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BRAIN DRAIN IN GLOBALIZATION: A GENERAL EQUILIBRIUM ANALYSIS FROM THE SENDING COUNTRIES' PERSPECTIVE

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According to the economic literature, high-skilled emigration may either harm or benefit developing economies. Recent research highlighted several positive and negative channels through which the brain drain operates. This paper aims at evaluating the relative magnitudes of various brain drain channels and quantifying their global impact on migrants' sending countries. For this purpose, we develop a 10-region general equilibrium model of the world economy characterized by overlapping-generations dynamics. Our findings suggest that the short-run impact of brain drain on resident human capital is extremely crucial, as it affects not only the number of high-skilled workers available to domestic production, but also the sending economy's capacity to innovate/adopt modern technologies. This latter effect is particularly important in globalization, where capital investments are made in places with high production efficiencies. Hence, despite positive feedback effects, those countries facing prevalent high-skilled emigration are the most candid victims to brain drain. (*JEL* F22, J24, O57)

I. INTRODUCTION

Is brain drain a curse or a boon for the *sending* countries? The economic literature has put forward several positive and negative effects of high-skilled emigration, but little is known on the *relative magnitudes* of these different forces at work.[1] In order to study the global impact of brain drain on developing economies and to identify the dominant channels among the various static and dynamic effects, a generic framework is certainly required, which is capable of incorporating the main mechanisms identified in the existing literature. With this aim, we develop a 10-region general-equilibrium model characterized by overlapping-generations (OLG) dynamics and calibrated to real data. The implications of skill outflow are assessed on the basis of gross domestic product (GDP) per capita.[2] In such a framework, not only can we juxtapose the direct impacts of brain drain, but their

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1. See the survey conducted by Commander, Kangasniemi, and Winters (2004).

2. The analysis was also performed in terms of gross national income per capita and within-region inequality. These results are available upon request from the authors.

ABBREVIATIONS

CES: Constant Elasticity of Substitution
FDI: Foreign Direct Investment
GDP: Gross Domestic Product
IMF: International Monetary Fund
OECD: Organization for Economic Co-operation and Development
OLG: Overlapping Generations
TFP: Total Factor Productivity

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interactions and other indirect effects are also endogenously and dynamically generated. This is a very important step forward, as high-skilled emigration is not an isolated incident, but it ripples through the entire global economic system.

In the process of economic globalization, the international movement of production factors is an essential component that stimulates further integration of the world economy. On the one hand, financial liberalization and the practice of international arbitrage contribute to large cross-border flows of capital. While the amount of foreign direct investment (FDI) at the world level has increased from 13 billion U.S. dollars in 1970 to nearly 2 trillion in 2007 (measured at current prices), the rise in FDI per capita is far more remarkable in the developed economies *alias* "North," than in the developing economies *alias* "South." This North–South disparity reflects largely the wide gaps in total factor productivity (TFP), and not insignificantly, the higher risks involved in investing in many developing countries.[3]

On the other hand, international wage gaps are the most important pull factor luring economic migrants from the developing to the developed economies (Clemens and Pritchett 2008; Grogger and Hanson 2008). The immigration rate in high-income countries has tripled since 1960 and doubled since 1985. In addition, Docquier, Lowell, and Marfouk (2009) document that, in OECD countries, two-thirds of the increase in immigration stocks during the 1990s are accounted for by the South-to-North movement. Moreover, when skill heterogeneity is taken into account, they find that the number of highly educated immigrants has increased by 70%, whereas the corresponding figure for immigrants with lower educational attainments is a dwarfed 30%. Although this difference does not necessarily imply an increasing trend of brain drain,[4] the same authors show that there exists a strong positive selection of emigrants, especially in the least developed countries. In many developing countries, high-skilled emigration rates are well above 40%, particularly for sub-Saharan African countries, Central American countries, and small states.

Furthermore, international flows of production factors are not independent of one another, but the direction of their interdependencies is ambiguous. For example, static trade models predict that an exogenous reallocation of labor to the North from the South must raise returns to capital at the destination and induce capital outflow from the origin. In the meantime, however, the empirical evidence on network externalities indicate that emigration and FDI inflows may well act as complements, especially from a dynamic perspective.[5] Moreover, technology diffusion through skilled diaspora can also augment the marginal productivity of capital in the South and attract more capital investments (e.g., Agrawal, Kapur, and McHale 2008; Kerr 2008; Lodigiani 2008). Last but not the least, the officially recorded amount of remittances has been increasing at a fast rate,[6] suggesting yet another complementary and important link between labor emigration and capital inflows (Walmsley and Winters 2005). This further promotes economic growth in the relatively capital-scarce developing countries, particularly those with less-developed financial systems (Giuliano and Ruiz-Arranz 2009).

To assess the impact of South-to-North brain drain on the sending economies, this paper utilizes a calibrated general-equilibrium OLG model. Our framework is similar to the general-equilibrium models analyzing the macroeconomic consequences of domestic demographic changes (e.g., De Nardi, Imrohoroglu, and Sargent 1999), and its multiregional characteristic makes it close in spirit to the latest developments of such models that allow for capital mobility (Attanasio, Kitao, and Violante 2007). More precisely, our open-economy model divides the world into three developed and seven developing regions; moreover, cross-border flows of labor are necessarily incorporated on top of capital mobility. We treat the probability to emigrate

3. See, for example, the country risk classification produced by the Organization for Economic Co-operation and Development (OECD).

4. In fact, Defoort (2008) demonstrates that brain drain rates, measured as the emigration rates of the highly skilled natives, were relatively stable over time. This may be because of the general rise in educational attainments in developing countries; thus, increases in the number of high-skilled emigrants are accompanied by a more educated population at origin.

5. For instance, Kugler and Rapoport (2007) observe dynamic complementarity but contemporaneous substitutability between emigration and FDI inflows. While the former finding suggests the existence of network externalities, the latter is consistent with factor reallocation in the trade models.

6. In 2005, the officially recorded amount of remittances to developing countries exceeded total development aid and equalized total FDI. It continued to grow at a double-digit rate during 2005–2007, but slowed down in 2008, likely because of the global financial crisis (see the World Bank's *Global Economic Prospects* [Baffes et al. 2009]).

TABLE 1
Global Impact of the Brain Drain (BD): Methodology

Step 1: Calibration of BD Shocks		**Step 2: General-Equilibrium Analysis**		
Calibrating the BD channels	⇒	Introducing the new paths of the BD channels in the general-equilibrium (GE) model	⇒	**Outcome/Focus**
The four channels: (i) Demography (ii) Human capital (iii) Technological progress (iv) Risk premium		*Advantages of the GE approach:* (accounts for interactions, direct and indirect effects, static and dynamic effects)		(i) Global impact on GDP per capita (ii) Relative effects of the different channels on GDP per capita

as exogenous or, at least, not as an individual choice variable. This is a common assumption in the brain drain literature. Indeed, interdependencies between migration decisions and economic performances have received scant attention and have rarely been investigated in a satisfactory way. There are exceptions such as Galor (1986) or Vidal, Michel, and Crettez (1996) who studied the welfare implications of migration in stylized OLG models. More recently, de la Croix and Docquier (2012) endogenized high-skilled emigration decisions and income levels in developing countries. They only consider emigration to a representative high-income country, disregard South–South and low-skilled migration flows, and treat economic characteristics in the high-income region as exogenous. This simple framework is rich enough to generate multiple equilibria.

On the contrary, our goal is to evaluate the effect of exogenous migration shocks on regional economic performances and inequality. In each decade from 2010–2020 to 2050–2060, we increase by 20% the forecasted flow of high-skilled migrants from every developing region to each developed region. Increases in high-skilled immigration in the North may be owed to increasingly skill-biased immigration policy in response to aging, occupational shortage, and so forth. The originality of our approach is that we account for four main channels through which the brain drain affects sending economies. To evaluate the global economic impact of the four brain drain channels, we proceed in two steps, as described in Table 1. As the first step, we compute the impact of increased high-skilled emigration on the main channels, summarized by changes in four variables (see the following text). The new paths for these variables are generated outside the core of the model by using estimates from published forecasts and existing empirical studies. Then, as the second step, we introduce these new paths into our multiregional framework. This model of the world economy is necessary to generate the total *economic* impact as well as the relative effects of the various channels. These results are illustrated in terms of changes in GDP per capita.

Table 2 provides a summary description of the main channels through which the brain drain operates. First, as migrants tend to be young, demographic changes in the age structure reduce the working-age population that needs to support the retirees in developing regions. Second, high-skilled emigration directly reduces the size of high-skilled population, but in the meantime, a higher probability to emigrate raises the expected return to education and thereby the number of people investing in higher education. This incentive effect on human capital formation contributes to "brain gain" in regions where high-skilled emigration is less prevalent (Beine, Docquier, and Rapoport 2001, 2008).[7] Third, technological progress is accelerated in technologically less-advanced regions, where the high-skilled diaspora plays an important role in facilitating technology diffusion; on the other hand, however, the loss of high-skilled human capital also breeds dynamic impacts that slow down the catching-up of technology (Kerr 2008; Lodigiani 2008). Fourth, an enlarged diaspora helps to reduce information-related investment risks at origin, and thus contributes to attracting more FDI inflows (Docquier and Lodigiani 2012; Kugler and Rapoport 2007).

Because these four channels have ambiguous effects on GDP per capita, it is necessary to adopt a unified approach to evaluate their global impact. More importantly, the greatest advantage of the general-equilibrium analysis is that it does not only account for the channels affected by the brain drain, but it also

7. See also Mountford (1997), Stark, Helmenstein, and Prskawetz (1997, 1998), Vidal (1998), Stark and Wang (2002), Stark (2004).

TABLE 2
Summary of the Main Channels of the Brain Drain (BD)

Channel	Mechanism	Impact on GDP per Capita	Calibration
Demography	BD affects the demographic structure through the outflow of young workers	Negative	U.N. Population Prospects (2006 Revision)
Human capital	BD reduces HC via ex post loss of high-skilled workers	Negative	Estimates from Beine, Docquier, and Rapoport (2008)
	BD enhances HC via ex ante incentives to be highly educated	Positive	
Technological progress	BD produces positive externality on TFP by facilitating technology diffusion from the North	Positive	Estimates from Lodigiani (2008)
	BD negatively affects TFP via loss of high-skilled workers who are crucial to innovate/adopt technologies	Negative	
Risk premium	BD reduces information risks and induces more FDI inflows	Positive	Estimates from Docquier and Lodigiani (2012)

takes into consideration the interactions between these channels, along with various static and dynamic effects as well as direct and indirect impacts. This is especially important in a globalized economy, where international flows of people are often accompanied by international flows of other factors, as mentioned earlier. In fact, our model accounts for endogenous changes in the allocation of capital across regions, which follow from the impact of migration flows on the capital-labor ratios in sending and destination regions. Moreover, the OLG framework captures the effects of brain drain through the age structure, and it also allows for dynamic effects via asset accumulation.[8]

Our findings suggest that the winners and losers of brain drain can be distinguished by the short-run impacts on their resident human capital, which in turn affects technological progress via a region's capacity to innovate or to adopt modern technologies. Therefore, the loser regions are characterized by high emigration rates among their highly skilled, which make them less likely to benefit from the "brain gain" effect. Most importantly, it is found that the reason why the impacts working through the technology mechanism generates a large impact is greatly because of international capital mobility, as production technology defines production efficiency, which is one of the most important determinants of returns to physical capital. In other words, the benefits and the harms of brain drain can be amplified when it takes place *in globalization*.[9]

The rest of the paper is organized as follows. Section II presents the calibrated OLG model of the world economy. In Section III, the simulated results are summarized and followed by a detailed analysis, where the dominant channels are identified through which brain drain affects the developing economies, and the conditions are explained under which each channel generates positive or negative impacts. Finally, Section IV concludes.

II. AN OLG MODEL OF THE WORLD ECONOMY

We introduce international migration with skill heterogeneity into a general-equilibrium model with OLG of individuals. The model economy is composed of 10 regions as listed in Table 3. We distinguish three *developed* regions (the *North*) and seven *developing* regions (the *South*).[10]

8. Docquier and Rapoport (2012) study the overall costs and benefits of brain drain on the per country basis. However, in their partial equilibrium setting, all effects occur through the production parameters except labor endowment. Moreover, all direct impacts of brain drain are simulated outside the production equation. Hence, their study incorporates neither the changes in international capital flows, nor the impacts on the demographic structure and the amounts of consumption and savings.

9. Klein and Ventura (2009) analyze the effects of removing barriers to labor mobility in a world characterized by productivity differences. In their parameterized model, they find large output gains not only due to free labor mobility, but also thanks to capital. In fact, it is concluded that "the reallocation of capital across locations and capital accumulation act as amplification mechanisms." However, they do not take into account the effects of (skilled) migration on productivity.

10. The detailed list of countries by region can be found in Table A1.

TABLE 3
List of 10 World Regions

North	NAM	North America
	JAP	Japan
	ADV	Other high-income advanced countries
South	EAS	Eastern Europe
	MEN	Middle East and Northern Africa
	LAC	Latin America and the Caribbean
	SSA	Sub-Saharan Africa
	RUS	The Former Soviet Union
	CHI	The Chinese world
	IND	The Indian world and Pacific Islands

TABLE 4
Regional Characteristics for the South in 2000 (in %)

Region	Demog	Skill	Aemig	Hemig	Lemig	Rem/Y
EAS	3.9	12.4	6.6	11.8	5.3	1.3
MEN	6.2	8.5	3.5	8.5	2.8	2.8
LAC	10.2	11.8	4.3	11.0	3.1	2.0
SSA	9.7	2.8	0.8	12.9	0.4	2.6
RUS	3.0	18.9	2.0	2.6	1.8	0.6
CHI	36.6	3.8	0.5	7.3	0.2	0.8
IND	30.3	4.5	0.4	5.2	0.2	1.8
Total	100.0					

Source: Docquier and Marfouk (2006) and the International Monetary Fund (IMF).

Table 4 provides a glimpse at the regional characteristics of the South in 2000, which includes a region's demographic share of the population aged 25 or over among all developing regions (Demog), then for each region itself, the proportion of the highly skilled in the resident population (Skill),[11] the average emigration rate toward the OECD countries (Aemig), the high-skilled emigration rate (Hemig), the low-skilled emigration rate (Lemig), and the ratio of remittances to GDP (Rem/Y).[12] Each developing region exhibits a strong pattern of positive selection into emigration, with the high-skilled emigration rate exceeding, in some cases by more than 30 times, the low-skilled emigration rate. Moreover, in certain regions such as SSA, the loss of human capital seems particularly alarming given its low proportion of high-skilled population. Finally, albeit their significance for many migrant communities, the ratio of remittances to GDP remains small for every developing region.[13]

Our OLG model is dynamically calibrated to real data and using the empirical elasticities estimated in the literature, so that it matches to a very high degree the regional structures and the interregional disparities over the period 1950–2000. Once incorporated with the calibrated evolution of demographic variables, human capital, and the magnitudes of skilled diaspora and migrant network externalities, the micro-founded general-equilibrium model then generates predictions for the world output, prices, remittances, asset accumulation, the geographical allocation of assets, the international flows of capital income, and other endogenous variables. In order to assess the global impact of brain drain on the developing economies, demographic shocks of additional high-skilled emigration are introduced during the period 2010–2050, and the analysis will focus on the transitional path during the period 2000–2100.[14] In the ensuing sections, we will describe the demographic structure and present the general-equilibrium model characterized by OLG dynamics. Then, the migration shocks will be specified in the context of the model economy, and the direct implications of high-skilled emigration will be discussed.

A. Demographic Structure

At each period, there are eight OLG denoted by a, with $a = 0$ standing for the age class 15–24, $a = 1$ for 25–34, and so on, up to $a = 7$ for 85–94.[15] Individuals have uncertain longevities, meaning that they may die at the end of every period. Each individual of the same generation faces an identical cumulative survival

11. Because of data availability, the highly skilled are proxied as those with post-secondary degrees.

12. Regarding remittances, the amounts presented in Table 4 are taken from the International Monetary Fund (IMF) database and are usually seen as underestimating the reality as many transfers are channeled through the informal sector. It is a priori difficult to estimate the region-specific bias. Thus, we will only consider the official IMF numbers in our analysis.

13. Brain drain increases the proportion of migrants in developed regions and thereby the amount of remittances received at origin. Our framework accounts for this mechanism (see the Appendix); however, the fraction of remittances in regional GDP's is small and only negligibly affected by further high-skilled emigration.

14. The model economy starts from an initial steady state in 1870, and after demographic shocks are introduced, the new steady state is reached several periods after 2200. Starting the simulations in 1870 and ending them in 2300 allow us to isolate the period in which we are interested from the initial and final conditions.

15. The calibration method of the demographic structure and its associated parameters is discussed in the Appendix.

probability, which decreases with age. Hence, the size of each generation ($N_{a,t+a}$) declines deterministically over time:

$$(1)\quad N_{a,t+a} = P_{a,t+a} N_{0,t} \quad a = \{0, 1, \ldots, 7\},$$

where $P_{a,t+a} \in [0, 1]$ is the exogenous fraction of generation a born at period t alive at period $t + a$, with $P_{0,t} = 1$.

The size of the young generation ($a = 0$) increases over time at an exogenous growth rate:

$$(2)\qquad N_{0,t} = m_{t-1} N_{0,t-1},$$

where $N_{0,t}$ measures the size of the young generation, and m_{t-1} is one plus the population growth rate, which includes both fertility and migration. It is assumed that migration takes place at the first period of life (i.e., $a = 0$) and is permanent. This is a reasonable assumption as (1) migrants tend to be young adults and (2) we focus on the South-to-North migration of the highly skilled, who are likely to migrate on a more permanent basis.[16]

Individuals belonging to the same generation are heterogeneous in terms of their skills. They are either highly or lowly skilled (denoted by h and l, respectively). It is assumed that an individual obtains post-secondary schooling and becomes high-skilled before reaching age 25.[17] Let ϕ_t stand for the proportion of the highly skilled among the young generation born at period t. The populations of the high- and the low-skilled young are then given respectively by:

$$(3)\qquad \begin{array}{rcl} N^h_{0,t} & = & \phi_t N_{0,t} \\ N^l_{0,t} & = & (1 - \phi_t) N_{0,t} \end{array}, \quad \phi_t \in [0, 1].$$

An exogenous profile of participation in the labor market is assumed per age and skill group (denoted by $\lambda^j_{a,t}$). Hence, labor supply of a type j individual at period t is given by

$$(4)\qquad L^j_t = \sum_{a=0}^{7} \lambda^j_{a,t} N^j_{a,t} \quad j = \{h, l\}.$$

Specifically, full participation is assumed except for the following three groups. The high-skilled young spend a fraction of their time in obtaining education and do not fully participate in the labor market. At age 55–64, people partly retire. After age 64, they fully retire.

B. *The General-Equilibrium Model*

Each region has three types of agents: households, the firm, and the government.

Households. Each individual derives utility from her/his lifetime consumption. The expected utility function is assumed to be time-separable and logarithmic:

$$(5)\quad E\left(U^j_t\right) = \sum_{a=0}^{7} P_{a,t+a} \ln\left(c^j_{a,t+a}\right) \quad j = \{h, l\},$$

where $c^j_{a,t+a} \geq 0$ denotes the amount of goods consumed by an individual of generation a at period $t + a$. The price of goods is normalized to unity; therefore, $c^j_{a,t+a}$ also equals to her total expenditures of the same period.

Following de la Croix and Docquier (2007), we postulate the existence of an insurance mechanism à la Arrow-Debreu. The assets of an individual, who does not survive to the next period, are equally distributed among individuals belonging to the same generation (and living in the same region).[18] Individuals thus maximize their expected utility subject to a budget constraint requiring equality between the expected value of expenditures and the expected value of incomes (I)

$$(6)\quad \sum_{a=0}^{7} \frac{P_{a,t+a}}{\prod_{v=1}^{a} R^*_{t+v}} (1 + \tau^c_{t+a}) c^j_{a,t+a} = \sum_{a=0}^{7} \frac{P_{a,t+a}}{\prod_{v=1}^{a} R^*_{t+v}} I^j_{a,t+a} \quad j = \{h, l\},$$

where R^*_t is one plus the international interest rate, and τ^c_t denotes the consumption tax rate. Incomes consist of labor income (w^j_t), pension

16. This assumption is made also out of consideration for analytical tractability, so that migrants and natives living in the same region have identical asset accumulations.

17. Our perception of high- versus low-skilled labor is similar to the one described in the study by Cervellati and Sunde (2005). Each individual is endowed with one unit of low-skilled labor; however, it is transformed into a high-skilled unit upon the completion of post-secondary education, when one has acquired the ability of abstract reasoning. This specification is consistent with empirical evidence showing perfect substitutability between high school graduates and dropouts (Card 2009; Ottaviano and Peri 2008), and it also explains why the high-skilled diaspora is unique in facilitating technology diffusion (see Section I).

18. This is to ensure that an individual's skill type is the only source of heterogeneity in our model so that individuals of the same skill type have identical asset accumulations.

benefits (b_t^j), and other welfare transfers (ζ_a^j) represented as a time-constant fraction of labor income, as shown by

$$I_{a,t+a}^j = \Big[\lambda_{a,t+a}^j(1-e_{t+a}^j)(1-\tau_{t+a}^w)w_{t+a}^j + (1-\lambda_{a,t+a}^j)b_{t+a}^j + \psi_{t+a}\zeta_a^j w_{t+a}^j\Big] \quad j=\{h,l\},$$

where τ_t^w stands for the income tax rate. Moreover, individuals spend an exogenous fraction e_t^j of their total time on obtaining higher education (which is only positive in their first period of life). Finally, ψ_t is the generosity factor, by which other welfare transfers are multiplied at time t. It measures the average magnitude of welfare program in each region at different periods.

Firm. At each period and in each region, a representative and profit-maximizing firm uses efficient labor (L_t) and physical capital (K_t) to produce a composite good (Y_t).[19] A Cobb-Douglas production function is assumed with constant returns to scale,[20]

$$(7) \qquad Y_t = K_t^{\alpha}(A_t L_t)^{1-\alpha} \quad \alpha \in [0,1],$$

where α measures the capital intensity of production, and under the assumption of perfect competition with unity goods price, it also stands for the share of gross capital returns in the total domestic product. The exogenous parameter $A_t > 0$ represents the Harrod neutral technological progress.

The total efficient labor is a combination of high- and low-skilled labor (denoted by L_t^h and L_t^l, respectively) according to a constant elasticity of substitution (CES) function:

$$(8) \quad L_t = [\upsilon_t (L_t^h)^{\sigma} + (1-\upsilon_t)(L_t^l)^{\sigma}]^{1/\sigma} \quad \sigma < 1,$$

where υ_t is an exogenous skill-biased technical change, and $\sigma \equiv 1 - 1/\epsilon$, with ϵ denoting the elasticity of substitution between high- and low-skilled labor. The high- and low-skilled wage rates (respectively w_t^h and w_t^l) are determined by their respective marginal productivities. The skill wage premium is therefore

$$(9) \qquad \frac{w_t^h}{w_t^l} = \left(\frac{\upsilon_t}{1-\upsilon_t}\right)\cdot\left(\frac{L_t^h}{L_t^l}\right)^{\sigma-1}.$$

Capital is perfectly mobile across regions up to a region-specific risk premium ($\pi_t \geq 0$), which reflects investment risks. Capital receives its marginal product net of depreciation, with the depreciation rate denoted by δ.[21] The net returns to capital are equal to the international interest factor augmented by the region-specific risk premium:

$$(10) \quad R_t^{*}(1+\pi_t) = 1 + \alpha\left(\frac{A_t L_t}{K_t}\right)^{1-\alpha} - \delta.$$

Finally, the aggregate value of world assets equals the market value of the world-wide capital stock plus the sum of the debts of all regions as in

$$(11) \qquad \sum_{x\in X}\Omega_t^x = \sum_{x\in X}(K_t^x + d_t^x Y_t^x),$$

where X is the set containing each world region. In region x at time t, Ω_t^x is the sum of the assets of all the cohorts, K_t^x is the sum of capital stock, and $d_t^x Y_t^x$ is the level of debt, which is expressed as a proportion d of total output Y.[22]

Government. The government levies taxes on labor earnings and consumption expenditures in order to finance general public spending, pension benefits, and other welfare transfers.[23] The government surplus (S_t) can be written as follows:

(12)

$$S_t = \tau_t^w \sum_{j=\{h,l\}} L_t^j w_t^j + \tau_t^c \sum_{j=\{h,l\}}\sum_{a=0}^{7}\phi_{t-a}^j N_{a,t} c_{a,t}^j - \sum_{j=\{h,l\}} b_t^j \sum_{a=0}^{7}\phi_{t-a}^j N_{a,t}(1-e_t^j)(1-\lambda_{a,t}^j)$$

19. With our modeling of the production sector, we implicitly assume that every region produces homogeneous goods. They are traded freely, and the international goods market is cleared by Walras' law. Hence, a region either imports or exports and no bidirectional trade exists. Given our focus on factor flows and their (real) prices, we choose this parsimonious modeling of international trade. Furthermore, if the Heckscher-Ohlin type of assumptions are satisfied, free trade would have led to factor price equalization even without factor mobility. However, these assumptions are not satisfied in our setting. As discussed later, the ex post gross returns to capital do not equalize because of region-specific risk premiums, while cross-country differences in technology, along with capital endowment differentials, contribute to international wage gaps.

20. The calibration method of the production parameters is discussed in the Appendix.

21. For the calibration, δ is set to 0.4 so that the annual depreciation rate is 5%.

22. For notational convenience, the regional index x was hidden in previous equations and will again be dropped in subsequent formulas.

23. The calibration method of the government-related parameters is discussed in the Appendix.

$$- \psi_t \sum_{j=\{h,l\}} w_t^j \sum_{a=0}^{7} \phi_{t-a}^j N_{a,t}(1-e_t^j)$$
$$\times \zeta_a^j - c_t^g Y_t - a_t Y_t + \Lambda_t \ ,$$

where c_t^g is a fraction of national income used to finance general public spending. Moreover, every developed region spends a percentage of output in aid (a_t), while governments of every developing region receive foreign development aid (Λ_t).

The government also issues bonds and pays interests on public debt. Thus, the government's budget constraint can be written as

$$(13) \qquad d_{t+1}Y_{t+1} = R_t^* d_t Y_t - S_t \ ,$$

where d_t represents the debt-to-GDP ratio. Equation (13) says that public debt in $t+1$ depends on past debt in t and its interests minus the government's surplus S_t. The government budget constraint is satisfied at each period by adjusting the wage tax rate, as transfers and taxes on consumption are exogenous.

The pension system is modeled in a way as to allow for different pension systems in each region, which are captured by a region-specific parameter ρ_t.

$$(14) \qquad \begin{aligned} b_t^l &= \chi_t w_t^l, \\ b_t^h &= \chi_t \left[\rho_t w_t^h + (1-\rho_t) w_t^l\right], \end{aligned}$$

where $\chi_t \in]0,1[$ is the replacement rate, which stands for the generosity of the pension system, whereas ρ_t indicates how redistributive it is. A value for ρ_t close to 0 implies more redistributive pension systems, as low- and high-skilled would receive similar amounts of benefits when retired.

Equilibrium. Given an initial stock of capital $\{K_t\}_{t=0}$, an initial distribution of wealth $\{Z_{a,t+a}^j\}_{a=1..7,\,t=0,j=h,l}$ with $\{Z_{a,t}^j = 0\}_{a=0,t\geq 0}$, an exogenous distribution of high-skilled individuals $\{\phi_{a,t-a}^j\}_{a=0..7,\,j=h,l,t\geq 0}$ and an exogenous demographic structure summarized by $\{N_{a,t}\}_{a=0..7,\,t\geq 0}$, a competitive equilibrium in an economy with perfect capital mobility, up to a regional risk premium, is

- a vector of individual variables $\{c_{a,t}^j\}_{a=0..7,\,t\geq 0,j=h,l}$ that are the optimal solutions to the households' maximization problem, that is, Equation (5) subject to Equation (6);
- a vector of the firm's variables $\{K_t, L_t^j\}_{t\geq 0,\,j=h,l}$ that maximize the firm's profit subject to technology in Equation (7);
- a vector of income taxes $\{\tau_t^w\}$ balancing the budget of the government in Equation (13);
- a vector of wages $\{w_t^j\}_{t\geq 0,j=h,l}$ such that labor markets are in equilibrium, that is, Equation (9) holds;
- an interest factor $\{R_t\}_{t\geq 0}$ satisfying the no arbitrage condition of the rates of return to capital, that is, Equation (10) holds;
- and, finally, an international interest factor R_t^* satisfying the equality between the aggregate value of world assets and the market value of the world-wide capital stock plus the sum of the debts of all regions, that is, Equation (11) holds.

The equilibrium on the goods market is achieved by Walras' law.

C. Calibrating the Brain Drain Shock

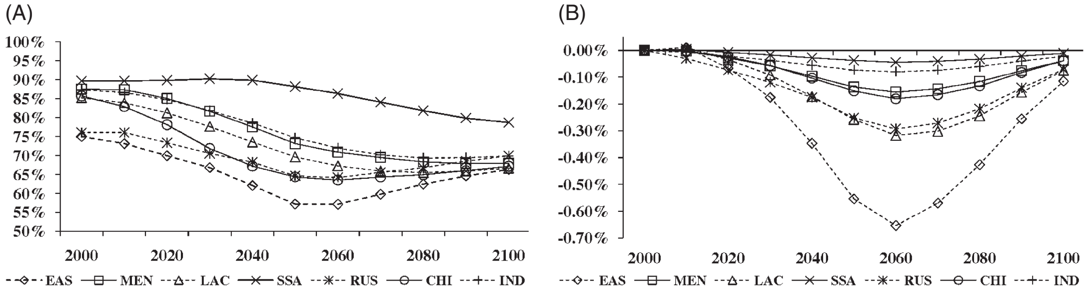
Starting from the U.N. forecasts, the demographic shock takes place in each decennial period from 2010–2020 to 2050–2060 and constitutes a 20% increase in the forecasted flow of high-skilled migrants from every developing region to each developed region.[24] Consistent with the model assumption, the additional migrants are considered to belong to the age class $a = 0$, or aged 15–24.[25] In our aggregated approach, it is implicitly assumed that all changes induced by the five waves of emigration shocks are homogeneously experienced by every country within the same region. Hence, the simulated changes per developing region are in effect more indicative of those experienced by large countries, because of their heavier weight in the aggregation. In the following, we discuss how the demographic shock changes some key regional characteristics from the baseline. We focus on the transitional period 2000–2100, or the period before the first wave of additional migrants is introduced until the period when the additional migrants of the last wave are entirely retired.

24. Notice that the scale of the additional high-skilled emigration is minuscule when compared with the regional population. In fact, the demographic shock implies a long-run reduction in the labor force that exceeds 1% only in LAC (1.28%) and EAS (2.19%) (see Table A2 for relative changes in total labor force by region). Hence, it is expected that the impacts induced by the migration shocks are of tiny magnitudes.

25. In the calibration, a *high-skilled* migrant is a young adult who is forecast to complete post-secondary education.

FIGURE 1

Support Ratio (SR_t). (A) Baseline Value. (B) After Shocks (% Change Compared to Baseline)



Demography. Naturally, demographic evolution affects an economy's support ratio, which is defined here as the ratio of resident labor force to resident population:[26]

$$SR_t = \frac{\sum_{a=0}^{7}\sum_{j=\{h,l\}}\lambda_{a,t}^{j}N_{a,t}^{j}}{\sum_{a=0}^{7}\sum_{j=\{h,l\}}N_{a,t}^{j}}.$$

Figure 1A depicts its baseline evolution. It is observed that all regions will be affected by the aging process, thus experiencing shrinking shares of working-age population, with EAS facing the lowest support ratio and SSA the highest at all periods. Figure 1B then shows the relative changes after migration shocks are introduced. As expected, all regions are adversely affected by the loss of working-age population caused by the demographic shock that alters population dynamics via m_t in Equation (2). However, EAS is most seriously hit because of the combination of a large share of aged population and a high emigration rate among the highly skilled within its rather educated population. The effects reach their respective maxima in 2060, with EAS confronted by a decline of 0.65%.

Human capital. A recent wave of theoretical and empirical studies suggests that high-skilled emigration can generate a positive incentive effect on human capital formation (see Section I). This positive effect on human capital may outweigh the loss of human capital due to brain drain, especially in countries with low emigration rates among the highly skilled. At the baseline, it is considered that the net effects of high-skilled emigration on human capital formation are already embodied in the calibration based on real data. Let us define the *resident* human capital level as the proportion of the highly skilled among the resident labor force:

$$HC_t^{rs} = \frac{\sum_{a=0}^{7}\lambda_{a,t}^{h}N_{a,t}^{h}}{\sum_{a=0}^{7}\sum_{j=\{h,l\}}\lambda_{a,t}^{j}N_{a,t}^{j}}.$$

Figure 2A depicts its baseline evolution by region.

In order to incorporate the "brain gain" effect, our calibration follows Beine, Docquier, and Rapoport (2008), who find evidence that the prospect of high-skilled emigration is positively associated with gross (premigration) human capital in cross-country regressions. We obtain the after-shock levels of gross human capital (HC_t^{nt}) by applying the brain gain elasticity estimated in their parsimonious specification:

$$\left(\frac{\Delta HC_t^{nt}}{HC_t^{nt}}\right)\cdot\left(\frac{m_t^h}{\Delta m_t^h}\right) = 0.0481.$$

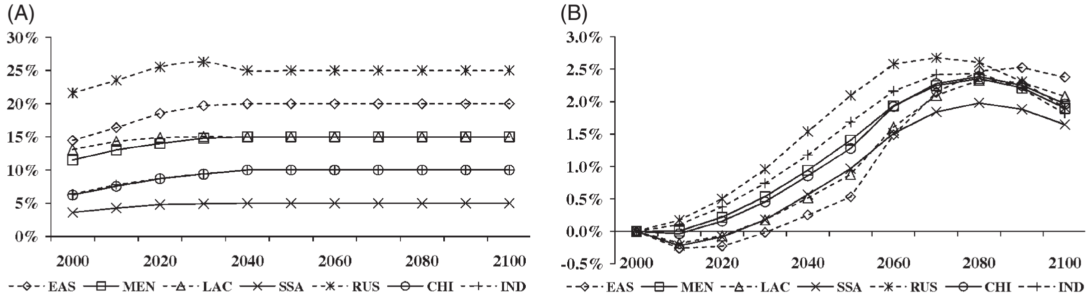
Then, we compute the after-shock levels of resident human capital HC_t^{rs} according to Equation (A2) in the Appendix.[27] Figure 2B depicts the relative changes in resident human capital. It is observed that, after the initial shocks, increased skill outflows negatively affect the skill composition among the young generation,

26. Note that m_{t-1} in Equation (2) already takes into account population changes due to migration; therefore, $N_{a,t}$ measures the resident population of age class a at period t.

27. The Appendix outlines the calibration method that allows us to take into account the incentive effect on human capital formation. Notice that we have abstracted from explicitly modeling the schooling decision in order to maintain the model's tractability. If we were to model the schooling decision, regardless of the modeling strategy (e.g., to endogenize the amount of time spent on education), the parameter which we will need to calibrate eventually is the schooling elasticity of migration probability, that is, how the probability of receiving tertiary education changes in response to a change in the probability to migrate. At the aggregate, this will be equivalent to calibrating how the gross stock of human capital changes in response to a change in migration probability.

FIGURE 2

Human Capital (HC_t^{rs}). (A) Baseline Value. (B) After Shocks (% Change Compared to Baseline)



or ϕ_t in Equation (3). Hence, resident human capital is decreased, specifically for regions characterized by distinctively high emigration rates among the highly skilled, namely EAS, LAC, and SSA (see Table 4). However, the incentive effect on human capital formation of better migration prospects for the highly skilled (or the *brain gain* effect) eventually benefits all regions, enhancing resident human capital by maximally 2%–3%.[28]

Technological progress. In order to take into account the diaspora externality in enhancing technology diffusion from the North to the South, we follow Lodigiani (2008), who extended Vandenbussche, Aghion, and Meghir (2006) by adding high-skilled diaspora in their specification.[29] It estimates TFP growth fueled by a neo-Schumpeterian technological progress:

(15)

$$\Delta\ln(\mathrm{TFP}_t) = 0.59 - 0.29 \cdot \ln\left(\frac{\mathrm{TFP}_t}{\mathrm{TFP}_t^{\mathrm{NAM}}}\right) + 1.44 \cdot \mathrm{HC}_t^{rs} - 0.10 \cdot \ln(M_t^h) + 0.88 \cdot \ln\left(\frac{\mathrm{TFP}_t}{\mathrm{TFP}_t^{\mathrm{NAM}}}\right) \cdot \mathrm{HC}_t^{rs} - 0.06 \cdot \ln\left(\frac{\mathrm{TFP}_t}{\mathrm{TFP}_t^{\mathrm{NAM}}}\right) \cdot \ln(M_t^h) + \mu_t$$

where $\mathrm{TFP}_t \equiv A_t^{1-\alpha}$ in Equation (7), and $(\mathrm{TFP}_t/\mathrm{TFP}_t^{\mathrm{NAM}})$ is a monotonic transformation of a region's distance to the technology frontier (A_t/A_t^{NAM}). $\Delta ln\,(\mathrm{TFP}_t)$ denotes the rate of TFP growth over a 5-year interval. M_t^h is a developing region's stock of high-skilled emigrants living in the North.[30] Finally, μ_t captures the exogenous time trend. The basic idea lying behind this specification is that TFP growth is determined by a region's capacity to innovate or to adopt modern technologies. On the one hand, in a technologically less-advanced region that relies on the adoption of technologies innovated in the North, high-skilled emigrants facilitate technology diffusion back to the South; thus, it helps to augment TFP growth.[31] On the other hand, however, high-skilled human capital is crucial not only for technology innovation but also for the adoption of technologies diffused from the North; therefore, brain drain negatively affects TFP growth, and this effect is especially pessimistic for regions far from the technological frontier because of their inability to innovate and lack of high-skilled workers to adopt modern technologies.[32]

28. As our aggregate approach has the effects in every region dominated by the large countries, this result is consistent with Beine, Docquier, and Rapoport (2008)'s findings about winners and losers of brain drain, where "the most populated countries [...] are all among the winners."

29. The calibration method of technological progress is outlined in the Appendix.

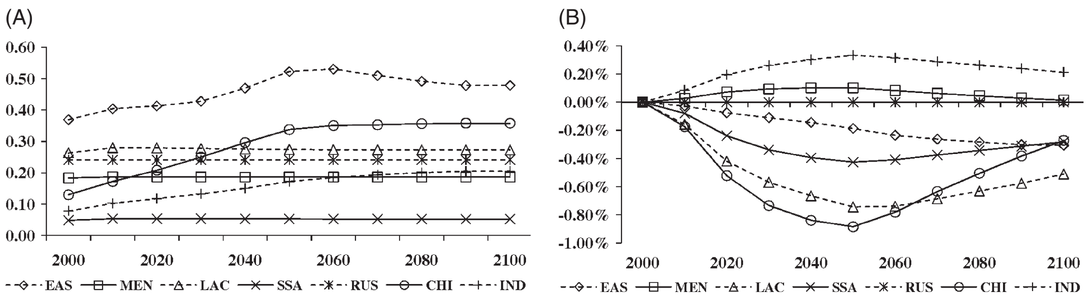
30. It is implicitly assumed that, as the high-skilled diaspora located in NAM, high-skilled emigrants living in JAP and in ADV generate the same externality in diffusing modern technologies. We regard it as a safe assumption given their narrow technology gaps to NAM.

31. Docquier and Rapoport (2012) point out that the log-specification of diaspora externality in Lodigiani (2008) leads to counter-intuitive results that technology diffusion is very strong in small countries. Our aggregate approach makes this mis-specification a very minor problem when making cross-region comparisons; however, it may imply that the positive effect generated through technology diffusion is to some degree underestimated. We choose to follow this specification as it is the only existing empirical study that is highly compatible with our model.

32. Using a similar framework, Papageorgiou and Spilimbergo (2009) identify that foreign-educated students also facilitate technological diffusion back to their home countries. Using patent citation data, Agrawal, Kapur, and McHale (2008) conclude that the emigration of highly

FIGURE 3

Distance to the Technology Frontier (A_t/A_t^{NAM}). (A) Baseline Value. (B) After Shocks (% Change Compared to Baseline)



The baseline evolution of A_t/A_t^{NAM} is depicted in Figure 3A. Figure 3B plots the relative changes induced by migration shocks. Small positive effects are observed in MEN and IND, both with low emigration rates among the highly skilled and located far from the technology frontier. For them, the enlarged high-skilled diaspora in the North acts to facilitate the diffusion of more advanced technology back to the South. In comparison, the initial losses of resident human capital observed in EAS, LAC, SSA, and CHI have negative dynamic effects on their capacity to innovate or to adopt modern technologies;[33] meanwhile, the compensatory role played by high-skilled diaspora in technology diffusion is of less importance for technologically more advanced regions, for example, EAS as well as CHI in the second half of the twenty-first century.

skilled Indians *on average* harms domestic knowledge access, because of a strong spillover effect created by colocation of innovators. In comparison, technology diffusion facilitated by high-skilled diaspora has a positive yet much smaller effect. The exceptions are the most frequently cited innovations, which may imply that diaspora externality operates mainly for the extremely high-end and hard-to-be-absorbed frontier knowledge.

33. For CHI, its distance to the technological frontier is not low enough for it to benefit much from the diaspora externality on technology diffusion, but it is sufficiently low for it to suffer greatly from the loss of high-skilled workers. This is why CHI's technological progress is so adversely affected even though it faces only a slightly negative impact on resident human capital after the first wave of migration shock. Notice that CHI's inability to benefit much from technology diffusion is rather at odds with Kerr (2008)'s finding that China is the main beneficiary from the U.S. innovations. This is again due to the misspecification problem mentioned in Footnote 31 given that CHI has the largest high-skilled diaspora at all periods along the transitional path.

Risk premium. As discussed in Section I, high-skilled diaspora may contribute to reducing information-related risks for capital investments in migrants' home countries, and thus attracting more FDI inflows in the South. In order to incorporate this type of network externality, we compute the elasticity of the risk premium to skilled diaspora by transforming the elasticity estimated by Docquier and Lodigiani (2012) of FDI per worker to the (5-year) lagged number of skilled emigrants:

$$\left(\frac{\Delta fdi_\tau}{fdi_\tau}\right)\cdot\left(\frac{M^h_{\tau-5}}{\Delta M^h_{\tau-5}}\right)=0.025,$$

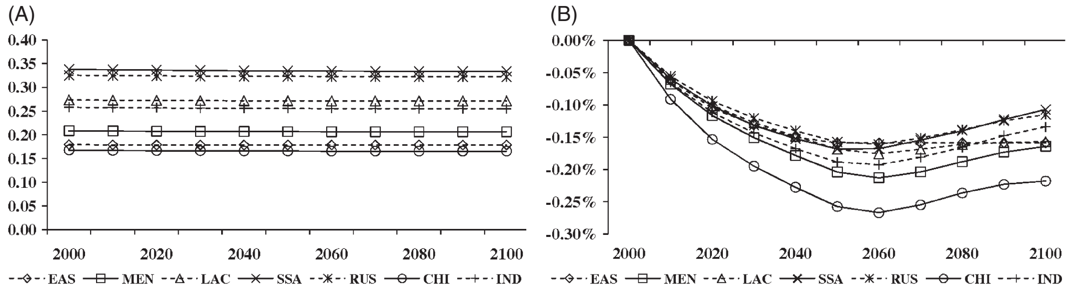
where fdi_τ denotes FDI per worker at year τ.[34] The baseline evolution of risk premium is depicted in Figure 4A. Following the migration shocks, Figure 4B describes its relative changes. It is found that, through the enlarged diaspora, all developing regions benefit from reductions in risk premiums, which will then imply *ceteris paribus* greater FDI inflows in the open economy. The relative changes in 2060 ranged between 0.16% and 0.27%.

III. RESULTS AND ANALYSIS

This section presents and analyzes the simulated results of the calibrated OLG model. By introducing the demographic shock of additional South-to-North brain drain specified earlier, we would like to answer the following questions: (1) What are the economic implications on the developing economies when they are faced with

34. The detailed calibration method of risk premium is outlined in the Appendix.

FIGURE 4
Risk Premium (π_t). (A) Baseline Value. (B) After Shocks (% Change Compared to Baseline)



larger skill outflows? (2) Which channels are dominant? (3) Do they induce positive or negative effects on the South, and under which conditions? To begin with, we examine how the shock of additional high-skilled emigration affects GDP per capita through different channels by comparing simulated results at the baseline and after shocks.

A. *Disentangled Effects on GDP per Capita*

The disentangled effects of the demographic shock on GDP per capita, defined as Y_t/N_t, are depicted in Figure 5 by each channel. All effects are expressed as relative changes from the baseline.

Demography (m_t). The loss of working-age population accelerates the aging process and results in a lower support ratio. In other words, with each migration shock, it implies a downsized domestic production yet proportioned by the same number of retirees. Hence, GDP per capita is negatively affected in all regions, with the maxima reached in 2060 and ranged between 0.2% and 0.7%. Consistent with the impact on the support ratio, EAS is the hardest hit region.

Human capital (ϕ_t). It is observed that the incentive effect of brain drain, which eventually contributes to "brain gain" in all regions via more human capital formation, also improves GDP per capita. For most regions, this positive impact begins to level off in 2060, with RUS benefiting the most at 1.0% and SSA the least at 0.2%. In line with the relative changes in resident human capital, the adverse short-run effects are more severe in regions characterized by high emigration rates among the highly skilled.[35] In comparison, the medium-to-long-run benefits of the incentive effect are most visible in regions where the labor force is better skilled, including EAS and LAC where the negative short-run result is actually the greatest.

Technological progress (A_t): As the Harrod neutral technological progress has the multiplier effect on domestic outputs (see Equation (7)), its impact on GDP per capita naturally follows the pattern of relative changes in technological progress discussed in Section II.C, with MEN and IND seeing positive outcomes up to 0.1% and 0.3%, respectively, thanks to technology diffusion that increases the efficiency of the production factors. In the meantime, those regions suffering initially from the loss of resident human capital have to cope with long-lasting negative dynamic consequences on their capacities to innovate or to adopt modern technologies; therefore, with the undermined production efficiencies, returns to capital decline, which discourages capital investments in these regions. LAC and CHI are most seriously affected in this respect, with their GDP per capita dwindled by about 0.9% maximally.[36]

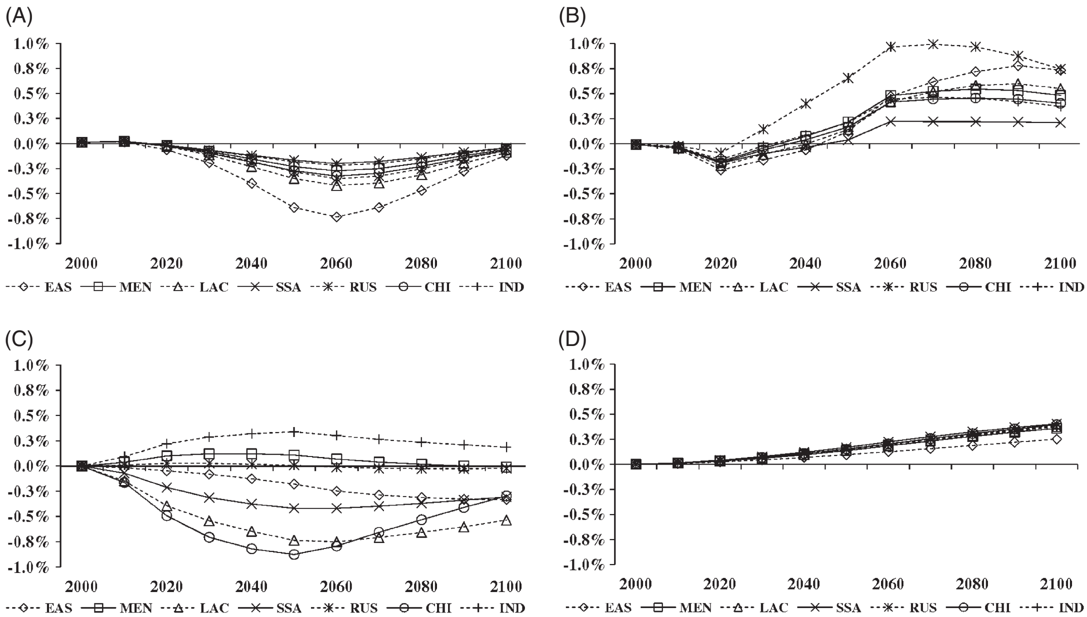
Risk premium (π_t): In an open economy, the level of risk premium is one of the crucial factors that determines the volume of physical

35. In order to single out the impact of the incentive effect, all parameter values are held at the baseline, except ϕ_t. Although increased high-skilled emigration leads to a larger share of high-skilled young already in the short-run for some regions (see Figure 2B), the efficiency units of labor are decreased because by assumption high-skilled young do not fully participate in the labor market.

36. However, we believe that the total impact of brain drain on CHI through the technology channel may be largely downward biased, as a result of the problem of mis-specification in the adopted empirical equation. See the discussion in Footnotes 31 and 33.

FIGURE 5

Disentangled Effects on GDP per Capita (Measured as Relative Changes from the Baseline). (A) Through Demography (m_t). (B) Through Human Capital (ϕ_t). (C) Through Technological Progress (A_t). (D) Through Risk Premium (π_t)



capital invested in domestic production. As every region experiences reduced risk premium with the enlargement of diaspora, they also enjoy increases in GDP per capita through this channel. It is observed that the positive effects are of similar magnitudes in nearly all regions, ranging between 0.01% and 0.03% in 2060. EAS benefits slightly less because, under the migration shocks, its diaspora has a smaller relative increase in size. Note that this effect is rather small in the short-run; nonetheless, it grows larger with accumulative migration shocks and its impact is long-lasting.

Now that we have understood better the channels through which the demographic shock of additional brain drain affects GDP per capita, we proceed further to the discussion of the total impact.

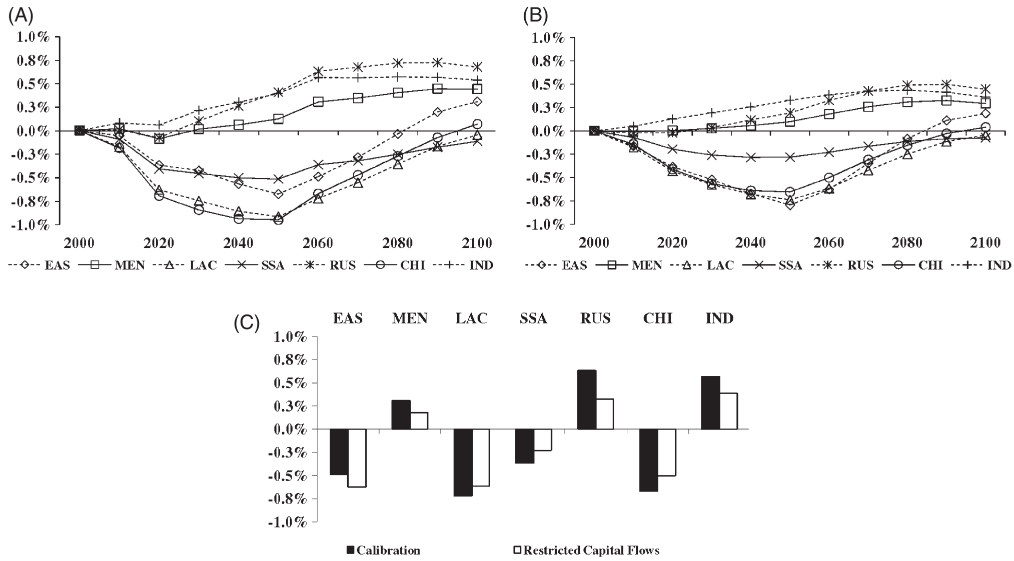
B. Total Impact on GDP per Capita

Figure 6A presents the total impact of the demographic shock on GDP per capita. In the medium to long run, it is found that all the seven developing regions either enjoy increased GDP per capita or face a very slightly negative outcome, thanks to the dynamic incentive effect on human capital formation and to the gradual reductions of risk premium. Nevertheless, while some experience positive results already in the short run (i.e., MEN, RUS, IND, with 0.3%–0.6% increases in 2060), others have to first undergo long periods of economic downturn along the transitional path (i.e., EAS, LAC, SSA, and CHI, with 0.4%–0.7% decreases in 2060). Except for RUS, what distinguishes the winners from the losers in the shorter run is the effect working through the technology channel, which is closely related to a region's resident human capital and its distance to the technological frontier. It is observed that all the loser regions suffer from the dynamic implications on technological progress originating from the initial losses of their resident human capital as depicted in Figure 2B. Besides CHI, all other loser regions have distinctively high emigration rates among the highly skilled, which are also the characteristics of the regions that are less likely to enjoy brain gain according to Beine, Docquier, and Rapoport (2008).

However, human capital, or labor inputs in general, is not the only factor used in the production of goods, but physical capital also plays an indispensable role. Hence, it is important

FIGURE 6

Total Impact on GDP per Capita. (A) Calibration. (B) Restricted Capital Flows. (C) Comparison in 2060



to gauge the effect operating through capital mobility in the context of a globalized economy. Given the dominance of the technology channel, which determines production efficiency and thus affects marginal product of capital in each region, we conduct an alternative scenario where capital flows do not react to changes in technological progress. In other words, *capital flows are exogenously and partially restricted*.[37]

Figure 6B presents the after-shock consequences under this alternative scenario. Notice first that, globally speaking, restricted capital mobility prevents capital to be allocated in the most efficient way. Thus, it is to be expected that, when compared to the calibrated scenario, the world outputs are decreased and the capital accumulation slows down as a result. However, a very interesting observation emerges in the alternative scenario—whereas all the short-run winners become worse off, three out of the four loser regions, namely LAC, SSA, and CHI, actually *benefit* from restricted capital flows against all tides (see Figure 6C for the comparison in 2060). This implies that the negative effects generated via the technology channel can largely be attributed to capital retreat or flight from these negatively impacted regions.

To prove the point, Table 5 records the allocation of world capital stock among all 10 regions under the calibrated and the alternative scenarios, and it also provides the relative changes in each region's share when the capital flows become more mobile. We can regard the changes in the North as the benchmark, which suggests the efficiency gain from capital mobility. It is observed that, on the one hand, the shares of world capital investments are severely reduced for LAC, SSA, and CHI, when capital movement reacts endogenously to the negative impacts that they experience in terms of technological progress (i.e., in the calibrated scenario). On the other hand, in MEN and IND, the two regions with enhanced technological progress do enjoy positive relative changes of world capital share that are well above the benchmark. It indicates that capital mobility enables them to take a much greater advantage of their improved production efficiency.[38]

37. More precisely, we predict for each region the after-shock stocks of physical capital (K_t) by holding the Harrod neutral technological progress (A_t) at the baseline. Then, we run the usual calibrated simulation except that K_t takes the predicted values.

38. It is found that RUS' relative changes in world capital share follow closely those in the North. This implies that the discrepancy of its experienced impacts between the two scenarios mainly come from capital mobility itself and have little to do with the technology channel. Indeed, in the calibration, the demographic shocks do not alter the technological distance to the frontier for RUS.

TABLE 5
Regional Shares of World Capital Stock (in %)

		2000	2010	2020	2030	2040	2050	2060	2070	2080	2090	2100
Calibrated scenario	NAM	28.19	27.09	26.68	26.29	26.09	26.15	26.77	27.45	27.88	28.05	28.12
	ADV	28.21	25.25	23.10	21.30	19.97	18.87	18.20	17.73	17.49	17.32	17.24
	JAP	9.17	8.03	7.06	6.19	5.43	4.87	4.56	4.23	4.02	3.91	3.83
	EAS	2.46	2.25	1.99	1.79	1.62	1.47	1.34	1.22	1.14	1.09	1.10
	MEN	3.42	3.77	4.07	4.32	4.36	4.29	4.34	4.38	4.36	4.35	4.36
	LAC	5.68	6.09	6.23	6.18	5.88	5.55	5.40	5.30	5.23	5.20	5.21
	SSA	1.20	1.44	1.69	2.00	2.30	2.58	2.83	2.99	3.08	3.10	3.10
	RUS	2.50	2.19	1.93	1.69	1.45	1.24	1.14	1.08	1.04	1.03	1.03
	CHI	13.23	15.94	17.71	19.12	20.21	20.76	20.34	19.93	19.69	19.58	19.62
	IND	5.93	7.96	9.54	11.13	12.69	14.21	15.09	15.69	16.08	16.36	16.39
Restricted flows of capital scenario	NAM	28.19	27.09	26.65	26.25	26.04	26.10	26.72	27.42	27.85	28.03	28.10
	ADV	28.21	25.25	23.08	21.27	19.93	18.84	18.17	17.71	17.47	17.31	17.23
	JAP	9.17	8.03	7.06	6.18	5.42	4.87	4.56	4.22	4.01	3.90	3.83
	EAS	2.46	2.25	1.99	1.79	1.62	1.47	1.34	1.22	1.14	1.09	1.10
	MEN	3.42	3.76	4.06	4.31	4.34	4.27	4.33	4.37	4.36	4.35	4.36
	LAC	5.68	6.10	6.25	6.21	5.91	5.58	5.43	5.33	5.26	5.23	5.24
	SSA	1.20	1.44	1.69	2.00	2.30	2.59	2.83	3.00	3.08	3.10	3.11
	RUS	2.50	2.19	1.93	1.68	1.45	1.24	1.14	1.08	1.04	1.03	1.03
	CHI	13.23	15.96	17.78	19.24	20.34	20.91	20.46	20.03	19.77	19.64	19.67
	IND	5.93	7.95	9.51	11.08	12.63	14.13	15.02	15.62	16.02	16.30	16.34
Relative change in world capital share	NAM	0.00	0.03	0.11	0.16	0.18	0.19	0.16	0.13	0.10	0.07	0.05
	ADV	0.00	0.03	0.11	0.16	0.18	0.19	0.16	0.13	0.10	0.07	0.05
	JAP	0.00	0.03	0.11	0.16	0.18	0.19	0.16	0.13	0.10	0.07	0.05
	EAS	0.00	0.00	0.02	0.04	0.03	0.00	−0.07	−0.13	−0.18	−0.22	−0.25
	MEN	0.00	0.06	0.17	0.24	0.28	0.29	0.25	0.20	0.15	0.11	0.08
	LAC	0.00	−0.13	−0.33	−0.43	−0.49	−0.56	−0.57	−0.55	−0.52	−0.49	−0.45
	SSA	0.00	−0.05	−0.15	−0.20	−0.22	−0.24	−0.24	−0.24	−0.23	−0.23	−0.22
	RUS	0.00	0.03	0.09	0.14	0.17	0.19	0.17	0.14	0.11	0.09	0.07
	CHI	0.00	−0.14	−0.42	−0.59	−0.66	−0.70	−0.62	−0.50	−0.40	−0.30	−0.21
	IND	0.00	0.11	0.29	0.41	0.48	0.52	0.48	0.42	0.37	0.32	0.28

As for EAS, its relative changes in the world capital investments are firstly positive and then turn negative from 2060 onwards. Despite the positive changes in the beginning periods, the magnitudes are much below the benchmark. It is consistent with the fact that EAS also experiences unfavorable impacts on its technological progress because of the initial loss of resident human capital. However, this adverse impact is less strong in EAS, as we can see from Figure 5C. In fact, the more dominant effect on its GDP per capita in the shorter run is operating through the demography channel (see Figure 5A), as EAS has a large share of senior residents who are not part of the labor force but proportion the downsized domestic products. This is why, unlike other loser regions, EAS is no better off when capital movement is restrained from responding to changes in technological progress.

The alternative scenario of restricted capital flows teaches us a very important lesson, as it indicates that studies of *brain drain in globalization* shall not merely look at its direct implications on human capital and other economic determinants on which human capital have first-order causal effects. As brain drain affects the economic environment in the South, other factor flows will respond to these changes and may act to magnify the total impacts of brain drain through, for example, changes in technological progress as we have shown earlier.

IV. CONCLUSION

Many concerns as well as hopes have been raised over the issue of brain drain, in particular skill outflows from the developing South to the developed North. On the one hand, the direct impact of losing high-skilled human capital and its potentially negative externality may do harm to domestic production and adversely affect those left behind in the developing economies.

On the other hand, recent empirical studies have demonstrated a series of positive feedback effects, suggesting that high-skilled emigration may inspire more human capital formation and that, on top of remittances, emigrants may contribute to the home economy through diaspora externalities.

The novelty of this paper is to construct a unified generic framework that is capable of combining many direct impacts of brain drain; moreover, their interactions and other indirect effects are also endogenously and dynamically generated. Compared with a partial equilibrium setting, the general-equilibrium framework is able to assess the global impact of brain drain on developing economies and to identify the dominant channels among various static and dynamic impacts. Furthermore, it allows us to incorporate many essential features, such as age structure and capital flows, through which brain drain may impact the developing economies in a direct and/or an indirect manner. It is identified that the short-run impact of brain drain on resident human capital is extremely crucial, because it not only determines the number of high-skilled workers available to domestic production, but it also affects an economy's capacity to innovate or to adopt modern technologies, which acts to determine the production efficiency and greatly influences the volume of capital in- and outflows. Therefore, the impacts working through the technology channel on production efficiencies are magnified in the open economy where capital investments conform to international arbitrage. Thus, when flows of physical capital are restricted, it is observed that those regions experiencing positive outcomes on GDP per capita now enjoy more limited benefits, whereas the regions suffering from slowdowns in technological progress are more insulated from foreign capital retreat and native capital flight.

Notice that, while free trade is incorporated in the current framework, there is only one production sector in each region and the final composite goods are identical across regions. Therefore, this paper does not take into account the potential effects of high-skilled emigration on the bilateral trade of specialized goods (Gould 1994; Head and Ries 1998). A possible future extension could be to consider that each region specializes in one intermediate good production, and the intermediate goods are traded across regions in order to produce the homogenous final good, such as in Backus, Kehoe, and Kydland (1995).

As mentioned in Section C, our aggregate regional approach implies that the simulated results are more indicative of those experienced by large countries. Despite this disadvantage, the aggregate results still provide significant implications also on the per country basis. Given the importance of how brain drain impacts resident human capital in the short run and its ensuing dynamic effects on technological progress, it can be concluded that countries with high emigration rates among their highly skilled are the most vulnerable to increased high-skilled emigration, as Beine, Docquier, and Rapoport (2008) provide evidence that they are the least likely to benefit from "brain gain" out of brain drain. They are composed of a long list of developing countries, especially in sub-Saharan Africa, Central America, and also many small states.

However, the same caveats apply as in the brain gain debate, largely due to data availability. That is, while cross-country regressions provide confirming results, they might still be flawed by mis-specification biases and the impossibility to capture unobserved heterogeneity between countries. Moreover, although issues of reverse causality can be alleviated by instrumentation techniques, the exact causality between human capital formation and skilled emigration is not easy to detect in a cross-country setting. According to our findings, a weaker brain gain effect could turn the whole picture bleaker. This is true also in the long run, especially owing to dynamic implications on technological progress.

All in all, is brain drain a curse or a boon? There is not a uniform answer, and it varies with the sending country's characteristics. For example, in Eastern European countries, brain drain does not only negatively affect its short-run human capital, but it also significantly increases the burden of their working-age residents to support the large share of retirees. Besides, for the technologically less-advanced countries where high-skilled emigration is not a prevalent phenomenon, brain drain may not be an unwelcome event; not only because it has the potential to raise resident human capital, but also because their high-skilled diaspora may facilitate the diffusion of up-to-date technologies, which accelerates technological progress in these economies. However, the certain losers of brain drain are those countries that have already experienced large outflows of their highly skilled, and their loss is not alleviated but magnified as it takes place in a globalized world where skill outflows generate influences also upon other flows of factors, most notably physical capital.

APPENDIX: CALIBRATION METHODS

Remittances

In order to incorporate remittances into our framework, the consumption of *migrants*—those born in the South and living in the North—is assumed to be a combination of goods consumption ($c^{M,j}$) and remittances ($RM^{M,j}$):

$$\text{(A1)} \qquad c^{j}_{a,t+a} = (c^{M,j}_{a,t+a})^{1-\gamma^j}(\text{RM}^{M,j}_{a,t+a})^{\gamma^j} \qquad j = \{h, l\},$$

where $\gamma^j \in [0, 1]$ is a time-invariant and age-invariant propensity to remit. It determines the share of total expenditures that a migrant of skill type j sends home as remittances. This exogenous parameter is region-specific and calibrated using the IMF recorded remittance receipts in 2003 (see Table 4). Owing to data restrictions, it is assumed that $\gamma^h = \gamma^l$ and that remittances are distributed equally among all residents living in the same developing region.[39]

Demographic Parameters

The survival probability $P_{a,t+a}$ in Equation (1) and the population growth rate m_t in Equation (2) are calibrated for the period 1950–2050, using the U.N. World Population Prospects, the 2006 Revision. In order to compute the high-skilled share of every generation, we use the Barro-Lee (2001) Dataset, which provides yearly by-country data on the educational attainment of individuals aged 25–74 for the period 1950–2000.[40] It is assumed that the high-skilled share of the young generation, ϕ_t in Equation (3), remains the same from year 2000 onwards.

Our definition of migrants refers to foreign-born individuals living in the destination regions. In order to calibrate the South-to-North migration stocks and flows at the baseline, we explicitly track migrants from the seven developing to the three developed regions.[41] In other words, our calibration strategy is based on the proportion of total immigrant stock to total resident population observed in each of the three developed regions.

For year 2000, the number, the age structure, and the skill type (proxied by educational attainment) of immigrants are calibrated using published statistics in the U.N. and the Docquier-Marfouk (2006) datasets. From the gross stock of immigrants in each developed region, we subtract migrants aged 0–14 and all North-to-North migrants, then we compute the shares of immigrants by skill and by region of origin. Anchored to the 2000 numbers, we use survival probabilities as well as the growth rates of the immigrant population to construct the retrospective numbers of migrants before 2000. For immigration forecasts, we start from the 2000 numbers and let migrants die according to the survival probability forecasts. Assuming that all future migrants are aged 15–24, we let changes in the stock of immigrants follow the U.N. forecasts (from which we subtract those aged 0–14 and North-to-North migrants using the 2000 proportions). It is assumed that future migrants are distributed by skill and by region as they are in 2000.

Production Parameters

The share of gross capital returns in the total domestic output, or α in Equation (7), is set to one-third as estimated in the growth accounting literature à la Solow (1957).

The Harrod neutral technological progress (A_t) is calibrated as follows. North America is assumed to be the technologically leading economy at all periods considered, with the level of technology denoted by A_t^{NAM}. Its evolution is calibrated with real observations up to year 2000, and for future periods, the annual growth rate is assumed to be equal to 1.84%. In order to obtain A_t for nonleading regions, we use the observed paths of GDP ratio, Y_t/Y_t^{NAM}, where Y_t^{NAM} measures the leader's GDP. We swap the exogenous variable A_t/A_t^{NAM} for the endogenous variable Y_t/Y_t^{NAM} and then solve the identification steps.[42] The ratios of GDP's are computed by employing the World Development Indicators (WDI) data of GDP per purchasing power parity for years 1980, 1990, and 2000, and the values in 1980 are adopted for the periods preceding 1980. For the periods following 2000, the calibration of the forecast technological progress will be discussed later when changes in resident human capital and technology diffusion are explicitly taken into account.[43]

Following Acemoglu (2002), the elasticity of substitution between high- and low-skilled labor (ϵ) is set to

39. Remittances are modeled in this way for the same reason explained in Footnote 16. The age-invariance of the propensity to remit comes from our implicit assumption that there is no remittances decay because of scant empirical evidence. Although we do not consider skill heterogeneity, that is, $\gamma^h = \gamma^l$, it turns out to be infeasible that high-skilled migrants could have a much lower propensity to remit when we calibrate the parameters to the official remittances data. Otherwise, remittances from low-skilled migrants will have to account for an unreasonably large share of total remittance receipts, which would then require that they remit an extremely large share of their total income.

40. We first aggregate this dataset by region and then partition it to obtain shares of highly skilled per age class. We proceed as follows. First, it is reasonable to assume that, at each period, the share of high-skilled individuals is higher for the younger age class. In particular, we assume that the share of high-skilled individuals aged 85–94 corresponds arbitrarily to 80% of the share of the highly skilled aged 75–84, which in turn is equal to 80% of that of the next younger age class, and so forth. As all the shares of the highly skilled per age class then depend on the share of the highly skilled aged 25–34, we compute this share so that it matches the total share of the highly skilled in 1950, as given by the Barro-Lee Dataset. Second, we report the values of the shares of the age classes 25–34 to 65–74 of the following years. For example, the share of the highly skilled aged 35–44 in 1960 is equal to the share of the highly skilled aged 25–34 in 1950, as we assume that high- and low-skilled individuals have the same probability to be alive at the beginning of each period. Third, for all the following years, we compute the share of the highly skilled aged 25–34 in the same way as for the year 1950. Lastly, the share of the highly skilled aged 15–24 in 1950 is simply equal to the share of the highly skilled aged 25–34 in 1960.

41. North-to-North and South-to-South migrants are implicitly dealt with through the U.N. population data and forecasts.

42. We follow the methodology developed in de la Croix and Docquier (2007). They use a backsolving identification method to calibrate TFP with the Dynare algorithm (Juillard 1996).

43. For ADV and JAP, the values in 2000 are adopted for all periods following 2000.

TABLE A1
List of Countries by Region

Region Code	Region Name	Country List
NAM	North America	the United States and Canada.
ADV	Advanced Countries	Australia, Austria, Belgium, Denmark, Finland, France, Germany, Greece, Iceland, Ireland, Italy, Luxembourg, the Netherlands, New Zealand, Norway, Portugal, Spain, Sweden, Switzerland, and the United Kingdom.
JAP	Japan	Japan.
EAS	Eastern Europe	Albania, Bosnia and Herzegovina, Bulgaria, Croatia, Czech Republic, Estonia, Hungary, Latvia, Lithuania, Macedonia, Poland, Romania, Serbia and Montenegro, Slovakia, and Slovenia.
MEN	Middle East and North Africa	Algeria, Bahrain, Cyprus, Egypt, Iran (Islamic Republic of), Iraq, Israel, Jordan, Kuwait, Lebanon, Libyan Arab Jamahiriya, Malta, Morocco, Occupied Palestinian Territory, Oman, Qatar, Saudi Arabia, Syrian Arab Republic, Tunisia, Turkey, the United Arab Emirates, and Yemen.
LAC	Latin America and Caribbean	Argentina, Bahamas, Barbados, Belize, Bolivia, Brazil, Chile, Colombia, Costa Rica, Cuba, Dominican Republic, Ecuador, El Salvador, Guatemala, Guyana, Haiti, Honduras, Jamaica, Mexico, Nicaragua, Panama, Paraguay, Peru, Saint Lucia, Saint Vincent and the Grenadines, Suriname, Trinidad and Tobago, Uruguay, and Venezuela.
SSA	Sub-Saharan Africa	Angola, Benin, Botswana, Burkina Faso, Burundi, Cameroon, Cape Verde, Central African Republic, Chad, Comoros, Congo, Congo Democratic Republic, Djibouti, Equatorial Guinea, Eritrea, Ethiopia, Ivory Coast, Gabon, Gambia, Ghana, Guinea, Guinea-Bissau, Kenya, Lesotho, Liberia, Madagascar, Malawi, Mali, Mauritania, Mauritius, Mozambique, Namibia, Niger, Nigeria, Rwanda, Sao Tome and Principe, Senegal, Sierra Leone, Somalia, South Africa, Sudan, Swaziland, Tanzania, Togo, Uganda, Zambia, and Zimbabwe.
RUS	Former Soviet Union	Armenia, Azerbaijan, Belarus, Georgia, Kazakhstan, Kyrgyzstan, Moldova, Russian Federation, Tajikistan, Turkmenistan, Ukraine, and Uzbekistan.
CHI	Chinese World	Brunei, Burma, Cambodia, China, East Timor, Hong Kong, Korea, Lao People's Democratic Republic, Macau, Mongolia, Philippines, Singapore, Thailand, and Vietnam.
IND	Indian World and Pacific Islands	Afghanistan, Bangladesh, Bhutan, Federated States of Micronesia, Fiji, India, Indonesia, Malaysia, Maldives, Nepal, Pakistan, Papua New Guinea, Samoa, Solomon Islands, Sri Lanka, Tonga, and Vanuatu.

1.4, so the corresponding parameter σ in Equation (8) is equal to 0.2857. Regarding the skill-biased technical change (υ_t), the exogenous variable $\upsilon_t/(1-\upsilon_t)$ is swapped for the endogenous variable w_t^h/w_t^l in Equation (9) using the aforementioned procedure. Skill premiums in 2000 are arbitrarily fixed for each region.[44] For the periods preceding 2000, the values vary according to the 1950–2000 pattern of college wage premiums in the United States (Acemoglu 2003). For the periods following 2000, the values in 2000 are adopted.

Government-Related Parameters

The amount of foreign aid is calibrated with the OECD data of official development assistance. Recall in Equation (12) that every developed region spends a percentage of output in aid (a_t), whereas governments of every developing region receive foreign development aid (Λ_t). Formally, $a_t > 0$ and $\Lambda = 0$ for NAM, ADV, and JAP, while elsewhere $a_t = 0$ and $\Lambda > 0$. Moreover, total aid received by a developing region v from a developed region w ($\Lambda_t^{v,w}$) corresponds to the percentage of output spent in aid by a developed region w in favor of developing region v ($\widetilde{a}_t^{w,v} Y_t^w$). Therefore,

$$\Lambda_t^v = \widetilde{a}_t^{\text{NAM},v} Y_t^{\text{NAM}} + \widetilde{a}_t^{\text{ADV},v} Y_t^{\text{ADV}} + \widetilde{a}_t^{\text{JAP},v} Y_t^{\text{JAP}} \ ;$$

$$a_t^w Y_t^w = \sum_{v \in V} \widetilde{a}_t^{w,v} Y_t^w \ ,$$

where V is the set of developing countries.

Next, the evolution of the public debt in Equation (13) is exogenously given and is computed from the WDI data. The exceptions are the public debt in ADV and in JAP, which are obtained from the OECD data on gross financial liabilities. The replacement rate, or χ_t in Equation (14), is used to match the share of public pension spending to GDP of the year 2000. The data for this last variable originate from the OECD (2005) and for developing countries from Table A.5 of Palacios (1996). Finally, the region-specific

44. The skill wage premiums in 2000 are: 2.35 for ADV, 3 for NAM, JAP, EAS, and MEN, 3.15 for LAC, 3.25 for RUS, CHI, and IND, and finally 3.5 for SSA.

TABLE A2
Relative Changes of the Total Labor Force Due to Increased Emigration (in %)

	2000	2010	2020	2030	2040	2050	2060	2070	2080	2090	2100
EAS	0.00	−0.09	−0.25	−0.47	−0.77	−1.24	−1.64	−1.90	−2.09	−2.19	−2.19
MEN	0.00	−0.03	−0.09	−0.15	−0.23	−0.34	−0.42	−0.48	−0.52	−0.54	−0.54
LAC	0.00	−0.08	−0.19	−0.34	−0.53	−0.77	−0.97	−1.12	−1.23	−1.28	−1.28
SSA	0.00	−0.02	−0.06	−0.11	−0.16	−0.21	−0.24	−0.27	−0.28	−0.29	−0.29
RUS	0.00	−0.03	−0.08	−0.17	−0.29	−0.46	−0.63	−0.75	−0.84	−0.88	−0.88
CHI	0.00	−0.02	−0.06	−0.13	−0.22	−0.34	−0.45	−0.53	−0.58	−0.61	−0.61
IND	0.00	−0.01	−0.03	−0.06	−0.09	−0.14	−0.17	−0.20	−0.22	−0.23	−0.23

Note: Additional migrants belonging to the fifth wave of demographic shock (i.e., aged 15–24 in 2050) are entirely retired in 2100.

parameter for the pension system, or ρ_t in Equation (14) is calibrated via the data in Casamatta, Cremer, and Pestieau (2000).

Brain Drain versus Brain Gain

To begin with, we build on Docquier and Marfouk (2006)'s data and compute the relative changes in high-skilled emigration rates ($\Delta m_t^h / m_t^h$) resulted from the rise in emigration flows to the North. At the baseline, the gross human capital level at period t, measured as the proportion of the highly skilled among *natives* (including emigrants and residents), is computed according to

(A2) $$HC_t^{nt} = \frac{(1 - m_t^l) HC_t^{rs}}{1 - m_t^h (1 - HC_t^{rs}) - m_t^l HC_t^{rs}},$$

which is a transformation of Equation (6) in Beine, Docquier, and Rapoport (2008), and m_t^l denotes the low-skilled emigration rate. Then, we use the brain gain elasticity estimated in their parsimonious specification to obtain the after-shock level of gross human capital, which is then transformed back to the after-shock level of resident human capital.[45]

Technological Progress

Changes in resident human capital and the diaspora externality in technology diffusion are explicitly taken into account for the forecast of the Harrod neutral technological progress, that is, from period 2000 onwards. The forecasts of migration and of resident human capital are plugged into the estimation specified in Equation (15) in order to predict the evolution of TFP_t, which is then transformed into A_t.

Over the period 1950–2000, we calibrate μ_t so that the baseline simulations perfectly match the observations of GDP ratios, Y_t / Y_t^{NAM}. The calibrated path for μ_t is rather stationary and distributed around zero in all regions except for EAS, CHI, and IND, where positive trends are observed. Thus, we consider that μ_t is equal to zero everywhere except in EAS, CHI, and IND, where the exogenous trends remain positive until 2050. Finally, due to data availability in calibration, $A_t^{\text{RUS}} / A_t^{\text{NAM}}$ is assumed to remain constant from 2000 onwards.

45. Notice that, given the framework of eight OLG, the change in resident human capital at period t needs to be taken into account also in the next periods.

Risk Premium

The dynamic complementarity between high-skilled emigration and reductions in risk premium is captured as follows:

(A3) $$\text{If } M_t^h > M_{t-1}^h,\ (1 + \pi_{t+1}) = (1 + \pi_t) \cdot \left(1 - \phi \cdot \frac{M_t^h - M_{t-1}^h}{M_{t-1}^h}\right);$$
$$\text{otherwise,} \qquad \pi_{t+1} = \pi_t.$$

$-\phi \equiv -\theta(1 - \alpha)(FDI_t / K_t)$ is the elasticity of risk premium to the lagged size of high-skilled diaspora.[46] θ is defined as

$$\frac{\Delta fdi_t}{fdi_t} \cdot \frac{M_{t-1}^h}{\Delta M_{t-1}^h},$$

with fdi_t denoting FDI per worker. We calibrate θ according to the panel estimation result obtained in Docquier and Lodigiani (2012). (FDI_t / K_t) is set to 12.5%, which is approximately the average share of FDI among total investments in developing countries.

We anchor the evolution of risk premiums to the 2000 values, which are calibrated with the OECD's Country Risk Classification.[47] For the periods preceding 2000, the values in 2000 are adopted. For the periods following 2000, the migration forecast is plugged into Equation (A3) to obtain the evolution of risk premiums.

46. The definition of ϕ is derived from the combination of $(1 + \pi_{t+1}) = (1 + \pi_0)\left(M_t^h\right)^{-\phi}$ and Equation (10), by setting the depreciation rate δ to 1 for technical reasons. It can be shown that ϕ is increasing in δ; thus, if we take the calibrated value of δ instead, the risk premium channel will only grow (slightly) less important than it already is.

47. It is based on the Knaepen Package, a system for assessing country credit risk and classifies countries into eight country risk categories, from no risk (0) to high risk (7). Basically, it measures the credit risk of a country. There are no risks for the three developed regions whereas the risk classifications in 2000 for each of the seven developing regions are as follows: 3.4 for EAS, 4.0 for MEN, 5.2 for LAC, 6.4 for SSA, 6.2 for RUS, 3.2 for CHI, and 4.9 for IND. In order to transform these values into risk premiums, we use the formula: $\pi_{2000} = 0.37 \cdot (RC/7)$, where RC denotes a region's risk classification and $\max(\pi_{2000}) = 0.37$ is based on the calibration to Caselli (2007), who finds that the average returns to capital are about 1.25 times higher in developing than in developed economies, after correction for price differences.

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