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

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ABSTRACT

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JEL Classification: F22, J24 and O15
Keywords: brain drain, capital flow, development and human capital

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Brain drain in globalization

A general equilibrium analysis from the sending countries' perspective

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Abstract

High-skilled emigration has been found to affect developing economies via different channels. With a calibrated general equilibrium framework, this paper finds that the short-run impact of brain drain on resident human capital is extremely crucial, as it does not only determine the number of high-skilled workers available to domestic production, but it affects the sending economy's capacity to innovate/adopt modern technologies. The latter impact is particularly important in globalization, where capital investments are made in places with higher production efficiencies. Hence, despite the positive feedback effects, those countries facing prevalent high-skilled emigration are the most candid victims to brain drain.

JEL Classifications: F22, J24, O15
Keywords: Brain Drain, Capital Flow, Development, Human Capital

1. Introduction

Is brain drain a curse or a boon for the sending countries? The economic literature has put forward several possible 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

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[1]See the survey conducted by Commander et al. (2004).

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 ten-region general equilibrium model characterized by overlapping-generations (OLG) dynamics and calibrated to real data, and the implications of skill outflow are assessed on the basis of Gross Domestic Product (GDP) per capita. In such a framework, not only can we juxtapose the direct impacts of brain drain, but their 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, 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 13,346 millions in 1970 to 1,833,324 millions in 2007 (measured in US$ 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” (see Figure 1). This North-South disparity reflects largely the wide gaps in terms of total factor productivity, and not insignificantly, the higher risks involved in investing in many developing countries.[2]

Similarly, international wage gaps are the most important pull factor that lures 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. Moreover, Docquier et al. (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. When skill heterogeneity is taken into account, it is found that the number of highly educated immigrants has increased by 70 percent, whereas the corresponding figure for immigrants with lower educational attainments is a dwarfed 30 percent. Although this

[2]See, for example, the Country Risk Classification produced by the Organisation for Economic Co-operation and Development (OECD).

difference does not necessarily imply an increasing trend of brain drain,[3] stylized facts show that there does exist strong positive selection of emigrants, especially in the lower income countries (see Figure 2). In many developing countries, high-skilled emigration rates are well above 40 percent, particularly for sub-Saharan African countries, Central American countries, and small states.

This positive selection may originate from either self-selection into emigration or from the destination country's immigration policy. As shown by Grogger and Hanson (2008), the larger international wage differences for high- than for low-skilled workers are consistent with positive self-selection. Moreover, in poorer countries, this pattern can be further reinforced when credit constraints are binding such that lowly skilled potential migrants cannot afford migration costs (Chiquiar and Hanson, 2005). On the other hand, admission criterion adopted by major labor-receiving countries have grown progressively skilled-biased.[4] This raises the probability to migrate for highly-educated young workers, while restrictions imposed on low-skilled immigration are generally not relaxed, if not increased. Despite that trade barriers have been greatly reduced and capital markets liberalized, the national barriers to immigration remain substantial; consequently, notwithstanding the rise in immigration rates, *people flows in globalization* are much less in extent when compared to other international flows of factors and goods (Freeman, 2006).

Although the debate over open/close border to immigration has so far remained mainly in the political and philosophical domains,[5] the economic

[3]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 due to 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.

[4]In 1967, Canada adopted the point system that favors highly educated and highly skilled young individuals. Australia followed suit in 1989, then New Zealand in 1991. In 2006, a detailed plan was presented in the British Parliament on how to implement a points-based immigration system. In the United States, the immigration reform bill of 2007, although failed, also includes a similarly merit-based system. In the same year, the European Commission announced her "Blue Card" scheme in the hope of luring more high-skilled migrants.

[5]There are some economic studies discussing the issue of migration barriers and their welfare costs, see for example, Freeman (2006) and Clemens and Pritchett (2008).

literature of brain drain has already gained major attention back in the 1970s. This can be attributed to the pioneering works of Bhagwati (1972, 1976a,b), where the well-known "Bhagwati Tax" was proposed and aimed to compensate for the loss incurred by skill outflow in the developing countries. However, in Bhagwati and Hamada (1974, 1975), this loss is predicted in a partial equilibrium framework characterized by wage rigidity, unemployment, and fiscal costs, with brain drain worsening wage distortions and accentuating fiscal externality, yet generating few potentially counteracting effects. Moreover, as high-skilled labor serves as a pivotal engine of growth, modern theories of brain drain based on endogenous growth models also predict pessimistic outcomes, due to externalities related to human capital formation (Miyagiwa, 1991; Haque and Kim, 1995; Wong and Yip, 1999). On top of these theoretical adverse effects, emigration in general implies loss of working-age population in the sending countries. This may pose as a serious threat to those developing economies with high emigration rates as well as a substantial degree of population aging, most notably the Eastern European countries.[6]

Recent developments in the migration literature, however, have identified a series of positive feedback effects. Starting from Mountford (1997), it is demonstrated that increased migration prospects for the highly skilled could stimulate more human capital formation, thanks to higher expected returns to education; thus, in countries with low emigration rates among the highly skilled, their post-migration human capital stocks may increase as a result.[7] Furthermore, diaspora at the destination countries may reduce information-related investment risks and is shown to spur FDI at the origin countries (Kugler and Rapoport, 2007; Docquier and Lodigiani, 2009). Through immigrants' ties with their home countries, diaspora may also lower transaction costs, and empirical evidence suggests that it encourages bilateral trade flows (Gould, 1994; Head and Ries, 1998). While the aforementioned network externalities are not specific to more educated migrants, high-skilled diaspora nevertheless plays a unique role in promoting international technology diffu-

[6]In less developed regions, the average share of population aged 65 or over is expected to rise from 5.0 % in 2000 to 14.6 % in 2050; however, when Eastern Europe is considered alone, the rise goes from 12.9 % in 2000 to 25.4 % in 2050 (see the United Nations' World Population Prospects: The 2008 Revision).

[7]See Stark et al. (1997, 1998), Vidal (1998), Stark and Wang (2002), Stark (2004), and the empirical evidence in Beine et al. (2001, 2008).

sion, which raises the total factor productivity (TFP) in immigrants' home countries (e.g., Kerr, 2008).[8] Arguably, the list of potentially positive effects of diaspora may also include transfers of norms, which could alter fertility behavior (Beine et al., 2009) or bring about institutional reforms (Spilimbergo, 2009),[9] and thus indirectly enhancing economic development at the origin.

From the above, it is apparent that international flows of factors and goods/services are not independent of one another, as already demonstrated in the traditional trade theory. However, their inter-dependencies are not unambiguous. For example, static trade models predict that, a change in factor endowment differential, due to 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, the aforementioned evidence on network externalities indicate that emigration and FDI inflows may well act as complements, especially from a dynamic perspective;[10] moreover, technology diffusion can also augment the marginal productivity of capital in the South and attract more capital investments. Last but not the least, the officially recorded amount of remittances has been increasing at a fast rate,[11] suggesting yet another complementary and important link between labor emigration and capital inflows (Walmsley and Winters, 2005), and it further promotes economic growth in the relatively capital-scarce developing countries, particularly those with less developed financial systems

[8]Kerr (2008) finds that, how technology diffusion spurs output growth differs with the home country's development level. In less developed countries, this positive effect is more likely to transmit through the reallocation of labor from the agricultural to the manufacturing sector. However, our paper does not distinguish different sectors due to the already complex setting of the dynamic model.

[9]Notice that Spilimbergo (2009) does not exactly study the diaspora effect on institutional reforms. Alternatively but relatedly, he studies whether foreign educated individuals play a role in promoting democracy in their home country, and he finds a positive impact if foreign education is acquired in democratic countries.

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

[11]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 due to the global financial crisis (see the World Bank's Global Economic Prospects 2009).

(Giuliano and Ruiz-Arranz, 2008).

In order to assess the global effects of South-to-North brain drain on the sending economies, this paper utilizes a calibrated OLG model, which divides the world into three developed and seven developing regions. In each decade from 2010-20 to 2050-60, we increase by 20 percent the forecast 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 either an enlarging international gap of high-skilled wage, or to an increasingly skilled-biased immigration policy in response to aging, occupational shortage, and so forth. However, in order to maintain tractability in the already complex setting, these decennial 20-percent increases are treated as exogenous shocks. Moreover, whereas our generic framework is capable of incorporating many of the potential effects of brain drain reported in the existing literature, some of them are not included due to compatibility issues (e.g., increasing bilateral trade flows, transfers of norms, etc.).

Despite the constraints, the greatest advantage of our unified generic framework is that it allows for the interactions between different forces at work. This is especially important in a globalized economy, where international flows of people are often accompanied by international flows of other factors, as mentioned above. Moreover, the OLG framework makes it feasible to take into account the impacts of brain drain through the age structure, and it also allows for dynamic effects via asset accumulation.[12] In the simulations, it is observed that the demographic shock of additional brain drain generates multiple positive and negative effects through four channels. First, demographic changes in the age structure result in less working-age population to support the retirees. Second, the incentive effect on human capital formation contribute to "brain gain" in regions where high-skilled emigration is less prevalent. 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

[12]Docquier and Rapoport (2009) studies the overall costs and benefits of brain drain on the per country basis. However, in their partial equilibrium setting where all effects occur through the production parameters except labor endowment, 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.

the catching-up of technology. Fourth, an enlarged diaspora helps to reduce information-related investment risks at origin, and thus attracting more FDI inflows.

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 due to 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*.

The rest of the paper is organized as follows. Section 2 presents the calibrated OLG model of the world economy. In Section 3, 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 4 concludes.

2. The Calibrated OLG Model of the World Economy

We introduce international migration with skill heterogeneity into a general equilibrium model with overlapping generations of individuals. The model economy is composed of ten regions as listed in Table 1. We distinguish three *developed* regions (the *North*) and seven *developing* regions (the *South*).[13]

Table 2 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),[14] the average emigration rate towards the OECD countries (Aemig), the high-skilled

[13]The detailed list of countries by region can be found in Table A.1.

[14]Due to data availability, the highly skilled are proxied as those with post-secondary degrees.

Table 1: List of ten 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 2: 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					

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

emigration rate (Hemig), the low-skilled emigration rate (Lemig), and the ratio of remittances to GDP (Rem/Y).[15] Each region exhibits a strong pattern of positive selection into emigration, with the high-skilled emigration rate exceeds, 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, the ratio of remittances to GDP is small but non-negligible for

[15]Regarding remittances, the amounts presented in Table 2 are taken from the IMF database and are usually seen as underestimating the reality since 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.

every region.

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 inter-regional disparities over the period 1950-2000. Once incorporated with the calibrated evolution of demographic variables, human capital, and the magnitude of diaspora 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.[16]

In the ensuing sections, we will describe the demographic structure and specify the migration shocks in the context of the model economy. Then, the general equilibrium model characterized by OLG dynamics will be formally presented, and the direct implications of high-skilled emigration will be discussed.

2.1. Demographic Structure

At each period, there are eight overlapping generations 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.[17] 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 probability, which decreases with age. Hence, the size of each generation ($N_{a,t+a}$) declines deterministically over time:

$$N_{a,t+a} = P_{a,t+a} N_{0,t} \qquad a = \{0, 1, \ldots, 7\}, \tag{1}$$

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 exoge-

[16] The model economy starts from an initial steady-state in 1870, and after demographic shocks are introduced, the new steady state is reached in 2200.

[17] The calibration method of the demographic structure and its associated parameters is discussed in Appendix A.1.

nous growth rate:

$$N_{0,t} = m_{t-1} N_{0,t-1}, \tag{2}$$

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 since i) migrants tend to be young adults, and ii) we focus on the South-to-North migration of the highly skilled, who are likely to migrate on a more permanent basis.[18]

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.[19] 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:

$$\begin{array}{rcl} N_{0,t}^h & = & \phi_t N_{0,t} \\ N_{0,t}^l & = & (1-\phi_t) N_{0,t} \end{array}, \qquad \phi_t \in [0,1]. \tag{3}$$

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

$$L_t^j = \sum_{a=0}^{7} \lambda_{a,t}^j N_{a,t}^j \qquad j = \{h, l\}. \tag{4}$$

Specifically, full participation is assumed except for the following three groups. The high-skilled young spend a fraction of their time in obtain-

[18] 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.

[19] Our perception of high- versus low-skilled labor is similar to the one described in 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 (Ottaviano and Peri, 2008; Card, 2009), and it also explains why the high-skilled diaspora is unique in facilitating technology diffusion (see Section 1).

ing education and do not fully participate in the labor market. At age 55-64, people partly retire. After age 64, they fully retire.

2.2. Demographic Shock of Additional High-Skilled Emigration

Starting from the U.N. forecasts, in each decennial period from 2010-20 to 2050-60, the demographic shock constitutes a 20 percent increase in the forecast flow of high-skilled migrants from every developing region to each developed region.[20] Consistent with the model assumption, the additional migrants are considered to belong to the age class $a = 0$, or aged 15-24.[21] Notice, however, it is implicitly assumed in our aggregate approach 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, due to their heavier weight in the aggregation. Below, 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.

Naturally, demographic evolution affects an economy's support ratio, which is defined here as the ratio of resident labor force to resident population:[22]

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

Figure 3.a 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 3.b then shows the relative changes after migration

[20]Notice that the scale of the additional high-skilled emigration is miniscule 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 A.2 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.

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

[22]Note that m_{t-1} in Eq. (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.

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 Eq. (2). However, EAS is most seriously hit due to the combination of a relatively large share of aged population and a high emigration rate among the highly skilled within its rather educated populace. The effects reach their respective maxima in 2060, with EAS confronted by a decline of 0.65%.

As mentioned in Section 1, a recent wave of theoretical and empirical studies suggest that high-skilled emigration can generate a positive incentive effect on human capital formation, which 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 4.a depicts its baseline evolution by region.

In order to incorporate the "brain gain" effect in computing the after-shock levels, our calibration follows Beine et al. (2008), who find evidence that the prospect of high-skilled emigration is positively associated with gross (pre-migration) human capital levels in cross-country regressions.[23] Figure 4.b 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, or ϕ_t in Eq. (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 2). However, the incentive effect on human capital formation of better migration prospects for the highly skilled (or the *brain gain* effect) eventually benefit all regions, enhancing resident human capital by maximally 2-3%.[24]

[23] Appendix A.2 outlines the calibration method that allows us to take into account the incentive effect on human capital formation.

[24] As our aggregate approach has the effects in every region dominated by the large countries, this result is consistent with Beine et al. (2008)'s findings about winners and

2.3. The General Equilibrium Model

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

⊙ *Households:* Each *non-migrant* individual derives utility from her lifetime consumption. The expected utility function is assumed to be time-separable and logarithmic:

$$E\left(U_t^j\right) = \sum_{a=0}^{7} P_{a,t+a} \ln\left(c_{a,t+a}^j\right) \qquad j = \{h, l\},$$

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

However, *migrants*, i.e., those born in the South and living in the North, are assumed to derive utility from a combination of goods consumption ($c^{M,j}$) and remittances ($RM^{M,j}$):

$$c_{a,t+a}^j = (c_{a,t+a}^{M,j})^{1-\gamma^j} (RM_{a,t+a}^{M,j})^{\gamma^j} \qquad j = \{h, l\}, \tag{5}$$

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. Due 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.[25]

Following de la Croix and Docquier (2007), we postulate the existence of an insurance mechanism à la Arrow-Debreu. Each time after an individual deceases, her assets are equally distributed among individuals belonging to the same generation living in the same region. Individuals thus maximize their expected utility subject to a budget constraint requiring equality between the discounted expected value of expenditures and the discounted

losers of brain drain, where "the most populated countries [. . .] are all among the winners."

[25]Remittances are modeled in this way for the same reason explained in Footnote 18. The age-invariance of the propensity to remit comes from our implicit assumption that there is no remittances decay, due to scant empirical evidence. More discussions about the propensity to remit can be found in Appendix A.3.

expected value of income, which consists of net labor income, pension benefits, other welfare transfers, and net remittances. The household optimization problem determines the age profiles for consumption, remittances, savings, and asset accumulation.

⊙ *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).[26] A Cobb-Douglas production function is assumed with constant returns to scale,[27]

$$Y_t = K_t^{\alpha}(A_t L_t)^{1-\alpha} \qquad \alpha \in [0,1], \tag{6}$$

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. In order to take into account the diaspora externality in enhancing technology diffusion from the North to the South (see Section 1), we follow Lodigiani (2008), who extended Vandenbussche et al. (2006) by adding high-skilled diaspora in their specification. It estimates TFP growth fueled by a neo-Schumpeterian technological progress:

$$\begin{aligned} \Delta ln\,(TFP_t) \;\; = \;\; & 0.59 - 0.29 \cdot \ln\left(\frac{TFP_t}{TFP_t^{NAM}}\right) + 1.44 \cdot HC_t^{rs} \\ & -0.10 \cdot \ln(M_t^h) + 0.88 \cdot \ln\left(\frac{TFP_t}{TFP_t^{NAM}}\right) \cdot HC_t^{rs} \\ & -0.06 \cdot \ln\left(\frac{TFP_t}{TFP_t^{NAM}}\right) \cdot \ln(M_t^h) + \mu_t \end{aligned} \tag{7}$$

[26] 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 bilateral trade exists. Given our focus on factor flows and their (real) prices, we choose this parsimonious modeling of international trade. Furthermore, if the Hecksher-Ohlin type of assumptions are satisfied, free trade would have led to factor price equalization even without factor mobility. However, these assumption 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.

[27] The calibration method of the production parameters is discussed in Appendix A.4.

where $TFP_t \equiv A_t^{1-\alpha}$ in Eq. (6), and (TFP_t/TFP_t^{NAM}) is a monotonic transformation of a region's distance to the technology frontier (A_t/A_t^{NAM}). $\Delta ln\,(TFP_t)$ denotes the rate of TFP growth over a five-year interval. M_t^h is a developing region's stock of high-skilled emigrants living in the North.[28] 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.[29] On the other hand, however, high-skilled human capital is crucial 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.[30]

The baseline evolution of A_t/A_t^{NAM} is depicted in Figure 5.a. Figure 5.b plots the relative changes induced by migration shocks. Small positive effects are observed in MEN and IND, both with relatively 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

[28]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.

[29]Docquier and Rapoport (2009) 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 misspecification 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.

[30]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 et al. (2008) conclude that the emigration of highly skilled Indians *on average* harms domestic knowledge access, due to a strong spillover effect created by co-location 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.

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;[31] meanwhile, the compensatory role played by high-skilled diaspora in technology diffusion is of less importance for technologically more advanced regions, e.g., EAS as well as CHI in the second-half of the 21^{st} century.

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:

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

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

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

Finally, capital receives its marginal product net of depreciation, with the depreciation rate denoted by δ.[32] Since it is assumed that physical capital is mobile across regions, the net returns to capital are equal to the international interest factor R_t^* augmented by the region-specific risk premium ($\pi_t \geq 0$), which reflects investment risks:

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

[31] 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 may be again due to the mis-specification problem mentioned in Footnote 29 given that CHI has the largest high-skilled diaspora at all periods along the transitional path.

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

As discussed in Section 1, high-skilled diaspora may contribute to reducing information-related risks for capital investments in the migrants' home countries, and thus attracting more FDI inflows in the South. In order to incorporate this type of network externality, we transform the elasticity of FDI per worker to the lagged size of diaspora estimated in Docquier and Lodigiani (2009).[33] The baseline evolution of risk premium is depicted in Figure 6.a. Following the migration shocks, Figure 6.b 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 range between 0.16-0.27%.

⊙ *Government:* The government levies taxes on labor earnings and on consumption expenditures in order to finance general public consumption, pension benefits, and other welfare transfers. The government also issues bonds and pays interests on public debt. In every developing region, the government receives foreign development aid, and the amount of which is calibrated with the OECD data of official development assistance. The government budget constraint is satisfied at each period by adjusting the wage tax rate. 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. Public debt is computed from the World Bank's World Development Index (WDI), with the exceptions being the public debt in ADV and in JAP, which are obtained from the OECD data on Gross Financial Liabilities.

⊙ *Equilibrium:* A competitive equilibrium of the open economy is characterized by (i) households' and the firm's first order conditions, (ii) market-clearing conditions on the goods and labor markets, (iii) budget balance for each regional government, (iv) the equality between the aggregate quantity of world assets and the quantity of the world capital stock plus the sum of public debts of all regions, and finally (v) the international arbitrage condition of returns to capital. The equilibrium on the goods market is achieved by Walras' law.

[33]The calibration method of risk premium is outlined in Appendix A.5.

3. 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 above, we would like to answer the following questions: i) What are the economic implications on the developing economies when they are faced with larger skill outflows? ii) Which channels are more dominant? 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.

3.1. 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 7 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 0.2-0.7%. 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.[34] In comparison, the medium-to-long-run benefits of the incentive effect are most

[34]In order to single out the impact of the incentive effect, all parameter values are held at the baseline, except ϕ_t. Even though increased high-skilled emigration leads to a larger share of high-skilled young already in the short-run for some regions (see Figure 4.b), the efficiency units of labor are decreased because by assumption high-skilled young do not fully participate in the labor market.

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): Since the Harrod neutral technological progress has the multiplier effect on domestic outputs (see Eq. (6)), its impact on GDP per capita naturally follows the pattern of relative changes in technological progress discussed in Section 2.2, 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 mean time, 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.[35]

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 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 0.01-0.03% 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.

3.2. Total Impact on GDP Per Capita

Figure 8.a 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

[35]However, we believe that the total impact of brain drain on CHI through the technology channel may be largely downward biased, due to the problem of mis-specification in the adopted empirical equation. See the discussion in Footnotes 29 and 31.

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 4.b. 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 et al. (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 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*.[36]

Figure 8.b 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 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 8.c for the comparison in 2060). This implies

[36]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.

that the negative effects generated via the technology channel can be largely attributed to capital retreat or flight from these negatively impacted regions.

To prove the point, Table 4 records the allocation of world capital stock amongst all ten regions under the calibrated and the alternative scenarios, and it also provides the relative changes in each region's share when 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.[37]

As for EAS, its relative changes in the world capital investments are firstly positive, then turn negative from 2060. 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 due to the initial loss of resident human capital. However, this adverse impact is less strong in EAS, as we can see from Figure 7.c. In fact, the more dominant effect on its GDP per capita in the shorter-run is operating through the demography channel (see Figure 7.a), 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

[37]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.

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 above.

4. 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 harms 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. Table 3 provides a summary description of the channels through which the brain drain operates.

It is identified that the short-run impact of brain drain on resident human capital is extremely crucial, since it does not only determine 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 out-flows. 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.

Table 3: 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 et al. (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 (2009)

As mentioned in Section 2.2, 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 et al. (2008) provides 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 mispecification 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 picure 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 relatively 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.

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Appendices

A. Calibration Methods

A.1. Demographic Parameters

The survival probability $P_{a,t+a}$ in Eq. (1) and the population growth rate m_t in Eq. (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 Dataset (2001), which provides yearly by-country data on the educational attainment of individuals aged 25-74 for the period 1950-2000.[38] It is assumed that the high-skilled share of the young generation, ϕ_t in Eq. (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.[39] 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

[38]We firstly aggregate this data set 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 to 94 corresponds arbitrarily to 80% of the share of the highly skilled aged 75 to 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 to 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 to 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 to 34 in the same way as for the year 1950. Lastly, the share of the highly skilled aged 15 to 24 in 1950 is simply equal to the share of the highly skilled aged 25 to 34 in 1960.

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

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.

A.2. 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

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

which is a transformation of Eq. (6) in Beine et al. (2008), and m_t^l denotes the low-skilled emigration rate. Then, we use the brain gain elasticity estimated in their parsimonious specification:

$$\frac{\Delta HC_t^{nt}}{HC_t^{nt}} \cdot \frac{m_t^h}{\Delta m_t^h} = 0.0481,$$

to obtain the after-shock level of gross human capital, which is then transformed back to the after-shock level of resident human capital.[40]

A.3. Propensity to Remit

The calibration strategy for the propensity to remit, or γ^j in Eq. (5), is based on the officially recorded remittances to GDP ratio for each developing region (see Table 2). Due to data availability, we do not have information on the potential heterogeneity in propensities to remit between skill types.[41] Neither do

[40]Notice that, given the framework of eight overlapping generations, the change in resident human capital at period t needs to be taken into account also in the next periods.

[41]While Ratha (2003) claims that high-skilled migrants send more remittances due to higher earnings, empirical evidence put forth by Faini (2007) and Nimii et al. (2008) suggest that, compared to their low-skilled counterpart, high-skilled migrants have a lower propensity to remit.

we know about the distributional pattern of remittance receipts in migrants' home country.[42] Notice, however, when calibrated to the official remittances data, it turned out to be infeasible that high-skilled migrants could have a much lower propensity to remit. 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.

A.4. Production Parameters

The share of gross capital returns in the total domestic output, or α in Eq. (6), 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 percent. In order to obtain A_t for non-leading 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.[43] The ratios of GDP's are computed by employing the 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.[44]

Following Acemoglu (2002), the elasticity of substitution between high- and low-skilled labor (ϵ) is set to 1.4, so the corresponding parameter σ in Eq. (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 Eq. (9) using the aforementioned procedure. Skill premiums in 2000 are arbitrarily fixed

[42]On the one hand, some studies find that remittances are distributed rather evenly among different income groups (e.g., Taylor and Wyatt, 1996) while others identify that inequality is deepened with migration and remittances (e.g., Barham and Boucher, 1998). On the other hand, the relationship between migration/remittances and inequality may be characterized by an inverse U-shaped pattern, suggesting that the short- and long-run effects may be of opposite signs (Stark et al., 1986; McKenzie and Rapoport, 2007; Shen et al., 2009).

[43]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).

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

for each region.[45] 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.

As mentioned earlier, 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, i.e., from period 2000 onwards. The forecasts of migration and of resident human capital are plugged into the estimation specified in Eq. (7) in order to predict the evolution of TFP_t, which is then transformed into A_t; moreover, we consider that μ_t is equal to zero everywhere except in EAS, CHI, and IND, where the exogenous trends remain positive until 2050.[46]

A.5. Risk Premium

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

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

$-\phi \equiv -\theta(1-\alpha)(FDI_t/K_t)$ is the elasticity of risk premium to the lagged size of high-skilled diaspora.[47] θ is defined and estimated in Docquier and Lodigiani (2009)'s panel regression as

$$\frac{\Delta fdi_y}{fdi_y}\cdot\frac{M_{y-5}^h}{\Delta M_{y-5}^h} = 0.025\,,$$

with fdi_y denoting FDI per worker at year y, so θ is its elasticity to the lagged size of high-skilled diaspora over a five-year interval. (FDI_t/K_t) is set to 12.5

[45] 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.

[46] 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. Due to data availability in calibration, A_t^{RUS}/A_t^{NAM} is assumed to remain constant from 2000 onwards.

[47] The definition of ϕ is derived from the combination of $(1+\pi_{t+1}) = (1+\pi_0)\left(M_t^h\right)^{-\phi}$ and Eq. (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.

percent, 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.[48] For the periods preceding 2000, the values in 2000 are adopted. For the periods following 2000, the migration forecast is plugged into Eq. (A.1) to obtain the evolution of risk premiums.

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[48]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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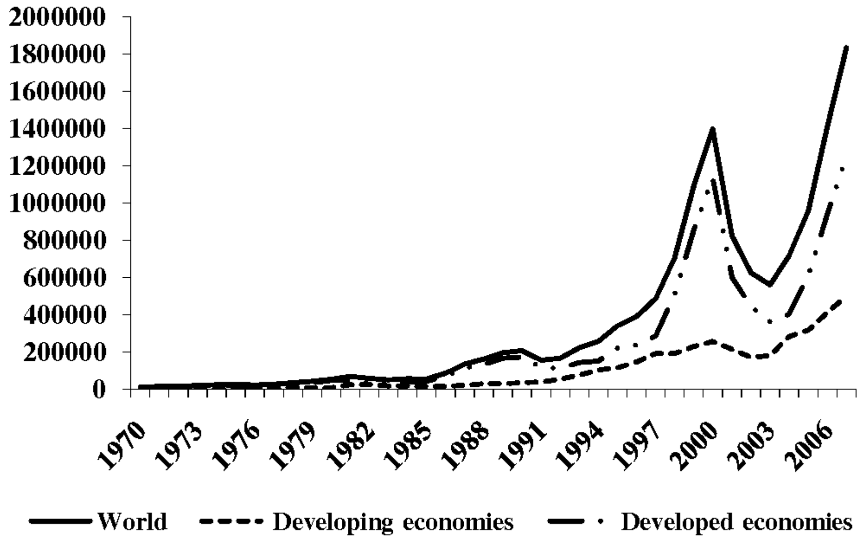
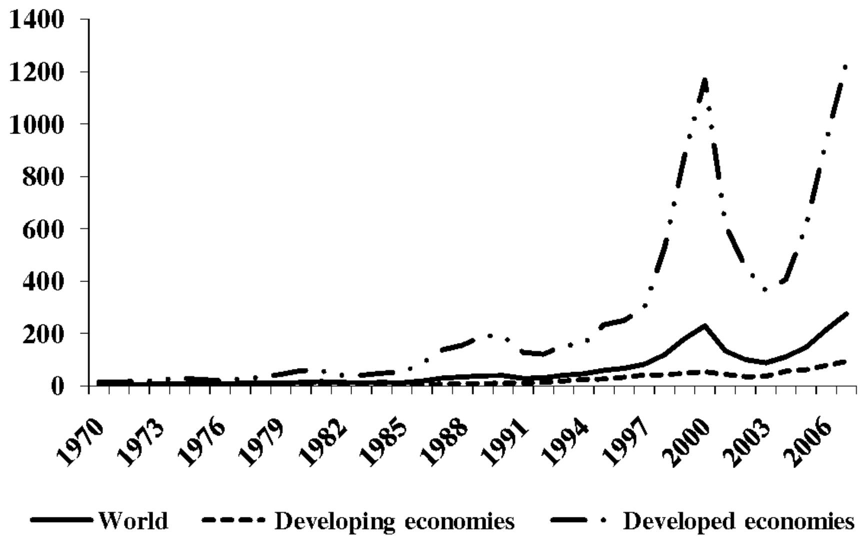
Figure 1: FDI inward (US$ at current prices)



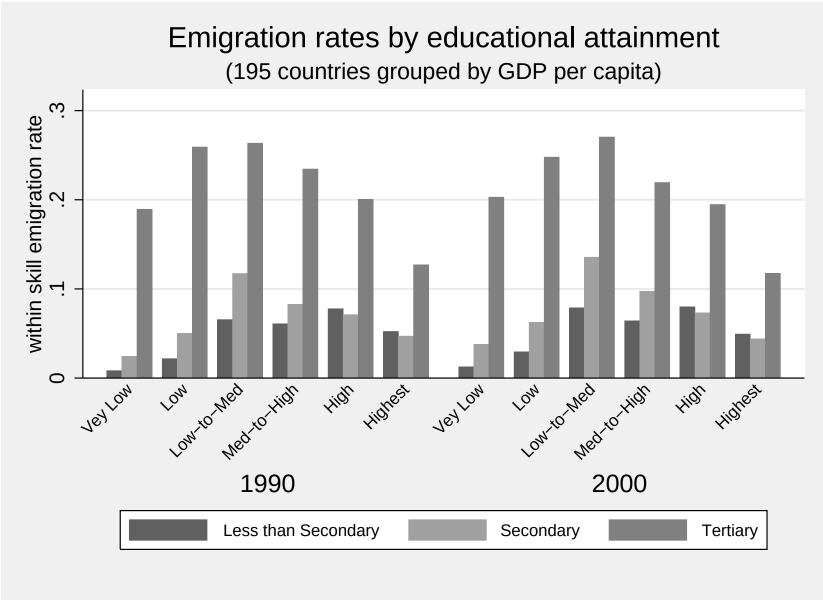
a. total (in millions)



b. per capita

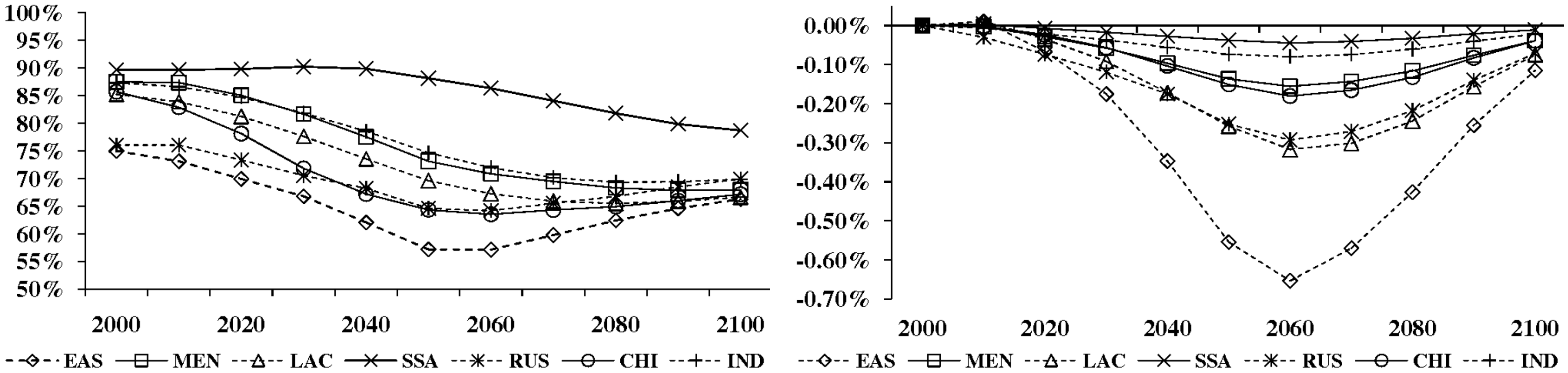
Data source: UNCTAD/WIR (2008)

Figure 2: Positive Selection of International Migration



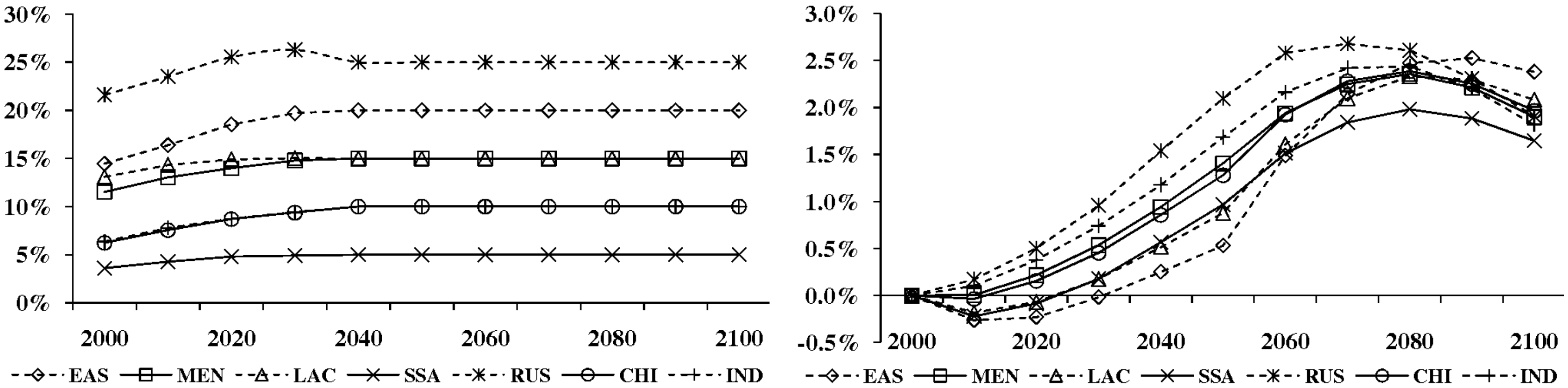
Data source: Docquier and Marfouk (2006)

Figure 3: Support Ratio (SR_t)



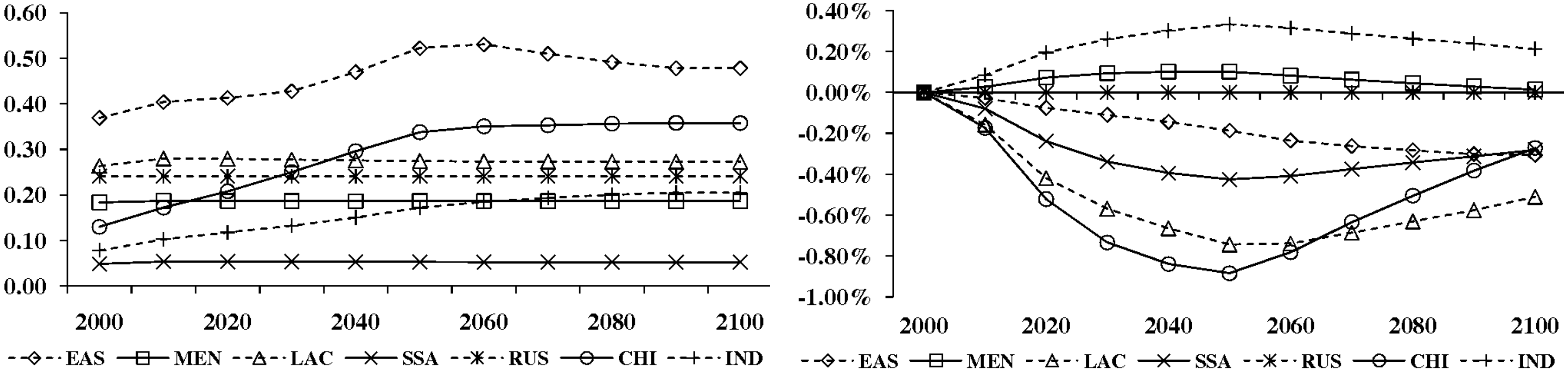
a. Baseline value *b. After shocks (% change compared to baseline)*

Figure 4: Human Capital (HC_t^{rs})



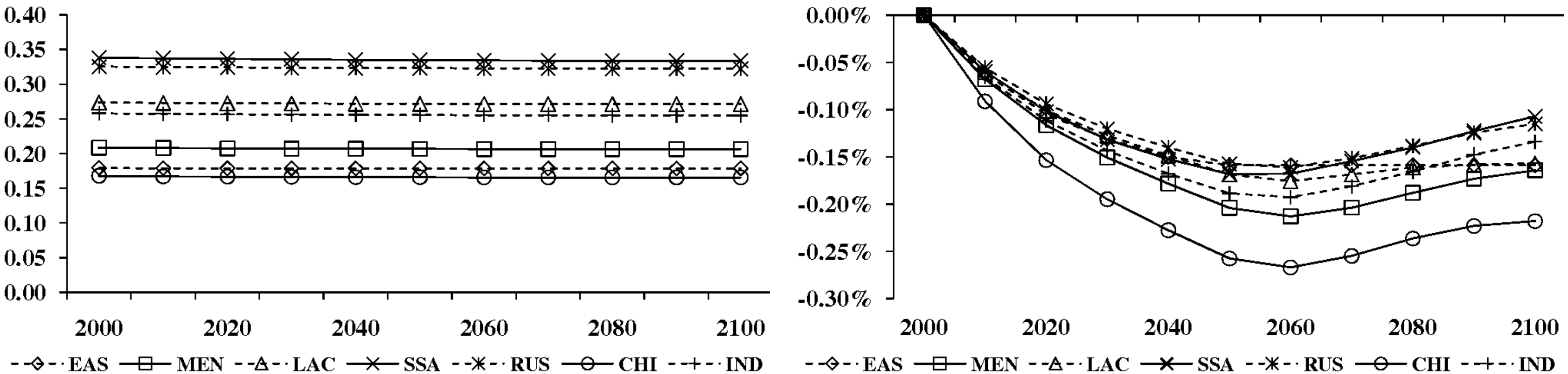
a. Baseline value *b. After shocks (% change compared to baseline)*

Figure 5: Distance to the Technology Frontier (A_t/A_t^{NAM})



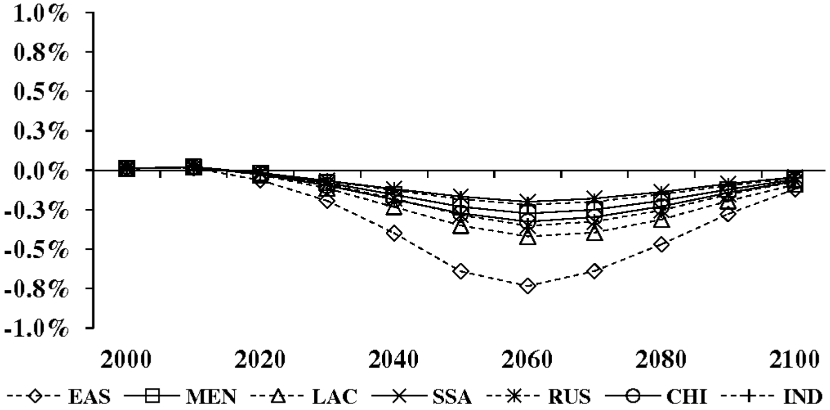
a. Baseline value *b. After shocks (% change compared to baseline)*

Figure 6: Risk Premium (π_t)

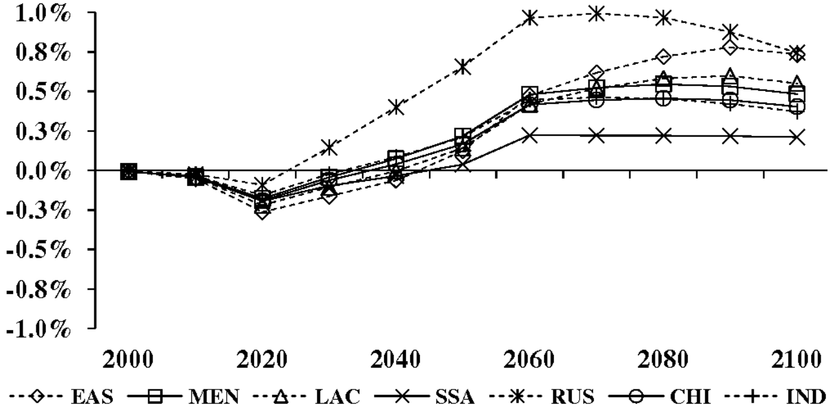


a. Baseline value *b. After shocks (% change compared to baseline)*

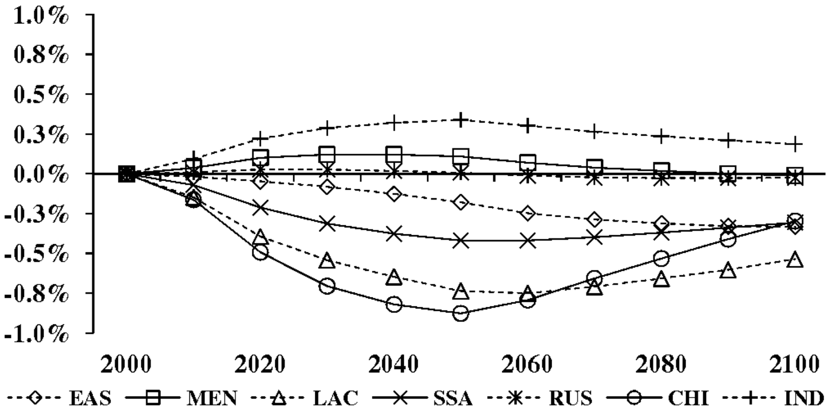
Figure 7: Disentangled effects on GDP per capita (measured as relative changes from the baseline)



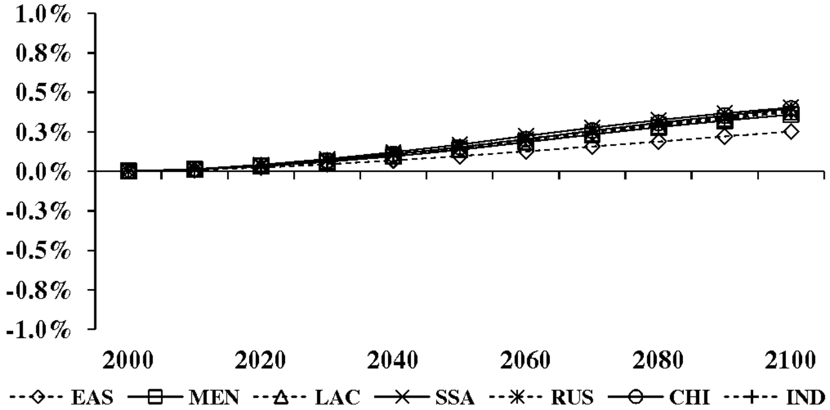
a. Through demography (m_t)



b. Through human capital (ϕ_t)

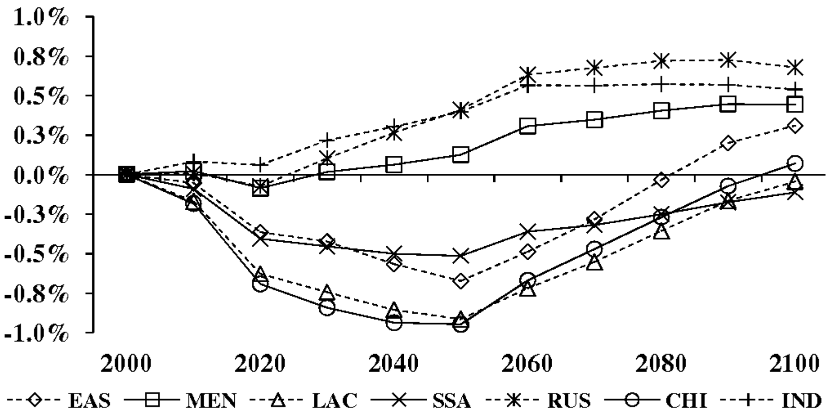


c. Through technological progress (A_t)

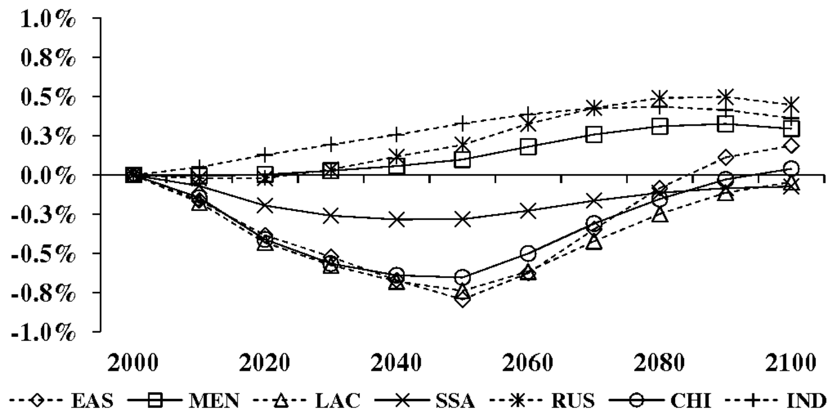


d. Through risk premium (π_t)

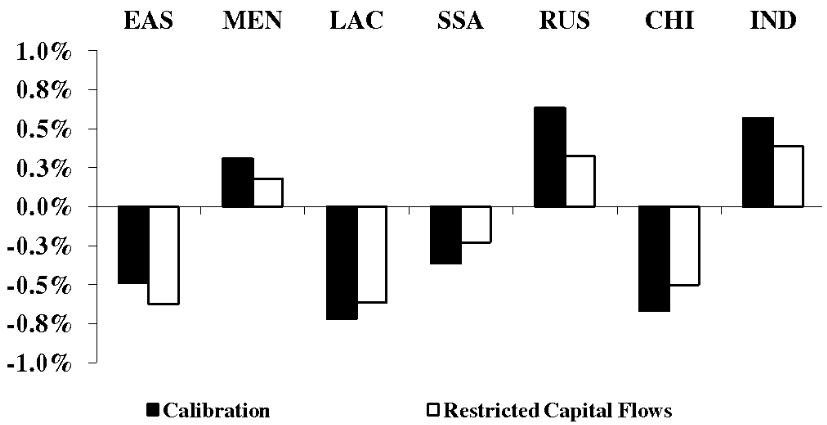
Figure 8: Total impact on GDP per capita



a. Calibration



b. Restricted capital flows



c. Comparison in 2060

Table 4: 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

Table A.1: List of countries by region

Region Code	**Region Name**	**Countries**
NAM	North America	United States, and Canada.
ADV	Advanced Countries	Australia, Austria, Belgium, Denmark, Finland, France, Germany, Greece, Iceland, Ireland, Italy, Luxembourg, Netherlands, New Zealand, Norway, Portugal, Spain, Sweden, Switzerland, and 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, Iraq, Israel, Jordan, Kuwait, Lebanon, Libyan Arab Jamahiriya, Malta, Morocco, Occupied Palestinian Territory, Oman, Qatar, Saudi Arabia, Syrian Arab Republic, Tunisia, Turkey, 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.

Table A.2: Relative changes of the total labor force (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.