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The Brain Drain and the World Distribution of Income and Population

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Non-Technical Abstract

This paper models the evolution of the world distribution of income and shows that while the distribution of income per capita across economies in the world will be stable in the long run, the world distribution of population may be divergent. The paper then uses this model to analyze the impact of the current trend towards predominantly skilled emigration from poor to rich countries on fertility, human capital formation, and growth, in both the sending and receiving countries. It shows that in the long run, brain drain migration patterns may increase world inequality as relatively poor countries grow large in terms of population. In the short run however, it is possible for world inequality to fall due to rises in GDP per capita in large developing economies with low skilled emigration rates.

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March 2007

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Keywords: Migration, Growth, Brain Drain, World Distribution of Income.
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1 Introduction

The world distribution of income depends on the relative size of countries' population as well as on the distribution of income within and across countries. This paper models the joint evolution of the world distribution of income per capita and the world distribution of population and shows that even if the former is be stable in the long run, the latter may be divergent. The paper then uses this model to analyze the impact of the current trend towards predominantly skilled emigration from poor to rich countries on fertility, human capital formation, and growth, in both the sending and receiving countries. It shows that in the long run, brain drain migration patterns may increase inequality in the world distribution of income, as relatively poor countries grow large in terms of population. In the short run however, it is possible for world inequality to fall due to rises in GDP per capita in large developing economies with low skilled emigration rates.

It is important to analyze the effects of brain drain migration patterns on the world distribution of income since this type of migration has been growing significantly over the last 25 years. Throughout the 1990s the growth rate of international skilled migration has been nearly triple that of unskilled migration, and most of that increase is due to skilled migration from developing to developed countries. Emigration rates in 2000 were three times higher than average for the highly educated and skilled – and twelve times higher for emigrants from low-income countries (Docquier and Marfouk, 2006).[1]

This significant development in the world economy gives rise to important economic questions. Is the brain drain from developing to developed countries likely to be a transitory or a permanent feature of the world economy? Will it increase the rate of economic growth in the sending economies, in the receiving economies, and in the world economy? Will the brain drain promote convergence or divergence in the world distribution of income? To answer these questions this paper develops a model with endogenous education, fertility, and migration decisions by individual agents in both the sending and receiving economies. It shows that skilled migration may improve the growth rate, and reduce the fertility rate, of all economies in the world. Furthermore, when both receiving and sending economies benefit from brain drain migration, it is possible that the more advanced economy benefits more from this process and for world inequality to increase as a result. Based on the model's predictions and on recent findings of the empirical brain drain literature, the implications of brain drain migration for the world distribution of income are derived. We show that the implied impact will strengthen the trends predicted by Sala-I-Martin (2006): a decrease in world inequality in the next few decades as the main globalizers grow, but then a renewed increase as the forces for divergence become increasingly dominant.

The analysis extends the existing literature in two directions. Firstly it provides a dynamic analysis of the effects of the brain drain on both the sending and receiving economies. This is an important contribution since the previous literature, from the seminal papers of Bhagwati and Hamada (1974) to the more recent models of Mountford (1997), Vidal (1998), Beine *et al.* (2001) or Kanbur and Rapoport (2005), have only analyzed the implications for the sending economy. Analyzing the effect on receiving countries is important because it demonstrates that the effects of migration on the sending and receiving economies need not be opposites of one another. In particular it is shown how it is possible for brain drain migration to reduce fertility rates and increase the rates of human capital accumulation and economic growth in both the sending and receiving economies.

This paper's second contribution is to link the brain drain to fertility decisions in both the sending and receiving economies. This is important because the shape of the world distribution of

[1] See section 2.2 below for a discussion of the empirical trends.

income is affected by the relative numbers of people in advanced and less advanced economies as well as by their relative income per head and it is a fact that sending countries tend to have higher rates of fertility and lower levels of human capital accumulation than the receiving economies. This paper uses a Becker (1981) quality versus quantity trade off argument for fertility decisions to show how these patterns may be reinforced by brain drain migration in equilibrium.

The observed growth in selective migration is almost surely related to another key empirical phenomenon which has been the subject of a great deal of recent economic analysis, namely, the expansion in human capital accumulation in developing and developed economies. In this paper we adopt the approach of Galor and Moav (2000) in modeling this rise. Galor and Moav (2000) argue that education makes workers more adaptable and so makes them relatively more productive in conditions of technological change. Thus while the level of technology is skill-neutral, the *rate* of growth of technology is skill-biased. We extend this approach to the international environment by assuming that the rate of growth of frontier technology is skill-biased but that the rate of growth from internationally diffused or imitation technology is not skill biased. When brain drain migration is added to this environment there is a two way interaction between growth and the migration of skilled workers. Higher technological growth in an advanced economy increases the incentives for agents to migrate to the advanced economy and this spurs (gross) human capital accumulation in the sending economy. Skilled immigration also increases the growth rate of technology in the advanced economy and this further increases the incentives for skilled agents to migrate to the advanced economy as well as increases the incentives for human capital accumulation in the advanced economy itself.

The rest of this paper is organized as follows. Section 2 briefly reviews the recent evidence on the evolution of the world distribution of income, on the growth of brain drain migration, and on the impact of brain drain migration on the development of the sending economies. Section 3 describes an autarkic theoretical economy. Section 4 analyzes the impact of brain drain migration on both the sending and receiving economies. Section 5 analyzes the evolution of the world economy and derives the main results of the paper. Section 6 concludes.

2 Empirical background

2.1 The world distribution of income: recent trends

Inequality in the world distribution of income is a combination of inequality within and between countries. Using different possible measures of inequality among world citizens, Sala-I-Martin (2006) concludes that world inequality remained more or less constant during the 1970s and then declined during the 1980s and 1990s, with the size of the decline ranging between 4 to 30 percent depending on the exact measure used. This decline is noteworthy in that it comes after a secular trend of rising inequality at the world level (Bourguignon and Morrisson, 2002). The reversal is more than accounted for by the convergence in income per capita of countries such as India, China, and other Asian countries, while other regions of the world (especially Africa, which includes many small and medium-sized countries) have kept diverging. Using a sub-set of inequality measures that allow for decomposing global inequality, Sala-I-Martin (2006) shows that global inequality is due mostly to inequality across countries. However, within-country inequality has been rising since the 1970s. Nevertheless, this increase in within-country inequality is more than offset by the decrease in (weighted) between-country inequality, resulting in an overall decline in inequality at the world level.

How will these trends be affected by the international migration of people? In particular, how will the world distribution of income be impacted by the emergence of brain drain migration as a dominant pattern of international migration? Before we model the main channels through which skilled migration is likely to affect global inequality, we first present recent statistical and empirical evidence to substantiate our claim that the brain drain is indeed a phenomenon of growing importance, with potentially significant impacts on developing countries.

2.2 The growth of 'brain drain' migration, 1970-2000

Recent comparative data on international migration by skill level reveal that over the last few decades the brain drain has increased not only in magnitude (i.e., in terms of total number of highly skilled immigrants) but also, in most cases, in intensity (i.e., relative to the stock of highly educated people remaining in the source countries). This means that the rate of growth of international skilled migration has been even more rapid than that of educational attainments in most regions of the developing world. Figure 1 shows this evolution using panel data from Defoort (2006), where skilled emigration rates are expressed in percentage of the labor force.

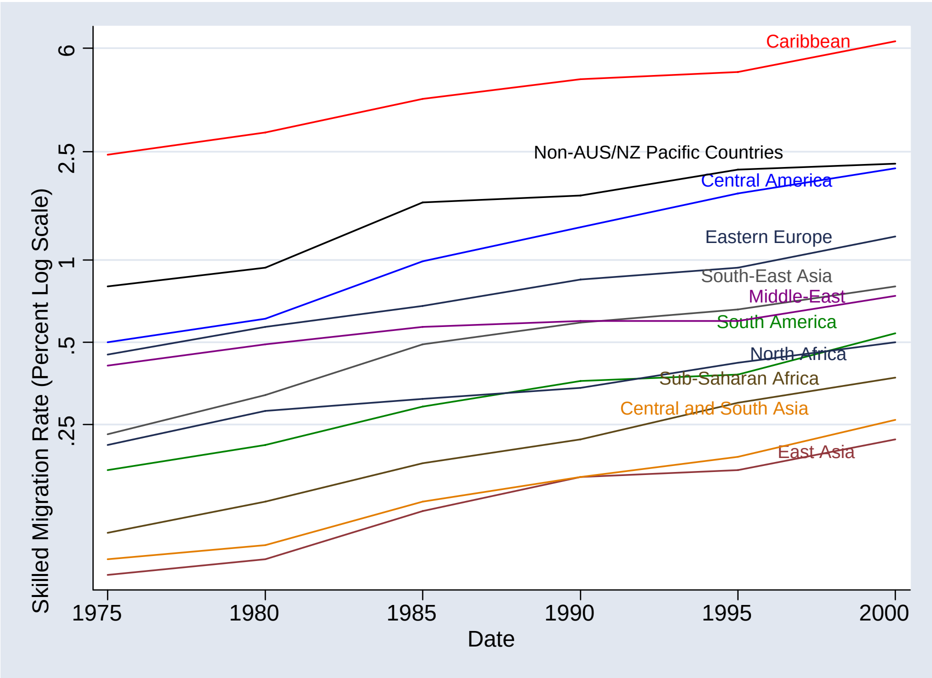

Figure 1: The increase in brain drain migration over the last three decades.
Source: Defoort (2006).

The rise in brain drain migration has been caused by a combination of selective immigration policies on the demand side and an increased tendency for workers to positively self-select into migration on the supply side. Selective immigration policies such as the point-system were first introduced in Australia and Canada in the early 1980s, and then gradually spread to other OECD countries. Most recent examples include the adoption of the point-system by the United Kingdom in 2005 and the "chosen immigration" policy adopted in France in 2006.

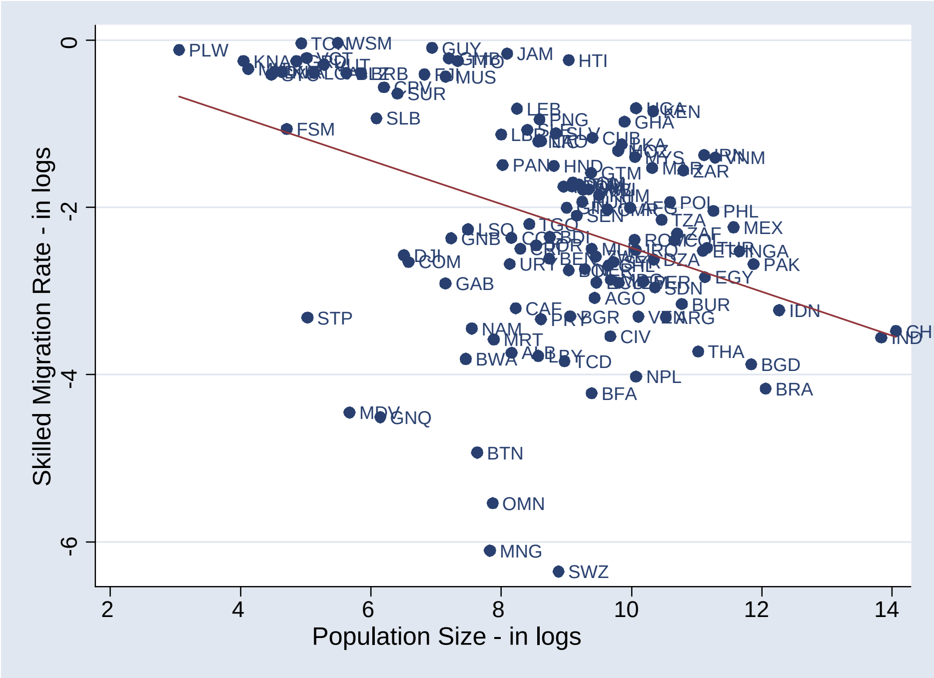

Figure 2: The inverse relationship between the skilled emigration rate and population size (in 2000). Source: Docquier and Marfouk (2006).

There is a clear decreasing relationship between emigration rates and country size (see Figure 2). Docquier and Marfouk (2006) show that these differences cannot be attributed to the educational structure of the home country population or to a higher ratio of skilled to total emigration rates in small countries. The latter are simply more open to migration (as they are for trade). Note that the largest developing countries exhibit relatively low rates of skilled emigration. Besides country size, another significant explanatory variable for skilled emigration rates is a country's income level with the highest skilled emigration rates being observed in middle-income countries. The fact that skilled emigration rates tend to be lower in relatively affluent countries is explained by the relatively low wage differentials between these countries and potential destinations. The reasons why they are also lower in poor countries are less obvious and could be due to a variety of causes, including the role of credit constraints on education and migration decisions or the lower transferability of human capital, which we do not attempt to model in this paper.

2.3 Estimation of the effects of the brain drain on developing countries' human capital formation

The theoretical model will show that the brain drain can have a positive or negative effect on human capital accumulation in the sending economy depending *ceteris paribus* on the rate of emigration of skilled workers. As in previous models, the potential for brain drain migration to be beneficial to the sending economy is based on the assumption that the ability to migrate is uncertain and that migration prospects affect agents' education decisions in the sending economies.[2] Beine, Docquier and Rapoport (2007) first estimated the effect of the brain drain on gross human capital formation

[2]There is much empirical evidence supporting this assumption at both the micro and macro level. Micro-level evidence comes mainly from sectoral case-studies looking at certain professions (generally health professionals or engineers) in specific countries Macro-level evidence is provided by Beine, Docquier and Rapoport (2001, 2007). See Commander, Kangasniemi and Winters (2004) and Docquier and Rapoport (2004) for surveys of this literature.

out of a cross-section of developing countries and found a significant positive effect. They then used the cross-sectional results to estimate the net effect (i.e., once emigration is netted out) through country-specific counterfactual experiments.[3] Their results (see Figure 3) show that the countries that experience a "beneficial brain drain" generally combine low levels of human capital and low migration rates, whereas the countries experiencing a net loss are typically characterized by high migration rates and/or high levels of human capital. There appears to be more losers than winners among sending countries, however the latter include the largest countries in terms of population size (China, India, Indonesia, Brazil). The implications of these forces for the evolution of the world distribution of income will be derived in Section 5.

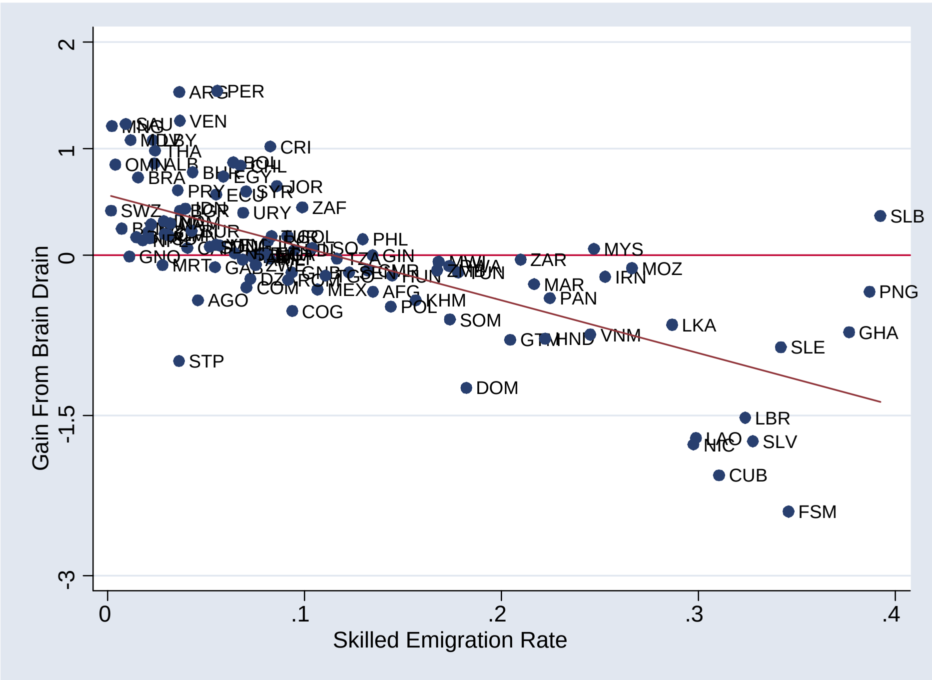

Figure 3: The inverse relationship between the emigration rate and the gains from skilled emigration. Source: Beine et al. (2007).

3 An Autarkic Economy

In this section we describe an economy when there is no migration. We consider an overlapping generations economy where in each period t output, Y_t, may be produced using two factors of production, skilled labor, H_t, and unskilled labor L_t, under perfect competition. The levels of H_t and L_t are determined endogenously by the optimal decisions of agents. Agents live for two periods and are endowed with one unit of labor in their second period. Agents are identical in all respects except for their level of ability, a, which we will assume is distributed uniformly over the unit interval, $[0, 1]$ and independently of the ability level of their parent. To become skilled an agent must be educated at a cost to their parents. If the agent becomes skilled, then agent i can supply $g_t + a_i$ efficiency units of skilled labor, where g_t is the rate of growth of frontier technology. Otherwise the agent remains unskilled and supplies one efficiency unit of unskilled labor. This

[3] The counterfactual simulation consists for each country to set skilled emigration rates at the level observed for its unskilled workers.

implies that an increase in the rate of technological progress will increase the number of efficiency units a skilled worker supplies and will *cetris paribus* increase the relative wage of skilled workers, as in Galor and Moav (2000) and Gould, Moav and Weinberg (2001).[4] The level of technology, A_t, in each period is given and technological progress from one period to the next is related to the level of human capital accumulation in the economy and so is also determined endogenously.

We first set out the production function and factor prices before analyzing agents' fertility and education decisions and the economy's dynamics.

3.1 Production and Factor Prices

In each period output is produced using two factors according to a constant returns to scale production function

$$Y_t = A_t H_t^{\alpha} L_t^{1-\alpha} \tag{1}$$

where H_t and L_t are the levels of skilled labor in the economy.

Defining $h_t \equiv H_t/L_t$, factor prices for each factor are given by their marginal products and hence

$$w_t^H = \alpha A_t h_t^{\alpha-1}; \qquad w_t^L = (1-\alpha) A_t h_t^{\alpha} \tag{2}$$

Thus we can write

$$\frac{w_t^L}{w_t^H} = \frac{(1-\alpha)}{\alpha} h_t \tag{3}$$

3.2 Individuals' Preferences and Budget Constraints

Individuals live for two periods and are identical in all respects except for their levels of ability, a, which we will assume is distributed uniformly over the unit interval, $[0,1]$ and independently of the ability level of their parent. In their first period of life they are dependent on their parent and may or may not become skilled. As described above, skilled individuals can supply $g_t + a_i$ efficiency units of skilled labor while those remaining unskilled can supply one efficiency unit of unskilled labor.

Individuals make optimal decisions over fertility, consumption and the training of their offspring (Becker (1981)). Following de la Croix and Doepke (2003), (2004), Galor and Mountford (2006) and Moav (2005) the preferences of a member of generation t (i.e. an individual who is born in period $t-1$) are defined over their consumption in period t, c_t, and the total income of their offspring, d_{t+1}, and are represented by the utility function.

$$u_t = c_t^{\theta} d_{t+1}^{1-\theta} \tag{4}$$

Individuals are assumed to be 'small' and so take the wage rate and growth rate in periods t and $t+1$ as given. Individuals optimally allocate their time between labor force participation and child rearing. Denoting the time required to bring up skilled offspring as, τ^s, and the time required to bring up unskilled offspring as, τ^u, where we assume that $0 < \tau^u < \tau^s < 1$, the budget constraint of a member i of generation t, is

[4] For simplicity this paper abstracts away from the 'erosion' effect of technological progress analyzed by Galor and Moav (2004). However an 'erosion effect', whereby a higher rate of growth of technological progress has a disruptive effect on current worker productivity while also having a positive effect on future productivity, could easily be included without qualitatively affecting the results of the paper by adding a factor $(1 - \varepsilon g_t)$ to the expressions for the efficiency units of labor supplied by skilled and unskilled workers.

$$c_t + w_t^i(\tau^s n_t^H + \tau^u n_t^L) \leq w_t^i \text{ for } \ i = \ s, \ u \tag{5}$$

where n_t^H and n_t^L are the measures of skilled and unskilled offspring respectively.

3.3 Optimization

Agents choose a measure of fertility, n.[5] For each offspring the parent must make an education decision. Since each family is a price taker in the labor market this amounts to choosing a threshold ability level, $a_{t+1}^\star$, such that all offspring with ability level above $a_{t+1}^\star$ will be educated.

A member i of generation t's optimization problem can thus be written as the following

$$\{c_t, n_t, a_{t+1}^\star\} = \arg\max c_t^\theta (n_t[w_{t+1}^H \int_{a_{t+1}^\star}^1 (g_{t+1} + a_i)di + w_{t+1}^L a_{t+1}^\star])^{1-\theta} \tag{6}$$

such that, for $i = s, u$,

$$c_t + n_t[\tau^s(1 - a_{t+1}^\star) + \tau^u a_{t+1}^\star]w_t^i = w_t^i \tag{7}$$

The optimization gives the following optimal decision rules for consumption and fertility.

$$c_t = \theta w_t^i \tag{8}$$

$$n_t = \frac{1-\theta}{\tau^s(1 - a_{t+1}^\star) + \tau^u a_{t+1}^\star} \tag{9}$$

3.3.1 The Education Decision

Optimization with respect to $a_{t+1}^\star$ implies that

$$\frac{(w_{t+1}^H(g_{t+1} + a_{t+1}^\star) - w_{t+1}^L)}{w_{t+1}^H \int_{a_{t+1}^\star}^1 (g_{t+1} + a_i)di + w_{t+1}^L a_{t+1}^\star} = \frac{\tau^s - \tau^u}{\tau^s(1 - a_{t+1}^\star) + \tau^u a_{t+1}^\star} \tag{10}$$

Equation (10) provides an intuitive condition for the parental educational choice. If the cost of rearing skilled and unskilled offspring were the same, then it would be optimal to educate offspring up to the point where the earnings of the marginal worker, with ability level $a_{t+1}^\star$, would be the same whether s/he became skilled or not. However the extra cost of rearing skilled offspring implies that parents will need to get a greater return from education (i.e., the opportunity costs of education is the possibility of increasing fertility by $(\tau^s - \tau^u)/(\tau^s(1 - a_{t+1}^\star) + \tau^u a_{t+1}^\star)$). Hence in equilibrium it must be the case that $w_{t+1}^H(g_{t+1} + a_{t+1}^\star)$ is greater than w_{t+1}^L.

[5] This is a sensible approach in the representative agent framework and is commonly used in the literature, see for example Becker (1981), de la Croix and Doepke (2003), (2004) and Doepke (2005).

3.4 Technological Progress

We assume, following Galor and Moav (2000), that the rate of technological progress, $g_t \equiv (A_t - A_{t-1})/A_{t-1}$ is an increasing function of the skill intensity of the economy.[6] That is:

$$g_t = \phi(h_{t-1}), \quad \text{where} \quad \phi'(h_{t-1}) > 0. \tag{11}$$

3.5 Equilibrium

In this section we show that there exists a unique equilibrium level of $a^{\star}_{t+1}$. We further show that an exogenous increase in the rate of growth decreases the equilibrium level of $a^{\star}_{t+1}$ and so increases the proportion of offspring becoming educated and reduces the rate of fertility. These properties of the equilibrium are set out in the following propositions.

Proposition 1 *In each period there a unique equilibrium level of $a^{\star}_{t+1}$.*

Proof. Using Figure 4 and equations (3) and (10). Equation (10) can be rearranged and simplified to give

$$\frac{w^L_{t+1}}{w^H_{t+1}} = \frac{(g_{t+1} + a^{\star}_{t+1})(\tau^s(1 - a^{\star}_{t+1}) + \tau^u a^{\star}_{t+1}) - (\tau^s - \tau^u)\int_{a^{\star}_{t+1}}^{1}(g_{t+1} + a_i)di}{\tau^s} \tag{12}$$

which is an increasing function of $a^{\star}_{t+1}$. This is the ratio of inverse factor supply functions and is labelled 'supply' in Figure 4.

Equation (3) can be written

$$\frac{w^L_{t+1}}{w^H_{t+1}} = \frac{(1-\alpha)}{\alpha}\frac{\int_{a^{\star}_{t+1}}^{1}(g_{t+1} + a_i)di}{a^*} \tag{13}$$

which is a decreasing function of $a^{\star}_{t+1}$. This is the inverse ratio of inverse factor demand functions and is labelled 'demand' in Figure 4.

Figure 4 plots both these conditions and illustrates the equilibrium level of $a^{\star}_{t+1}$ □

[6] The assumption of a positive relationship between growth and human capital accumulation is a common one in the literature, see for example Nelson and Phelps (1966), Findlay (1978), Barro and Sala-I-Martin (1995) and also Galor and Moav (2004), who provide an excellent survey of empirical support for this relationship.

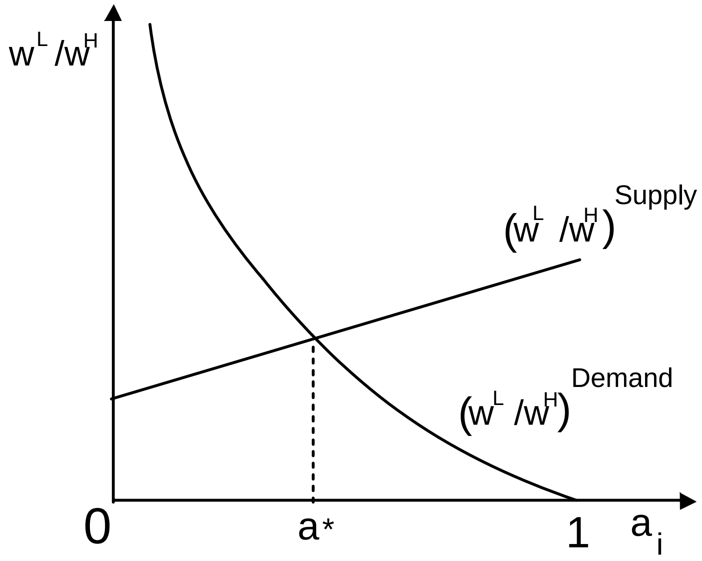

Figure 4: A unique equilibrium level of $a^{\star}_{t+1}$ under no migration.

Proposition 2 *An exogenous increase in the rate of growth, g_t, increases the equilibrium level of h_t.*

Proof. In equilibrium both equations (13) and (12) hold and so we can write after a little manipulation

$$\frac{(1-\alpha)}{\alpha}\frac{\int_{a^{\star}_{t+1}}^{1}(g_{t+1}+a_i)di}{a^{*}} - \frac{(g_{t+1}+a^{\star}_{t+1})(\tau^s(1-a^{\star}_{t+1})+\tau^u a^{\star}_{t+1})-(\tau^s-\tau^u)\int_{a^{\star}_{t+1}}^{1}(g+a_i)di}{\tau^s} = 0$$

Totally differentiating this expression with respect to g_{t+1} for every given level of a^* and rearranging gives the following

$$\frac{da^{\star}_{t+1}}{dg_{t+1}} = \frac{(1-\alpha)(1-a^{\star}_{t+1})/\alpha a^{\star}_{t+1} - \tau^u/\tau^s}{(1-\alpha)[a^{\star}_{t+1}(g_{t+1}+a^{\star}_{t+1})+\int_{a^{\star}_{t+1}}^{1}(g+a_i)di)]/\alpha + (\tau^s(1-a^{\star}_{t+1})+\tau^u a^{\star}_{t+1})/\tau^s}$$

Hence $\frac{da^{\star}_{t+1}}{dg_{t+1}} < 0$ iff $(1-\alpha)(1-a^{\star}_{t+1})/\alpha a^{\star}_{t+1} < \tau^u/\tau^s$. But given that $g_{t+1} \geq 0$ this will always be the case. Thus an increase in g_{t+1} reduces $a^{\star}_{t+1}$ and so increases h_{t+1}. □

Corollary 1 *An increase in the rate of growth, g_t, decreases the equilibrium level of n_t.*

Proof. This follows from equation (9) and proposition 2. □

3.6 Growth Dynamics In An Economy With No Migration

Proposition 2 shows that h_t is an increasing continuous function of g_t and from equation (11) g_{t+1} is an increasing function of h_t. Together these imply the following first order difference equation for the growth rate of technology,

$$g_{t+1} = \phi(h_t(g_t)) \tag{14}$$

where from above it follows that $dg_{t+1}/dg_t > 0$.

Since $dg_{t+1}/dg_t > 0 \; \forall g_t$ it follows that steady state levels of g_t will be either stable or unstable. Figure 5 depicts the case of multiple steady state equilibria. The case of a unique steady state equilibrium is depicted by placing the origin on the unstable steady state equilibrium.

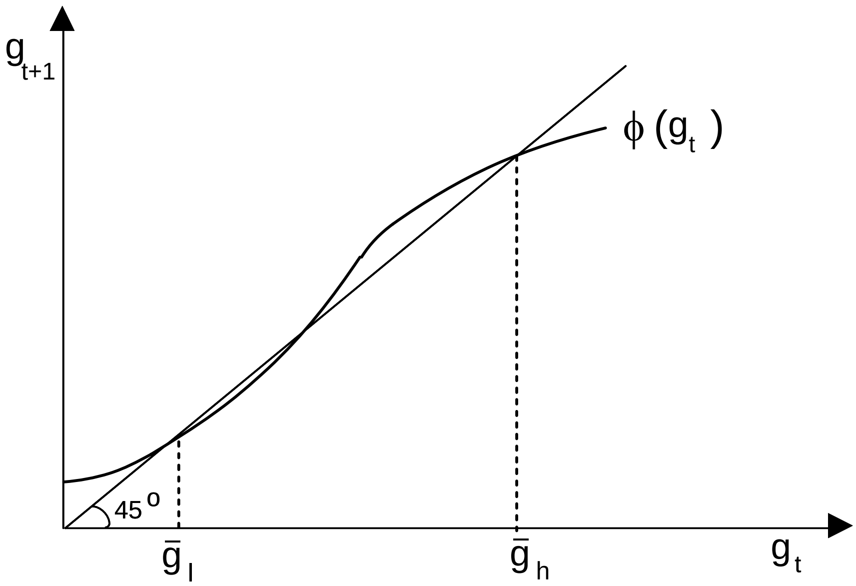

Figure 5: Growth Dynamics.

4 The Effect of Brain Drain Migration on Sending and Receiving Countries

In this section we will describe the effects of a permanent brain drain on both the sending and receiving economies. We show that a brain drain can increase the growth rate in both the sending and receiving economies. We do this for each economy separately. In section 5 we put the two economies together and analyze the joint evolution of the income and population in the world economy. We assume for simplicity that migration is limited to a proportion, x%, of the receiving economy's working population.[7]

4.1 The Receiving Economy

The permanent immigration of skilled workers to an economy will have both static and dynamic effects on the receiving economy. The static effect reduces the proportion of indigenous agents who choose to become skilled workers and this *ceteris paribus* increases the fertility rate. The dynamic effect is for the receiving economy to converge to a new higher steady state growth rate. This has a positive effect on the proportion of agents who choose to become skilled workers and a

[7] This is a simplifying assumption but one which, we conjecture, would be the equilibrium policy in a simple median voter political economy model of the receiving economy where agents also receive utility from an exogenous public good such as land and where this utility is decreasing in the level of the population.

negative effect on the fertility rate. Thus if the dynamic effect outweighs the static effect, the long run effect of the permanent immigration of skilled workers will be a raised level of human capital accumulation, a lower fertility rate and an increase in the growth rate in the receiving economy. We demonstrate these results in the following subsections

4.1.1 Static Effects

The immigration of skilled workers to an economy will, *ceteris paribus,* decrease the equilibrium wage of skilled workers. This will, *ceteris paribus,* reduce the proportion of indigenous agents who choose to become skilled workers and so increase the fertility rate. Nevertheless the proportion of skilled labor in the economy, h, will increase as a result of the skilled immigration. This is shown in the following lemma and corollary where we denote the equilibrium ratio of skilled to unskilled labor after the immigration of M skilled workers, as $h^A_{BD}(M)$, where M is $x\%$, of the receiving economy's working population

Lemma 1 *The immigration of M skilled workers in the advanced economy A, ceteris paribus increases the equilibrium ratio of skilled to unskilled labor, with $h^A_{BD}(M)$ an increasing function of M.*

Proof. Using Figure 6 and equations (13) and (12). An inflow of M skilled workers written means that the equilibrium factor price ratio becomes

$$\frac{w^L_{t+1}}{w^H_{t+1}} = \frac{(1-\alpha)}{\alpha} \frac{\int_{a^\star_{t+1}}^1 (g_{t+1} + a_i)di + M(g_{t+1} + \overline{a}_M)}{a^*_{t+1}} \tag{15}$$

where $\overline{a}_M$ is the average ability level of the immigrating workers. Thus the factor price relationship (13) shifts upward. i.e. the increased supply of skilled labor will increase the equilibrium level of w^L_{t+1}/w^H_{t+1} for every given level of $a^\star_{t+1}$.

The relationship between w^L_t/w^H_t and the optimal threshold level of $a^\star_{t+1}$ for indigenous workers is not affected by the inflow of skilled workers. Thus as Figure 6 shows, in equilibrium the optimal level of at $a^\star_{t+1}$ rises but so does w^L_t/w^H_t. Since $w^L_t/w^H_t = ((1-\alpha)/\alpha)h_t$ this implies that h_t also rises in equilibrium. □

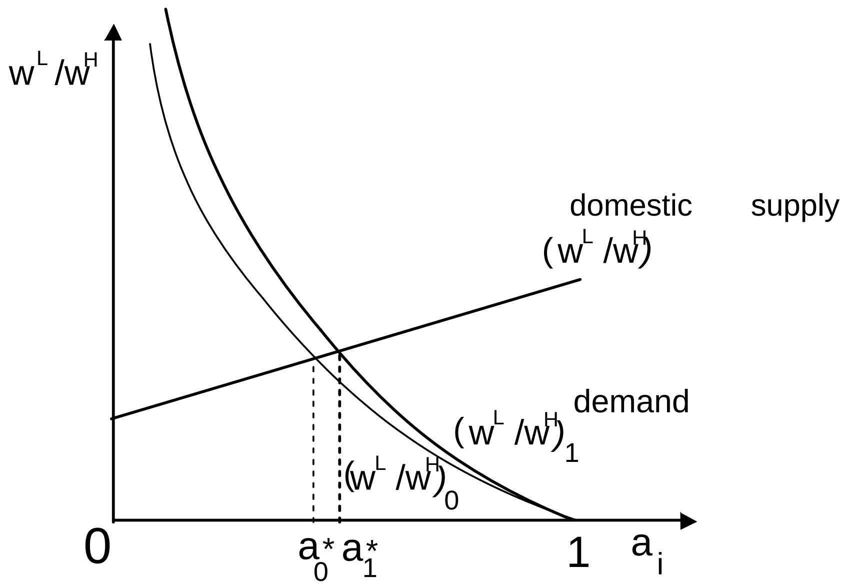

Figure 6: For a given growth rate, skilled immigration reduces the proportion of indigenous agents becoming skilled.

Corollary 2 *The immigration of skilled workers in the advanced economy A, ceteris paribus increases the fertility rate,* n_t*, of economy A.*

Proof. From lemma 1 we know that an inflow of skilled workers will increase the optimal level of $a^{\star}_{t+1}$ and hence from equation (9) the corollary follows. □

4.1.2 Dynamic Effects

For every given level of g_t, lemma 1 shows that the inflow of $x\%$ skilled workers will increase the equilibrium level of h_t. This will increase g_{t+1} and so may lead ultimately to a fall in fertility in the receiving economy as the following lemma and corollary demonstrate.

Lemma 2 *The permanent immigration of* $x\%$ *skilled workers in the advanced economy A, increases the equilibrium growth rate of economy A.*

Proof. The inflow of $x\%$ skilled workers increases the equilibrium level of h_t. This implies that the dynamic equation now becomes $g_t = \phi(h_{t-1}(g_{t-1}, x))$ where h_{t-1} is an increasing function of both arguments. Thus as depicted in Figure 7, a permanent immigration of $x\%$ skilled workers each period shifts up the function $\phi(h_{t-1}(g_{t-1}, x))$ relative to $\phi(h_{t-1}(g_{t-1}, 0))$ and so increases the steady state rate of growth. □

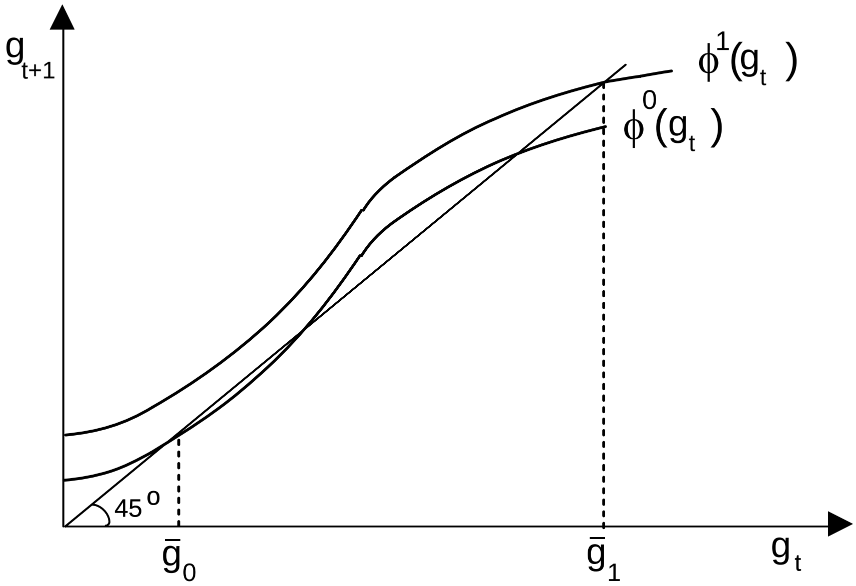

Figure 7: Dynamic effects of Brain Drain Immigration.

This implies that if the growth effect is sufficiently strong, permanent skilled immigration can increase human capital levels and reduce the fertility levels in the receiving economy. This is shown in the following corollary

Corollary 3 *If the growth effect from permanent skilled immigration is sufficiently strong, then permanent skilled immigration can increase human capital levels and reduce the rate of population growth in the receiving economy*

Proof. By example. Consider the economy where $\alpha = 1/3, \tau^s = 0.95, \tau^u = \tau^s/2, \theta = 1/3$. Then if $g = 0.01$ then $a^{\star}_{t+1} = 0.819$ and $n = 1.188$. If there is a 1% inflow of skilled immigrants each period and g remains at 0.01 then $a^{\star}_{t+1}$ rises to 0.820 and n rises to 1.189. If however there is a 1% inflow of skilled immigrants each period and g rises to 0.5 then $a^{\star}_{t+1}$ falls to 0.817 and n falls to 1.186. □

When the growth effect on fertility of a permanent brain drain outweighs the static effect so that the long run rate of population growth falls, we shall say that Condition A is satisfied

Condition A *A permanent skilled immigration reduces the rate of population growth in the receiving economy*

It is important to note two things about condition A. Firstly it can be interpreted as a non-agglomeration condition i.e. if it does not hold then by definition the sending economy cannot, *ceteris paribus*, remain large relative to an initially small receiving economy. While the contrary is an interesting possibility, it does not appear to be relevent for the world economy as the rate of population growth in sending economies is typically much higher than in the receiving economies.

We therefore choose not to focus on this possibility. Secondly, one should note that condition A is only a sufficient condition for the sending economy to remain large relative to the receiving economy. If the sending economy has a higher autarkic rate of population growth, due perhaps to the existence of multiple steady state equilibria in equation (11) or differences in the relative costs of raising children across economies due to exogenous differences in institutions, then condition A need not hold for the sending economy to remain large relative to the receiving economy under brain drain migration patterns. This is discussed in section 5.

4.2 The Sending Economy

The emigration of skilled workers may increase or decrease the growth rate in the sending economy. The loss of emigrating skilled agents will *ceteris paribus* reduce the level of h_t but the possibility of emigration will also increase the incentive to accumulate human capital. In this section we demonstrate that the latter effect dominates the former if emigration is limited and the wage gain from emigration is sufficiently high. This case has been analyzed in the literature before, see for example Mountford (1997) and Kanbur and Rapoport (2005), and the same intuition applies here.

We will assume that the sending economy takes the immigration policy of the receiving economy as given, so that each level of $x\%$ of the working population of the receiving economy translates into a maximum number, M, of emigrants from the sending economy. We will also assume that the ability to emigrate is randomly allocated in the event that there is an excess of qualified candidates and so the probability of successful emigration, p, is equal to $M_t/(1-a^\star_{t+1})N_t^B$ where N_t^B is the population of the sending economy in period t.[8]

The factor market equilibrium condition under emigration now becomes

$$\frac{w_{t+1}^{L,B}}{w_{t+1}^{H,B}} = \frac{(1-\alpha)}{\alpha}\left[\frac{\int_{a^\star_{t+1}}^{1}(g_{t+1}+a_i)di - M(g+(1+a^\star_{t+1})/2)}{a^*}\right] \tag{16}$$

where $(1+a^\star_{t+1})/2 = \overline{a}_M$ is the average ability level of an emigrant and $w_{t+1}^{H,B}$ and $w_{t+1}^{L,B}$ are the skilled and unskilled wages in the sending economy B.

The individual agents' decision problem is also changed by the possibility of emigration. A member i of generation t now optimizes the following, taking factor prices and p as given.

$$c_t^\theta(n_t[(pw_{t+1}^{H,A}\int_{a^\star_{t+1}}^{1}(g_{t+1}^A+a_i)di + (1-p)w_{t+1}^{H,B}\int_{a^\star_{t+1}}^{1}(g_{t+1}^B+a_i)di) + w_{t+1}^{L,B}a^\star_{t+1}])^{1-\theta} \tag{17}$$

where $w_{t+1}^{H,A}$ is the skilled wage in the receiving economy, economy A. This expression is maximized subject to the same budget constraint, equation (7), and gives rise to the following optimality condition for $a^\star_{t+1}$,

$$\begin{aligned}\frac{w_{t+1}^{L,B}}{w_{t+1}^{H,B}} &= \frac{(p(w_{t+1}^{H,A}/w_{t+1}^{H,B})(g_{t+1}^A+a^\star_{t+1}) + (1-p)(g_{t+1}^B+a^\star_{t+1}))(\tau^s(1-a^\star_{t+1})+\tau^u a^\star_{t+1})}{\tau^s} \\ &\quad - \frac{(\tau^s-\tau^u)(p(w_{t+1}^{H,A}/w_{t+1}^{H,B})\int_{a^\star_{t+1}}^{1}(g_{t+1}^A+a^\star_{t+1}) + (1-p)\int_{a^\star_{t+1}}^{1}(g_{t+1}^B+a_i)di)}{\tau^s}\end{aligned} \tag{18}$$

[8] We are assuming that the receiving economy can only observe the level of education of an agent not his/her level of ability, a_i.

Note that since $w^{H,A}_{t+1} > w^{H,B}_{t+1}$ this relationship implies a higher level of $w^{L,B}_{t+1}/w^{H,B}_{t+1}$ for every level of $a^{\star}_{t+1}$ than that in equation (12) for when there is no migration.

Lemma 3 *The possibility for M skilled workers to emigrate from the less advanced economy, B, to the advanced economy A, increases the proportion of agents who choose to become skilled in economy, B.*

Proof. Using equations (16) and (18) and Figure 3. Noting that an increase in M shifts down the factor demand relationship for $w^{L,B}_{t+1}/w^{H,B}_{t+1}$ in equation (16) and that the factor supply relationship for $w^{L,B}_{t+1}/w^{H,B}_{t+1}$ in equation (18) is always above that for when there is no migration in equation (12) then using Figure 3 it follows that the equilibrium level of a^* will be lowered by Brain Drain emigration. □

Corollary 4 *The ability of M skilled workers to emigrate from the less advanced economy, B, decreases the fertility rate of economy B*

Proof. From Lemma 3 we know that an outflow of M skilled workers will decrease the optimal level of $a^{\star}_{t+1}$ in economy B and hence from equation (9) the corollary follows. □

Whether the emigration of M skilled workers raises the equilibrium level of h in economy B depends on whether the positive effect of an increase in human skill accumulation is stronger than the negative effect of emigration. In the following proposition we show that if $w^{H,A}_{t+1}$ is sufficiently high for a given level of M then the level of h in economy B will increase.

Lemma 4 *The possibility for M skilled workers to emigrate from the less advanced economy B to the advanced economy A increases the equilibrium level of h_t in economy B if the skilled wage in the advanced economy, $w^{H,A}_{t+1}$, is sufficiently large*

Proof. The factor demand relationship for $w^{L,B}_{t+1}/w^{H,B}_{t+1}$ in equation (16) does not depend on $w^{H,A}_{t+1}$ and is downward sloping in the $(w^{L,B}_{t+1}/w^{H,B}_{t+1}, a^*)$ space. Whereas the factor supply relationship for $w^{L,B}_{t+1}/w^{H,B}_{t+1}$ in equation (18) does depend on $w^{H,A}_{t+1}$. Equation (18) can be rearranged to give,

$$\frac{w^{L,B}_{t+1}}{w^{H,B}_{t+1}} = \frac{(p(w^{H,A}_{t+1}/w^{H,B}_{t+1})[(g^{A}_{t+1}+a^{\star}_{t+1})(\tau^{s}(1-a^{\star}_{t+1})+\tau^{u}a^{\star}_{t+1})-(\tau^{s}-\tau^{u})\int_{a^{\star}_{t+1}}^{1}(g^{A}_{t+1}+a^{\star}_{t+1})di]}{\tau^{s}} + \frac{(1-p)[(g^{B}_{t+1}+a^{\star}_{t+1})(\tau^{s}(1-a^{\star}_{t+1})+\tau^{u}a^{\star}_{t+1})-(\tau^{s}-\tau^{u})\int_{a^{\star}_{t+1}}^{1}(g^{B}_{t+1}+a^{\star}_{t+1})di)}{\tau^{s}} \quad (19)$$

which implies that an increase in $w^{H,A}_{t+1}$ increases this relationship and so increases the equilibrium ratio $w^{L,B}_{t+1}/w^{H,B}_{t+1}$ for a given level of M. □

5 The Evolution of the World Economy

In this section we derive the joint evolution of the world distribution of income per capita and population and show how brain drain migration patterns can affect this evolution. We assume a world economy made up of two economies A and B where the technological level in economy A is higher than that in economy B, i.e. $A^{A}_{t} > A^{B}_{t}$. We begin in section 5.1 by describing the dynamics of technological diffusion in the world economy. In section 5.2 we then describe the evolution of the world economy when there is no migration. We show when there is no migration that if economies A and B are identical and tending to the same steady state growth rate, then the world distribution of population and income will be stable. However if economies are tending towards different steady state equilibria, due to innate differences across countries or multiple steady states, then although the world distribution of income per capita across economies will be stable, the world distribution of population will diverge as poorer economies grow large in terms of population. In section 5.3 we analyze three scenarios for the effect of the brain drain on the world distribution of income and show how the brain drain can potentially increase divergence in the world economy. In contrast to the case in section 5.2 with no migration, the brain drain may cause two identical economies that would otherwise converge to the same steady state growth rate, to diverge from one another in terms of population. We also show that if the brain drain increases the level of human capital in the sending economy sufficiently, it is possible for the brain drain to enable an economy on a lower steady state growth path to catch up with an economy on a higher steady state growth path. Finally we demonstrate the possibility for a brain drain to decrease the skill ratio in the sending economy. We argue that the current evolution of the world income distribution as described by Sala-I-Martin (2006) can be seen as a combination of these three scenarios. Some large economies with low skilled emigration rates may well be on a catching up trajectory while other economies may be losers or only temporary gainers.

5.1 Technological Diffusion in the World Economy

We assume, in the spirit of Findlay (1978) and Nelson and Phelps (1966), that frontier technology diffuses from the most advanced economy, A, to the less advanced economy, B, with a lag.[9] In keeping with the discussion in section 1 we assume that this diffusion of technology raises the level of technology and increases the productivity of both skilled and unskilled labor in an unbiased manner. This contrasts with the growth of frontier knowledge which following Galor and Moav (2000) is assumed to be skill biased.[10] We follow Findlay (1978) and Nelson and Phelps (1966) in assuming that the rate of diffusion is positively related to the size of the gap between the technological levels in the two economies, $A^A - A^B$, that is[11]

$$A_t^B = A_{t-1}^B(1 + g_t^B) + \lambda(A_{t-1}^A - A_{t-1}^B) \tag{20}$$

where $\lambda > \overline{g}^B$. As economies A and B tend to their steady states, their growth rates g_t^A and g_t^B will tend to their constant steady state growth rates, $\overline{g}^A$ and $\overline{g}^B$. It is possible to extend this formulation by making λ depend on h_{t-1}^B or on the level of brain drain Migration, M. This is discussed in section 5.3.

5.2 Evolution of the World Economy Under No Migration

In this section we show that if economies A and B are identical and tending to a unique steady state growth rate then the world distribution of income will be stable. This is shown in proposition 3. However if economies are tending towards different steady state equilibria, then although the

[9] See Keller (2001) for evidence on the importance of technological diffusion for technology growth in developing economies.

[10] One can allow for diffused technological growth to be skill biased so long as the skill bias for an economy whose technological growth is strongly dependent on international technology diffusion is significantly less than that for an economy whose technological growth is completely due to increasing frontier technology.

[11] See Basu and Weil (1998) for a discussion of the issue of different types of advances in technology and on the importance of appropriate factor endowments for technology diffusion.

world distribution of income per capita across economies will be stable, the world distribution of population will diverge as poorer economies grow large in terms of population.

Proposition 3 *If economies A and B are identical except for their initial levels of population and technology and are converging to the same steady state rate of growth, i.e.* $\overline{g}_t^A = \overline{g}_t^B$*, then the world will converge to a stable equilibrium, with a stable income distribution and a constant proportion of the world population in each economy.*

Proof. By assumption both countries will have the same steady state equilibrium growth rate of technology, i.e. $\overline{g}^A = \overline{g}^B$ and so will have the same equilibrium levels of human capital accumulation and fertility. When both economies have attained their steady state growth rates, equation (20) can be iterated forward to show that in the limit $A_t^A = A_t^B$ and so there is no tendency for levels of technology in the two economies to diverge, thus the proposition follows. □

Proposition 4 *If economies A and B are tending to different steady state rates of growth where* $\overline{g}_t^A > \overline{g}_t^B$ *but are otherwise identical, then the long run world distribution of income per capita across economies will be stable but the world distribution of population will be divergent as poorer economies grow large in terms of population.*

Proof. When both economies have attained their steady state growth rates equation (20) can be iterated forward to show that in the long run the technological level of economy B tends to a constant fraction of that of economy A,

$$A_t^B = \frac{\lambda}{\lambda + \overline{g}^A - \overline{g}^B} A_t^A \tag{21}$$

Thus the ratio of the technology levels in the two economies will be stable. Given that both economies will also tend to a steady state level of g and h this implies that the ratio of per capita income in the two economies will also be constant. The fertility rates in the two economies, however will be different since $\overline{g}_t^A > \overline{g}_t^B$. From proposition 2 and lemma 1 the rate of population growth in economy B will be higher than that in economy A and so economy B will grow large in terms of population. □.

We illustrate the evolution of the world economy described in proposition 4 below in Figure 8. The first frame of Figure 8 shows the initial distribution of income in the world economy of two economies which differ only in their autarkic steady state growth rate[12]. The distribution is normed by setting the wage of unskilled workers in the advanced economy to equal 100 in each period. The second frame demonstrates the divergence of the world economy over time and shows the world distribution of income after several periods, one hundred in this example. It shows that although the ratio of skilled to unskilled wages within and across economies has not changed, the numbers of people in the less advanced economy has grown by more than in the advanced economy and hence that the world distribution of income is becoming skewed towards the income in the less advanced economy.

[12]In this simulation $\alpha = 1/3, \theta = 1/3$, $\tau^{s,A} = \tau^{s,B} = 0.85, \tau^{u,A} = \tau^{u,B} = 0.6$, and $N^A = N^B = 10000$. Finally the dynamic equations are set such that economy A is above a dynamic growth threshold so that $g_{t+1}^A = (h_t^A)^{0.5}$ while economy B is below a growth threshold so that $g_{t+1}^B = (h_t^B)^{0.5}/1000$ i.e. frontier growth in economy B is practically zero. The technological diffusion parameter is set to follow $\lambda = 0.3 + h_{t-1}^B$ and the initial levels of technology in the two economies are $A^A = 10$ and $A^B = 4.4$.

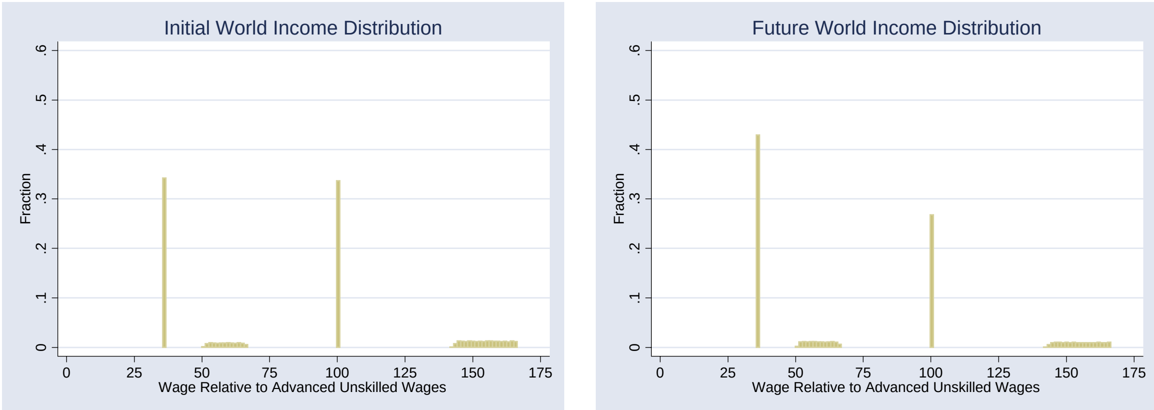

Figure 8. The evolution of the world income distribution under no migration when the poorer economy has a lower autarkic steady state growth rate

5.3 Evolution of the World Economy Under Brain Drain Migration

In this section we focus on three scenarios to illustrate the potential effects of the brain drain on the world distribution of income. We first show how a brain drain can cause divergence in the world economy by causing two economies that would otherwise converge to the same steady state level of income and rate of population growth to diverge. We next show that if the brain drain increases the level of human capital in the sending economy sufficiently, it is also possible for the brain drain to enable an economy on a lower steady state growth path to catch up with an economy on a higher steady state growth path. Finally we also demonstrate the possibility for a brain drain to decrease the skill ratio in the sending economy. While the early literature focused on the last of these scenarios (i.e. a brain drain being detrimental to the sending economy), the evidence presented above in section 2 suggests that all three scenarios may be present in the world economy.

5.3.1 Scenario 1: Divergence with human capital gains in both economies

When there is brain drain migration, proposition 3 no longer holds and so two identical economies that would otherwise converge to the same steady state equilibria can converge to different steady state equilibria as a result of brain drain migration. In this case the brain drain will have *caused* a divergence in the world economy and will have increased world inequality of income. It should be stressed however that in this case the brain drain will also have increased the world rate of growth and so increased long run income levels in all economies of the world. This is demonstrated in the following proposition and corollaries:

Proposition 5 *If economies A and B are identical except for their levels of population and technology, where $A_t^A > A_t^B$, the probability of emigration is sufficiently low and condition A holds, then the equilibrium of the world economy will be stable and have the following properties:*

(i) there is a permanent brain drain migration of agents from economy B to economy A

(ii) the level of output per capita in economy B will be a constant fraction of that in economy A

(iii) the rate of population growth will be higher in economy B than in economy A.

Proof. As the probability of emigration is sufficiently small, from equation (18), economy B tends to its autarkic equilibrium. From lemma 2 this implies that $g^A > g^B$. If condition A is satisfied then economy A's rate of population growth will be below that of economy B. Thus the equilibrium is stable: economy A will maintain its lead in frontier technology while economy B will maintain its lead in population size. □

Corollary 5 *Income inequality between countries is increasing in the rate of brain drain migration in the neighborhood of the equilibrium described in proposition 5.*

Proof. Economy B is close to its autarkic equilibrium and so h_t^B can be treated as a constant and hence g^B and λ are constants also. Once economy A is in the neighborhood of its new steady state then h_t^A and g^A can also be treated as constants and hence equation (21) holds. It follows that the ratio of A_t^B/A_t^A declines when g^A increases. □

Corollary 6 *World growth is increasing in the rate of brain drain migration in the neighborhood of the equilibrium described in proposition 5.*

Proof. Growth in economy A will increase from lemma 2 and growth in economy B will increase from the technology diffusion equation (20) . □

Finally one should emphasize that condition A is a sufficient but not a necessary condition for such an equilibrium to be locally stable. If economies A and B differ for exogenous reasons, such as differences in growth institutions or multiple steady state equilibria, so that under no migration $g^A > g^B$, then it follows from corollary 1 that the rate of population growth in economy B is greater than that in economy A. Brain drain migration will thus reinforce the pattern of relative technological growth rates but, if condition A does not hold, it will work against the pattern of relative population growth rates. However as long as the population growth rate in economy B is greater than that in economy A then the equilibrium will still be stable.

To illustrate this we simulate the evolution of the world income distribution for the case where the initial technological levels in the two economies are $A^A = 10$ and $A^B = 3.33$, the level of immigration into A is 0.1% of A's working population, $\alpha = 1/3, \theta = 1/3$, $\tau^{s,A} = 0.85, \tau^{u,A} = 0.6, \tau^{s,B} = 0.95, \tau^{u,B} = 0.5, N^A = 10000$ and $N^B = 10000$. Finally the dynamic equations are set such that economy A is above a dynamic growth threshold so that $g_{t+1}^A = (h_t^A)^{0.5}$ while economy B is below a growth threshold so that $g_{t+1}^B = (h_t^B)^{0.5}/1000$ (i.e., frontier growth in economy B is practically zero). The technological diffusion parameter is set to follow $\lambda = 0.3 + h_{t-1}^B$.

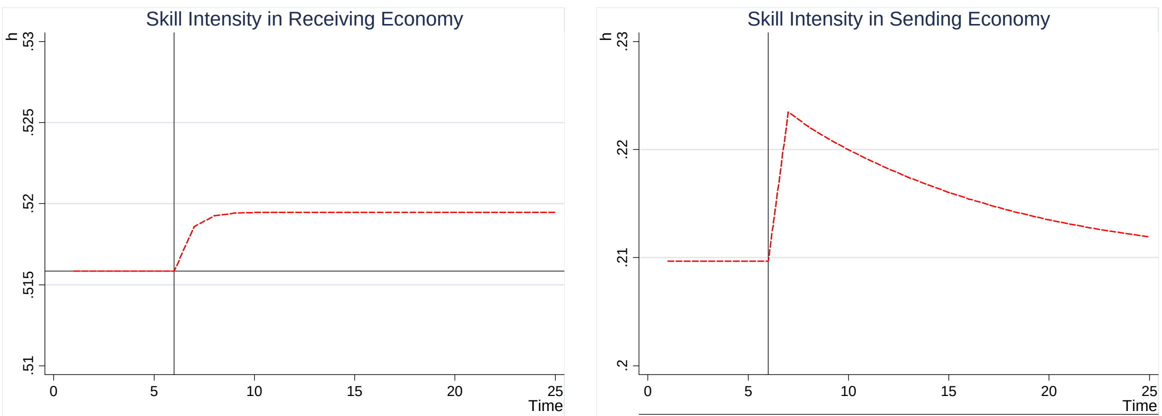

Figure 9 A brain drain with increased human capital accumulation in both the receiving and sending economies but with divergence in the world economy as the sending economy grows large in population.

Brain drain migration begins in period 6. The simulations show that the brain drain causes the skill intensity to rise in economy A which quickly converges to a new steady state. The skill intensity in economy B also rises as the incentive to invest in human capital is high since the technological difference between A and B is large while the actual numbers leaving economy B is small. This situation is stable as the population growth rate of economy B is higher than that of economy A. The incentive to invest in human capital in economy B falls as the probability of successfully emigrating falls. In the limit economy B returns to its autarkic skill intensity while economy A remains at its new higher skill intensity. Although in the long run world inequality will have been increased, as Figure 9 shows, it could well be that in short run, the brain drain will have caused a temporary decrease in world inequality due to the increased skill accumulation in the sending economy. Despite increasing world inequality, by increasing the world rate of growth, the brain drain will also have increased the long run income of all agents in the world via technological diffusion.[13]

5.3.2 Scenario 2: Catching Up Dynamics

It is also possible for the brain drain to enable an economy on a lower steady state growth path to catch up with an economy on a higher steady state growth path. Consider the case depicted in Figure 10 where in autarky economy A has a higher steady state growth rate than economy B. Supposing that economy A and B are precesily the same except that Economy A is above a threshold level of h which implies a higher steady state level of growth. If the brain drain increases the level of h in economy B so that it rises above the threshold then economy B will converge to a new higher steady state rate of growth. This is the case shown in Figure 10.[14]

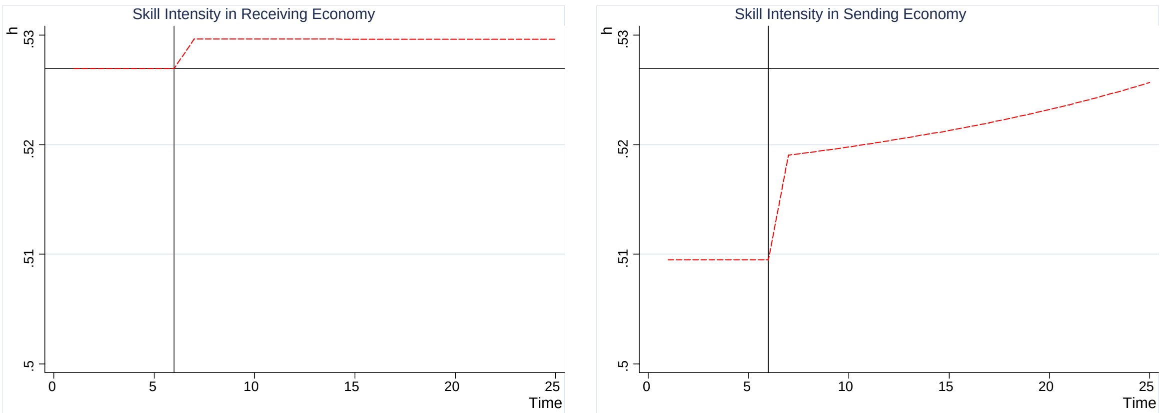

Figure 10 Catching up dynamics in the sending economy due to brain drain migration.

5.3.3 Scenario 3: Human Capital Depletion in the Sending Economies

The brain drain can also reduce the skill intensity in the sending economy. This case is depicted in Figure 11. As implied by lemma 4, if the technological gap between economies is small, as is

[13] This contribution of brain drain migration to a global public good (knowledge, technological progress) was emphasized by Grubel and Scott (1966).

[14] In this simulation $\alpha = 1/3, \theta = 1/3$, $\tau^{s,A} = \tau^{s,B} = 0.85, \tau^{u,A} = \tau^{u,B} = 0.6$, and $N^A = N^B = 10000$. Finally the dynamic equations are set such that economy A is above a dynamic growth threshold so that $g^A_{t+1} = 0.75$ while economy B is below a growth threshold so that $g^B_{t+1} = 0.7$ and the technological diffusion parameter is set to follow $\lambda = 0.7$.

the case between developed economies, there is little extra incentive to accumulate human capital in the sending economy in order to migrate. Nonetheless, skilled agents will still emigrate since wages are higher in the more advanced economy hence the sending economy will experience a reduction in its equilibrium skill intensity.

A counterfactual aspect of the model is that when the technological gap between sending and receiving countries is large, then human capital depletion does not occur except at very high probabilities of successful migration where the population of the sending economy declines significantly. Nevertheless, human capital depletion would still occur in less advanced economies at lower rates of skilled emigration if the extra incentive to accumulate human capital in order to migrate was counteracted by the inability of the sending economy to easily expand its education provision. This could be due, for example, to credit constraints on human capital and migration investment, as we suggested in Section 2 to explain the lower skilled emigration rates in the poorest countries.[15]

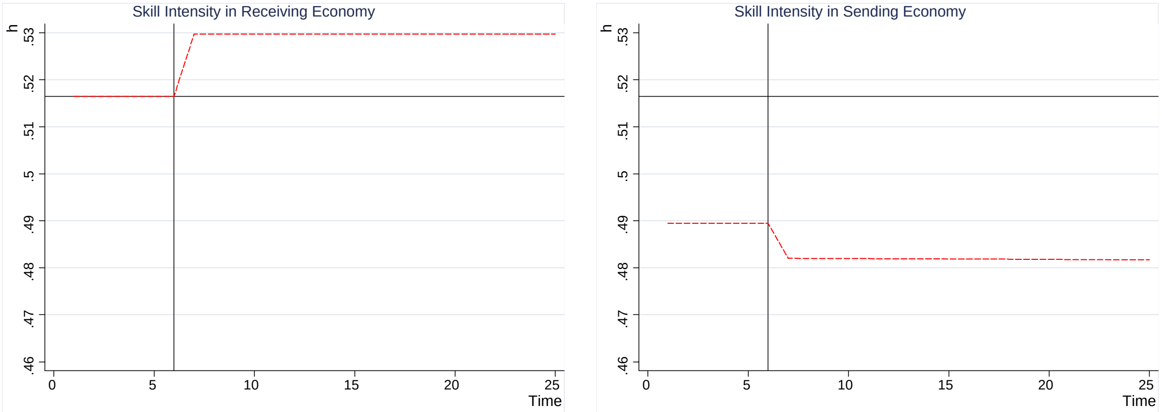

Figure 11 Human Capital Depletion in the sending economy due to brain drain migration

[15] In this simulation $\alpha = 1/3, \theta = 1/3$, $\tau^{s,A} = 0.85, \tau^{u,A} = 0.6$, $\tau^{s,B} = 0.798, \tau^{u,B} = 0.539$,and $N^A = N^B = 10000$. Finally the dynamic equations are set such that economy A is above a dynamic growth threshold so that $g^A_{t+1} = 0.72$ while economy B is below a growth threshold so that $g^B_{t+1} = 0.7$ and the technological diffusion parameter is set to follow $\lambda = 0.7$.

6 Conclusion

This paper develops a model for the joint evolution of the world distribution of income per capita and the world distribution of population. It shows that while the distribution of income per capita of economies in the world will be stable in the long run, the world distribution of income may be divergent due to differences in population growth rates. Brain drain migration may exacerbate this potential for divergence in the world economy, although it should be stressed that while brain drain migration patterns can increase inequality in terms of income per capita between countries and skew the world distribution of income towards the poorer economies with higher rates of population growth, the brain drain is also likely to increase the growth rate of income per capita in both the sending and receiving economies.

The paper shows that the emergence of the brain drain as a dominant pattern of international migration is likely to reinforce the current evolution of the world income distribution as described by Sala-I-Martin (2006) through a combination of the three scenarios described in section 5. In the short run it is possible for world inequality to fall due to rises in GDP per capita in large developing economies with low skilled emigration rates as in scenarios 1 and 2, but in the long run, inequality in the world distribution of income may increase as relatively poor countries grow large in terms of population.

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