.$
$A_P^{'} = 1.3A_P$ **(nspl→nspl)**	**18.32**	**0.212**	**0.323**	**32.2%**	**31.0%**	**9.7%**	**7.2%**
$A_P^{'} = 1.5A_P$ **(nspl→spl)**	**18.75**	**0.217**	**0.523**	**16.6%**	**14.2%**	**17.4%**	**13.9%**
$A_P^{'} = 2.0A_P$ **(nspl→spl)**	**18.75**	**0.217**	**1.177**	**0.29%**	**-1.46%**	**35.2%**	**30.9%**

In the first case, the new level of technology in the poor region is not high enough to cause the rich one to specialize. As seen in Section 3, the steady state capital of the rich country, as well the labor it devotes to the production of good 2, increase in response to an increase in A_P, both by 17.7%. The steady state price does not change; as mentioned earlier, the long run capital-labor ratio and thus the price are pinned down completely by the rich country's parameters. However, the transition price is higher than the steady state price overshooting by about 5% at the time of the transfer. The welfare gain is shown as an equivalent variation in baseline income, considering only steady states, as well as including the transition, which is nearly complete in 35 years. When the transition is included, the

[37] The differential equations for the dynamic system were computed using MATLAB's *ode23* routine; the program is available from the authors.

benefit to the poor country (31%) outstrips the benefit to the rich (7.2%); the rich country's gain is, however, not trivial. If welfare across steady states alone were compared, both countries would achieve even higher welfare gains. For the poor country, the increase in the price of its import good during transition tempers welfare gains. For the rich country, the initial increase in investment reduces consumption and tempers welfare gains.

In the second and third cases, the increase in A_P is high enough to cause the rich country to specialize. The increase in resources devoted to the production of good 2 is more pronounced.[38] The steady state price is no longer pinned down by the capital-labor ratio of the rich country and increases, by about 62% in the second case, and by more than 250% in the third case. Alternately, the relative price of good 1 ("food") drops by 38% in the second case, and 72% in the third; the decrease of 50% in food prices reported in the sources cited in the introduction is in between these two figures. As A_P' increases, the welfare gain increases for the rich region and decreases for the poor region. For instance, when $A_P' = 1.5A_P$, the benefit to both countries is about the same. When $A_P' = 2.0A_P$, the benefit to the rich country is more than 30% of baseline income; the poor country's welfare actually decreases once the transition is included. These figures are consistent with the earlier theoretical results – the large increases in the rich country's terms of trade when it is specialized, benefit the rich country more than the poor country.

The choice of θ, the parameter that weights food in the utility function, could be open to debate. Therefore, we examine the effect on welfare when θ is increased for the intermediate case of $A_P' = 1.5A_P$. Welfare increases, but only for the poor country – it increases from 14.2% when $\theta = 0.1$ to 48% when $\theta = 0.3$; for the rich country, it drops from 13.9% to 0.4%.[39]

---

[38] Note that there there is an increase in the capital stock of country 2 because we are moving to the specialized regime from a non-specialized regime.

[39] In the direct computation presented in Fernandes and Kumar (2003), the welfare gains from the Green Revolution correspond to a 10% equivalent variation in the vase year income. This increases monotonically with θ and reaches 40% for the case $\theta = 0.3$. The results are similar across rich and poor countries. These figures, though not trivial, might seem small (especially considering the close to 160% increase in income for the poor and 125% increase in income for the rich seen in this forty-year period). However, they appear sizeable when one realizes that we have attempted to isolate one single event from the many forces governing income growth over the last forty years. Moreover, as the quote from Evenson and Gollin (2001) in the introduction eloquently asserts, millions of people who are alive today owe their lives to the Green Revolution, an effect that cannot be captured by the per capita analysis we have been constrained to do.

The possibility of isolating changes, which the simulation analysis enables, could explain the larger welfare gains, as well as the interesting differences between the gains of the rich and the poor discussed above.

7 A Discussion on Tariffs

As mentioned in the introduction, our focus differs considerably from that of the tariff literature. Under reasonable parametrization, technology improvements can benefit the rich *and* the poor countries; on the other hand, even if benefits accrue to the rich country when tariffs are levied, they necessarily hurt the poor country. Even these benefits seem more of a theoretical possibility, as in reality retaliatory tariffs follow. Our representative agent setup is also not suited to study the political and distributional issues that often accompany discussions on tariffs. In spite of these reservations, we provide a brief discussion of tariffs in this section. Our aim is to illustrate how the levying of tariffs might interact with technology improvements as well as to study the robustness of the welfare estimates presented in the previous section to the addition of tariffs. In fact, protectionist policies were prevalent in the OECD countries even as the productivity of agriculture in poor countries was on the rise. These could have negated some of the welfare gains.

We assume that the government of the rich region levies a tariff of rate τ on good 1, its import good. The price of this good in the rich country is now $(1+\tau)$. The results crucially depend on what is done with the collected tariffs; we assume that the government repatriates all revenues in a lumpsum fashion to the consumer, as suggested by Dixit and Norman (1980, p. 153).[40].

The rich country's welfare increases with the tariff rate when it is non-specialized and decreases when it is specialized. When there is no specialization, the increase in surplus to producers of good 2 and in the revenues collected increase welfare. The poor will lose due to an increase in p. In fact, the model is not well posed to answer the question of optimal tariffs for the rich country. The optimum in the usual case is governed by the inverse of the foreign country's supply elasticity; since the foreign (poor) country's supply is inelastic here by assumption, welfare always increases. The analysis, however, does point to the intriguing possibility that the rich country can use an increase in (A_P) or an increase in tariffs (τ) as alternate instruments to increase its own welfare. Only the technology improvement will benefit both countries; the poor lose with tariffs. Motives of altruism and self-interest can be reconciled if the rich country chooses technology improvement over tariffs.[41] When the rich country is specialized, an increase in tariffs decreases p; the poor country exports less of its good 1, and can afford to import less of good 2 from the rich country. The absence of a producer surplus from the increased price of good 1 and a loss of it in good 2, combined with a loss of consumer surplus decrease the welfare for the rich. The poor actually gain due to the decrease in p.

[40] Fernandes and Kumar (2003) also consider the case in which the government purchases both goods in the same ratio as the consumers do and uses it for purposes that do not affect utility.

[41] The study of these issues in a model amenable to the analysis of optimal tariffs is left for future research.

The harm caused to the developing countries by the agricultural protectionism of the developed countries has received considerable attention in the literature.[42] But from the quantitative point of view of our model, did the protectionist policy followed by the developed countries undercut the welfare gains reported in the previous section? Cohen and Sisler (1971) analyze imports by Europe, Japan, UK, and the USSR from the LDCs and find that they grew in the 60s; imports of rice from LDCs, a crop particularly relevant to the Green Revolution, grew at a healthy 7.2% a year. They conclude that the world demand for the products exported by developing nations had been much stronger than predicted. Evidently, protectionism did not completely choke off imports from the LDCs so as to overturn the predictions of our model.

For reasons mentioned in the previous section, we do not calibrate the model to world tariffs; we instead ask the question, "How high do tariff rates have to be before the steady-state welfare gains realized from an increase in A_P are negated?" We assume a 50% increase in A_P, an intermediate value considered in the simulations; recall that the rich country goes from being non-specialized to specialized in this case. The parameter values are the same as those used earlier. A 25% tariff rate is enough to negate the gains for the rich.[43] The tariff rates, levied on rice, for instance, have varied widely across developed countries, with low rates in the US and high rates in Japan. Nevertheless, it is clear that the rich countries would realize greater gains from an increase in A_P if they do not levy tariffs on the crops whose productivity they increase.

8 Conclusion

In this paper we have demonstrated, under various assumptions, that rich countries have an economic incentive to improve the technology specific to poor countries. While altruistic and humanitarian considerations have cornered most public attention, we show there are also economic reasons for the rich countries to become involved in solving problems particular to developing countries. The estimated effects on welfare for the Green Revolution, a classic case of such an "intervention," while not huge, are nevertheless positive. With the various changes both rich and poor countries have undergone in the last forty years, isolating one episode in a macro context is difficult; we, therefore, view the positive results as an encouraging sign for the applicability of our model.

In the numerical simulation presented in Section 6, we have assumed negligible costs for

[42] See Morisset (1998) for a recent example and the references therein.

[43] When the government uses the revenues to purchase goods for its own consumption, the tariff rate has to be more than 200% for the welfare gains from an increase in A_P for the rich to be completely negated. For the poor, a tariff rate of 63% would negate their gains. These are high values even for protectionist regimes. They also point to the importance of the assumption made regarding the disbursement of tariff revenues.

developing technologies. If enough data could be collected to allow the calibration of an R&D cost function, we might be able to shed quantitative light on the optimal technological investment by the rich country, thus complementing the theoretical analysis done in Section 4. As mentioned in the introduction, we have been silent on the issues of coordination among rich countries that make such a collective endeavor possible in the first place, as well as on the nature of commitment, or lack thereof, by the poor to behave in ways expected by the rich who donate the technology to them. Our representative agent framework also dismisses political economy questions. Modeling these features explicitly will allow us to better understand why such collective efforts have not been more widespread and are limited to certain types of technological improvements, most notably agriculture. These are topics of ongoing research.

A Appendix

A.1 The Static Model

The exact expression for the terms of trade and equilibrium incomes of rich and poor in section 2 are:

$$
\begin{aligned}
p &= \left(\frac{1-\theta}{\theta}\right)\left[\frac{\left(A_P^1 L_P - m_P\right) + \left(A_R^1 L_R - m_R\right)}{A_P^2 K_P + A_R^2 K_R}\right], \\
I_P &\equiv Y_P^1 + pY_P^2 = \frac{\left(A_P^2 K_P + \theta A_R^2 K_R\right)\left(A_P^1 L_P - m_P\right) + (1-\theta) A_P^2 K_P \left(A_R^1 L_R - m_R\right)}{\theta\left(A_P^2 K_P + A_R^2 K_R\right)} + m_P, \\
I_R &= Y_R^1 + pY_R^2 = \frac{\left(\theta A_P^2 K_P + A_R^2 K_R\right)\left(A_R^1 L_R - m_R\right) + (1-\theta) A_R^2 K_R \left(A_P^1 L_P - m_P\right)}{\theta\left(A_P^2 K_P + A_R^2 K_R\right)} + m_R.
\end{aligned}
$$

The relative price p for the case $\alpha = 0$, $\beta < 1$ is:

$$
p = \frac{1}{(1-\beta)}\left\{\frac{\left(A_P^1 L_P - m_P\right) + \left(A_R^1 L_R - m_R\right)}{\left(1 + \frac{\theta}{(1-\beta)(1-\theta)}\right)\left[\frac{\left(A_P^2\right)^{\frac{1}{\beta}}}{\left(A_P^1\right)^{\frac{1-\beta}{\beta}}} K_P + \frac{\left(A_R^2\right)^{\frac{1}{\beta}}}{\left(A_R^1\right)^{\frac{1-\beta}{\beta}}} K_R\right]}\right\}^{\beta}.
$$

A.2 Results for Non-specialization Steady State

The precise formula for the equilibrium value of L_R^1, derived from (17) and (19), is:

$$
L_R^1 = \frac{\frac{\theta}{(1-\beta)}\left(\frac{\rho+\delta(1-\beta)}{\rho+\delta}\right) A_R^1 L_R - (1-\theta)\left[A_P L_P - (m_P + m_R)\right]}{\left[(1-\theta) + \frac{\theta(\rho+\delta(1-\beta))}{(\rho+\delta)(1-\beta)}\right] A_R^1}.
$$

The change in L_R^1 when A_P changes is:

$$
\frac{\partial L_R^1}{\partial A_P} = -\frac{(1-\theta)}{\left[(1-\theta) + \frac{\theta(\rho+\delta(1-\beta))}{(\rho+\delta)(1-\beta)}\right] A_R^1} L_P.
$$

Total income in the rich country is:

$$
I_R = \frac{(\rho + \delta(1-\beta)) A_R^1 L_R + \beta\rho(1-\theta)\left(A_P L_P - (m_P + m_R)\right)}{(1-\beta)(\rho+\delta) + \beta\rho\theta}.
$$

The world's output of good 1 also increases with A_P:

$$
\frac{\partial\left(Y_P + Y_R^1\right)}{\partial A_P} = \theta\frac{\rho + \delta(1-\beta)}{(\rho+\delta)(1-\beta) + \theta\beta\rho} L_P > 0.
$$

A.3 Inappropriate vs Appropriate Technology Investment

We consider the possibility for the rich of simultaneously increasing A_P and A_R^1. The resource constraint now reads:

$$c_R^1+p(c_R^2+i_R+rc(A_P',A_P))+rc((A_R^1)',A_R^1)\leq A_R^1L_R^1+pA_R^2(L_R-L_R^1)^{1-\beta}K_R^\beta.$$

We have already derived the first-order condition for the optimal investment in A_P, in (36) The corresponding condition for investments in A_R^1 is:

$$\frac{\partial Y_R^1}{\partial A_R^1}+\frac{\partial p}{\partial A_R^1}[\bar{Y}^2-c_R^2-i_R-rc(A_P',A_P)-rc((A_R^1)',A_R^1)]+p\frac{\partial Y_R^2}{\partial A_R^1}\leq pr\frac{\partial c((A_R^1)',A_R^1)}{\partial A_R^1},\quad (40)$$

with the condition holding with equality if the investment in A_R^1 is strictly positive. The term within the square brackets is equal to the poor country's consumption of good 2, c_P^2.

Under the quadratic cost specification introduced above, the optimal choice of A_P' is:

$$A_P'=A_P+\frac{1}{r}\frac{(1-\beta)(\frac{\beta}{\rho+\delta})^{\frac{\beta}{1-\beta}}(A_R^2)^{\frac{1}{1-\beta}}}{A_R^1}\frac{\beta\rho(1-\theta)}{(1-\beta)(\rho+\delta)+\beta\rho\theta}L_P,\quad (41)$$

which depends positively on L_P, a manifestation of the scale effect mentioned earlier. Could it be the case that the rich country prefers not to invest in its own, appropriate technology? This can happen only if the left-hand side of (40) evaluated at $(A_R^1)'=A_R^1$ is negative, since the marginal cost is zero with no improvement; that is, if:

$$\frac{\partial Y_R^1}{\partial A_R^1}+\frac{\partial p}{\partial A_R^1}c_P^2+p\frac{\partial Y_R^2}{\partial A_R^1}\leq 0.\quad (42)$$

Some tedious algebra shows that the condition for this to happen is:

$$\frac{\theta}{1-\beta}\frac{\rho+\delta(1-\beta)}{\rho+\delta}A_R^1L_R-(1-\theta)\left(\frac{1}{1-\beta}-\left((1-\theta)+\theta\frac{\rho+\delta(1-\beta)}{(\rho+\delta)(1-\beta)}\right)\right)((Y_P)'-m_P)+\frac{1-\theta}{1-\beta}m_R\leq 0,$$

where $(Y_P)'$ indicates the new output of good 1 in the poor country given that the optimal investment in A_P is being undertaken. It can be shown that the coefficient multiplying $((Y_P)'-m_P)$ is negative. Using (41), we get:

$$(Y_P)'=A_PL_P+\frac{1}{r}\frac{(1-\beta)(\frac{\beta}{\rho+\delta})^{\frac{\beta}{1-\beta}}(A_R^2)^{\frac{1}{1-\beta}}}{A_R^1}\frac{\beta\rho(1-\theta)}{(1-\beta)(\rho+\delta)+\beta\rho\theta}(L_P)^2.$$

Therefore, there exists a large enough L_P to make the inequality (42) hold in a strict sense; this is particularly so since $(Y_P)'$ includes a term in the square of L_P.

Recall from section 3.2, that the rich country's incentive to invest in the poor country's technology, A_P, is amplified by the size of its labor force, L_P. With a quadratic cost specification, the improvement in A_P is linear in L_P. Given the production technology, $Y_P=A_PL_P$, the square term in the size of the labor force manifests in the above expression for the improved output. The endogenous response of technology improvement to L_P makes it more likely for the rich country to improve the poor country's technology rather than its own, if L_P is large enough.

A.4 Endogenizing the Interest Rate

In this section, we argue that endogenizing the interest rate, which enters the periodic cost of R&D will not affect the qualitative results. In order to endogenize r, we consider the decentralized environment in which firms operate the technology and rent the capital stock from consumers. The problem of sector 2 firms in the rich country would be:

$$\max_{K_R, L_R - L_R^1} pA_R^2 \left(L_R - L_R^1\right)^{1-\beta} K_R^\beta - (r+\delta) K_R - w\left(L_R - L_R^1\right).$$

It is assumed that there exist competitive markets in the inputs capital and labor. Given this, the first-order condition with respect to capital is:

$$pA_R^2 \beta \left(\frac{L_R - L_R^1}{K_R}\right)^{1-\beta} - \delta = r. \tag{43}$$

This is the only additional condition needed to close the welfare analysis above when steady-states are considered. Since no capital is used in the poor country, we can think of the expression found for r in (43) as describing the world-wide interest rate. Given that the price p does not depend on A_P under the non-specialization regime, neither does the interest rate. The welfare analysis of section 4 goes through without further qualifications. In the specialization regime, however, we must take into account the positive relationship between the interest rate and the price. As an example, the first-order condition for the optimal investment of the rich country, equation (**??**), should be modified to read:

$$\frac{\partial p}{\partial A_P} c_P^2 = pr \frac{\partial c\left(A_P', A_P\right)}{\partial A_P} + pc\left(A_P', A_P\right) \frac{\partial r}{\partial p} \frac{\partial p}{\partial A_p},$$

with an additional term on the right-hand side to capture the change in cost associated with the change in the interest rate. This additional term should also be added to the first-order condition of country 1. These changes do not qualitatively affect the analysis in the text.

A.5 Differential Equations for Non-Specialization

Write the equilibrium condition out of steady state as:

$$\theta p \left(Y_R^2 - i_R\right) = (1-\theta)\left[Y_P + Y_R^1 - (m_P + m_R)\right]. \tag{44}$$

Note $Y_P = A_P L_P$, $Y_R^1 = A_R^1 \left(L_R - L_R^2\right)$, and $Y_R^2 = A_R^2 K_R^\beta \left(L_R^2\right)^{1-\beta}$. Use these, the law of motion for capital for I_R, and (39) in (44) to get the first differential equation:

$$\begin{aligned} \dot{K}_R &= \left\{1 + (1-\beta)\left(\frac{1-\theta}{\theta}\right)\right\} A_R^2 K_R^\beta \left(L_R^2\right)^{1-\beta} - \delta K_R \\ &\quad - \left(\frac{1-\theta}{\theta}\right)(1-\beta)\left[A_P L_P - m_P + A_R^1 L_R - m_R\right]\left(\frac{A_R^2}{A_R^1}\right)\left(\frac{K_R}{L_R^2}\right)^\beta. \end{aligned} \tag{45}$$

Using, $\lambda_1 p = \lambda$ and (16) in (13) we get:

$$\frac{\dot{\lambda}}{\lambda} = (\rho + \delta) - \beta \frac{A_R^2}{\left(\frac{K_R}{L_R^2}\right)^{1-\beta}}. \tag{46}$$

We can use the FOCs for consumption and (44) in the rich country's budget constraint and show:

$$\frac{\theta}{1-\theta}pc_R^2 = (1-\theta)(A_P L_P - m_P) + \left(A_R^1 L_R^1 - m_R\right).$$

Since the FOC is $\frac{1-\theta}{c_R^2} = \lambda_1 p = \lambda$, using the above equation for pc_R^2 yields:

$$\frac{\theta p}{\lambda} = (1-\theta)(A_P L_P - m_P) + \left(A_R^1 L_R^1 - m_R\right).$$

Differentiate this with respect to time and note that $L_R^1 = -L_R^2$ to get:

$$\frac{\dot{p}}{p} - \frac{\dot{\lambda}}{\lambda} = \frac{-A_R^1 \dot{L}_R^2}{(1-\theta)(A_P L_P - m_P) + (A_R^1 L_R^1 - m_R)}.$$

Differentiating (39) with respect to time, assuming the technology coefficients of the rich country do not change, we get, $\frac{\dot{p}}{p} = \beta\left(\frac{\dot{L}_R^2}{L_R^2} - \frac{\dot{K}_R}{K_R}\right)$. Use this and (46) above to get:

$$\beta\left(\frac{\dot{L}_R^2}{L_R^2} - \frac{\dot{K}_R}{K_R}\right) - (\rho+\delta) + \beta A_R^2\left(\frac{L_R^2}{K_R}\right)^{1-\beta} = \frac{-A_R^1 \dot{L}_R^2}{(1-\theta)(A_P L_P - m_P) + (A_R^1 L_R - m_R) - A_R^1 L_R^2}.$$

We can substitute (45) in the above differential equation, and simplify to get:

$$\begin{aligned}\frac{\dot{L}_R^2}{L_R^2} &= \frac{\left[(1-\theta)(A_P L_P - m_P) + \left(A_R^1 L_R - m_R\right)\right] - A_R^1 L_R^2}{\beta\left[(1-\theta)(A_P L_P - m_P) + (A_R^1 L_R - m_R)\right] + (1-\beta) A_R^1 L_R^2} \cdot \\ &\quad \left\{[\rho + (1-\beta)\delta] - \frac{\beta(1-\beta)(1-\theta)}{\theta} A_R^2 \left(\frac{L_R^2}{K_R}\right)^{1-\beta}\left[\frac{(A_P L_P - m_P) + \left(A_R^1 L_R - m_R\right)}{A_R^1 L_R^2} - 1\right]\right\} \quad (47)\end{aligned}$$

These differential equations yield the following expressions for the steady state:

$$\begin{aligned}\left(\frac{K_R}{L_R^2}\right)_*^{1-\beta} &= \frac{\beta A_R^2}{\rho+\delta} \\ (K_R)_{*,NS} &= \left(\frac{\beta A_R^2}{\rho+\delta}\right)^{\frac{1}{1-\beta}} \left\{\frac{(1-\theta)\left(A_P L_P - m_P + A_R^1 L_R - m_R\right)}{A_R^1 \frac{(1-\beta)(\rho+\delta)+\beta\rho\theta}{(1-\beta)(\rho+\delta)}}\right\} \\ \left(L_R^2\right)_{*,NS} &= \frac{(1-\theta)\left(A_P L_P - m_P + A_R^1 L_R - m_R\right)}{A_R^1 \frac{(1-\beta)(\rho+\delta)+\beta\rho\theta}{(1-\beta)(\rho+\delta)}}.\end{aligned}$$

A.6 Proof of Claim 5

We draw the phase diagram for the non-specialized system given in (45) and (47). Note that the $\dot{K}_R = 0$ locus is:

$$\begin{aligned}K_R &= \left(\frac{1}{\delta}\right)^{\frac{1}{1-\beta}} \left\{1 + (1-\beta)\left(\frac{1-\theta}{\theta}\right) A_R^2 \left(L_R^2\right)^{1-\beta} \right. \\ &\quad \left. - \left(\frac{1-\theta}{\theta}\right)(1-\beta)\left[A_P L_P - m_P + A_R^1 L_R - m_R\right]\left(\frac{A_R^2}{A_R^1}\right)\left(\frac{1}{L_R^2}\right)^{\beta}\right\}^{\frac{1}{1-\beta}}.\end{aligned}$$

Clearly, K_R is increasing in L_R^2. When $L_R^2 \to 0$, $K_R \to -\infty$. When $L_R^2 \to \infty$, $K_R \to \infty$. At $\widehat{L_R^2}$, $K_R = 0$, where,

$$\widehat{L_R^2} = \frac{\left[A_P L_P - m_P + A_R^1 L_R - m_R\right]}{A_R^1 \left[1 + \frac{\theta}{(1-\beta)(1-\theta)}\right]}.$$

We would like to focus attention on the range of positive values for capital; i.e. where $L_R^2 > \widehat{L_R^2}$.

To get the $\dot{L}_R^2 = 0$ locus, note only the second term can be zero. This yields:

$$K_R = \frac{\beta\,(1-\beta)\,(1-\theta)}{\theta\,[\rho + (1-\beta)\,\delta]} A_R^2 \left[\frac{(A_P L_P - m_P) + \left(A_R^1 L_R - m_R\right)}{A_R^1\,(L_R^2)^\beta} - \left(L_R^2\right)^{1-\beta}\right]^{\frac{1}{1-\beta}},$$

as the locus. Clearly, K_R is decreasing in L_R^2. When $L_R^2 \to 0$, $K_R \to \infty$. When $L_R^2 \to \infty$, $K_R \to -\infty$. At $\widetilde{L_R^2}$, $K_R = 0$, where:

$$\widetilde{L_R^2} = \frac{\left[A_P L_P - m_P + A_R^1 L_R - m_R\right]}{A_R^1}.$$

Again, we will focus attention on positive values for capital. It can be seen that $\widetilde{L_R^2} > \widehat{L_R^2}$ and, given the nature of the two loci, a unique intersection, that is a steady state, exists.

To complete the ingredients of the phase diagram, note that, to the right of the $K_R = 0$ locus, K_R is increasing since K_R is increasing in L_R^2; likewise to the left it is decreasing. Above the $L_R^2 = 0$ locus, L_R^2 is increasing, since L_R^2 is increasing in K_R. Likewise, below the locus it is decreasing. The phase diagram is shown in Figure 3. The stable manifold is downward sloping.

Figure 3

Dynamics without specialization: Phase diagram

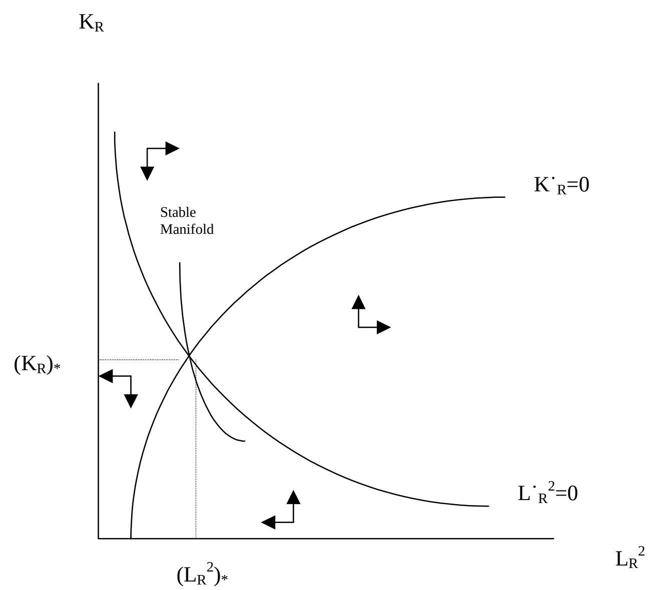
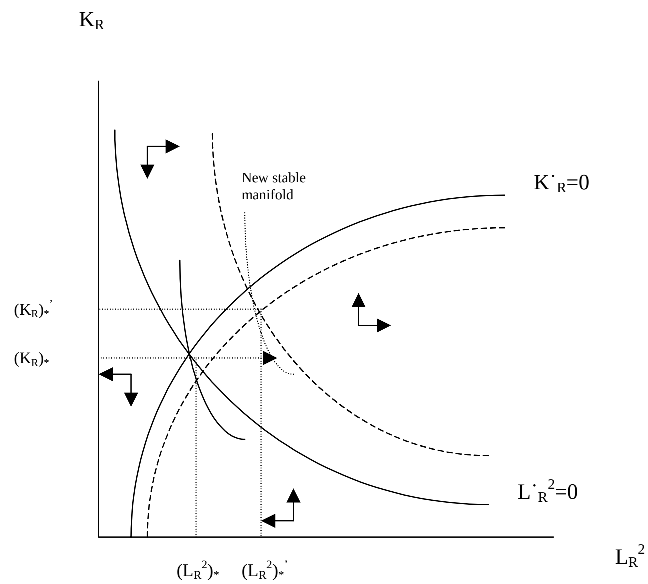


Figure 4

Dynamics without specialization: Phase diagram after A_P increase



What happens when A_P increases? The following quantities clearly increase: $(K_R)_*$, $\left(L_R^2\right)_*$, (both by the same factor, to keep, $\frac{K_R}{L_R^2}$ and thus p unaltered), $\widehat{L_R^2}$ and $\widetilde{L_R^2}$. Also, both loci shift outward. The new phase diagram is shown in Figure 4.

The dotted lines show the new loci and the stable manifold. K_R cannot jump at the time of increase in A_P. But L_R^2 does along the dotted arrow; it in fact overshoots and decreases along the new manifold to its new steady state value. K_R increases to its new steady state value along the new stable manifold. From (39) we can see that the price p also jumps.

A.7 Differential Equations for Specialization

When all capital labor in the rich country is allocated to the production of good 2 we have:

$$\frac{\dot{\lambda}}{\lambda} = (\rho + \delta) - \beta A_R^2 \left(\frac{L_R}{K_R}\right)^{1-\beta}.$$

Using $Y_R^1 = 0$ and $Y_R^2 = A_R^2 K_R^{\beta} L_R^{1-\beta}$ in (44) and using the law of motion for capital yields the following differential equation:

$$\dot{K}_R = A_R^2 K_R^{\beta} L_R^{1-\beta} - \left(\frac{1-\theta}{\theta}\right)\left(\frac{A_P L_P - (m_P + m_R)}{p}\right) - \delta K_R. \tag{48}$$

Again, using (44) it is possible to see that $c_R^1 - m_R$ is time-invariant and thus so is λ_1 and hence $\lambda_1 p = \lambda$ now implies that $\frac{\dot{p}}{p} = \frac{\dot{\lambda}}{\lambda}$. Therefore:

$$\frac{\dot{p}}{p} = (\rho + \delta) - \beta A_R^2 \left(\frac{L_R}{K_R}\right)^{1-\beta}. \tag{49}$$

The steady state quantities are:

$$
\begin{aligned}
(K_R)_{*,S} &= \left(\frac{\beta A_R^2}{\rho+\delta}\right)^{\frac{1}{1-\beta}} L_R, \\
(I_R)_{*,S} &= A_R^2 \left(K_R^*\right)^{\beta} L_R^{1-\beta} - \delta K_R^* = \frac{(\rho+\delta(1-\beta))}{\beta} (K_R)_{*,S} \\
(p)_{*,S} &= \left(\frac{1-\theta}{\theta}\right)\left(\frac{I_P - m_P - m_R}{I_R^*}\right).
\end{aligned}
$$

A.8 Proof of Claim 6

We draw the phase diagram for the system in (48) and (49). The $\dot{K}_R = 0$ locus is given by:

$$
A_R^2 K_R^{\beta} L_R^{1-\beta} - \delta K_R = \left(\frac{1-\theta}{\theta}\right)\left(\frac{A_P L_P - (m_P + m_R)}{p}\right).
$$

The left hand side is increasing in K_R for all values less than $(K_R)_{*,S}$, which is where we will focus attention. It is clear that the $K_R = 0$ locus is decreasing in p. From (48) we can see that to the right of the locus (higher p), K_R is increasing and to the left of the locus it is decreasing. The $\dot{p} = 0$ locus is:

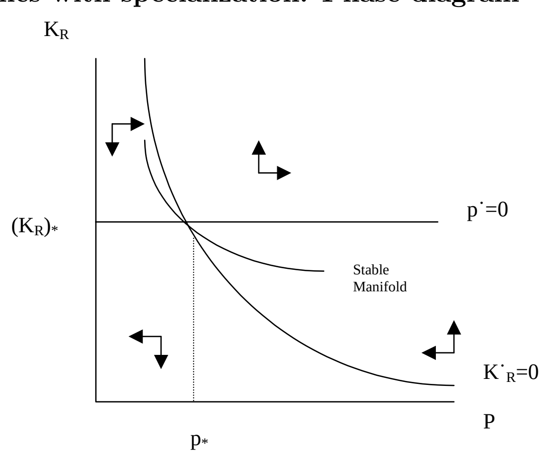
$$
K_R = \left(\frac{\beta A_R^2}{\rho+\delta}\right)^{\frac{1}{1-\beta}} L_R = (K_R)_{*,S}
$$

which is independent of p. From (49) we can see that, above the locus (higher K_R), p is increasing and, below the locus, it is decreasing. The phase diagram for the specialized regime is given in Figure 5.

When A_P increases, the $K_R = 0$ locus shifts rightward, while the $\dot{p} = 0$ locus is unchanged. For a change in A_P that cause eventual specialization by the rich country, there are two cases to consider – the case where the rich country was specialized to begin with and where it was non-specialized.

Figure 5

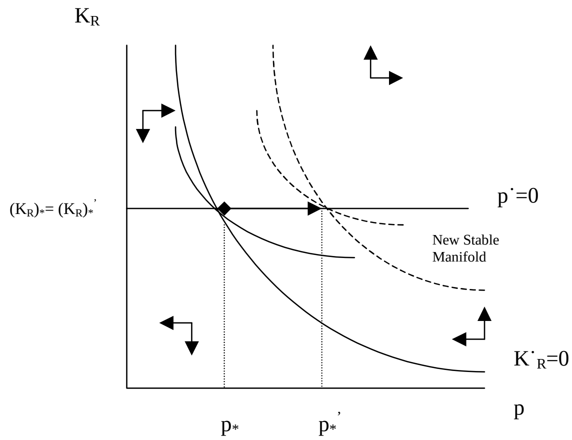
Dynamics with specialization: Phase diagram



When the rich country is specialized initially, any increase in A_P will only reinforce specialization; see (26). There will be no change in the rich country's steady state capital and the steady state price will increase, which can be seen from the above expression for p_S^* where $I_P = A_P L_P$ increases. The adjustment is instantaneous, along the $\dot{p} = 0$ locus as shown in Figure 6.

Figure 6

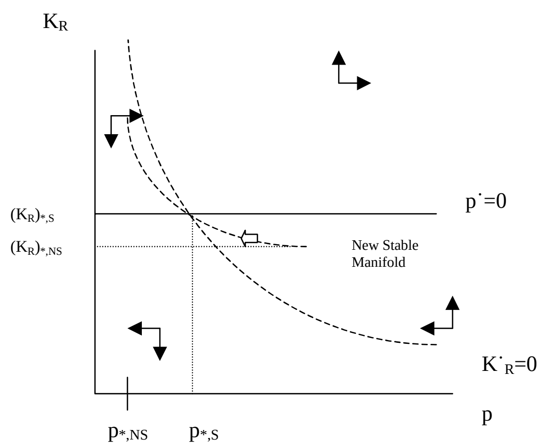
Dynamics with specialization: After A_P increase; spl.→spl.



When the rich country is non-specialized initially, the dynamics are more interesting.

Figure 7

Dynamics with specialization: After A_P increase; non-spl.→spl.



From the steady state capital stock expressions for the two regimes, we can write:

$$(K_R)_{*,NS} = \left(\frac{\beta A_R^2}{\rho + \delta}\right)^{\frac{1}{1-\beta}} \left(L_R^2\right)_* < \left(\frac{\beta A_R^2}{\rho + \delta}\right)^{\frac{1}{1-\beta}} L_R = (K_R)_{*,S},$$

given that $\left(L_R^2\right)_* < L_R$ when the rich country is not specialized. From (12), one can see that when the rich country is specialized it has to be the case that $A_R^1 < (1-\beta)\, p A_R^2 \left(K_R\right)^{\beta} \left(L_R\right)^{-\beta}$, and for this to be true at the steady state we need:

$$(p)_{*,S} > \frac{A_R^1}{(1-\beta)\left(\frac{\beta}{\rho+\delta}\right)^{\frac{\beta}{1-\beta}} \left(A_R^2\right)^{\frac{1}{1-\beta}}} = (p)_{*,NS}\,,$$

where the expression for $(K_R)_{*,S}$ is used.

Therefore, during transition, the capital stock increases monotonically from $(K_R)_{*,NS}$ to $(K_R)_{*,S}$ according to (48). From the phase diagram shown in Figure 7 (where only the new loci are shown as they are the relevant ones), we can see that p overshoots and decreases monotonically to its new, higher steady state level according to (49).

References

[1] Acemoglu, Daron., and Fabrizio Zilibotti. "Productivity Differences." *The Quarterly Journal of Economics*, 2001, vol 115, 563-606.

[2] Chatterjee, Satyajit and B. Ravikumar. "Minimum Consumption Requirements: Theoretical and Quantitative Implications for Growth and Distribution." *Macroeconomic Dynamics*, vol. 3, no. 4 (December 1999): 482-505.

[3] Cohen, Benjamin I., and Daniel G. Sisler. "Exports of Developing Countries in the 1960's." *The Review of Economics and Statistics*, vol. 53, no. 4 (November 1971): 354-361.

[4] Dixit, Avinash K., and Victor Norman. *Theory of International Trade*. Welwyn, UK: James Nisbet & Co. Ltd and Cambridge University Press, 1980.

[5] Evenson, R.E., and Douglas Gollin. "Chapter 2: Crop Genetic Improvement in Developing Countries: Overview and Summary," in Evenson, R.E. and D. Gollin, eds. *Crop Variety Improvement and Its Effect on Productivity: The Impact of International Agricultural Research*. Wallingford, UK: CAB International, 2001.

[6] Evenson, R.E., and M. Rosegrant. "Chapter 23: The Economic Consequences of CGI Programs," in Evenson, R.E. and D. Gollin, eds. *Crop Variety Improvement and Its Effect on Productivity: The Impact of International Agricultural Research*. Wallingford, UK: CAB International, 2001.

[7] Gallup, John Luke and Jeffrey D. Sachs. "The Economic Burden of Malaria." *Center for International Development, Harvard University, Working Paper* 52, July 2000.

[8] Hall, Robert E., and Charles I. Jones. "Why Do Some Countries Produce So Much More Output Per Worker Than Others?" *The Quarterly Journal of Economics*, 1999, vol 114, 83-116.

[9] Fernandes, Ana, and Krishna B. Kumar. "Inappropriate Technology (with expanded appendices)." USC working paper, January 2003, http://www-rcf.usc.edu/~kbkumar/inappexp.pdf

[10] Matsuyama, Kiminori. "A Ricardian Model with a Continuum of Goods under Non-homothetic Preferences: Demand Complementarities, Income Distribution, and North-South Trade." *Journal of Political Economy* 108, no.6 (December 2000): 1093-1120.

[11] McArthur, John W., and Jeffrey D. Sachs. "Institutions and Geography: Comment on Acemoglu, Johnson, and Robinson (2000)." *NBER Working Paper* 8114, February 2001.

[12] Morisset, Jacques. "Unfair Trade? The Increasing Gap between World and Domestic Prices in Commodity Markets during the Past 25 Years" *The World Bank Economic Review* 12, no.3 (1998): 503-526.

[13] Rivera-Batiz, Luis A. and Paul M. Romer. "Economic Integration and Endogenous Growth." *Quarterly Journal of Economics* 1991: 531-555.

[14] Romer, Paul M. "Endogenous Technological Change." *Journal of Political Economy* 98, no.5 (October 1990): S71-S102.

[15] Sachs, Jeffrey D. "Helping the world's poorest." *The Economist* August 12, 1999.

[16] Sachs, Jeffrey D, Michael Kremer, and Amar Hamoudi. "The Case for a Vaccine Purchase Fund." *Center for International Development Policy Paper, Harvard University, Working Paper*, 2001.