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Do brain drain and poverty result from coordination failures?

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Abstract The bidirectional causal links between high-skilled emigration and poverty can give rise to multiple equilibria and coordination failures. Two countries sharing identical characteristics may end up in either a "low poverty-low brain drain" equilibrium or in a "high poverty-high brain drain" equilibrium. In this paper, we build a model which endogenizes high-skilled emigration and economic performances in order to derive the conditions under which multiplicity occurs. After identifying country-specific parameters, we find that in the majority of developing countries, the best equilibrium is selected and that the observed brain drain is inevitable. In 22 small developing countries however, the worse equilibrium prevails, implying that poverty and brain drain are increased by coordination failure. These countries require appropriate development policies, such as a temporary subsidization of the repatriation of their high-skilled expatriates. Our results are robust to the inclusion of a brain gain mechanism.

Keywords Brain drain · Development · Multiple equilibria · Coordination failure

JEL Classification F22 · O11 · O15 · C62

1 Introduction

High-skilled (e)migration (i.e. the brain drain) from developing to developed countries is on the rise. The number of highly educated immigrants living in the developed countries increased by 70% during the 1990s and doubled for those originating from developing countries (see Docquier et al. 2009). This phenomenon has motivated the development of a large

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literature, which examines the links between high-skilled emigration and economic development. Although causality is bidirectional, those links investigated to date only consider a single direction.

A first strand of literature is essentially empirical and endogenizes the size and composition of migration flows. It shows that a lack of economic growth, rampant poverty and correlates of poverty (bad institutions, discriminations, political repression, lack of freedoms, etc.) motivate people to flee their own country; with highly skilled workers found to be far more responsive to economic push-pull factors when compared to the low skilled. Docquier et al. (2007) for example, show that the brain drain increases with political instability and the degree of fractionalization, but decreases with the level of development at origin. Grogger and Hanson (2011) and Belot and Hatton (2008) find that a simple model of income maximization can account for positive selection (higher emigration rates for the skilled) and positive sorting (positive effect of wage differentials on the share of skilled in bilateral migration). Rosenzweig (2007, 2008) demonstrates that skill-price differentials between countries regulate the bilateral flows of students. In these studies, country characteristics are usually treated as exogenous.

A second strand of literature focuses upon the effect of the brain drain on the economic performance of origin countries. Earlier studies (referred to as the 'traditional' literature) have long considered the brain drain as a curse for the source country. For example, Bhagwati and Hamada (1974) or McCullock and Yellen (1975, 1977) stress the negative impact of the brain drain for developing countries. Later, relying on the existence of externalities linked to human capital, the endogenous growth framework offered an appropriate environment to reinforce the traditional view (see Miyagiwa 1991; Haque and Kim 1995). The more recent literature (referred to as the 'brain gain' literature) suggests that the emigration of skilled workers can induce additional investments in education in sending countries leading to positive feedback effects (Mountford 1997; Stark et al. 1998; Beine et al. 2001).[1] In these 'traditional' and 'brain gain' models, the endogeneity of the emigration probability is usually ignored.

Our goal is to combine these two strands of literature to explore the interdependencies between high-skill emigration decisions and poverty in developing countries. We first consider the 'traditional' view and disregard 'brain gain' mechanisms. The bidirectional causal link between emigration and poverty induces both vicious and virtuous circles, due to strategic complementarities in individual emigration decisions. Indeed, when a significant brain drain movement is initiated, it might have adverse effects on the economy begetting yet further waves of high-skill emigration.[2] The converse also holds true, when a mechanism of net return prevails, it provides incentives to further waves of returnees.[3] These multiplier effects open the possibility of multiple equilibria. This implies that two countries sharing identical

[1] In particular, prospects of emigration to countries where skills are rewarded more generously can lead not only to increased investment in skills before migration (ex-ante), but also to a larger higher-educated domestic population after migration (ex-post).

[2] History has shown that massive and rapid outflows of high-skill people can generate negative economic impacts that are difficult to reverse. The case of Iran has been comprehensively discussed in newspaper articles (e.g. Torbat 2002). The Iranian brain drain started in 1978–1979 during the Cultural Revolution. In Ireland, a wave of mass emigration of university and college graduates was observed in the 1980s; it sucked the marrow out of Ireland's social and economic development. A more recent example is the one observed in the former Soviet states (such as Russia and Moldova) in which many scientists and academics went abroad following independence.

[3] Cases of virtuous circles are also documented. In the 1980s, the return of educated elites and high-skill workers played a crucial role in Taiwan's economic takeoff. In Ireland, the major fiscal reforms embraced after 1987 attracted foreign companies and investments; a huge movement of return migration operated and contributed to the Irish remarkable growth performance throughout the 1990s (Barret 2001).

characteristics may end up on different paths, a good one with ‘low poverty-low brain drain’ or a bad one with ‘high poverty-high brain drain’. The selection of the bad equilibrium results from a coordination failure in high-skill emigration decisions.

If some developing countries suffer from coordination failure, they require specific development policies to target the problem. While major economic reforms are needed to break vicious circles and exit poverty,[4] the effectiveness of these reforms will likely be negligible if talented workers lack confidence in institutions, in which case they will continue to emigrate abroad. In cases of coordination failure, an appropriate policy would be to subsidize returns of high-skilled expatriates for a given period of time (say 10–15 years). These subsidies would cover both their income loss in PPP as well as non-economic costs. As return migration operates and contributes to increasing competitiveness and productivity, the economy is likely to experience a permanent improvement and return migration decisions will become incentive-compatible (even in the absence of subsidies).

Are cases of coordination failure likely to be observed in the developing world? On the one hand, Barro and Lee (2001) show that the mean skill-ratio (i.e. ratio of tertiary to non-tertiary educated workers) of high-income countries in 2000 was about 0.25, with values around 0.4 in the very richest countries. This ratio was lower than 0.05 in most low-income countries. On the other hand, the data set compiled by Docquier et al. (2009) show that the brain drain exceeds 40% in many developing countries. By repatriating high-skilled emigrants to their homeland, 23 developing countries would exhibit a skill-ratio above 0.25[5] and many other countries would be better off. If such returns were important enough to generate a takeoff and eradicate incentives to emigrate, a temporary repatriation policy could help break the vicious circularity of the ‘high brain drain-high poverty’ scenario.

This paper addresses this fundamental issue, building on a simple model generating indeterminacy and multiple long-run equilibria. A novelty of our approach is that we identify the parameters of the model using country-specific data, and identify cases of coordination failure. We show that small countries geographically or culturally close to richer countries are more likely to suffer a coordination failure as when compared to large, landlocked and remote countries. Our numerical experiments reveal that the majority of developing countries are on the good path; in these countries, some observed brain drain is inevitable, as a corollary of poverty.[6] However, 22 countries (including 20 small states with less than 2 million inhabitants) are on the bad path and suffer a serious coordination failure. These represent 15% of our sample of 147 countries, but only 1% of the population living in the developing world. Our results are robust to our identification strategy and to the inclusion of ‘brain gain’ mechanisms.

The paper is organized as follows. Section 2 describes the theoretical framework and derives the conditions under which multiplicity is obtained. Our benchmark model follows the “traditional” literature on brain drain and development, i.e. considers the brain drain as

[4] We refer here to democratic reforms, not dictatorial ones. East-Germany opted for an authoritative policy by walling off the city of Berlin in 1961. Preventing the vicious circle of brain drain, impoverishment and the considerable abuse of the East-German education system, were the main economic motivations for the construction of the Berlin wall.

[5] Saint Kitts and Nevis (0.866) would be close to the US and Canada; Grenada (0.611) and Dominica (0.471) and other small states would be close to Australia (0.514). Other larger countries such as the Philippines (0.333), Peru (0.309), Jamaica (0.279) or Latvia (0.271) would have more human capital than many high-income countries.

[6] This is the case of Russia or Iran which loose large absolute numbers of tertiary educated (475,095 for Russia and 315,640 for Iran). Given their sizes, these numbers represent relatively small proportions of their educated labor forces (2.4% in Russia and 14.7% in Iran). These proportions are too low to be the result of coordination problems.

unambiguously detrimental for human capital accumulation. In Sect. 3, we use macro-level data to identify country-specific characteristics. This allows us to characterize the type of equilibrium observed in each developing country. In Sect. 4, we analyze the robustness of our results in accounting for our identifying assumptions and additionally consider the recent "brain gain" literature. Finally, Sect. 5 concludes.

2 Theory

Our model depicts one developing economy with endogenous technology, high-skill emigration and human-capital accumulation. In Sect. 2.1, we describe our assumptions and define the intertemporal equilibrium. Section 2.2 characterizes the conditions under which multiplicity and coordination failures are obtained. Section 2.3 discusses a refinement of the obtained Nash equilibria. Finally, we discuss the dynamic properties of our equilibria in Sect. 2.4.

2.1 Assumptions and definitions

Time is discrete. One period is meant to describe the active life of one generation. Each developing country is characterized by a linear production function with two perfectly substitutable inputs, high-skill and low-skill labor (H_t and L_t), and an endogenous productivity factor λ_t:

$$Y_t = \lambda_t \left(\overline{\omega} L_t + H_t\right) \tag{1}$$

where $\overline{\omega} < 1$ is the average productivity of low-skill workers relative to high-skill workers. With competitive pricing, high-skill workers' income is equal to λ_t whereas low-skill workers earn $\overline{\omega}\lambda_t$. The assumption of perfect substitutability of the two types of labor implies that the skill premium is exogenous. Although it is made for mathematical simplicity, this assumption is in line with many empirical studies advocating to use a high elasticity of substitution to match data on the skill premium in developing countries.[7] It is also comforted by Rosenzweig (2007, 2008) who shows that cross-country differences in skill prices across developing countries are more affected by differences in base wages (λ_t) than by differences in returns to skills ($1/\overline{\omega}$). Finally, models combining a formal sector and an informal sector (with constant marginal productivity of labor) would also generate invariant skill premia (see Schneider and Enste 2000).

Notice also that introducing physical capital into the model would lead to unchanged conclusions provided that the following two conditions are met: first, physical capital and skilled workers are complements,[8] while the combination of the two is substitute to low skilled workers. Second, interest rate is given by world markets and capital is perfectly mobile across countries. We would then have $Y_t = \lambda_t(\min[BK_t, H_t] + \overline{\omega}L_t)$. Perfect capital mobility implies $BK_t = H_t$ provided that $\lambda_t B$ is greater than the world interest rate. Combining the two conditions, production would be given by the expression in (1).

We consider a Lucas-type technological externality (see Lucas 1988) and assume that the scale productivity factor is a concave function of the skill-ratio in the resident labor force.

7 Ottaviano and Peri (2008) use a range of estimates between 1.5 and 3 whereas Angrist (1995) recommends a value above 2 to explain trends in college premia in the Palestinian labor market.

8 This assumption is shown to explain the empirical regularities about wage inequality, see Krusell et al. (2000).

Hence, we have

$$\lambda_t = A\rho^t k_t^{\alpha} \qquad \text{with } k_t \equiv \frac{H_t}{L_t} \tag{2}$$

where A is a country fixed effect, ρ^t is a time trend which is common to all developing and developed countries ($\rho > 1$). This formulation implies that cross-country disparities in growth rates are governed by differences in human capital accumulation. All growth rates will converge asymptotically to ρ provided that human capital converges to some long-run level. This is in line with neo-Shumpeterian models à la Benhabib and Spiegel (2005). The parameter α is the structural elasticity of production to the skill ratio. It is assumed to be homogenous across countries, in line with the empirical literature (see Acemoglu and Angrist 2000; Angrist 1995, or Moretti 2004a,b).

We now formalize emigration decisions. We disregard low-skilled migration, which means that the emigration rate of low-skilled workers is assumed to be null in the theory (and exogenous in the quantitative analysis). This choice is justified by the fact that low-skilled emigration rates are very low in developing countries: Docquier et al. (2009) report an average rate of 1.3% in 2000. In addition, empirical studies show that low-skilled emigration is less responsive to economic variables than high-skilled emigration. Its main determinants are geographic distance, colonial links, existence of guest-workers agreements (see Grogger and Hanson 2011; Belot and Hatton 2008, or Docquier et al. 2007). On the contrary, high-skilled migration is more responsive to economic variables. We thus consider that high-skilled individuals have the choice between staying in their country or emigrating to a richer industrialized country before entering the labor market.[9] Migration is permanent and we disregard the links between migrants and their origin country (such as remittances[10] and diaspora externalities).

Preferences are represented by an indirect utility function assumed to be logarithmic in income. Income at destination is exogenous and denoted by $\bar{\lambda}_t = \bar{A}\rho^t$ with $\bar{A} > 0$. We do not endogenize $\bar{A}$ as a function of the skill-ratio at destination, implicitly assuming that high-skill immigration from each developing country is too small to affect productivity. Hence, our model is only relevant to the analysis of developing countries.

Migration induces heterogenous moving costs which must be subtracted from the utility level. We denote the migration cost of individual i by $\tilde{\varepsilon}_i \in \mathbb{R}$ ($\tilde{\varepsilon}_i$ can be negative, as some individuals enjoy moving). Hence, migration is optimal for individual i if and only if

$$\ln \bar{A} - \tilde{\varepsilon}_i \geq \ln A + \alpha \ln k_t.$$

At time t, all individuals with migration costs below a critical value ε_t find it optimal to emigrate. The critical value is given by

$$\varepsilon_t = \ln \bar{A} - \ln A - \alpha \ln k_t \tag{3}$$

The threshold ε_t is decreasing with the skill-ratio k_t and characterizes the income differential (in logs) with high-income destinations. At the margin, the migration costs for the individual who is indifferent between migrating or staying is equal to the income differential. It can reasonably be used as an index of poverty (or underdevelopment) of the country.

9 The assumption that education is obtained in the home country is corroborated by our data: the percentage of skilled migrants having left home after the age of 22, that is, after having obtained some tertiary education, is equal to 75% on average; in all the 147 developing countries, a majority of skilled migrants has left home after the age of 22.

10 Remittances represent a small fraction of GDP in developing countries (less than 3%), and are likely to benefit low-skilled more than high-skilled workers.

Migration costs are distributed according to a cumulative distribution function $G(\tilde{\varepsilon})$ with location parameter (or shift parameter) $m \in \mathbb{R}$ and scale parameter (or dispersion parameter) $b \in \mathbb{R}_+$. In the case of a normal distribution, m would be the mean and b the standard error. Parameters m and b are country-specific. Indeed, the large empirical literature on the determinants of migration shows that distance to high-income countries, language, colonial links, country size and other characteristics affect migration costs and migration responsiveness to economic shocks.

We will also use the function

$$M\left(\frac{\varepsilon_j - m_j}{b_j}\right) = G(\varepsilon_j)$$

which is a standardized version of $G()$.

$G(\varepsilon_t)$ measures the proportion of high-skill emigrants at time t, i.e. the rate of brain drain. We impose Assumption 1 on $G(\tilde{\varepsilon})$.

Assumption 1 The distribution function of migration costs satisfies[11]

$$G'(x) = o\left(\exp\left(-x/\alpha\right)\right) \text{ when } x \to +\infty$$

As it will be evident later,[12] Assumption 1 is a sufficient condition to obtain multiplicity of equilibria and coordination failures. It holds when $G'(\tilde{\varepsilon})$ goes to 0 (i.e. $G(\tilde{\varepsilon})$ goes to 1) faster than $\exp\left(-\tilde{\varepsilon}/\alpha\right)$ as $\tilde{\varepsilon}$ goes to infinity. This implies that the migration choice is sensitive enough to the wage differential when this differential is large or, stated otherwise, that there are very few high skilled people with extremely large migration cost.

Assumption 1 holds therefore when the right tail of the distribution is sufficiently thin. It always holds when the cumulative distribution function $G(\tilde{\varepsilon})$ reaches one for a value of $x \in \mathbb{R}$. It is also always satisfied if $G(\tilde{\varepsilon})$ is a normal distribution with positive mean or if $G(\tilde{\varepsilon})$ is a Gumbel distribution with positive location. If $G(\tilde{\varepsilon})$ is a logistic distribution, Assumption 1 holds provided that b, the scale of the distribution, is smaller than the externality parameter α, which reflects well the idea that the density of migration costs should be concentrated enough.

At this stage, it is useful to distinguish k_t, the skill-ratio in the ex post (or after-migration) resident labor force and z_t, the skill-ratio in the ex ante (or before-migration) native labor force. Since only educated workers migrate at a rate $G(\varepsilon_t)$, we obviously have

$$k_t = z_t \left[1 - G(\varepsilon_t)\right] \tag{4}$$

The dynamics are governed by human capital accumulation. For simplicity, it is assumed that high-skill workers educate all their children whereas low-skill workers only educate a fraction $q \in (0, 1)$ of them. It is natural to consider that q, reflecting education policy, urbanization and other country characteristics, vary across countries. As policy is not modeled here, we treat q as exogenous. Denoting the skilled population by Z^s and the low-skill population by Z^u, their dynamics are given by

$$\begin{aligned} Z^s_{t+1} &= n^s Z^s_t \left[1 - G(\varepsilon_t)\right] + q\, n^u\, Z^u_t \\ Z^u_{t+1} &= (1 - q)\, n^u\, Z^u_t \end{aligned}$$

where n^s and n^u measure the number of children in high-skill and low-skill households. We assume that, in line with the literature on differential fertility, $n^s < n^u$. Denoting by

[11] $o(.)$ means little-o of (Landau notation).

[12] In Fig. 1, Assumption 1 is necessary for the black and the grey curve to intersect for large ε.

$n = n^s/n^u$ the relative number of children in high-skill households (compared to the number in low-skill households), we have

$$z_{t+1} = Z^s_{t+1}/Z^u_{t+1} = \frac{1 - G(\varepsilon_t)}{1 - q}\, n\, z_t + \frac{q}{1 - q} \tag{5}$$

Parameter n could be country-specific, reflecting disparities in the cost of raising children across educational groups and other country characteristics. However data on n are only available for a limited set of developing countries (see Kremer and Chen 1999). Therefore we treat is as a common parameter. This assumption is be justified by the fact that n does not vary so much across countries, as explained in Sect. 3.1.

Our model is made up of Eqs. 1–5. In these equations, we consider that parameters $\bar{A} > 0$, $\alpha \in (0, 1)$ and $n \in (0, 1)$ are identical across developing countries. The other exogenous parameters A, q, m and b are country-specific. Hence, a developing country can be identified as follows.

Definition 1 A developing country is a quadruple $\Omega = \{A, q, m, b\}$ representing the technological fixed effect ($A > 0$), the fraction of educated children in low-skill households ($q \in (0, 1)$), the location and the scale parameters of the distribution of migration costs ($m \in \mathbb{R}, b > 0$).

The parameters and country characteristics determine the level and the time path of the two main endogenous variables, the index of poverty ε_t and the ex ante skill-ratio z_t. Indeed, when trajectories for ε_t and z_t are known, it is straightforward to compute the trajectories of the other endogenous variables (λ_t, Y_t, k_t). In other words, the system of Eqs. 1–5 can easily be reduced to a two-variable system.

Definition 2 Given an initial skill-ratio in the native labor force $\bar{z}_0 > 0$, an inter-temporal equilibrium with migration is a vector of skill-ratios $\{z_t\}_{t \geq 0} \in \mathbb{R}^{\infty}_{+}$ and a vector of poverty indexes $\{\varepsilon_t\}_{t \geq 0} \in \mathbb{R}^{\infty}$ such that $z_0 = \bar{z}_0$ and $\forall t \geq 0$:

$$\varepsilon_t = \ln \bar{A} - \ln A\, [(1 - G(\varepsilon_t))\, z_t]^{\alpha} \equiv f(\varepsilon_t, z_t), \tag{6}$$

$$z_{t+1} = \frac{q}{1 - q} + \frac{1 - G(\varepsilon_t)}{1 - q} n z_t \equiv h(\varepsilon_t, z_t). \tag{7}$$

Equation 6 is a static incentive compatibility condition. For a given ex ante skill-ratio z_t, it characterizes the combination(s) of poverty index ε_t and high-skill emigration rate $G(\varepsilon_t)$ compatible with the technology level and households' emigration decisions at time t. Equation 7 is dynamic and characterizes human-capital accumulation. For a given ex ante skill-ratio and poverty index at time t, it gives the ex ante skill-ratio at time $t + 1$.

2.2 Indeterminacy

In this model, multiplicity roots in the joint determination of productivity and emigration decisions. This bidirectional link is reflected in the implicit form of the static incentive compatibility condition (Eq. 6). To show this result we first need the following lemma:

Lemma 1 *Under Assumption 1, there exists a threshold $\hat{z}$ such that, in equilibrium, $z_t > \hat{z}\ \forall t \geq 0$.*

Proof We prove the lemma using a reductio ad absurdum argument. Suppose we have an equilibrium with, at some date s, $z_s < \hat{z}$. We will show that there can be no ε_s satisfying

$\varepsilon_s - f(\varepsilon_s, z_s) = 0$, that is, solving Eq. 6 for z_s we obtain

$$z_s = \Phi \frac{\exp(-\varepsilon_s/\alpha)}{1 - G(\varepsilon_s)} \equiv \phi(\varepsilon_s) \quad \text{with} \quad \Phi = \left(\frac{\bar{A}}{A}\right)^{1/\alpha}.$$

The function $\phi(\varepsilon)$ is continuous. Its limit when $\varepsilon \to -\infty$ is equal to $+\infty$. Under Assumption 1, its limit when $\varepsilon \to +\infty$ is equal to $+\infty$. It therefore has a global minimum at some $\hat{\varepsilon}$. This global minimum should satisfy:

$$\phi'(\hat{\varepsilon}) = 0 \Leftrightarrow 1 - G(\hat{\varepsilon}) - \alpha G'(\hat{\varepsilon}) = 0$$

Let us define $\hat{z} = \phi(\hat{\varepsilon})$. There is no $\varepsilon \in \mathbb{R}$ such that $\phi(\varepsilon) < \hat{z}$. As a consequence there is no $\varepsilon \in \mathbb{R}$ solving Eq. 6 for $z < \hat{z}$. Hence, when $z_s < \hat{z}$, Eq. 6 could not hold and this cannot be an equilibrium. □

We now introduce a second assumption, which is in no way crucial for the following results, but greatly simplifies the analysis.

Assumption 2 The distribution function of migration costs is such that there is a unique ε satisfying

$$1 - G(\varepsilon) - \alpha G'(\varepsilon) = 0.$$

This implies that:

Lemma 2 *Under Assumptions 1 and 2, for any level $z_t > \hat{z}$ there exist two values of ε_t, $\varepsilon^+(z_t) > \varepsilon^-(z_t)$, such that the incentive constraint $\varepsilon_t = f(\varepsilon_t, z_t)$ holds.*

Proof Consider the function $z = \phi(\varepsilon) \Leftrightarrow \varepsilon - f(\varepsilon, z) = 0$. We have seen in the proof above that it goes from $+\infty$ to $+\infty$ as ε goes from $-\infty$ to $+\infty$, and has a global minimum at the point $(\hat{\varepsilon}, \hat{z})$. Assumption 2 implies that the slope of this function changes sign only once, at its minimum. As a consequence, for any $z_t > \hat{z}$, there are two values of ε_t such that $\varepsilon_t - f(\varepsilon_t, z_t) = 0$. Let us denote these two solutions $\varepsilon^+(z_t) > \varepsilon^-(z_t)$. □

The solution $\varepsilon^+(z_t)$ corresponds to a high poverty index and high brain drain: the ex post skill ratio k_t is well below the ex ante level z_t and the productivity level is low. Solution $\varepsilon^-(z_t)$ corresponds to a low poverty index and low brain drain: the ex post skill ratio k_t is closer to the ex ante level z_t and the productivity level is higher.

The two equilibrium values $\varepsilon^+(z_t)$ and $\varepsilon^-(z_t)$ can be interpreted as Nash equilibria of a game where players are high-skilled households. Before analyzing the dynamic properties of the inter-temporal equilibria, we examine whether the static Nash equilibria can be reached when strategies are perturbed.

2.3 Trembling-hand perfection

When multiplicity occurs in static Nash equilibria, it is very common to question the “stability” of these equilibria. Although this notion of stability is sometimes judged dynamically naive (see Varian 1992, p. 288),[13] it can be used as a tool to restrict the set of admissible Nash equilibria. An interesting notion proposed by Selten (1975) is that of the trembling-hand perfect Nash equilibrium, which selects Nash equilibria which are robust to the possibility that

[13] This is probably why Acemoglu (1995), among others, does not use a stability criterion to discriminate between static equilibria, but introduces the notion of stability only when he proposes a truly dynamic extension of his model.

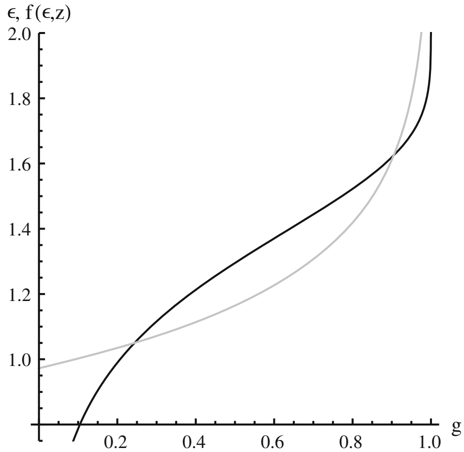


Fig. 1 Nash equilibria

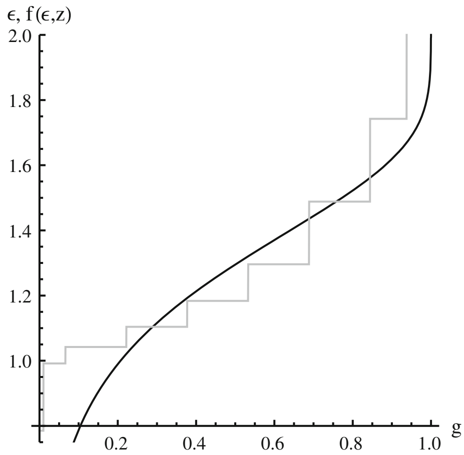
some players may make small mistakes. In order to apply this notion to our case, we draw the costs and benefits of migration, as a function of the migration rate. Letting migration g vary, the utility cost of the marginal person is $G^{-1}(g)$. The benefit from migration is, from Eq. 6,

$$f(\varepsilon, z) = \ln \bar{A} - \ln A\,[(1-g))\,z]^{\alpha}$$

Figure 1 plots the two functions. The concave-convex black curve is the cost $G^{-1}(g)$. The grey curve is the benefit. It is a convex function of migration because home productivity and wages are a concave function of the skill ratio. Under Assumptions 1 and 2, these curves intersect twice. We can now assess the trembling-hand perfection of the two Nash equilibria. Consider first the equilibrium on the left, which is the one with low poverty and low brain drain. Suppose that somebody made a mistake and that, for example, the person with a migration cost just above the threshold level ε migrated. As the grey curve is quite flat in that region, this move has only a slight positive effect on the relative gain of migration, through depressing local income via the externality. For him/her and the others with a higher ε_i, the cost (in black) is still higher than the benefit (in grey), and nobody moves. This equilibrium is trembling-hand perfect. Consider now the equilibrium on the right, the one with high poverty and high brain drain. If there is, by mistake, an additional migrant, we see that the benefit increases very sharply (the grey curve increases very fast at that point). This is because the economy is already poor in skilled persons, and so the marginal loss of an additional skilled worker is high. Then, for households with a higher ε_i, there is a gain in moving too. This equilibrium is not trembling-hand perfect.

Although such arguments are often used to select a unique Nash equilibrium, let us stress that they are not very robust. To illustrate this point, let us modify the externality we assumed in Eq. 2. Instead of following Lucas (1988), let us adopt Azariadis and Drazen (1990) view that there are threshold externalities in technology. Having a skill ratio above a certain threshold allows access to better technologies. λ_t would then be a step function of k_t: there would be a partition $\{k_0, k_1, \ldots, k_n\}$ of $\mathbb{R}_+$ representing the different thresholds, such that the function is constant on each (k_{i-1}, k_i). This case is represented in Fig. 2 where we have assumed a step function with many levels (considering Eq. 2 as a smooth approximation of a true model with a step function). The equilibrium on the right is now trembling-hand perfect: if an agent

Fig. 2 Nash equilibria with threshold externalities



deviates, this will neither affect the technology, nor the gain from migrating, as the grey curve is locally horizontal, and nobody else would deviate from this equilibrium.

A similar argument could be made on the basis of institutional choices rather than technology levels. If the skill ratio can buy a level of institutional development (affecting total factor productivity), equilibria are stable as long as agents strictly prefer the current regime to the alternatives. Then, any epsilon change in the environment should not perturb the equilibrium. These arguments show that it makes little sense to put too much weight on the refinement of the Nash equilibria in our context, as any result could easily be overturned by slightly changing the technology.

2.4 Dynamic implications

Let us now consider the dynamic implications of indeterminacy. At each t, there are two values of z_{t+1} compatible with Eqs. 6 and 7. The dynamics can be written as:

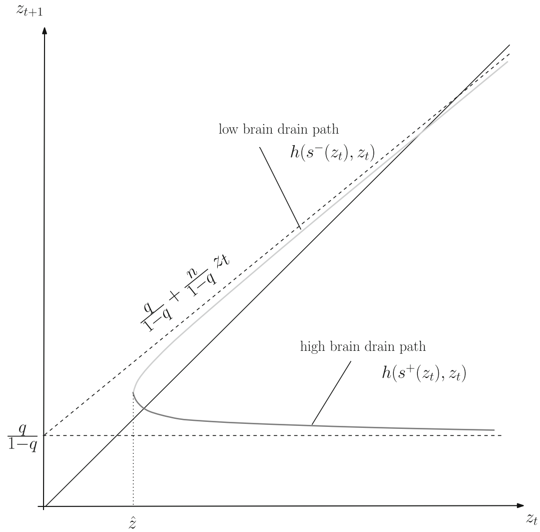
$$z_{t+1} = \begin{cases} h(\varepsilon^{+}(z_t), z_t) \\ \quad\text{or} \\ h(\varepsilon^{-}(z_t), z_t) \end{cases} \tag{8}$$

If these two values are above $\hat{z}$, we can compute four values of z_{t+2} using Eqs. 6 and 7, eight values of z_{t+3} and so on. Hence there may be an infinite number of equilibria, starting from the initial condition $\bar{z}_0$.

An infinite number of trajectories arises because a bad equilibrium can alternate with a good equilibrium at each period of time and vice versa. In practice, data show a strong inertia in human capital and brain drain indicators. This suggests that switches are extremely rare; when an economy starts on one path, it is very likely to stay on it. For this reason, it is important to describe the possible long-run solutions and check whether they are dynamically stable. To do so, we first list some properties of the two functions $h(\varepsilon^{+}(z_t), z_t)$ and $h(\varepsilon^{-}(z_t), z_t)$:

- $h(\varepsilon^{+}(\hat{z}), \hat{z}) = h(\varepsilon^{-}(\hat{z}), \hat{z}) = h(\hat{\varepsilon}, \hat{z})$;
- since $\phi'_{\varepsilon} < 0$ for $\varepsilon < \hat{\varepsilon}$, and $\varepsilon^{-}(z_t)$ is a decreasing function, the function $h(\varepsilon^{-}(z_t), z_t)$ is increasing in z_t;
- since $\varepsilon^{+}(z_t) > \varepsilon^{-}(z_t)$, $h(\varepsilon^{-}(z_t), z_t) > h(\varepsilon^{+}(z_t), z_t)$;

Fig. 3 Dynamic correspondence



- when z tends to infinity, the function $h(\varepsilon^-(z_t), z_t)$ tends to the oblique asymptote obtained under $G(\varepsilon) = 0$:

$$\frac{q}{1-q} + \frac{n}{1-q} z;$$

- when z tends to infinity, the function $h(\varepsilon^+(z_t), z_t)$ tends to the horizontal asymptote obtained under $G(\varepsilon) = 1$:

$$\frac{q}{1-q}.$$

Figure 3 represents a dynamic correspondence which satisfies the properties derived above.

The following proposition summarizes the conditions for the existence of an equilibrium.

Proposition 1 *Under Assumptions 1 and 2 an inter-temporal equilibrium exists under the conditions:*

When $h(\hat{\varepsilon}, \hat{z}) > \hat{z}$, an equilibrium exists if $z_0 > \hat{z}$.

When $h(\hat{\varepsilon}, \hat{z}) < \hat{z}$,

- *no equilibrium exists if $h(\varepsilon^-(z), z) < z$ for all $z > 0$.*
- *if there exists $\tilde{z} > 0$ such that $h(\varepsilon^-(\tilde{z}), \tilde{z}) > \tilde{z}$ and if $\bar{z}_0 \geq \underline{z}$, where $\underline{z}$ is the smallest steady state of the dynamics $z_{t+1} = h(\varepsilon^-(z_t), z_t)$, an equilibrium exists.*

Proof When $h(\hat{\varepsilon}, \hat{z}) > \hat{z}$, $z_0 > \hat{z}$ ensures that there is at least one inter-temporal equilibrium satisfying the monotone dynamics $z_{t+1} = h(\varepsilon^-(z_t), z_t)$.

When $h(\hat{\varepsilon}, \hat{z}) < \hat{z}$, if $h(\varepsilon^-(z), z) < z$ for all $z > 0$, the function $h(\varepsilon^-(z_t), z_t) < z_t$ lies below the forty-five degree line for all z_t, all the possible dynamics starting from $\bar{z}_0$ are decreasing, and there will inevitably be some date T at which $z_t < \hat{z}$. Hence, no inter-temporal equilibrium exists.

When $h(\hat{\varepsilon}, \hat{z}) < \hat{z}$, if there exists $\tilde{z} > 0$ such that $h(\varepsilon^-(\tilde{z}), \tilde{z}) > \tilde{z}$, the function $h(\varepsilon^-(z_t), z_t)$ cuts the forty-five degree line at some point; let us denote by $\underline{z}$ the smallest steady state of the dynamics $z_{t+1} = h(\varepsilon^-(z_t), z_t)$. Provided that $\bar{z}_0 \geq \underline{z}$, there exists at least one inter-temporal equilibrium (see De la Croix and Michel 2002, Proposition 3.6, for a similar case in the context of pension systems). □

Obviously, as soon as one inter-temporal equilibrium exists, an infinite number of such equilibria exist. Indeterminacy stems from the fact that total factor productivity and skill ratio are determined simultaneously. If, instead, we had assumed that the productivity reacts with a lag to human capital, the properties of the model would have been changed. Instead of indeterminacy, one would have had a determinate model with path dependency, along the lines of the vast literature on poverty traps (see e.g. Galor 1996; Graham and Temple 2006).

We have studied the properties of a determinate model in which productivity reacts with a lag to human capital. Results are very similar. For a given elasticity of productivity to human capital α, a determinate model generates the same steady state levels of human capital as our indeterminacy model. In the poverty trap model, the high steady state is always locally stable, and the low steady state is unstable (just like our low equilibrium was not trembling-hand perfect). However, they become both locally stable when threshold externalities à la Azariadis-Drazen are factored in. The quantitative analysis of Sects. 3 and 4 could therefore be transposed to a determinate model with path dependency. The difference between the two models would be in the interpretation of the poverty trap. In our set-up, it is an expectation driven poverty trap, while, with lagged externality, it would be a history-driven poverty trap. Policy implications would also be different. Given that, in our set-up, one model period lasts one generation, it seems reasonable to assume a contemporaneous link between total factor productivity and human capital. The examples in the introduction show that unexpected policy changes may lead to large waves of high skilled immigration (Ireland) or emigration (Iran) which have consequences for economic performance within a decade.

Finally, let us derive some additional results in the case where the function $G(\varepsilon)$ is a Gumbel distribution, which is a common assumption in endogenous migration models given the nice mathematical properties of that distribution:

$$G(\varepsilon) = 1 - e^{-e^{\frac{\varepsilon - m}{b}}}. \tag{9}$$

The key condition separating the two cases of Proposition 1, $h(\hat{\varepsilon}, \hat{z}) > \hat{z}$, can be expressed explicitly as a condition on the productivity parameter A. Indeed, using this functional form for $G()$, we can solve the inequality $h(\hat{\varepsilon}, \hat{z}) < \hat{z}$ for the parameter A:

$$A < \left(\frac{\bar{A}^{\frac{1}{\alpha}} e^{-\frac{m}{\alpha}} \left(e^{b/\alpha}(1-q) - n \right) \left(\frac{b}{\alpha}\right)^{-\frac{b}{\alpha}}}{q} \right)^{\alpha} \Leftrightarrow h(\hat{\varepsilon}, \hat{z}) < \hat{z}$$

Hence, the non-existence of equilibrium can only arise when productivity is small enough, given the other parameters.

We now derive some comparative static results in the context of a Gumbel distribution of migration costs. Results can be obtained for the point $p = \{\hat{z}, h(\hat{\varepsilon}, \hat{z})\}$:

$$\hat{z} = \Phi \left(\frac{b}{\alpha} \right)^{-b/\alpha} e^{(b-m)/\alpha},$$

and $\hat{\varepsilon} = m + b \ln \left(\frac{b}{\alpha}\right)$. We first compute $h(\hat{\varepsilon}, \hat{z})$ which gives:

$$h(\hat{\varepsilon}, \hat{z}) = \frac{q}{1-q} + \frac{n}{1-q} \Phi \left(\frac{b}{\alpha} \right)^{-b/\alpha} e^{-m/\alpha}.$$

Using the partial derivatives of $\hat{z}$ and $h(\hat{\varepsilon}, \hat{z})$ with respect to the parameters of interest, q, n, m, and Φ we get:

$$\frac{\partial p}{\partial q} = \left\{ 0, \frac{e^{-\frac{m}{\alpha}} n\Phi \left(\frac{b}{\alpha}\right)^{-\frac{b}{\alpha}} + 1}{(1-q)^2} \right\} \tag{10}$$

$$\frac{\partial p}{\partial n} = \left\{ 0, \frac{e^{-\frac{m}{\alpha}} \left(\frac{b}{\alpha}\right)^{-\frac{b}{\alpha}} \Phi}{1-q} \right\} \tag{11}$$

$$\frac{\partial p}{\partial m} = \left\{ -\frac{e^{\frac{-\log\left(\frac{b}{\alpha}\right)b+b-m}{\alpha}} \Phi}{\alpha}, -\frac{e^{-\frac{m}{\alpha}} n \left(\frac{b}{\alpha}\right)^{-\frac{b}{\alpha}} \Phi}{(1-q)\alpha} \right\} \tag{12}$$

$$\frac{\partial p}{\partial \Phi} = \left\{ e^{\frac{-\log\left(\frac{b}{\alpha}\right)b+b-m}{\alpha}}, \frac{e^{-\frac{m}{\alpha}} n \left(\frac{b}{\alpha}\right)^{-\frac{b}{\alpha}}}{1-q} \right\}. \tag{13}$$

Equations 10 and 11 indicate that, when q or n increases, the point p moves vertically upward. The conditions for existence would be unchanged in the case where $h(\hat{\varepsilon}, \hat{z}) > \hat{z}$ ($\hat{z}$ is unchanged) or easier to fulfil in the case where $h(\hat{\varepsilon}, \hat{z}) < \hat{z}$ as the smallest steady state $\underline{z}$ would be lowered. If the slope of the function does not change too much (which is what simulations indicate), it would also imply that the high steady state would be higher. This implies that education policies and/or population policies increasing n make the good stationary equilibrium better.

Equations 12 and 13 show that increasing location m or decreasing Φ (i.e. increasing productivity A) move the point p unambiguously to the South-West. Hence it enlarges the scope for the existence of equilibria ($\hat{z}$ is lower).

3 Quantitative assessment

Indeterminacy and coordination failures are not new in development economics. In their Big Push model, Murphy et al. (1989) show that a firm's decision whether to industrialize or not depends on the expectations of what other firms will do. The same authors showed that natural increasing returns in rent-seeking activities can lead to multiple equilibria (see Murphy et al. 1991, 1993); their model was extended by Mariani (2007) to examine the effect of emigration prospects on the selection of the equilibrium. However the concept of indeterminacy has rarely been submitted to a numerical assessment. Besides providing the first application to the literature on brain drain and development, an important novelty in this paper is that we apply quantitative theory to a large set of countries and identify the cases of coordination failure. "Quantitative theory uses simple, abstract economic models together with a small amount of economic data to highlight major economic mechanisms" (King 1995).[14]

[14] Looking at the recent trends in short-term macroeconomics and in monetary economics, this learning process obtained by confronting data to theory was of considerable importance to recent developments, since the quantitative theory approach is now the dominant research paradigm being used by economists incorporating rational expectations and dynamic choice into small-scale macroeconomic models (King 1995). But very little has been done so far with this methodology in long-term macroeconomic issues.

Table 1 Parameters—summary

Prm.	Definition	Source	Value
Global parameters			
α	Elasticity of productivity to human cap	Regressions 1990–2000	0.277
$\overline{A}$	Productivity in developed countries	Mean of 9 main dest	64.2
n	Fertility differential (as a ratio)	Kremer and Chen (1999)	0.605
Developing countries specific parameters			
A	Technological fixed effect	Eq. 16	
q	Prop of educ. children in low-skill hous.	Eq. 17	
m	Location of the mig. cost distrib.	Eq. 19	
b	Scale of the mig. cost distrib	Eq. 18	

Our quantitative assessment illustrates how we confront the theoretical model to real world data, although uncertainty still surrounds the quantitative conclusions. This mainly because we do not have all the needed country specific data, and because we are making a series of identifying assumptions which might be important for the results. We carry out extensive robustness checks on three of these identifying assumptions to limit the possible biases of the analysis.

We start by identifying common and country-specific parameters, draw the dynamic correspondence for each developing country, and determine whether the observed situation corresponds to the high brain drain or to the low brain drain path. We use data on highly skilled emigration stocks/rates and on the labor force by education level (available from Docquier et al. 2009). Data on GDP are from the Penn World Tables. Our calibration is based on the year 2000 and is summarized in Table 1.

3.1 Identification of common parameters

Remember that parameters $\alpha \in (0, 1)$ (the elasticity of productivity to the skill-ratio), $\bar{A} > 0$ (productivity in leading countries), and $n \in (0, 1)$ (the fertility differential between high-skill and low-skill workers) are assumed to be identical in all developing countries.

To identify α, we regress $\ln \lambda_{j,t}$ on $\ln k_{j,t}$. Data on the labor force by education level are used to compute $k_{j,t}$. Three levels of education are distinguished, individuals with upper-secondary education ($L^1_{j,t}$), those with less than upper-secondary ($L^2_{j,t}$), and those with post-secondary education ($H_{j,t}$). High-skill workers are defined as those in the last category. The numbers of high-skill, low-skill and medium-skill resident workers are available for each country j from Docquier, Lowell and Marfouk's database for 1990 and 2000. The skill-ratio in the resident labor force is given by

$$k_{j,t} = \frac{H_{j,t}}{L^1_{j,t} + L^2_{j,t}} \tag{14}$$

To compute $\lambda_{j,t}$, we use Eq. 1 given estimates of the relative productivity of low-skill and medium-skill workers, ω^1 and ω^2. In a sample including many developing countries, Rosenzweig (2007, 2008) estimated an average return to schooling of between 7 and 10% per year. Considering that high-skill workers have 15 more years of schooling than the low skilled and 6 more years than the medium skilled, this gives $0.21 < \omega_1 < 0.34$ and $0.56 < \omega_2 < 0.67$. In our simulations, we use $\omega_1 = 0.25$ and $\omega_2 = 0.60$. Given GDP data, the productivity scale factor of country j is obtained as a residual:

$$\lambda_{j,t} = \frac{Y_{j,t}}{\omega^1 L^1_{j,t} + \omega^2 L^2_{j,t} + H_{j,t}}. \tag{15}$$

We use data for 1990 and 2000, and normalize ρ^{00} to unity and $\rho^{90} = \bar{\lambda}_{90}/\bar{\lambda}_{00}$ in Equation (2). Regressing $\ln \lambda_{j,t}/\rho^t$ on $\ln k_{j,t}$ gives an estimate for α. Using a large sample of developing countries (142 observations), we obtain an elasticity of 0.277, significant at 1% (the R-squared of the regression is 0.24).[15] This elasticity will be used in the benchmark simulation. Using a larger sample of 195 developing and developed countries, we obtain an elasticity of 0.447 (the R-squared is 0.38). This larger value will be used in the robustness analysis.

We are aware that our simple regression method might suffer from an endogeneity bias. Our purpose is to get a plausible value for α that is compatible with our technology specification. There is some debate in the literature about magnitude of the human capital externality. Moretti (2004a,b) estimates the elasticity of productivity to the share of college educated between 0.75 and 1 across US cities. On the opposite end of the spectrum, Acemoglu and Angrist (2000) estimate essentially no productivity effect of increased schooling. Iranzo and Peri (2009) estimate an externality around 0.44 using US state-level data. Our full sample estimate is close to Iranzo and Peri's value, while the estimate obtained from the sample of developing countries looks somewhat conservative. The robustness analysis in Sect. 4 will show the importance of this parameter.

The productivity in leading countries, $\bar{A}$, is the weighted average of the productivity scale factors obtained from (15) for nine major destination countries (Australia, Canada, France, Germany, Japan, Korea, Saudi Arabia, the United Kingdom and the United States). The weights are the country's shares in the total labor force of the group. We obtain $\bar{A} = 64.18$.[16]

Unfortunately, there is no systematic country specific data for the differential fertility n. Using data from Kremer and Chen (1999), we compute the differential fertility in 1985-89 for 26 developing countries (to the best of our knowledge there is no broader set of data on differential fertility than this one). The correlation between country-specific fertility differentials and the human capital of women is so low (0.14) that we can consider the fertility differential as independent of the level of development. The average fertility differential n^s/n^u between high-skill (more than 10 years of education) and low-skill workers (less than 10 years of schooling) equals 0.605. Interestingly, in the available data set, this parameter varies little across countries.[17] We use the value $n = 0.605$ in all countries.

3.2 Identification of country-specific characteristics

As stated in Definition 1, each developing country j is characterized by a quadruple of parameters $\Omega_j = \{A_j, q_j, m_j, b_j\}$ representing the technological fixed effect ($A_j > 0$), the fraction of educated children in low-skill households ($q_j \in (0, 1)$), the location and the scale parameters of the distribution of migration cost ($m_j \in \mathbb{R}, b_j > 0$).

---

[15] Assuming that productivity reacts with a lag to human capital, we would have a very similar elasticity. Regressing the log of productivity in 2000 on the log of the skill ratio in 1975 gives an elasticity of 0.26 in the sample of developing countries (the R-squared value of the regression is 0.16). Hence, a determinate model of poverty trap would generate similar steady states as our indeterminacy model.

[16] Alternatively, one might want to compute country specific $\bar{A}$, based on the observed distribution of migrants from each source country across developed countries. This, however, would be at odds with the theory, as we do not endogenize migrants' choice of the host country.

[17] E.g. for large countries, Brazil: 0.54, Egypt: 0.67, Indonesia: 0.71, Mexico: 0.55, Thailand: 0.57.

The identification of the technological fixed effect A_j uses Eq. 2 and the estimated value for α:

$$\ln A_j = \ln \lambda_{2000,j} - 0.277 \ln k_{2000,j} \tag{16}$$

where $k_{2000,j}$ and $\lambda_{2000,j}$ are given by Eqs. 14 and 15.

To identify q_j, we use the dynamic Eq. 5 and consider that one period represents 25 years.[18] The proportion of high-skill workers in the resident labor force (ex post or after-migration labor force), $k_{j,75}$, can be obtained for 1975 from Defoort (2008), herself relying on different sources (mostly Barro and Lee 2001). The proportion of high-skill workers in the native labor force (ex ante or before-migration labor force), $z_{j,00}$, is obtained for 2000 by adding resident and emigrant workers by education level and computing the structure of the native labor force. Our identification strategy thus implicitly accounts for low-skilled emigration, although the number of low-skilled emigrants is treated as exogenous. Data on human capital and emigrants to OECD destinations in 2000 are taken from Docquier et al. (2009). Generally speaking, the skill level of immigrants to non-OECD countries is expected to be very low, except in a few countries such as South Africa, the member states of the Gulf Cooperation Council, and some East Asian countries such as Singapore or Hong Kong. Focusing on OECD destinations, the database should capture a large fraction of worldwide educated migration (between 80 and 90%), but is also likely to underestimate the number of emigrants from developing countries located in the neighborhood of important destinations. Here, we have collected or estimated data from non-OECD destinations to expand the coverage of previous studies. We double the number of destinations, adding 31 non-OECD destinations, compute more accurate measures of the brain drain for all the world countries, and characterize "South-South" and "North-South" emigration patterns. As expected, the inclusion of non-OECD countries such as the Gulf states, South Africa, and Singapore has a impact on the brain drain of neighboring countries (data available upon request).

As stated in Sect. 2, we do not endogenize low-skilled emigration. This is in line with the recent empirical literature showing that low-skilled emigration rates are low and less responsive to economic variables than high-skilled emigration rates. However, low-skilled emigration rates are not negligible in some countries and their inclusion may affect our quantitative predictions. Consequently, to identify q_j and allow our calibration method to account for low-skilled emigration, we modify Eq. 5. The exogenous low-skilled emigration rate in country j is denoted g_j. Equation 5 can be rewritten as

$$z_{j,00} = \frac{nk_{j,75}}{(1-g_j)(1-q_j)} + \frac{q_j}{1-q_j}.$$

Denoting $n_j \equiv n/(1-g_j)$ and solving for q_j yields:

$$q_j = \frac{z_{j,00} - n_j k_{j,75}}{1 + z_{j,00}}. \tag{17}$$

Adding an exogenous low-skilled emigration rate g in Eq. 5 is equivalent to multiplying the fertility rate of low-skilled households by $(1-g)$. In other words we divide the differential fertility by $(1-g)$. The data on g_j come from the same database as the high-skilled emigration rates.

[18] 25 Years represent less than the whole generation of the methodological part of the paper, but the data availability constraint is binding here.

The conditions under which unbounded growth is possible, i.e. under which the oblique asymptote on Fig. 3 has a slope larger than one, is:

$$n > (1 - q_j)(1 - g_j)$$

Six countries are in that situation: Dominica, Grenada, Guyana, Saint Kitts and Nevis, Antigua and Barbuda, and Barbados. Notice that if we had assumed that the emigration of the low-skilled observed over the 1975–2000 period would not persist in the future, then the condition for unbounded growth would become $n > (1 - q_j)$ and only Saint Kitts and Nevis would be in that situation.

Finally, we have to specify a functional form for the distribution of migration costs and estimate its parameters. In the benchmark analysis, migration costs are assumed to follow a Gumbel distribution with country-specific parameters $m \in \mathbb{R}$ (location) and $b > 0$ (scale). The Gumbel distribution is a continuous probability distribution belonging to the family of generalized extreme value distributions. It is traditionally used in migration models where utility includes an iid random component varying between individuals and countries of destination (see Grogger and Hanson 2011).[19] The mean and variance of the distribution are related to the location and scale parameters as follows: mean $= m - \gamma b$ where γ is Euler's constant (0.577), and variance $= \pi^2 b^2/6$. Inverting $M()$ gives $(\varepsilon_j - m_j)/b_j = M^{-1}(G_j) = \ln\left[-\ln(1 - G_j)\right]$. The logistic or normal distributions will be used in the robustness analysis.

Since this function has two country-specific parameters, we need two data points to identify them. The first one is given by the observation in 2000: for each developing country, we compute $\varepsilon_j \equiv \ln \bar{A} - \ln A - \alpha \ln k_j$ and observe G_j in 2000. This gives a point (ε_j, G_j) which is used to identify the parameters of the distribution. The second point is obtained as follows. Under the hypothesis that the developing country has the income level of a high income country, say the US income (ε_{US}), we assume that the brain drain of this developing country would equal the US brain drain (G_{US}). Figure 4 represents the identified Gumbel functions for Guatemala and Trinidad and Tobago. The two points used for identification are drawn. The point $(\varepsilon_{US}, G_{US})$ allows to determine the level of the distribution function for low levels of poverty, assumed to be identical for all countries. The country specific observations, $(\varepsilon_{Guatemala}, G_{Guatemala})$ and $(\varepsilon_{Trinidad}, G_{Trinidad})$ are crucial to identify the slope of the function. We also report on the same figure the point $(\varepsilon_{Qatar}, G_{Qatar})$ which is used as an alternative to the point $(\varepsilon_{US}, G_{US})$ in the robustness section. From the picture, we can already anticipate that this will not change the results much.

With the two points (ε_j, G_j) and $(\varepsilon_{US}, G_{US})$, (m_j, b_j) are uniquely identified as:

$$b_j = \frac{\varepsilon_j - \varepsilon_{US}}{M^{-1}(G_j) - M^{-1}(G_{US})} \tag{18}$$

$$m_j \equiv \varepsilon_j - b_j M^{-1}(G_j). \tag{19}$$

3.3 Validation

Above, we used all the degrees of freedom of the data to identify the needed coefficients. Consequently our model is exactly identified and cannot produce a test of its assumptions. In order to establish the relevance of our identification method, we examine whether our identified parameters exhibit realistic correlations with traditional explanatory variables from the econometric literature.

[19] As shown by McFadden (1984), when the iid component follows an extreme value distribution, the probability that an individual emigrates to a particular destination is governed by a simple logit expression.

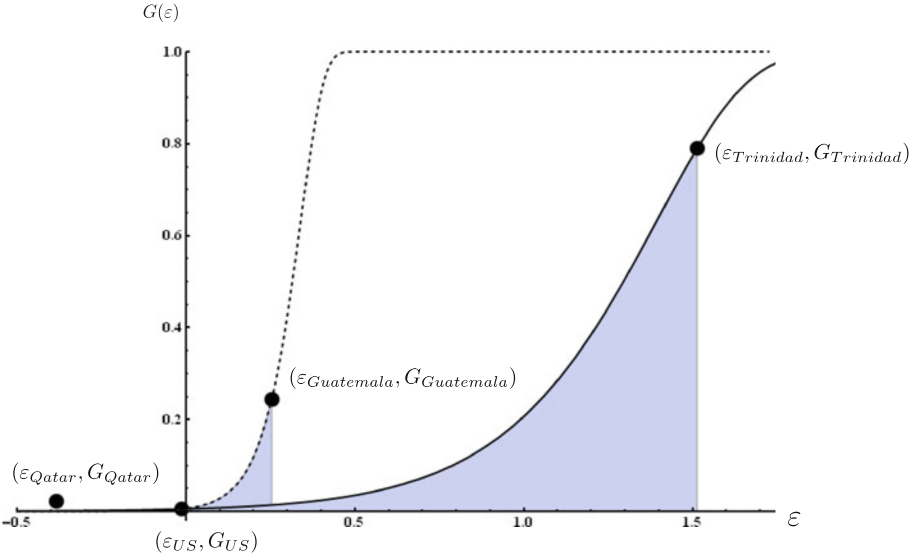


Fig. 4 Identification of the distribution of migration costs

The parameter q_j measures the intergenerational social mobility. It is likely to be affected by the generosity of the public education system, and other country specific variables. A simple cross-country correlation analysis reveals the following results. q_j is positively correlated with the share of public education spending in GDP (0.24), the logarithm of the urbanization rate (0.48), and the migration rate of the skilled (0.25). These results are in line with the empirical literature. For example, in Docquier et al. (2008), these variables are the three most important determinants of human capital formation.

The coefficients (m_j, b_j) capture the mean of migration costs and the average sensitivity of migration to income differentials. Given (18) and (19), m_j and b_j are perfectly collinear. The recent empirical literature on international migration reveals that the propensity to emigrate is a function of the distance to OECD countries, language spoken, country size and cultural links with potential destinations, etc. A simple correlation analysis reveals that m_j (and hence b_j) is positively correlated with population size (0.32) and distance to OECD (0.20), and negatively correlated with dummies capturing former colonial ties (−0.43), knowledge of English (−0.26) and being an oil producing country (−0.10).

Consequently, the mean of the distribution is low in small states, small islands, and regions such as Central America and the Caribbean, Northern and Southern Africa, the new members of the European Union and countries located in the neighborhood of the Persian Gulf states. On the contrary, m_j is higher in the ex-Soviet block, in South-East and East Asia, in many countries of South America, and Central Africa.

3.4 Benchmark results

We have identified country-specific parameters in such a way that the model matches perfectly the 2000 levels of GDP, human capital and high-skilled emigration observed in each developing country. In particular, we have used the observed brain drain level and GDP per capita to infer the location and scale parameters of the migration cost distribution function. Given these parameters, our theory predicts that there is another possible equilibrium, with

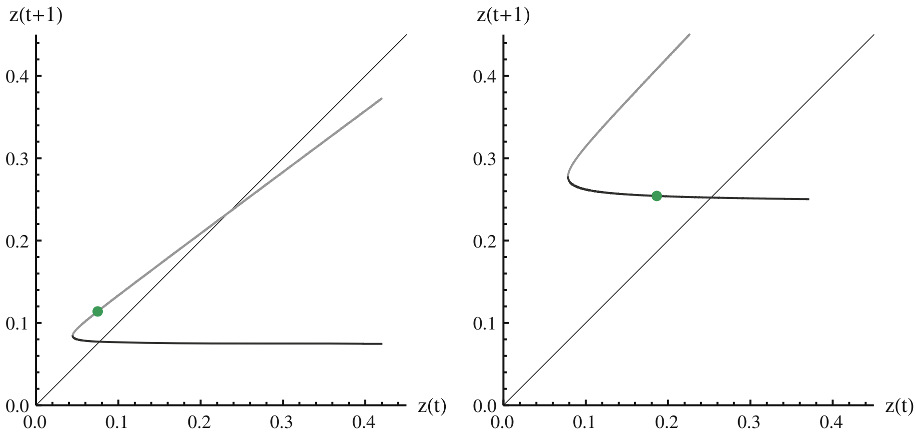


Fig. 5 Correspondences for Guatemala (*left*), and Trinidad and Tobago (*right*)

higher or lower brain drain, and allows us to identify the precise situation of each country (high or low equilibrium). Which equilibrium is observed, either high or low, is an outcome of the model, depending on technology parameters, on migration costs parameters and on observed brain drain and GDP per capita. We will see that countries on the "bad path" have in common a low b_j, reflecting a high sensitivity of migration to income differential, and a high observed brain drain.

We use the identified parameters to draw the dynamic correspondence (Eq. 8) for each country. The dynamic correspondence exhibits two possible paths for a given ex-ante skill ratio, one with high brain drain and another one with low brain drain. We also computed steady state equilibria, checked their stability, and compared the observed equilibrium path to the alternative one. Our numerical exercise was conducted on 147 developing countries and gave the following results.

Most of the countries are characterized by two locally stable steady state equilibria, the "low-brain-drain" steady state equilibrium (z^-, G^-) and the "high-brain-drain" steady state equilibrium (z^+, G^+).[20] Figure 5 represents the dynamic correspondence for two countries, Guatemala, and Trinidad and Tobago. In Guatemala, the observed dynamics lie on the upper part of the correspondence, i.e. on the low-brain-drain dynamics. If they stay on the same path, the dynamics will converge monotonically to a steady state, at the intersection of this path with the 45-degree line. In Trinidad and Tobago, the observed dynamics lie on the lower part of the correspondence, i.e. on the high-brain-drain dynamics. If they stay on the same path, the dynamics will converge with damped oscillations to a steady state. At each date, another path with lower brain drain is possible, though.

Large countries exhibit high migration costs. Considering the 105 countries with more than 2 million inhabitants, the observed equilibrium in 2000 (z_{00}, G_{00}) is on the good path in the vast majority of cases, as for Guatemala above. Only two cases are on the bad path. Jamaica exhibits a brain drain of 84.7%. Remaining on the bad path, its brain drain would reach 86.6% in 2025 and 86.5% at the steady state. Moving to the good path would reduce the long-run brain drain to 0.7%. Haiti exhibits a brain drain of 83.4%. Remaining on the

[20] In Croatia, (z^+, G^+) is unstable. As mentioned above, in Dominica, Grenada, Guyana, Saint Kitts andd Nevis, Antigua and Barbuda and Barbados the oblique asymptote on Fig. 3 has a slope higher than one implying that the dynamics can be unbounded.

bad path, its brain drain would reach 86.1% in 2025 and 85.9% at the steady state. Moving to the good path would reduce the long-run brain drain to 17.0%.

The 103 other countries with population above 2 million are on the good path. For many of these countries, the bad path is usually a trivial situation with an emigration rate slightly lower than 100% and very low income level. We identify a dozen exceptions for which the gap between the good and the bad steady states is smaller.[21] In these cases, a major adverse shock could have damaging long-run effects on the economy if it gives rise to a sudden emigration of the highly skilled.

In the 42 small states with less than 2 million inhabitants, the configuration is mixed. On the one hand, 22 small states are on the good path (z^{-}, G^{-}) in 2000. Except in the Solomon Islands, the brain drain is expected to decrease in these countries; the average emigration rate in this group amounts to 29.6% in 2000 and will fall to 17.6% in the long-run (22.8% in 2025). The alternative brain drain rate is below 85% in 15 countries which face substantial risks of coordination failure. On the other hand, 20 small states are on the bad path (z^{+}, G^{+}) in 2000. The emigration rate will increase in all these countries; the average rate equals 69.5% in 2000 and will reach 76.7% in the long-run (77.6% in 2025).

For other countries with populations above 2 million, we predict a significant decrease in the brain drain, provided that they remain on the same branch of the dynamic path. Exceptions are Jamaica and Haiti (on the bad path), Pakistan and Nigeria. The average emigration rate is equal to 19.1% in 2000. It will fall to 15.3% in 2025 and 11.9% in the long-run.

In sum, according to our model, 22 countries (including 20 small states, Jamaica and Haiti) suffer from a coordination failure. By repatriating highly skilled natives working abroad, they would reach a productivity level inciting high-skill workers to stay and generating more human capital accumulation. This represents 15% of the sample (and 47.6% of countries with less than 2 million inhabitants), but only 1% of the population living in the developing world. Hence, coordination failure leading to massive high-skill emigration is a key economic issue in small countries.

As abundantly documented in the literature, small states are more open to international exchanges, including "labor exchanges". This is reflected in our framework by the fact that small states exhibit lower average migration costs (i.e. lower m_j) and higher sensitivity of migration flows to income differentials (i.e. higher b_j). In our benchmark scenario, the mean of the distribution of migration costs in small states is on average four times lower than the mean obtained for large countries such as India, China, Indonesia, Brazil; and their average dispersion parameter is four times larger. Our simulations reveal that the risk of coordination failure is more important when migration is large and more responsive to income differential.

4 Robustness

In this section, we analyze the robustness of our results to the identifying strategy and to the brain-gain mechanism, which implies the endogeneity of q_j.

4.1 Robustness to identifying assumptions

Our benchmark numerical exercise is based on three major identifying assumptions:

[21] Examples of values of G^{-}_{ss} and G^{+}_{ss} in percent for such countries: Slovenia (0.3 vs 42.9%), Croatia (17.3 vs 50.5%), El Salvador (6.6 vs 83.7), Lebanon (4.0 vs 76.0), Macedonia (20.4 vs 87.7) Malaysia (1.8 vs 72.6), Namibia (18.5 vs 82.2), Uruguay (2.6 vs 78.5), Czech Republic (2.3 vs 87.5) and Hungary (2.6 vs 78.5).

- The elasticity of productivity to human capital is estimated on a sample of developing countries. We obtained $\underline{\alpha}= 0.277$. Using the full sample of 195 countries, the elasticity goes up to $\overline{\alpha} = 0.447$. A priori, a higher α can reinforce the possibility of multiple equilibria since it increases the sensitivity of economic performances to high-skill emigration.
- Individual migration costs are assumed to follow a Gumbel cumulative distribution function. In this section, we consider two other distributions characterized by two location and dispersion parameters, the logistic and the normal distributions.
- The identification of the parameters of the migration costs' distribution relies on the hypothesis that at the US income level ($\varepsilon_{US} = -0.013$), developing countries would have the same brain drain as the US (i.e. $G_{US} = 0.005$). Since most cases of coordination failure occur for small states, the minimal brain drain of these countries may be expected to exceed the US level at high income. In this section, we identify the parameters of the distribution on the Qatar income and brain-drain levels ($\varepsilon_{Qat} = -0.382$ and $G_{Qat} = 0.023$), Qatar being a small state (with about 745,000 inhabitants) according to our definition.

In Table 2, we identify the cases of coordination failures in 12 scenarios: 2 values for $\alpha \times$ 3 distributions $\times$ 2 values for $(\varepsilon_{\min}, G_{\min})$. Unsurprisingly, the number of coordination failures increases when $\overline{\alpha} = 0.447$, and decreases when the parameters of the migration costs' distribution are calibrated on Qatar. The use of the normal distribution (and logistic to a lesser extent) also reduces the number of countries on the bad path.

For seven countries, a coordination failure is obtained in all scenarios. These are Cape Verde, Grenada, Palau, St Kitts and Nevis, St Vincent and Grenadines, Malta, and Trinidad and Tobago. For seven other countries, a coordination default is obtained under 10 scenarios: Belize, Dominica, Guyana, Jamaica, Seychelles, Antigua and Barbuda, and Barbados. Mauritius and Cyprus are also robust cases.

4.2 Robustness to "brain gain" channel

As stated in the introduction, a new research has emerged since the mid-1990s around the idea that highly skilled emigration generates positive feedback effects for sending countries. In particular, it has been demonstrated that high-skill migration prospects can foster domestic enrolment in education in developing countries, raising the possibility of the brain drain being beneficial to the source country (Mountford 1997; Stark et al. 1998; Beine et al. 2001, 2008).

This "brain gain" hypothesis can be introduced into our model by endogenizing q_j as a function of the current emigration rate. A simple regression of identified q_j (obtained from 17) on observed high-skill emigration rates G_j shows a positive and highly significant relationship (p-value below 1%). We have $q_j = C + 0.095\ G_j + \eta_j$ where C is the intercept and η_j is a error term. Defining $q_{0,j} \equiv C + \eta_j$ as a country-specific constant, we obtain an identified model matching observations and compatible with the brain gain view. The brain gain variant is made of Eqs. 6 and 7 from Definition 2, and the training technology (subscript j is removed to be compatible with Definition 2):[22]

$$q = q_0 + 0.095\ G \equiv q(G). \tag{20}$$

[22] Identification of a causal impact of G on q is disputable, due to omitted variables and reverse causality. In the empirical literature, the OLS estimate of this incentive effect is considered as an upper-bound since reverse causality is likely to distort the coefficient upwards (see Docquier and Rapoport 2011). Indeed, increases in the quantity of education are usually accompanied by increases in its quality, making skills more internationally transferable. In addition, an increase in education can generate an excess supply of skills in the short-run

Table 2 Robustness to identifying assumptions: x indicates a coordination failure case

Identification m,b	USA						Qatar						USA
G(.)	Gumbel		Logistic		Normal		Gumbel		Logistic		Normal		Gumbel
α	$\underline{\alpha}$	$\overline{\alpha}$	$\underline{\alpha}$	$\overline{\alpha}$	$\underline{\alpha}$	$\overline{\alpha}$	$\underline{\alpha}$	$\overline{\alpha}$	$\underline{\alpha}$	$\overline{\alpha}$	$\underline{\alpha}$	$\overline{\alpha}$	$\underline{\alpha}$
Brain gain	no	no	no	no	no	no	no	no	no	no	no	no	yes
Belize	x	x	x	x	x	x	x	x		x		x	x
Cape Verde	x	x	x	x	x	x	x	x	x	x	x	x	x
Dominica	x	x	x	x	x	x	x	x		x		x	x
Fiji	x	x		x		x		x					x
Gambia		x		x									
Grenada	x	x	x	x	x	x	x	x	x	x	x	x	x
Guyana	x	x	x	x	x	x	x	x		x		x	x
Haiti	x	x		x		x	x	x					x
Jamaica	x	x	x	x	x	x	x	x		x		x	x
Kiribati				x									
Lebanon		x		x									
Mauritius	x	x	x	x	x	x		x		x		x	x
Micronesia		x		x									
Nauru		x		x									
Palau	x	x	x	x	x	x	x	x	x	x	x	x	x
Saint Kitts & Nevis	x	x	x	x	x	x	x	x	x	x	x	x	x
Saint Lucia	x	x	x	x		x		x		x		x	x
Saint Vinc & Gren	x	x	x	x	x	x	x	x	x	x	x	x	x
Samoa	x	x		x		x		x					x
Seychelles	x	x	x	x	x	x	x	x		x		x	x
Suriname	x	x	x	x		x		x					x
Tonga	x	x		x		x		x					x
Tuvalu		x		x									
Antigua & Barbuda	x	x	x	x	x	x	x	x		x		x	x
Bahamas		x		x									
Barbados	x	x	x	x	x	x	x	x		x		x	x
Cyprus	x	x	x	x	x	x		x		x		x	x
Malta	x	x	x	x	x	x	x	x	x	x	x	x	x
Trinidad & Tobago	x	x	x	x	x	x	x	x	x	x	x	x	x
Coordination failure	22	28	18	29	16	22	15	22	7	17	7	17	22

Unlike the benchmark model, the long-run level of human capital k_{ss} is now an ambiguous function of the high-skill emigration rate G. To illustrate this, let us first treat G as an exogenous variable and characterize its effect on human capital accumulation. At the steady state, combining Eqs. 4 and 5 gives

Footnote 20 contined
and translate into higher brain drain. Considering a lower slope in (20) would make the robustness exercise less demanding and reinforce our conclusion.

$$k_{ss} = \frac{(1-G)q(G)}{1-q(G)-n(1-G)}$$
$$\frac{\partial k_{ss}}{\partial G} = \frac{-q(G)\left[1-q(G)\right]+\frac{\partial q}{\partial G}(1-G)\left[1-n(1-G)\right]}{\left[1-q(G)-n(1-G)\right]^2}.$$

Under the traditional view of the benchmark model, we have $\partial q/\partial G = 0$ and $\partial k_{ss}/\partial G < 0$. When $\partial q/\partial G > 0$, $\partial k_{ss}/\partial G$ can be positive or negative. In particular, the high-skill emigration rate maximizing the long-run level of residents' human capital is positive if $[\partial k_{ss}/\partial G]_{G=0} > 0$. On average, this requires $0.095(1-n) > q_0(1-q_0)$ (i.e. $q_0 < 0.039$ since $n = 0.605$ in our calibration). This condition is very similar to that of Beine et al. (2008). Such a situation is obtained in 64 developing countries (out of 147). More generally, the growth-maximizing high-skill emigration rate G^* is the solution of $\partial k_{ss}/\partial G = 0$; our numerical experiment reveals that this rate G^* is a decreasing and non-linear function of q_0 which can be approximated by the linear function: $G^* = 0.411 - 10.12\, q_0$.

However, G is clearly endogenous and determined by our system of Eqs. 6–7–20. Solving this system for the 147 developing countries in our sample and provided that countries remain on the same path as in 2000, we can show that the long-run high-skill emigration rate resulting from utility maximization is lower than the growth maximizing level G^* in 57 cases (i.e. 38.8% of our sample). This result is obtained with the benchmark hypotheses: Gumbel distribution, identification of the parameters of the distribution of migration costs based on the US, and $\alpha = \underline{\alpha} = 0.277$.

The key question is: does the brain-gain channel modify the number of coordination failures? In the previous model disregarding the brain-gain channel, the low brain-drain equilibrium was always better than the high brain-drain solution in terms of economic performance at origin. Accounting for brain-gain effect, it is now theoretically possible that the high brain-drain equilibrium generates higher human capital and productivity at origin than the low brain-drain one.

However, our results do not support this possibility. Focusing on our two examples (Guatemala and Trinidad and Tobago), Fig. 6 shows that the dynamic correspondence changes compared to the model with exogenous q_j (see Fig. 5). For low levels of ex ante human capital z_t, the high brain-drain path (dark grey curve) is conducive to more ex ante human

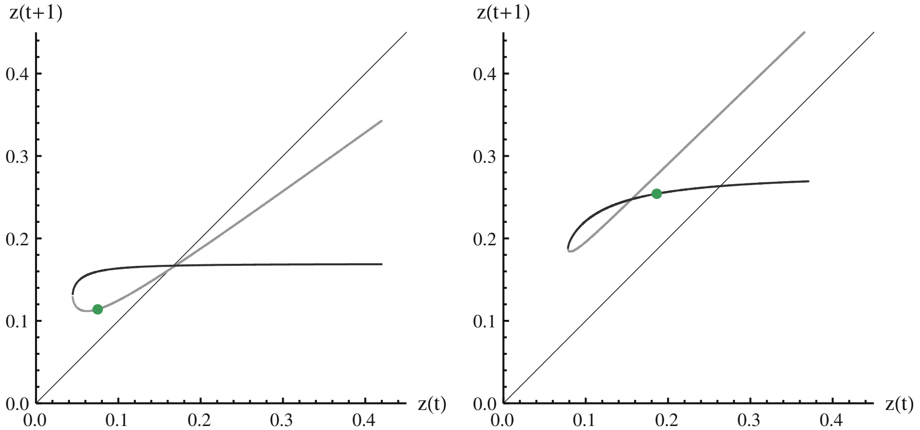


Fig. 6 Correspondences for Guatemala and Trinidad and Tobago with brain-gain effect

capital in the next period than the low brain-drain path (light grey curve). But the numerical results show that the high brain-drain path always corresponds to the case with low ex post human capital and high poverty.

Finally, the last row in Table 2 shows that the brain-gain channel does not modify the number of coordination failures compared to the benchmark scenario of the first row.

5 Conclusion

When high-skilled workers expect their home country to have low productivity and to be poorly governed, the most mobile of them will move to a better place. This can only reinforce the bad features present at home. On the contrary, if people expect high productivity and good governance, they will stay, promoting thereby high productivity, good governance, and human capital accumulation.

Such vicious or virtuous circles seem to arise very naturally when one takes into account the relationship between brain drain and development level in the home country. We accordingly built a model which is open to the possibility of multiple equilibria. We derived theoretical conditions under which they effectively arise. Identifying country-specific parameters in the data, we classified countries into different categories depending on whether multiple equilibria are possible, and whether the observed situation might be one of high brain drain and high poverty.

For a majority of countries, the observed equilibrium has higher income than the other possible ones. On the contrary, for 22 developing countries, including Jamaica, Haiti, and 20 small states, poverty and high brain drain are worsened by a coordination failure. Small states are more exposed to the risk of coordination failure because migration is more responsive to wage differentials. It can be argued that the number of coordination failures could be reduced by increasing emigration costs in small states. However such a policy might be difficult to implement since migration costs are mainly determined by distances and immigration restrictions at destination. An alternative policy could be to subsidize the repatriation of high-skill natives working abroad, until their country of origin reaches a productivity level inciting high-skill repatriates to stay and generate more human capital accumulation.

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References

Acemoglu, D. (1995). Reward structures and the allocation of talent. *European Economic Review, 39*, 17–33.

Acemoglu, D., & Angrist, J. (2000). How large are human capital externalities? Evidence from compulsory schooling laws. NBER Macroeconomic Annual 15.

Angrist, J. (1995). The economic returns to schooling in the West Bank and Gaza Strip. *American Economic Review, 85*, 1068–1087.

Azariadis, C., & Drazen, A. (1990). Threshold externalities in economic development. *The Quarterly Journal of Economics, 105*(2), 501–526.

Barret, A. (2001). Return migration of highly skilled Irish into Ireland and their impact on GNP and earnings inequality. In *International mobility of the highly skilled*. Paris: OECD Publishing.

Barro, R. J., & Lee, J.-W. (2001). International data on educational attainment: Updates and implications. *Oxford Economic Papers, 53*, 541–563.

Beine, M., Docquier, F., & Rapoport, H. (2001). Brain drain and economic growth: Theory and evidence. *Journal of Development Economics, 64*(1), 275–289.

Beine, M., Docquier, F., & Rapoport, H. (2008). Brain drain and human capital formation in developing countries: Winners and losers. *Economic Journal, 118*(4), 631–652.

Belot, M., & Hatton, T. J. (2008). Immigrant selection in the OECD. CEPR discussion paper no. 6675.

Benhabib, J., & Spiegel, M. (2005). Human capital and technology diffusion. In Aghion, P., Durlauf, S. (Eds.), *Handbook of economic growth* (Vol. 1, Chap. 13, pp. 935–966). New York: Elsevier.

Bhagwati, J. N., & Hamada, K. (1974). The brain drain, international integration of markets for professionals and unemployment. *Journal of Development Economics, 1*(1), 19–42.

Defoort, C. (2008). Tendances de long terme en migrations internationales: Analyse à partir de 6 pays receveurs. *Population-E, 63*, 285–318.

De la Croix, D., & Michel, P. (2002). *A theory of economic growth: Dynamics and policy in overlapping generations*. Cambridge: Cambridge University Press.

Docquier, F., Faye, O., & Pestieau, P. (2008). Is migration a good substitute for education subsidies?. *Journal of Development Economics, 86*, 263–276.

Docquier, F., Lohest, O., & Marfouk, A. (2007). Brain drain in developing countries. *World Bank Economic Review, 21*, 193–218.

Docquier, F., Lowell, B. L., & Marfouk, A. (2009). A gendered assessment of the brain drain. *Population and Development Review, 35*(2), 297–322.

Docquier, F., & Rapoport, H. (2011). Globalization, brain drain and development. *Journal of Economic Literature* (forthcoming).

Galor, O. (1996). Convergence? Inferences from theoretical models. *Economic Journal, 106*(437), 1056–1069.

Graham, B., & Temple, J. (2006). Rich nations, poor nations: How much can multiple equilibria explain?. *Journal of Economic Growth, 11*(1), 5–41.

Grogger, J., & Hanson, G. H. (2011). Income maximization and the selection and sorting of international migrants. *Journal of Development Economics, 95*(1), 42–57.

Haque, N. U., & Kim, S. (1995). Human capital flight: Impact of migration on income and growth. *IMF Staff Papers, 42*(3), 577–607.

Iranzo, S., & Peri, G. (2009). Migration and trade: Theory with an application to the Eastern-Western European integration. *Journal of International Economics, 79*(1), 1–19.

King, R. G., (1995). Quantitative theory and econometrics. *Economic Quarterly (Federal Reserve Bank of Richmond), 81*, 53–105.

Kremer, M., & Chen, D. (1999). Income-distribution dynamics with endogenous fertility. *American Economic Review, 89*(2), 155–160.

Krusell, P., Ohanian, L., Rios-Rull, J.-V., & Violante, G. (2000). Capital-skill complementarity and inequality: A macroeconomic analysis. *Econometrica, 68*(5), 1029–1054.

Lucas, R. E. (1988). On the mechanics of economic development. *Journal of Monetary Economics, 22*(3), 3–42.

Mariani, F. (2007). Migration as an antidote to rent-seeking?. *Journal of Development Economics, 84*(2), 609–630.

McCullock, R., & Yellen, J. T. (1975). Consequences of a tax on the brain drain for unemployment and income inequality in less developed countries. *Journal of Development Economics, 2*(3), 249–264.

McCullock, R., & Yellen, J. T. (1977). Factor mobility, regional development and the distribution of income. *Journal of Political Economy, 85*(1), 79–96.

McFadden, D. (1984). Econometric analysis of qualitative response models. In Z. Griliches & M. Intriligator, *Handbook of econometrics* (Vol. 2). Amsterdam: Elsevier/North-Holland.

Miyagiwa, K. (1991). Scale economies in education and the brain drain problem. *International Economic Review, 32*(3), 743–759.

Moretti, E. (2004a). estimating the social return to higher education: Evidence from longitudinal and repeated cross-sectional data. *Journal of Econometrics, 121*(1), 175–212.

Moretti, E. (2004b). Workers' education, spillovers and productivity: Evidence from plant-level production functions. *American Economic Review, 94*(3), 656–690.

Mountford, A. (1997). Can a brain drain be good for growth in the source economy? *Journal of Development Economics, 53*(2), 287–303.

Murphy, K. M., Shleifer, A., & Vishny, R. W. (1989). Industrialization and the big push. *Journal of Political Economy, 97*(5), 1003–1026.

Murphy, K. M., Shleifer, A., & Vishny, R. W. (1991). The allocation of talent: Implications for growth. *Quarterly Journal of Economics, 106*(2), 503–530.

Murphy, K. M., Shleifer, A., & Vishny, R. W. (1993). Why is rent-seeking so costly to growth? *American Economic Review, 83*(2), 409–414.

Ottaviano, G., & Peri, G. (2008). Immigration and national wages: Clarifying the theory and the empirics. Mimeo, UC Davis. .

Rosenzweig, M. R. (2007). Higher education and international migration in Asia: Brain circulation. Paper presented at the World Bank Annual Regional Conference, Beijing, January 2007.

Rosenzweig, M. R. (2008). The global migration of skill. Paper presented at the conference on “Migration and Development”. Lille—June 2008.

Schneider, F., & Enste, D. H. (2000). Shadow economies: Size, causes, and consequences. *Journal of Economic Literature, 38*(1), 77–114.

Selten, R. (1975). A reexamination of the perfectness concept for equilibrium points in extensive games. *International Journal of Game Theory, 4*, 25–55.

Stark, O., Helmenstein, C., & Prskawetz, A. (1998). Human capital depletion, human capital formation, and migration: A blessing or a ’curse’? *Economics Letters, 60*(3), 363–367.

Torbat, A. (2002). The brain drain from Iran to the United States. *Middle East Journal, 56*(2), 272–295.

Varian, H. R. (1992). *Microeconomic analysis*. New York: Norton.