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On the world economy and international migration

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A mes parents

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Contents

List of Tables

List of Figures

General Introduction

This thesis aims at exploring different economic implications of international migration. It can be divided into two parts, according to the methodology used in its different chapters. Part I comprises chapters 1 to 3, which raise issues studied within a computable general equilibrium (CGE) model calibrated on the world economy. Part II contains chapters 4 and 5 and builds on a theoretical analysis via models that feature overlapping generations of individuals.

The following paragraphs summarize the research issues addressed in each chapter of this thesis as well as our main findings. The analysis in **Part I**, labeled "CGE analysis", delivers solely numerical results.

Demographic projections for the 21^{st} century indicate that population is aging all over the world, due to decreasing birth rates and increased life expectancy. However the aging process is not synchronous across world regions and arises at a different pace in the various regions. While developed countries, especially Europe and Japan, will experience large increases in their old-age dependency ratios, other regions of the world will be facing relatively low ratios and still rising working-age populations. Since the world economy is more and more financially integrated and characterized by increasing capital mobility, this heterogeneity in the aging process can induce inter-temporal trade, through international capital flows, mitigating the effects of aging compared to a situation of economic and financial autarky. *Chapter 1* introduces an overlapping generations computable general equilibrium model of the world economy, in which the countries of the world are grouped into ten regions along geographical lines. The model is build to capture the effects of demographic differences between regions on international capital mobility in a world with integrated capital markets. The population of each region is therefore calibrated on the data of the United Nations' World Population Prospects, which predict the evolution of the population by country until the year 2050. Compared to similar models, an original feature of the model is that agents are skill heterogeneous. The purpose of this chapter is to describe the model's structure and to present the calibration of the baseline scenario, which over the next decades portrays the evolution of a world economy characterized by global aging. Furthermore, to describe the model's mechanisms, a population increase in one of the model's regions is simulated. This simple scenario shows the importance of taking into account international capital mobility as well as general equilibrium effects. In fact, the consequences of such a scenario will differ if analyzed in a framework where capital is mobile or not, and whether the model works in a partial or in a general equilibrium setting. Lastly, since regions have distinct characteristics, the implications on the world economy will also depend on the region experiencing the population increase. The two following chapters analyze the consequences of increased migration for migrants' host regions (chapter 2) and their regions of origin (chapter 3).

Chapter 2 analyzes the impact of immigration on the contribution rate in North-America and Western Europe, when holding the generosity of the welfare state constant at current levels. This issue is addressed within a calibrated overlapping generations model featuring integrated capital markets. The importance of accounting for capital mobility was analyzed in the previous chapter and may be summarized as follows. In a nutshell, a demographic transition raises the capital-labor ratio and affects factor prices in an economy experiencing no capital inflows. This impacts on a country's economic performance since a fall in wages reduces the saving rate of the youngest individuals, who are the highest net savers and whose resources are essentially made of labor incomes. Capital deepening may then partly alleviate the negative consequences of a demographic transition by mitigating changes in factor prices. This chapter investigates the implications of two immigration policies on pension systems: a selective one, where the majority of migrants are high-skilled, and a non-selective one, with a majority of low-skilled migrants. These policies are subsequently compared with realistic changes in labor market characteristics. It is found that increased immigration yields small fiscal gains and that both the selective and non-selective immigration policies induce similar tax cuts. Results show that comparable fiscal gains could be achieved as with the immigration policies, simply by postponing the retirement age of low-skilled workers by 2 years from 2010 onwards in Western Europe and by a gradual increase from 1% to 5% between 2010 and 2050 in skill-biased technical change in North-America.

Chapter 3, focuses on the implications of high-skilled emigration on migrants' sending regions.The literature on the brain drain puts forward several positive and negative effects of high-skilled emigration but there is no study identifying the dominant and minor mechanisms at work. Another shortcoming is the difficulty to assess the global impact of the brain drain on developing regions. The paper aims to address concerns of brain drain due to high-skill biased immigration policies. The potential impacts of South-North high-skilled migration are simulated on GDP per capita, GNI capita, and the high-to-low skill income inequality at origin. A ten-region CGE-OLG model is built and dynamically calibrated so as to match observations from the world economy. While our results reconfirm the important role of remittances in subsidizing the income of those left behind, they are also robust to different assumptions as to whether the highly skilled remit less or not. Furthermore, the paper assesses the significance of several feedback effects ignored in previous CGE works. First, it is shown that the high-skilled diaspora may greatly benefit domestic production by reducing information-related risks and bringing in more foreign direct investments. Second, the so-called “brain gain" effect acts to reduce the income disparity between workers of different skills. These feedback effects may well outweigh losses of high-skill labor, and they are especially pronounced for regions with small high-skilled emigration rates. In contrast, brain drain indeed poses as a curse for regions already facing severe high-skill outflows, including Eastern Europe, Latin America.

Part II, labeled “Theoretical analysis”, provides essentially theoretical results on the economic implications of international migration.

Chapter 4 analyzes the link between climate change and international migration.Without doubt there is a growing concern over how and whether climate change will affect international migration. Although the economic literature has dealt with many aspects of migration, the treatment of the relationship between climate change and migration has not yet been satisfactory. Our focus in this article is to shed some light on the interaction between endogenous climate change, international migration, optimal migratory policies and inequality. We employ a two-country overlapping generations model with endogenous climate change, in which the production in the North generates climate change which negatively affects the productivity of the South. Our main findings are that climate change will increase migration and that small impacts of climate change have significant impacts on the number of migrants. Moreover, a laxer immigration policy increases long-run migration, reduces climate change, increases North-South inequality if decreasing returns to scale in production are significant.

Finally, in *chapter 5* we study how high- and low- skilled migration affect fertility and human capital in migrants’ origin countries.The early literature on the brain drain stressed the negative impact that high-skilled migration might entail for sending countries by depriving them from their most talented workers. In contrast, the more recent literature claims that high-skilled emigration might entail positive side-effects for sending countries, which might possibly outweigh the direct negative impact of a brain drain. The main body of the literature has however neglected the impact of a high-skill exodus on fertility decisions at origin. As put forward by the endogenous population literature, the quantity-quality tradeoff that parents face in terms of the number and education of their children has a non-negligible impact on human capital formation and economic performance in developing countries. We therefore analyze the impact of high-skilled emigration on fertility decisions at origin. An overlapping generations model is set forth in which parents choose the number of high- and low-skilled children they would like to have. Individuals migrate and remit to their parents with a certain probability. It is found that a brain drain induces parents to have more high- and less low-educated children. Under specific conditions, fertility may either rise or decline due to a brain drain. Low-skilled emigration leads to reversed results, while the overall impact on human capital of either type of migration remains ambiguous. An application of the model shows that increased high-skilled emigration reduces fertility and fosters human capital accumulation.

Part I

CGE analysis

Chapter 1

MONALISA: A Multi-Regional Overlapping GeNerations Computable GenerAl EquiLibrium Model with Integrated Capital Markets and Skill-Heterogeneous Agents

Abstract. This note introduces an calibrated overlapping generations model of the world economy, in which the countries of the world are grouped into ten regions along geographical lines. The model is build to capture the effects of demographic differences between regions on international capital mobility in a world with integrated capital markets. Compared to similar models, an original feature of the model is that agents differ in their education level. The purpose of this note is to describe the model's structure and to present the calibration of the baseline scenario, which portrays the evolution over the next decades of a world economy characterized by global aging. Furthermore, to describe the model's mechanisms, a population increase in one of the model's regions is simulated. The consequences of such a scenario will differ if analyzed in a framework where capital is mobile or not, and whether the model works in a partial or in a general equilibrium setting. Lastly, since regions have distinct characteristics, the implications on the world economy will also depend on the region experiencing the population increase.

Keywords: CGE-OLG Model, aging, international capital flows
JEL classification: C68; D91; F21

1.1 Introduction

Demographic projections for the 21^{st} century indicate that population is aging all over the world, due to decreasing birth rates and increased life expectancy. As public transfers are strongly ascending, such a demographic transition imposes a strong pressure on the fiscal policy. Many dynamic and more specifically computable general equilibrium models have been developed to analyze the sustainability of the welfare state threatened by population aging. Most of these studies were undertaken in a closed economy framework, see e.g. Auerbach & Kotlikoff (1987).

There are however several reasons to adopt an open economy approach when addressing multi-country issues. First of all, the world economy is increasingly globalized, meaning that national economies integrate into the international economy. The world economy is thus characterized by larger trade, foreign direct investment, capital flows, migration, and the spread of technology. For instance, world trade has more than tripled since 1980. Building a model of the world economy in which countries behave as closed economies would discard major traits of the economic reality today. Another important observation regards the aging process, whose pace and intensity are different across countries and world regions (see for instance the United Nations' World Population Prospects which predict the evolution of the population by country until the year 2050). While population aging is quite advanced in OECD countries, like in Europe and Japan, other world regions will experience lower old-age dependency ratios and their working-age population will still rise. This heterogeneous aging process can induce reinforce intertemporal trade, through international capital flows, mitigating the effects of ageing compared to a situation of economic and financial autarky.

Hence more recent works have adopted an open economy approach and more specifically allowed for integrated capital markets. Large scale CGE models have been built to examine the consequences of aging on international capital flows. Attanasio & Violante (2000) examine the impact of capital mobility on welfare (GDP per capita growth) in a two-region model, with a Northern (US and Europe) and a Southern region (Latin America). The implications of international capital flows on current accounts are investigated by Feroli (2003) within a multi-country (G-7) model, as well as by Brooks (2003) and Aglietta et al. (2007) within a multi-regional world model. Other authors developed multi-country or multi-region frameworks, built upon demographic projections, to analyze the consequences of aging on pension systems when capital is mobile (Fehr et al., 2003; Börsch-Supan et al., 2006; Ingenue, 2005). Our model belongs to last vain of studies since it features pension systems. It is moreover closer to the world model developed by the Ingenue (2005), because similarly to them the world is divided into ten regions, according to similar geographical criteria and comprising developing and developed regions. Compared to other models, which restrict their analysis to developed regions (Fehr et al., 2003; Börsch-Supan et al., 2006), it allows to take into account the non-synchronous aging process in a more global way by letting the demographics of developing regions come into play. The aforementioned models are characterized by a homogeneous agent framework. The main novelty of our model is to differentiate households by their education level: agents are either low- or high-skilled.

This paper pursues two main objectives. The first aim is to present the mathematical structure of the model, to describe the calibration process of the baseline scenario and to examine the consequences of the demographic transition on the world economy over the 21^{st} century. We especially focus on the impact on the world real interest rate, the annual growth rate of the world GDP, regional growth rates, investment rates, saving rates and current accounts. The second objective is to highlight the importance of modeling a world economy in which the different regions are financially integrated. More precisely, policy analysis can yield different conclusions whether capital mobility and capital accumulation are endogenized or not. For that purpose, we propose to investigate the implications of a very simple scenario, in which there is a one-time increase in the population of one region: Western Europe. First, the consequences of this scenario will differ whether analysed in a framework where capital is mobile across regions or in one in which each region is treated as a closed economy. Second, general equilibrium effects prove to be significant. The population increase will for instance have a quite different impact on Western European GDP in a case where capital accumulation is endogenous compared to a partial equilibrium framework where the capital stock is fixed.

The paper is organized as follows. Section 1.2 introduces the mathematical structure of the world model. The calibration process is explained in section 1.3. Section 1.4 depicts the evolution of the world economy under our baseline scenario. The impact of the scenario of increased population is shown in section 1.5. Section 1.6 concludes.

1.2 The Model

This study builds upon a multi-region overlapping generations (OLG) computable general equilibrium (CGE) model. The countries of the world are grouped into 10 regions. Individuals live for 8 periods, each of 10 years. Age classes go from 15-24 to 85-94 years, implying that individuals are “born" at the age of 15 and die at the age of 95. However some individuals die before the age of 95, implying that agents face a positive probability of being alive at each period.

The model features agent heterogeneity by skills: there are high- and low-skilled individuals. “high-skilled individuals" identify individuals with an education above high-school degree (tertiary education), whereas “low-skilled individuals" comprise individuals having an educational level less than high-school (primary education) and with a high-school degree (secondary education). The educational choice (e) and thus also the proportion of high-skilled individuals among one generation (ϕ) are exogenously determined.

Furthermore, there is only one consumption good and its price is the numeraire of the model. There is one leading economy (North-America), in the sense that the technological progress of each region is expressed in terms of the one of the leading economy, and the evolution of technology is exogenous.

The model is also characterized by full-employment. Finally, each economy has three agents: households, a representative firm and a public sector. In the following subsections, we describe the regional decomposition of the world, agents' behavior and the equilibrium of the model.

1.2.1 Regions

The model splits the countries of the world into 10 regions (or groups of countries). Three of them consist of developed countries: Japan (JAP), North America (NAM), which comprises the United States plus Canada, and Western Europe (WEU), with Europe-15 as the major members.[1] We also distinguish seven developing regions, Eastern Europe (EAS), Middle East and Northern Africa (MEN), Latin America and the Caribbean (LAC), Sub-Saharan Africa (SSA), the Former Soviet Union (RUS), the Chinese world (CHI) and the Indian world (IND). See table 1.1 for more details.

1.2.2 Demography

At each date, some individuals die and a new generation appears. Individuals are aged from 15 to 94. Households reaching age 15 (labeled as age 0 in our notations) at year t belong to generation t. The size of the young generation increases over time at an exogenous growth rate:

$$N_{0,t} = m_{t-1} N_{0,t-1}, \tag{1.1}$$

where $N_{0,t}$ measures the initial size of generation t and m_{t-1} is one plus the demographic growth rate, including both fertility and migration.

[1] This region also comprises Australia and New-Zealand, while Pacific Islands are included in the Indian world. In contrast, the Ingenue (2005) add Australia, New-Zealand and all the Pacific Islands to their ‘North America’ region.

Table 1.1: Definition of the different regions

REGION CODE	REGION NAME	COUNTRY LIST
NAM	North America	United States and Canada.
WEU	Western Europe	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 (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, 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.

Each household lives a maximum of 8 periods ($a = 0, 1, ..., 7$) but faces a cumulative survival probability which is decreasing with age. Thus the size of each generation declines deterministically through time:

$$N_{a,t+a} = P_{a,t+a} N_{0,t}, \tag{1.2}$$

where $0 \leq P_{a,t+a} \leq 1$ is the fraction of generation t alive at age a (hence, at period $t + a$). Obviously, $P_{0,t} = 1$. Moreover, total population at time t amounts to $N_t = \sum_{a=0}^{7} N_{a,t}$. High- and low-skilled cohort sizes are given by:

$$\begin{aligned} N_{0,t}^h &= \phi_t^h N_{0,t} = \phi_t N_{0,t} \\ N_{0,t}^l &= \phi_t^l N_{0,t} = (1-\phi_t) N_{0,t} \end{aligned}$$

where ϕ_t^h equals ϕ_t and denotes the proportion of high-skilled (post-secondary educated) individuals among the generation born in t.

1.2.3 Preferences

Each time an individual dies, her/his assets will be equally distributed among individuals belonging to the same age class. This formalization avoids to increase agent heterogeneity in the model. In fact if the wealth of an individual would be redistributed to his/her children, the latter ones' initial wealth would differ in terms of assets compared to equally aged individuals. This annuity market allows that individuals belonging to one generation differ only in terms of their type of education.

As stated above, there is life uncertainty at the individual level since agents have a positive probability to die during each period of life. Instead of allowing for accidental bequests, we postulate the existence of an insurance mechanism à la Yaari 1965 (or à la Arrow-Debreu) as in de la Croix & Docquier (2007) or in the study by the Ingenue (2005), in which there is a perfect annuity market for every contingent consumption. It is as if there exist insurance companies offering competitive contracts and making zero profits. At the beginning of his life, each agent has the possibility to sign a contract with a company, which insures himself against uncertainty. At each period when an agent dies, his assets are seized by the insurance company, which redistributes them equally among the individuals belonging to the same age class and having survived. Hence, the problem of agents born at time t is to choose a consumption contingent plan in order to maximize their expected utility subject to their intertemporal budget constraint, given the sequence of contingent wages and prices. This insurance mechanism has also the interesting property of avoiding too much agent heterogeneity. In fact, if we would assume unintended bequests, then some individuals would be born with positive assets. This would add one more agent heterogeneity in terms of initial wealth and would further complicate the computation of the staedy-state in a model, where agents already differ in terms of age and education levels.

The expected utility function (U) of low- (upperscript l) and high-skilled (upperscript h) individuals is assumed to be time-separable and logarithmic:

$$E(U_t^j) = \sum_{a=0}^{7} P_{a,t+a} ln(c_{a,t+a}^j), \qquad j = h, l \tag{1.3}$$

where $c^j_{a,t+a}$ is the consumption of age class a at time $t + a$.[2]

The budget constraint of low- (l) and high-skilled (h) individuals requires equality between the expected value of expenditures and the expected value of incomes (I). It writes as follows for $j = h, l$:

$$\sum_{a=0}^{7} \frac{P_{a,t+a}}{\prod_{v=1}^{a} R^*_{t+v}} (1 + \tau^c_{t+a}) c^j_{a,t+a} = \sum_{a=0}^{7} \frac{P_{a,t+a}}{\prod_{v=1}^{a} R^*_{t+v}} I^j_{a,t+a}, \tag{1.4}$$

Incomes consist of labor income (w), pension benefits (b) and other welfare transfers (ζ)

$$I^j_{a,t+a} = \left[\lambda^j_{a,t+a}(1 - e^j_{t+a})(1 - \tau^w_{t+a}) w^j_{t+a} + (1 - \lambda^j_{a,t+a}) b^j_{t+a} + \psi_{t+a} \zeta^j_a w^j_{t+a} \right]$$

where $\lambda^j_{a,t+a}$ is the labor participation rate for a j type individual of age class a, w^j_t is labor income of a j type worker, R^*_t is one plus the international interest rate, τ^c_t is consumption tax, τ^w_t stands for income tax, b^j_t represents (individual) pension benefits, ζ^j_a are other welfare transfers received by an individual of type j and are represented as a time-constant fraction of labor income, and finally ψ_t is the generosity factor, which is the factor by which these other welfare transfers are multiplied at time t. Moreover, education is exogenous and individuals spend a fraction e^j_t of their total time (which is only positive in their first period of life).

Individuals maximize their utility (1.3) subject to their intertemporal budget constraint (1.4) with respect to the levels of consumption. The optimal (contingent) levels of consumption for both types of households $j = h, l$ will then be:

$$c^j_{a+1,t+a+1} = R^*_{t+a+1} c^j_{a,t+a}. \tag{1.5}$$

Equation (1.5) reveals that to know the optimal lifetime consumption (c_0 to c_7) of a cohort born in t can be known once its consumption level at age 0 is identified. The optimal level of consumption in the first period of life can be determined by substituting (1.5) in (1.4).

[2]It can be observed that there is no explicit time preference parameter in the utility function (more precisely, it is set to 1). The discount rate impacts on households' intertemporal consumption choices. But as in de la Croix et al. (2007) and de la Croix & Docquier (2007), the psychological discount factor is implicitly taken into account by the probabilities of being alive at each. With such an assumption, as in these two studies, our model provides a good shape of asset profiles per age. Hence, there is no need to suppose a pure time preference parameter on top of the mortality rate. Moreover, in our model we obtain a long-run value for the annual world real interest rate of 3.255%. This is compatible with the Ingenue world model. While using a different utility function, the discount factor is set close to one with a value of 0.99 and their long run path is calibrated to seek a level for the annual world interest rate lying between 3 and 3.5% (Income growth in the 21st century: Forecasts with an overlapping generations model, Agl).

Moreover, we can also define the implicit asset holdings of each age class. We assume that individuals are born with no assets at time t, or in other words, there are no bequests. At time $t+a$ with $a > 0$, assets of high- and low-skilled individuals ($Z^j_{a,t+a}$) depend on their assets in the previous period ($Z^j_{a,t+a-1}$) plus an interest rate as well as on current expenditures (consumption) and incomes (labor income, pension benefits and other welfare transfers). Formally, at the beginning of their first period of life (when $a = 0$), $Z^j_{0,t} = 0$ for all t. For $a > 0$, aggregated assets, for $j = h, l$, correspond to:

$$\begin{aligned} Z^j_{a+1,t+a+1} = R^*_{t+a} Z^j_{a,t+a} + \phi^j_t N_{a,t+a}[(1-\tau^w_{t+a})(1-e^j_{t+a})\lambda^j_{a,t+a} w^j_t \\ -(1+\tau^c_{t+a})c^j_{a,t+a} + (1-\lambda^j_{a,t+a})b^j_{t+a} + \psi_t \zeta^j_a w^j_t] \end{aligned} \qquad (1.6)$$

where $N_{a,t+a}$ represents the number of individuals of age class a living at time $t+a$, ϕ^j_t is the proportion of individuals of skill type j among generation t.

1.2.4 Firms

At each period of time and in each region, a representative firm uses efficient labor (L_t) and physical capital (K_t) to produce a composite good (Y_t). We assume a Cobb-Douglas production function with constant returns to scale:

$$Y_t = K^\alpha_t (A_t L_t)^{1-\alpha}, \qquad (1.7)$$

where α measures the share of wage income in the national product, and A_t is an exogenous process representing Harrod neutral technological progress.

Total efficient labor force combines the demands of high-skill (L^h_t) and of low-skill labor (L^l_t) according to the transformation function characterized by a constant elasticity of substitution (CES):

$$L_t = [\upsilon_t (L^h_t)^\sigma + (1-\upsilon_t)(L^l_t)^\sigma]^{1/\sigma}, \qquad (1.8)$$

where υ_t is an exogenous skill-biased technological progress, and σ is defined as σ=$1-\frac{1}{\varepsilon}$, with ε being the elasticity of substitution between high-skill and low-skill labor. In the present version of the model, σ is set to 1 meaning that high- and low-skill labor are perfect substitutes. In the labor markets labor is inelastically supplied and wages adjust so that labor demand is equal to labor supply at the full employment level:

$$L^j_t = \sum_{a=0}^{7} \phi^j_{t-a} N_{a,t}(1-e^j_t)\lambda^j_{a,t}. \qquad (1.9)$$

The profit maximization by firms requires the equality of the marginal productivity of each factor to its rate of return:

$$w_t^j \quad = \quad (1-\alpha)K_t^\alpha A_t^{1-\alpha} L_t^{-\alpha} \frac{\partial L_t}{\partial L_t^j}, \tag{1.10}$$

$$1 + \alpha K_t^{\alpha-1}(A_t L_t)^{1-\alpha} - \delta \quad = \quad R_t, \tag{1.11}$$

where δ represents the depreciation rate of capital and R_t is the regional interest factor, defined in section 1.2.5.

1.2.5 Government

The government levies taxes on labor earnings (τ_t^w) and consumption expenditures (τ_t^c) to finance general public consumption (c_t^g), pension benefits (b_t^j) and other welfare transfers (ζ_{a+1}^j). The government surplus (S_t) can be written as follows for $j = h, l$:

$$\begin{aligned} S_t = \tau_t^w \sum_{j=\{h,l\}} L_t^j w_t^j + \tau_t^c \sum_{j=\{h,l\}} \sum_{a=0}^{7} \phi_{t-a}^j N_{a,t} c_{a,t}^j \\ - \sum_{j=\{h,l\}} b_t^j \sum_{a=0}^{7} \phi_{t-a}^j N_{a,t} (1-e_t^j)(1-\lambda_{a,t}^j) \\ -\psi_t \sum_{j=\{h,l\}} w_t^j \sum_{a=0}^{7} \phi_{t-a}^j N_{a,t} (1-e_t^j) \zeta_a^j - c_t^g Y_t, \end{aligned} \tag{1.12}$$

where c_t^g is a part of national income used to finance general public spending.

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

$$d_{t+1} Y_{t+1} = R_t^* d_t Y_t - S_t, \tag{1.13}$$

where d represents the debt-to-GDP ratio, R^* is one plus the international interest rate and S is the government's surplus. Equation (1.13) says that public debt in $t+1$ depends on past debt in t and its interests, minus the government's surplus S. The evolution of the public debt is exogenously given. Since transfers and taxes on consumption are exogenous as well, the wage tax rate will adjust to satisfy the government's budget constraint (1.13).

Finally, in contrast to existing multi-regional models, the modeling of the pension systems should account for the skill-heterogeneous agents feature of our model. In fact, a social security system can be characterized not only by its generosity or size but also by its redistributiveness (Pestieau, 1999). In the following equations, the first characteristic is captured by the replacement rate χ_t and the second one by the parameter ρ, with both parameters comprised between 0 and 1. Pension benefits for low- (b_t^l) and high-skilled (b_t^h) write as follows

$$b_t^l = \chi_t w_t^l, \tag{1.14}$$

$$b_t^h = \chi_t \left[\rho w_t^h + (1-\rho) w_t^l\right], \tag{1.15}$$

A value for ρ close to 0 implies more redistributive pension systems, since low- and high-skilled would receive similar amounts of benefits when retired. If ρ is close to 1, then pension systems are weakly redistributive with replacement rates that are constant across income levels. This modeling allows regional pension systems to be partly Bismarckian or Beveridgian.[3]

1.2.6 International capital market

In an economy with perfect capital mobility - up to a confiscation rate on the returns to capital (see below) - 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:

$$\sum_{x \in X} \Omega_t^x = \sum_{x \in X} (K_t^x + d_t^x Y_t^x), \tag{1.16}$$

where X is the set containing each world region. Moreover, K_t^x is the sum of the capital stock of region x at time t, Ω is the sum of the assets of all the cohorts of region x, $d_t^x Y_t^x$ is the level of region x's debt at time t.

An economy with capital mobility is also characterized by the arbitrage condition of the returns to capital which requires the equality between the rates of return to capital in each region. However, there are several reasons why capital may not be perfectly mobile across regions. Transaction costs may reduce international capital mobility, but cross-border investments may also be refrained by investment risks induced by a region's poor institutional quality. In fact, investors' trust depends on the economic freedom within a region as well as on a government's capacity to enforce property rights and to restrain corruption. Thus we assume that, in each region, returns to investments are subject to a confiscation rate or a rent-seeking rate by the government. This confiscation rate captures

[3] Bismarckian systems can be defined as highly generous and poorly redistributive, while Beveridgian pension are small-sized and more redistributive. This remains however a simplistic categorization (Pestieau, 1999).

transaction costs and various investment risks faced by international investors and is modeled as a premium on the international rate of return to capital R^*. A region's domestic interest factor R is then equal to the international interest factor R^* up to the region's confiscation rate π,

$$R_t = R_t^*(1+\pi) \tag{1.17}$$

The confiscation rate in each region π is given by

$$\pi = \frac{q}{q^o}\pi^o, \tag{1.18}$$

where q is the risk classification of a region as defined by the OECD (2006a), q^o is the highest attainable risk rating and π^o is the maximum confiscation rate. The confiscation rate depends on the region's risk classification: the riskier the region, the higher the premium. This means that in a region with a risk rating close to the maximum q^o, the confiscation rate will be close to the highest possible one π^o.

The confiscation rate π is modeled here as a government tax on the returns to capital. In a risky region, the confiscation rate is the part of an investor's return to capital levied by the government and used in general public spending i.e. it is not redistributed to households or firms. A positive rent-seeking rate will induce a regional interest rate that is larger than the international one and investment in this region will be lower than in the absence of such rent-seeking. In North America, Western Europe and Japan, investment risk is zero.

1.2.7 Equilibrium

Definition (Competitive Equilibrium) *Given an initial stock of capital $\{K_t\}_{t=0}$, an exogenous demographic structure summarized by $\{N_{a,t}\}_{a=0..7,t\geq 0}$, an exogenous distribution of high-skilled individuals $\{\phi^j_{a,t-a}\}_{a=0..7,j=h,l,t\geq 0}$ and an initial distribution of wealth $\{Z^j_{a,t+a}\}_{a=1..7,t=0,j=h,l}$ with $\{Z^j_{a,t}=0\}_{a=0,t\geq 0}$, a competitive equilibrium in an economy with perfect capital mobility, up to a confiscation rate, is*

- ⋆ *a vector of individual variables $\{c^j_{a,t}\}_{a=0..7,t\geq 0,j=h,l}$ that are the optimal solutions to the households' maximization problem, i.e. equation (1.3) subject to (1.4);*
- ⋆ *a vector of the firm's variables $\{K_t, L^j_t\}_{t\geq 0,j=h,l}$ that maximize the firm's profits subject to technology (1.7);*
- ⋆ *a vector of income taxes $\{\tau^w_t\}$ balancing the budget of the government (1.13);*

- ⋆ *a vector of wages* $\{w_t^j\}_{t\geq 0, j=h,l}$ *such that labor markets are in equilibrium ;*

- ⋆ *an interest factor* $\{R_t\}_{t\geq 0}$ *satisfying the no arbitrage condition of the rates of return to capital, i.e. equation (1.17) 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, i.e. equation (1.16) holds.*

The equilibrium on the goods market is achieved by Walras' law.[4] Table 1.2 summarizes the model's structure by presenting its equations and endogenous variables.

1.3 Calibration of the baseline scenario

In this section we describe the data and explain the calibration of the parameters, the observed and unobserved exogenous variables. We also define the baseline scenario and the assumptions on the future. Finally, we illustrate the population aging process that occurs all over the world in the 21st century. Therefore, we focus on the evolution of the support ratio, which is a general indicator of the aging process. The support ratio is defined as the number of people of working age for one pensioner.

To forecast the economic consequences of an aging world population, we calibrate the model economies of ten world regions. This calibration is achieved by fixing some constant parameters, using data for observed exogenous variables and choosing (arbitrary) values to unobserved exogenous variables in order to match a series of characteristics.

The baseline predictions are based on official demographic forecasts and extrapolate the trends observed in the last decades (in terms of educational attainment, productivity growth, public consumptions, public debt, generosity of welfare programs, etc.). More precisely, the evolution of the population is based on the United Nations Population Projections, which cover the period 1950 to 2050. These forecasts are calibrated through the growth rate of the youngest cohort of individuals. The projections on the *age structure* of the population are matched

[4] In an open economy, the goods market is in equilibrium when domestic output equals the demand - both domestic and foreign - for domestic goods: $Y_t = C_t + I_t + G_t + X_t - M_t$, where C_t is total consumption, I_t is investment, G_t is government expenditure and $X_t - M_t$ is the trade balance, i.e. exports X_t minus imports purchases M_t. In terms of the model, $I_t = K_{t+1} - (1-\delta)K_t$ and $G_t = c_t^g Y_t$.

Table 1.2: The model's equations

ENDOGENOUS VARIABLE	EQUATION	EQUATION NUMBER
N_0	$N_{0,t} = m_{t-1}N_{0,t-1}$	(1.1)
N_1 to N_7	$N_{a+1,t+a+1} = P_{a+1,t+a+1}N_{0,t}$, for $a = 0, ..., 7$	(1.2)
c^j_0 to c^j_6	$c^j_{a+1,t+a+1} = R_{t+a+1}c^j_{a,t+a}$, for $a = 0, ..., 6$ and $j = h, l$	(1.5)
c^j_7	$\sum_{a=0}^{7} \frac{P_{a,t+a}}{\prod_{v=1}^{a} R^*_{t+v}}(1+\tau^c_{t+a})c^j_{a,t+a} = \sum_{a=0}^{7} \frac{P_{a,t+a}}{\prod_{v=1}^{a} R^*_{t+v}} I^j_{a,t+a}$, where $I^j_{a,t+a} = \lambda^j_{a,t+a}(1-e^j_{t+a})(1-\tau^w_{t+a})w^j_{t+a} +(1-\lambda^j_{a,t+a})b^j_{t+a} + \psi_{t+a}\zeta^j_a w^j_{t+a}$	(1.4)
Z^j_1 to Z^j_7	$Z^j_{a+1,t+a+1} = R_{t+a}Z^j_{a,t+a} +\phi^j_t N_{a,t+a}\big[(1-\tau^w_{t+a})(1-e^j_{t+a})\lambda^j_{a,t+a}w^j_t -(1+\tau^c_{t+a})c^j_{a,t+a} + (1-\lambda^j_{a,t+a})b^j_{t+a} + \psi_t\zeta^j_a w^j_t\big]$	(1.6)
τ^w	$d_{t+1}Y_{t+1} = R^*_t d_t Y_t - S_t$	(1.13)
b^l	$b^l_t = \chi_t w^l_t$	(1.14)
b^h	$b^h_t = \chi_t[\rho w^h_t + (1-\rho)w^l_t]$	(1.15)
Y	$Y_t = K^\alpha_t (A_t L_t)^{1-\alpha}$	(1.7)
L	$L_t = [\upsilon_t (L^h_t)^\sigma + (1-\upsilon_t)(L^l_t)^\sigma]^{1/\sigma}$	(1.8)
w^j	$L^j_t = \sum_{a=0}^{7} \phi^j_{t-a} N_{a,t}(1-e^j_t)\lambda^j_{a,t}$	(1.9)
L^j	$w^j_t = (1-\alpha)K^\alpha_t A^{1-\alpha}_t L^{-\alpha}_t \frac{\partial L_t}{\partial L^j_t}$	(1.10)
R^*	$\sum_{x\in X} \Omega^x_t = \sum_{x\in X}(K^x_t + d^x_t Y^x_t)$	(1.16)
R	$R_t = R^*_t(1+\pi)$,	(1.17)
π	$\pi = \frac{q}{q^o}\pi^o$	(1.18)
K	$R_t = 1 + \alpha(K_t)^{\alpha-1}(A_t L_t)^{1-\alpha} - \delta$	(1.11)

through each cohort's probability of being alive at the next period. After 2050 the growth rate of the first cohort and the probabilities of being alive are held constant over time. Individuals live for 8 periods of 10 years, hence the population structure starts from an initial state in 1870 and reaches a final steady state in 2130. Our model uses the *Dynare* algorithm to solve for the perfect foresight general equilibrium transition path of the economy.[5]

Before turning to the description of the calibration of observed and unobserved variables, let us first observe that two parameters δ and α are set a priori and are assumed to be identical for all the regions. As Income growth in the 21st century: Forecasts with an overlapping generations model (Agl) we argue that there is no reason to think that these parameters should differ across regions. We use an annual depreciation rate of capital of 5% like in Chojnicki et al. (2005) and de la Croix & Docquier (2007), which implies that δ equals 0.4. The capital share in output α is set to one third, 0.33, as estimated in the growth accounting literature (see also GTAP, 2008).

1.3.1 Observed exogenous variables

Table 1.3 exhibits the values of the time-constant transfer profiles in percentage of labor income, while other observed exogenous variables are displayed in table 1.4.

Social security transfer profiles ζ_a^j. The social security transfer profiles of each educational group are assumed to be stable over time. The data for the social security transfer profiles (ζ_a^j) come from US and European generational accounting studies (Chojnicki, 2005). For the US, he disaggregates the profiles in the homogeneous agent study of Gokhale et al. (2000) by individuals' education level: below high school, high school and above high school. These profiles are also used in Chojnicki & Docquier (2007) and comprise eight types of transfers: old age security, disability insurance, medicare and medicaid, unemployment insurance, general welfare, aid to families with dependent children, food stamps and finally, educational transfers. In our model we take the average profiles of the two first groups as the profiles of 'low-skilled' individuals for the North American region. For the Western European region, we rely on the same types of transfers by using the European data in Chojnicki (2005), which stem from Crettez et al. (1999). The time-constant transfer profiles for Japan are assumed to be similar than in Western Europe. For the developing regions data is hardly available and since we believe transfers to be less generous in these regions than in Western

[5]The Dynare pre-processor consists of a collection of MATLAB or SCILAB routines and applies a Newton-type algorithm to study the transitory dynamics of non-linear models. The details of the algorithm used in Dynare can be found in Juillard (1996).

Europe, the profiles are set equal to the North American ones (see table 1.3).

Table 1.3: Time-constant transfer profiles ζ (% of labor income)

Age groups	**15-24**	**25-64**	**65-74**	**+75**
WEU and JAP				
High-skilled	3%	6%	10%	15%
Low-skilled	10%	18%	20%	22%
NAM and other regions				
High-skilled	0.5%	1%	6%	12%
Low-skilled	7%	12%	20%	25%

Source: Chojnicki (2005) and own computations.

Table 1.4: Values for observed exogenous variables

Region	WEU	NAM	JAP	EAS	MEN	LAC	SSA	RUS	CHI	IND
d_{2000}	6.10%	6.62%	13.4%	0.35%	0.43%	0.41%	0.32%	0.30%	0.18%	0.25%
c^g_{2000}	19.6%	14.9%	16.5%	16.4%	15.4%	15.0%	15.0%	16.3%	12.5%	11.0%
q	0	0	0	3.40	3.95	5.19	6.40	6.17	3.18	4.89
ϕ_{2000}	30%	55%	35%	20%	15%	15%	5%	25%	10%	10%
ϕ_{1990}	28%	53%	32%	19%	13%	15%	4%	33%	7%	6%

Source: OECD (2006a,b), WDI (2007), Barro & Lee (2001a) and own computations.

Public debt, d_t, and public spending, c^g_t. Public debt and public spending are computed from the World Development Indicators (WDI, 2007). Exceptions are the public debt of Western Europe and Japan, which are obtained from the OECD (2006b).

Share of high-skilled individuals, ϕ_t. The share of high-skilled individuals is computed from the Barro and Lee data set (Barro & Lee, 2001a), which gives the proportion of high-skilled individuals aged 25 to 74 for the years 1950 to 2000. We have to disaggregate this data to obtain the share of high-skilled individuals per age group. It is not unreasonable to think that at each period the proportion of high-skilled is highest among the youngest age classes. In particular, we assume that the share of high-skilled aged 65 to 74 corresponds to 80% of the share of high-skilled aged 55 to 64, which in turn is equal to 80% of that of the 45-54, which finally corresponds to 80% of that of the 35-44, and which finally equals 80% of the share of high-skilled aged 25-34. The share of post-secondary educated individuals of the older age classes, 75-84 and 85-94, is also determined by this "80%" assumption. The age specific proportions of high-skilled are then a function of the proportion of the high-skilled aged 25-34, which is computed in order to match the total share of high-skilled in 1950 given by the Barro-Lee

Dataset. We thus have all the age specific proportions of high-skilled for the year 1950. The next step is to report the values of the shares of high-skilled among the 25-34 to 65-74 aged individuals to the following years. For example, the proportion of high-skilled aged 35-44 in 1960 is equal to the share of high-skilled aged 25-34 in 1950 (as we assume that the high- and low-skilled individuals have the same probability to be alive at the beginning of each period). For all the following years, the proportion of high-skilled aged 25-34 will again adjust to match the aggregate values of Barro and Lee. Moreover, the share of high-skilled aged 15 to 24 in 1950 is simply equal to the share of high-skilled aged 25-34 in 1960. Finally, for the years preceding 1950, we simply apply the shares of 1950 to the previous years e.g. the share of high-skilled aged 75-84 in 1940 correspond to the proportion of high-skilled aged 85-94 in 1950.

Region specific risk q. We use the data available from the OECD (2006a) for region specific risk q which rely upon the Knaepen Package methodology. The Knaepen Package is a system for assessing country credit risk, which classifies countries into eight country risk categories (0 - 7), from no risk (0) to high risk (7). It basically measures the country credit risk, i.e. the likelihood that a country will service its external debt. To compute the risk classification per region, we take an arithmetic mean of ratings of the available countries. For Western Europe, North America and Japan the risk is nil, it corresponds to 3.4 for the Eastern Countries, to 3.95 for the Mediterranean World, 5.19 for Latin America, to 6.40 for Sub-Saharan Africa, to 6.17 for the Russian World, 3.18 for the Chinese World and to 4.89 for the Indian World.

Demography, $P_{a,t+a}$ **and** m_t. Population growth rates and probabilities of being alive for the period 1870-2200 are obtained in two steps. In the first step, we compute the probabilities of being alive and the population growth rates for the period 1950 to 2050 *directly* from the dataset of the U.N. Population Division, which predicts the population per age group from 1950 to 2050 for almost every country in the world. By applying the probabilities of being alive of 1950 to the years 1880 to 1940, we obtain the age groups 15-24 to 75-84 of 1940, the age groups 15-24 to 65-74 of 1930, and so on until the 15-24 years old of 1880. Subsequently, we derive the population growth rates until 1880. We hold the growth rate of 1880 constant for the years before 1880 and apply the same probabilities of being alive as in 1950. By proceeding like this, we can restore the age groups 25-34 to 85-94 of 1880, the groups 35-44 to 85-94 of 1890 until the 75 to 84 years old of 1940. The age groups beyond the year 2050 are created by applying the probabilities of being alive of 2050 to the years 2060-2130 and fixing the population growth rate to 1 from 2050 onwards. This implies that the population size as well as its structure will be constant from 2130 onwards.

However, the probabilities of being alive, obtained in this first step, appear to be larger than 1 for some of the regions and for some age classes (i.e. mainly the regions WEU, NAM and JAP). Probabilities of being alive that are larger than 1 in some regions, may only happen if people migrate. However if migration is allowed in the model, it would generate further *agent heterogeneity*, because migrants may have different characteristics than natives (e.g. differences in human capital, assets etc). There should then be at each period and for each age class, multiple human capital levels, different accumulated assets for natives and migrants etc. This would complicate by much the computation of the steady-states and the dynamic path of our baseline as we already have, in each region and at each period, individuals that differ in terms of age (8 age classes) and in terms of skills (2 skill types).

Hence in a second step, we exclude this implicit migration contained in the data. We introduce these migrants (i.e. the "additional" individuals generated by probabilities that are larger than 1) right from the start in the destination regions by assuming that they have the same characteristics than natives. In other words, individuals migrate at the age of 15 years and start to live directly in the region of destination with total assimilation to natives. Thus no migration occurs during people's life in this model. In fact, in order not to have any probabilities to be alive above 1 at the ages 25-34 and 35-44, we replace in all the regions the probabilities of being alive at the ages 25-34 and 35-44 by the *world average* probabilities. We then recompute the first two age classes according to the new probabilities. This slightly changes the population of the first two age classes in each period and for each region, by keeping fixed the total world population of these two age classes. We also assume that no explicit migration will occur after 45 years. We put an upper bound of 1 if a probability of being alive exceeds one for age groups above 45 (which happens just a few times). Our procedure implies that the population of age groups 15-24 and 25-34 is increased in migrants' receiving regions, whereas the one in origin regions reduced. Even though the size of these two age groups is slightly changed, this calibration reproduces very accurately the structure of the population of the original data.

1.3.2 Unobserved exogenous variables

Values for unobserved variables are presented in the tables 1.5 and 1.6.

Labor participation, $\lambda^l_{a,t}$ and $\lambda^h_{a,t}$. The labor participation rates of high- and low-skilled individuals (respectively $\lambda^h_{a,t}$ and $\lambda^l_{a,t}$) are set to 1 for the age groups 15-24, 25-34, 35-44 and 45-54. Individuals work until 60 in all the regions, i.e. participation rates for individuals aged 55-64 equal 0.5 ($\lambda^j_{5,t} = 0.5$), except *high*-skilled individuals in North-America, Japan and Western Europe who work until 62 ($\lambda^h_{5,t} = 0.7$). The participation rate for the three last age groups equals 0 in all

Table 1.5: Values for unobserved exogenous variables

		developed regions	developing regions
time spent in education (high-skilled)	e^h	0.6	0.6
time spent in education (low-skilled)	e^l	0.2	0
participation rate of the 55-64 old (high-skilled)	λ_5^h	0.7	0.5
participation rate of the 55-64 old (low-skilled)	λ_5^l	0.5	0.5
generosity factor in 2000	ψ_{2000}	1	1
GDP growth rate	g	1.2	1.2

the regions.

Time spent in education, e^h **and** e^l**.** Time spent in education is set to 0.6 for high-skilled individuals, meaning that they obtain a secondary school diploma (or above) and start working at the age of 21. For low-skilled individuals e^l equals 0.2 in North-America, Japan and Western Europe and 0 in developing regions, indicating that they enter the labor force at 17 respectively 15.

Generosity factor of the social security transfers, ψ_t**.** This factor is set by assuming that the generosity factor increased during the period 1950-2000. It is thus set to 0.25 before 1960, to 0.4 in 1960, to 0.55 in 1970, to 0.7 in 1980, to 0.95 in 1990 and to 1 in 2000 and afterwards.

Replacement rate, χ_t **and the time-invariant pension scheme parameter** ρ**.** We calibrate the replacement rate in order to match the share of public pension spending to GDP of the year 1990. The data for this last variable come from Table A.5 of Palacios (1996) and from the World Bank (1994). We assume that the replacement rate of 1950 corresponds to 3/4 of the one of 1990. The replacement rates of 1960, 1970 and 1980 are chosen in order to build an linear upward trend between 1950 and 1990. The ones before 1950 are kept identically to the value of 1950, whereas the replacement rates after 1990 correspond to the value of 1990. The pension scheme parameter, ρ, captures the redistributiveness of the pension system and is specific to each region. We can set ρ by relying on the data on the size and redistributiveness of pension systems for several OECD countries collected by Johnson (1998) and exposed in Pestieau (1999).[6] According to this data, the ratio of replacement rates between the highest and lowest income levels is 0.33 in Canada and 0.5 in the United States. To be precise, this data reports replacement ratios for an average income level and for incomes that are half or twice as large as the average level. We take the ratio of replacement

[6]Since data on the size of the pension systems in Johnson (1998) comprises only several developed countries, we prefer to use the more complete data of the World Bank to calibrate χ.

rates between the highest and lowest income levels as a rough approximation of the ratios between high- and low-skilled wages. The ratio of replacement rates for North-America will correspond to the weighted average of the Canadian and US ratios (weighted by the population of both countries in 1990). By using the formulas (1.14) and (1.15) we can write this ratio in the terms of our model as $[\rho + (1-\rho)/H]$ where $H \equiv w^h/w^l$. Then ρ is set in order to match the ratio of replacement rates between high- and low-skilled individuals (the value of H is given below). We obtain a ρ of 0.2 for North America, and similarly ρ equals to 0.6 for Western Europe and to 0.8 for Japan.[7] We assume the developing regions of our model to be Beveridgian and set ρ equal to 0.

Table 1.6: Calibration of the replacement rate χ (year 2000)

	WEU	NAM	JAP	EAS	MEN	LAC	SSA	RUS	CHI	IND
Data:										
PPE /GDP	9.2	6.5	5	8	2.8	2	0.5	7.1	2.6	0.6
Calibration:										
χ	4.16	5.15	3.96	5.06	15.06	11.26	16.74	5.59	10.81	13.66

Source: Palacios (1996) and own computations. PPE stands for Public Pensions Expenditures.

1.3.3 Technology and skill-biased technical change

Growth in the leader's Harrod neutral technical progress, $g_t = A^*_{t+1}/A^*_t$. Based on observations, the future growth rate of the North-American technical progress is calibrated to 1.2, which means that the annual growth rate is equal to 1.84%.

Table 1.7: Calibration of labor-augmenting technical progress

		WEU	NAM	JAP	EAS	MEN	LAC	SSA	RUS	CHI	IND
(year 2000)	**Data:**										
	Y/Y^{NAM}	0.74	1	0.77	0.28	0.17	0.21	0.05	0.16	0.13	0.07
	Calibration:										
	A/A^{NAM}	0.96	100	0.99	0.43	0.24	0.32	0.09	0.25	0.19	0.12

Source: WDI (2007) and own computations.

Labor-augmenting technical progress, A_t **and the ratio of GDP's,** Y_t/Y_t^{NAM}. To obtain technical progress (A), we use the distance of a region's

[7] Pension systems differ quite a lot across Western European countries, with the largest countries as Italy, Germany and France being Bismarckian (i.e. with a large percentage of public spending for social security systems to GDP and a less equal redistribution), while smaller countries as the Netherlands being Beveridgian. In contrast, Canada and the United States are clearly more Beveridgian than Western Europe, with a smaller sized welfare system and a more egalitarian distribution of pension benefits across income levels.

GDP (Y_t) from the leader's GDP (Y_t^{NAM}) computed as a ratio of GDP's, $y_t/\bar{y}_t$. We proceed as in de la Croix & Docquier (2007), who use a backsolving identification method to calibrate Harrod-neutral technical progress. It consists in swapping the exogenous variable A_t for the endogenous variable Y_t/Y_t^{NAM} and solving the identification step with the Dynare algorithm Juillard (1996). The ratio of GDP's is computed by employing the data of the GDP per purchasing power parity from the World Development Indicators for the three years 1980, 1990 and 2000. We hold the value of 1980 (respectively 2000) constant for the years preceding 1980 (respectively following 2000).

Skill-biased technological progress, υ_t, skill premium H and σ. The parameter σ=$1-\frac{1}{\varepsilon}$, with ε being the elasticity of substitution between high-skill and low-skill labor. In the present version of the paper, σ equals 1 meaning that high- and low-skill labor are perfect substitutes. Skill-biased technological progress is set by the same backsolving method as A_t, and matches a skill premium H ($\equiv \frac{w^h}{w^l}$) of 2.35 in all regions. This indicates that the wage of a high-skilled individual is supposed to be 2.35 times higher than the one of a low-skilled individual.

1.3.4 Baseline and assumptions on the future

The model is calibrated on real data until 2000 as described in the previous paragraphs. From 2010 onwards the values of the exogenous variables are held constant to the values of the year 2000. However there are some exceptions and some points deserve a comment:

- *Population structure:* The main driving force of the model over the 21^{st} century is the evolution of the population structure, since the predictions of the United Nations Population Projections last until 2050. Thus, as said above, the growth rate of the first cohort and the probabilities of being alive are calibrated until 2050.

- *Education:* The proportion of high-skilled individuals among each new generation is held constant from 2000 onwards. As young cohorts are more educated than older cohorts (or in other words, cohorts born before 2000 are less educated than those born in 2000 and after), it implies that the proportion of educated workers continues to increase after 2000. In the long run, the proportion of educated individuals will equal the proportion of educated among the cohort born in 2000.

- *Pension systems:* In line with the policies conducted in many developed countries, we consider that pension systems will be less generous in the near future because of population aging. To represent these anticipated forthcoming pensions reforms, our baseline scenario for the first half of the

21^{st} century accounts for two changes compared to the year 2000. First, between 2000 and 2040, the retirement age is gradually postponed by 1/4 year for both low- and high-skilled individuals, meaning that the retirement age for low- and high-skilled increases from respectively 60 and 62 in 2000 to respectively 61 and 63 in 2040. Formally, for the age group 55-64, λ_5^l (respectively λ_5^h) passes steadily from 0.5 to 0.6 (respectively from 0.7 to 0.8) over the period 2000-2040 in Japan, Western Europe and North America. Second, the replacement rate of developed regions is reduced implying lower pension benefits in the next decades. Between 2000 and 2050, the replacement rate in North-America is gradually reduced from 41.5% to 36%, the one in Western Europe from 42.5% to 37% and one in Japan from 27.5% to 22%.

- *Harrod neutral technical progress:* In the baseline scenario, the distance of the Harrod neutral technical progress of each region to the technical progress of the leading economy (A/A^{NAM}) is assumed to be constant after 2000. Our baseline accounts however for a catch-up of China, India and Eastern Europe to North America. This would be in line with the recent accession of the majority of the Eastern European countries to the European Union and with the last years' increased growth pace of India and China. Likewise the assumptions of the Ingenue (2005), the Eastern Countries will have increased their technology level by 25% in 2100 compared to North America, while both the Chinese and Indian regions will have doubled it by 2100.

Technology

The path of the so obtained labor-augmenting technical progress is depicted in figure 1.1. North America is the leader at the beginning of the second half of the 20^{th} century and is ahead all along the 21^{st} century.[8] The technology levels of Japan and Western Europe are respectively at 99% and 96% of the one of North America from 2000 onwards. The drop in the productivity level of the Russian world after 1990 is explained by the fall of communism, while the Chinese and Indian worlds see their technology improved. Moreover, due to our convergence assumptions, the technology levels in the Eastern countries and in the Chinese and Indian worlds continue to rise after 2000 while the ones of all the other regions remain fixed at their 2000 level.

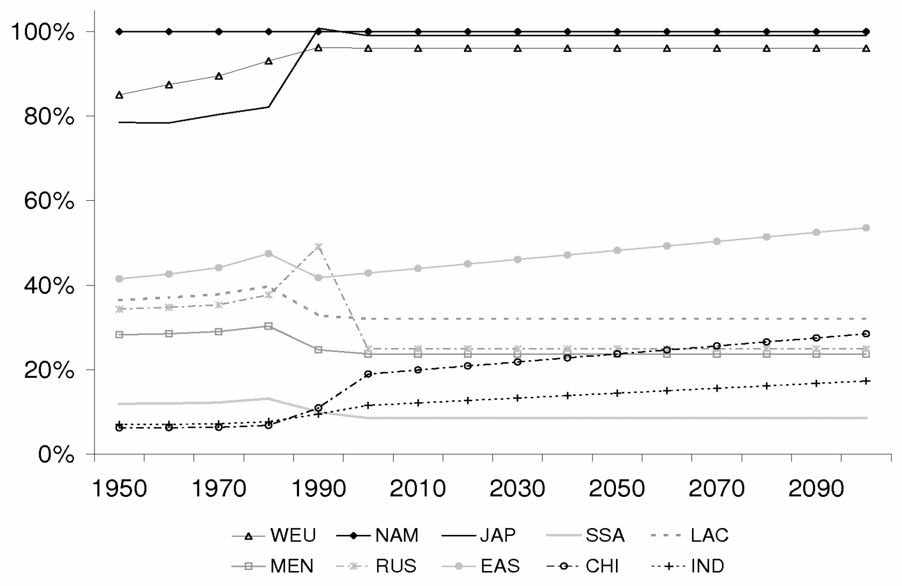
Demographic evolution of each region

Figure 1.2 describes the evolution of the support ratio, defined as the number of individuals of working age for one pensioner, over the period 1960-2050.

[8] Japan has a slightly higher technology level than North America in 1990.

This ratio decreases in the long-run for all the regions, but at a different pace for each region, because the aging process is not synchronous among regions. Nevertheless there are some similarities for some regions. For almost all of them, the support ratio strongly declines between 1980 and 2050. The exception is Sub-Saharan Africa where the support ratio only mildly diminishes between 1980 and 2020, then weakly recovers until 2040 and starts to drop at mid-century.

Figure 1.1: Evolution of labor-augmenting technical progress



Moreover, we can distinguish two groups of regions according to their aging pattern. In the first group, the Russian World, the Eastern Countries and the three developed regions with North America, Western Europe and Japan reached a low support ratio by the end of the 20th century, with less than 8 people of working age for one pensioner in 1980. Due to a huge decline in fertility after World War II, Japan is the fastest aging region and has the lowest number of working aged relative to elderly from 2000 onwards. The second group of regions comprises the other five regions and is aging at a slower pace than the first group. These regions start the 21st century with more than 11 individuals of working age for one pensioner, but have to cope with a very strong fall in their support ratios during the 21st century, which makes them slowly converge to the levels of the first group. Among these regions, the Chinese world will age most rapidly, as a consequence of its 'one child' policy. From 2050 onwards, the size of the youngest cohort in each region is assumed to be constant implying that support ratios stabilize after 2100.

Figure 1.2: Support ratio (ratio of working aged to pensioners)

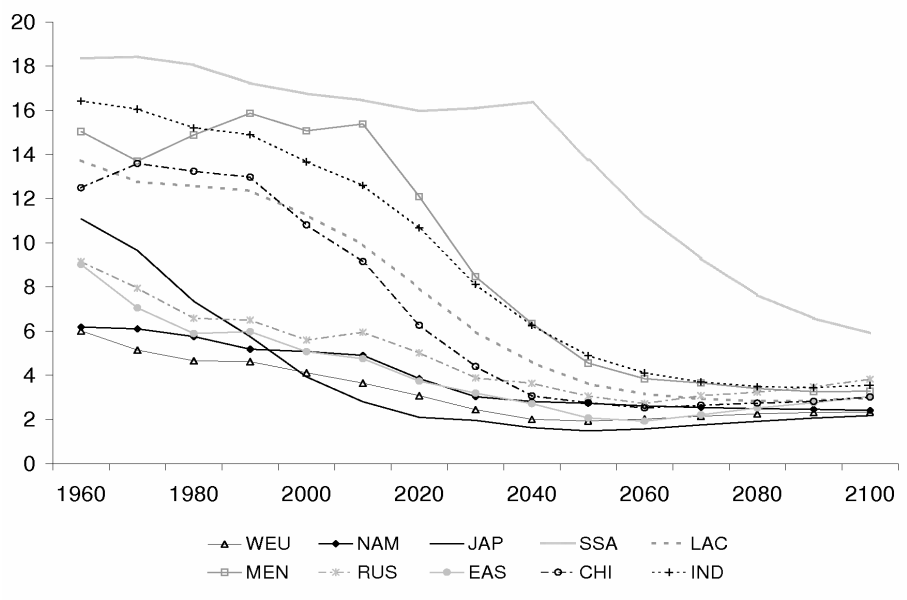


Figure 1.3: Annual growth rate in the working age population (15-64)

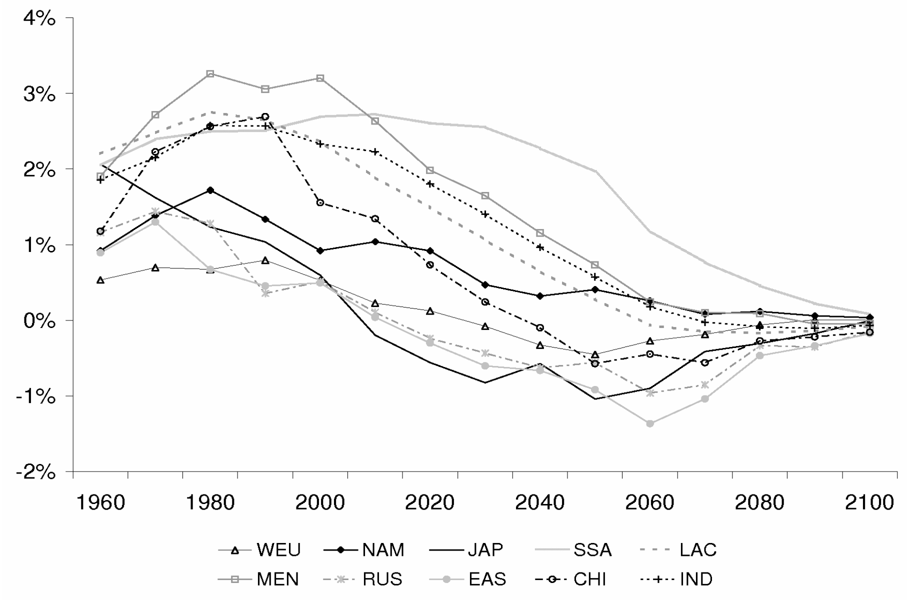


Figure 1.3 depicts the annual growth rate in the working age population, which is declining by the end of the 20^{th} century in all the regions. One exception

is the *growth rate* in the 15-64 age group of Sub-Saharan Africa, which rises until 2010 and falls afterwards but at a slower pace than the one of other regions. Moreover since its growth rate is always positive, the working age population in Sub-Saharan Africa is increasing all along the 21^{st} century. Besides Sub-Saharan Africa, some other regions have see their working age population grow during the first half of the 21^{st} century: the Middle East and North African region, the Indian world, Latin America and North America. North America is the only developed region that does not experience a reduction in its working age population, mainly because of immigration. In 1990, the Chinese world has the highest growth rate in the working age population after Sub-Saharan Africa, but afterwards the growth rate in the 15 to 64 years old individuals declines and becomes negative in 2040. In the other regions, i.e. Western Europe, the Russian world, the Eastern countries and Japan, the working age population decreases during most of the first half of the 21^{st} century. Finally, as the size of the youngest cohort is assumed to be stable from 2050 onwards, the growth rates in the working age population of each region start converging in the second half of the 21^{st} century and the size of the 15-64 age group becomes constant in each region from 2100 onwards.

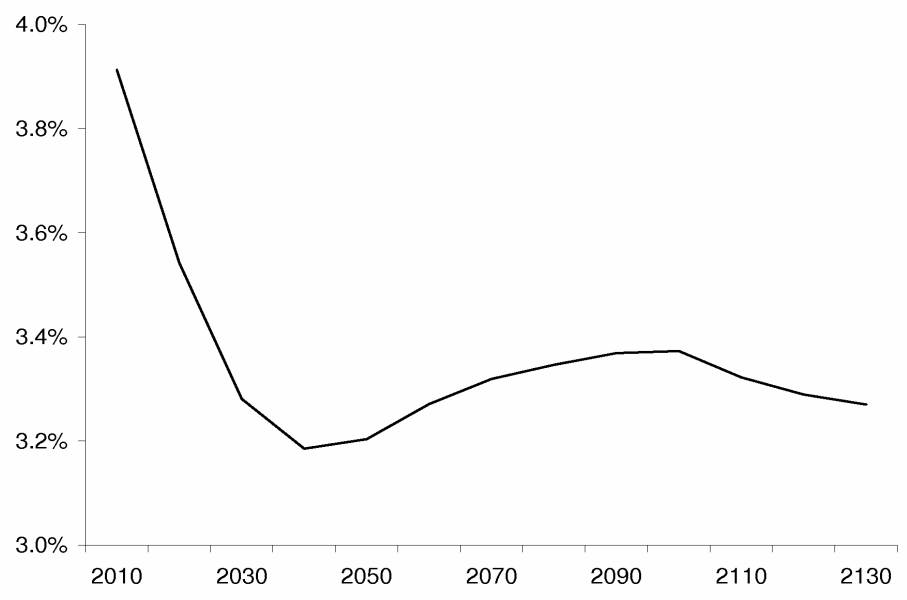
1.4 The world economy under the baseline scenario

The above described calibration process delivers a dynamic equilibrium path for the world economy. Population prospects are available until 2050, but generate population dynamics until 2130, since individuals live for (a maximum of) 8 periods of 10 years. Afterwards, populations become stationary. The world economy continues however to grow at a steady state annual growth rate of 1.84%. Our period of interest is 2010-2100. In the following paragraphs we describe the baseline scenario over this period in terms of the international capital market, economic growth and current accounts.

The world interest rate is determined on the world capital market by equating the world demand and the world supply of capital. In a context of global aging, the world experiences a decline in the growth rate of its working age population (potential labor force) and a rise in the capital to efficient labor ratio. This is translated by an increase in the marginal productivity of labor whereas marginal productivity of capital decreases. The world interest rate falls to reach a low in 2040 (see figure 1.4). From 2050 onwards the interest rate slightly augments with the recovering and stabilization of the world support ratio.

The annual growth rate in the world GDP follows a similar as the world interest rate (see figure 1.5), by going through a huge decline at the beginning of the 21^{st} century due to strong population aging and stabilizing after 2060 around an (exogenously imposed) 1.84% annual growth rate. Figure 1.6 reports a gen-

Figure 1.4: Evolution of the annual world real interest rate



eral slow down in the GDP growth rates at the regional level. From mid-century onwards, when the population structure begins stabilizing, the growth rates in the regional GDP's converge. Actually there are two driving forces behind the regional GDPs' growth rate: the dynamics of the working age population and the evolution of technology. After 2000, the GDP growth rates of all the regions are declining due to the demographic evolution and converge by the end of the century when their population structure stabilizes. Regions with high growth rates in their labor force maintain a more pronounced growth rates as e.g. Sub-Saharan Africa, the Indian region and the Middle East and North African region. The catch-up to the leader in terms of technology mitigates the decline in the GDP growth rates of China, India and the Eastern Countries and induces a convergence to the other regions' GDP growth rate only in 2110.

On the supply side of capital, the evolution of the net saving rate, i.e. the ratio of aggregate savings of all cohorts to GNI, is determined by demographic changes (figure 1.7). Regions facing serious aging of their population (strongly decreasing support ratios) see their saving rates decline sharply during the first half of the 21^{st} century. This is the case for the Eastern Countries, Russia, Japan and Western Europe. While North America belongs to the regions with a low support ratio, its saving rate is less affected, because it maintains a positive growth rate in its labor force thanks to large immigration. Latin America, India and the Middle East and North African region, have a similar aging pattern and experience a quite parallel

Figure 1.5: Annual world GDP growth rate

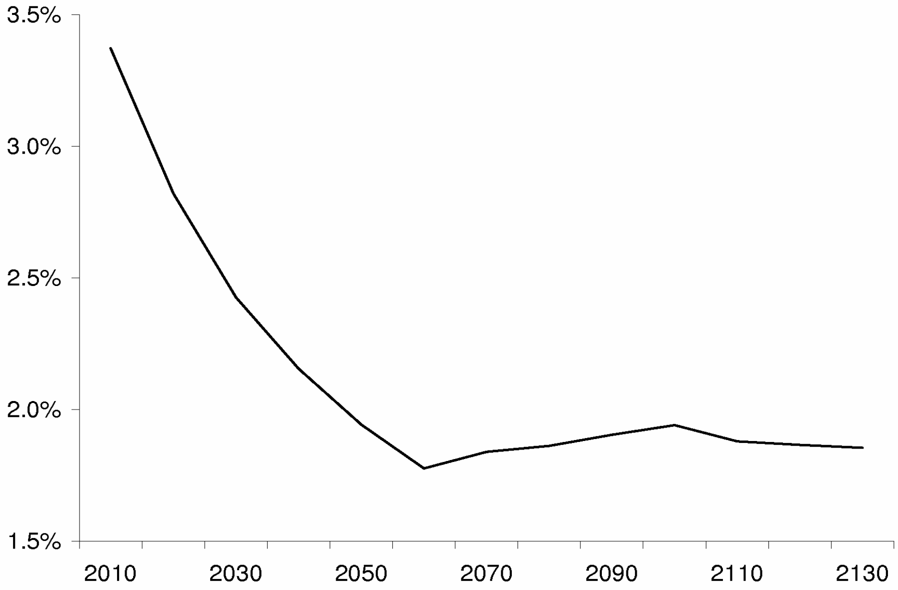
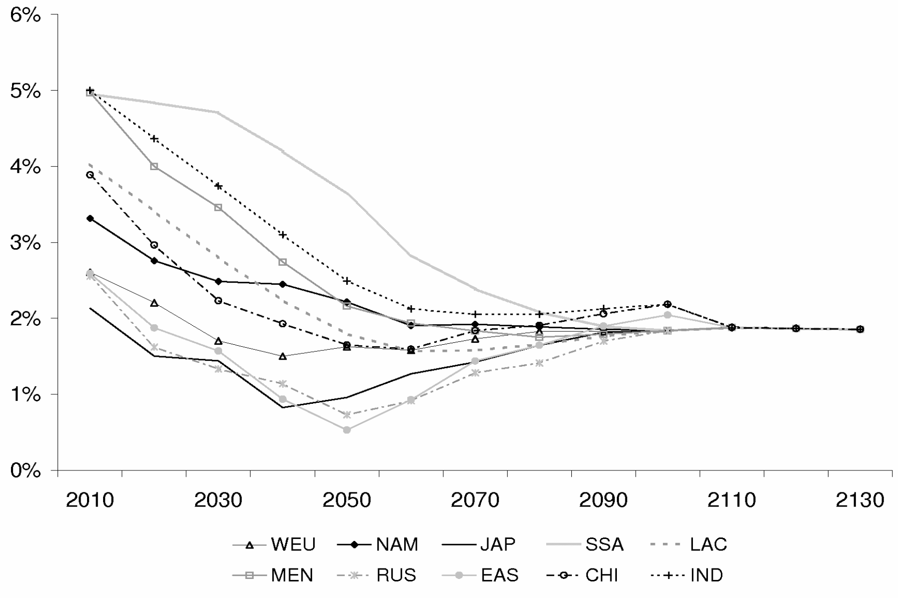


Figure 1.6: Annual growth rate of regional GDP's



trajectory in their saving rate. Thanks to a quite strong increase in its labor force and a high support ratio at the end of the 20^{th} century, China is the region with the

Figure 1.7: Regional saving rate (% of regional GNI)

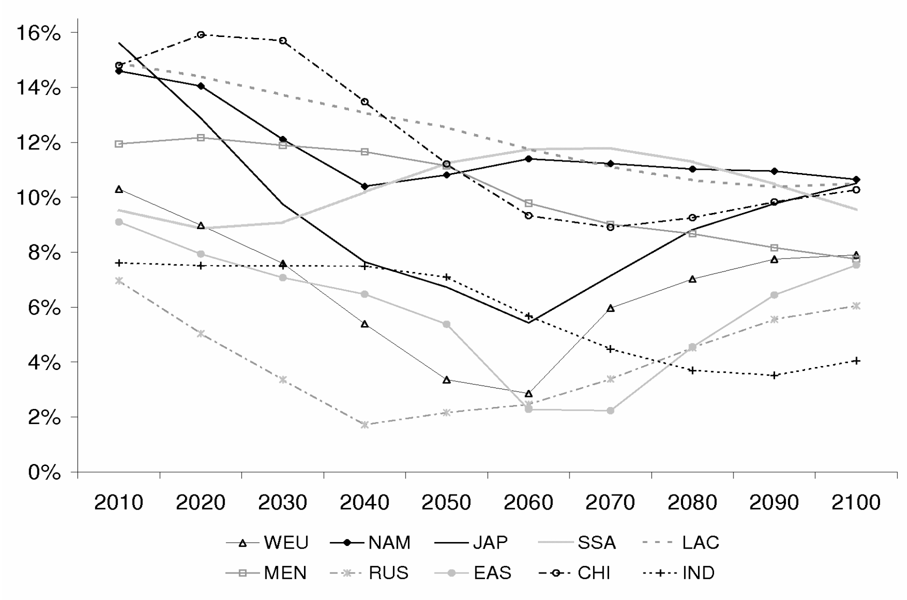
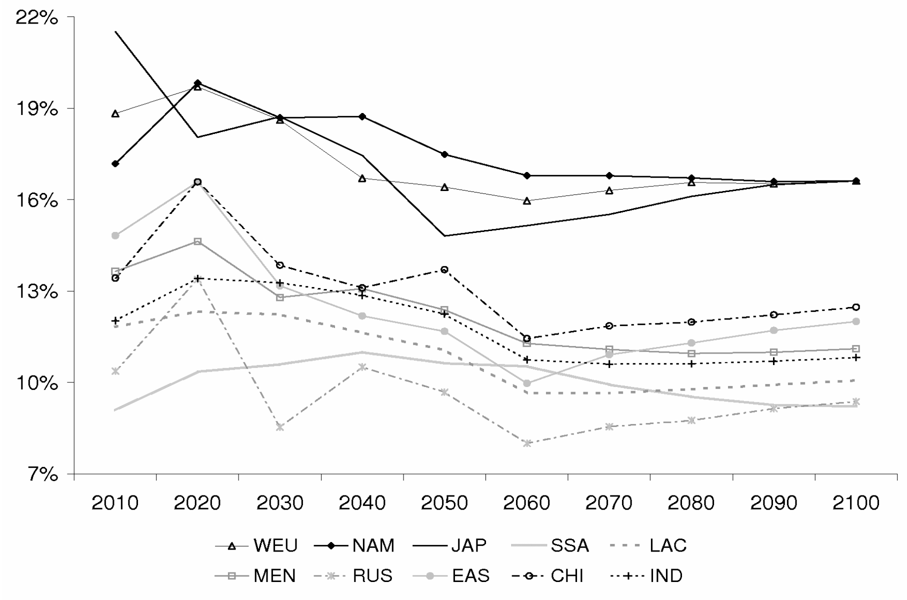


Figure 1.8: Gross investment (% of regional GDP)



highest saving rate at the beginning of the 21^{st} century. Afterwards, the growth in its labor force slows down and its support ratio drops, leading to a fall in its saving rate. Finally, being the region with highest share of working aged to pensioners and with one the strongest growth in labor force, the Sub-Saharan Africa sees its saving rate rise until 2070.

On the other hand, the demand side of capital, represented by the ratio of gross investment to GDP, is characterized by a slightly decreasing trend over the century, which is less strong than the one in the saving rate (figure 1.8). Thus as in Aglietta et al. (2007), the world interest rate is mostly driven by the movement on the supply side of capital. The reason is that on the demand side of capital, the negative effect of a declining labor force on capital accumulation can be partly offset by increases in capital intensity. In fact, gross investment is defined as $I_t = K_{t+1} - (1 - \delta)K_t$ and depends thus on net capital accumulation and capital replacement. In turn, capital stock rises with employment and with capital intensity, which is increasing in technology and decreasing in the return to capital and in the confiscation rate.[9] We also observe that developed regions keep a permanent higher investment rates than developing ones because of higher technology and of the absence of rent-seeking. Among the developed regions, Japan and to a lesser extent Western Europe undergo a marked decline in investment until 2050 due to their declining labor force, while the investment to GDP ratio in North America is less affected by aging. In contrast, in regions where the population is aging at a slower pace, India, Latin America and in particular Sub-Saharan Africa, the investment to GDP ratio is even slightly increasing during the first half of the 21^{st} century.

In an open economy, international trade is determined by the equality between net exports and net capital outflows. In our model, as it is standard in this literature[10], every region produces one consumption good and these goods are imperfectly substitutable. Thus we are confronted with a supply-side view of international trade i.e. trade is driven by net capital outflows. Current account balances are computed as the change in net foreign assets (NFA) which are themselves defined as total assets minus the sum of capital and debt $NFA_t = \Omega_t - (K_t + d_t Y_t)$. Current account deficits or surpluses arise from differences between domestic saving and domestic investment. Figures 1.9 and 1.10 plot the evolution of the current account balances as a share of regional GDP respectively as a share of world GDP. Our results on current accounts are compatible with Brooks (2003). When baby boomers dissave during retirement in the 21^{st} century, figure 1.9 shows that North America and Western Europe will depend on foreign capital. These demands for

[9]Capital intensity can be written as $\frac{K}{L} = \left[\frac{A}{R(1+\pi)}\right]^{\frac{1}{1-\alpha}}$.

[10]We refer to the specific strand of the literature dealing with international capital flows in large-scale multi-regional CGE models. One exception is the second version of the Ingenue model, “Ingenue 2", which incorporates regional-specific intermediate goods which are perfectly substitutable and implies imply the existence of real exchange rates between the different regions(see Ingenue, 2005).

Figure 1.9: Current account balances (% of regional GDP)

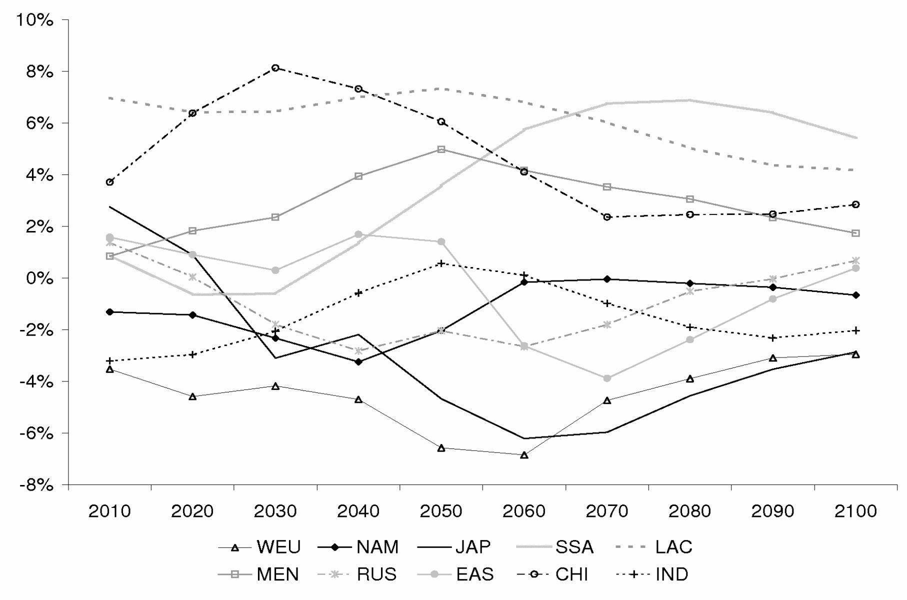
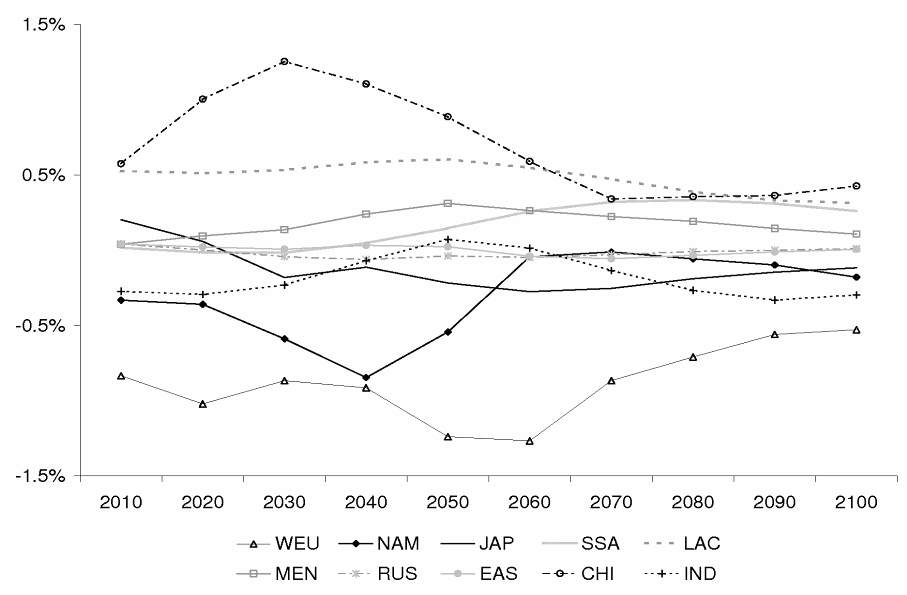
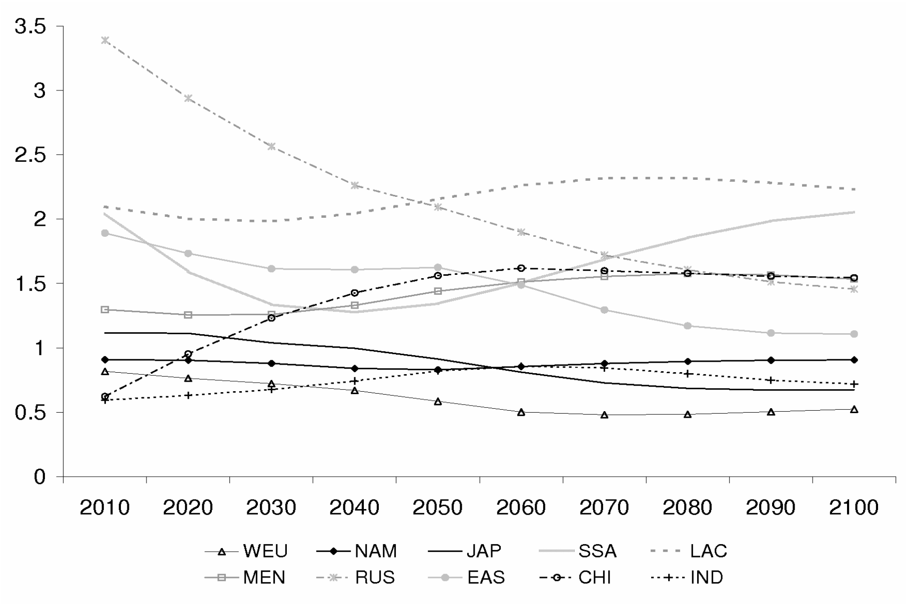


Figure 1.10: Current account balances (% of world GDP)



capital are largely financed by the regions of the Chinese World and Latin America and Caribbean. Moreover, the behavior of the current account of Sub-Saharan

Figure 1.11: Ownership ratio



Africa is also similar to Brooks (2003) and to the 'J2' region of Aglietta et al. (2007), which groups high fertility regions and comprises the African continent. We find that Sub-Saharan Africa will import capital or have a very low current account during the first decades of the 21^{st} century, because of high population growth.

In the second half of the 21^{st} century, disparities in current account balances across regions are significantly reduced (this can be seen more clearly from figure 1.10). By the end of the 21^{st}century, Western Europe runs a deficit representing -0.53% of world GDP, which fits with the -0.75% long run deficit in Aglietta et al. (2007). However in the latter study as well as in Ingenue (2005), North America has a slightly positive current account. Our path of the world economy suggests that three developed regions remain in deficit during the whole century, but after mid-century their current account balances improve when their population stabilizes.

Ownership ratios indicate the net external position of a region and are defined as the ratio of assets to the sum of capital and debt. A region with an ownership ratio above (respectively below 1) is a net creditor (respectively a net debtor) to the rest of the world. North America, Western Europe and India are net debtors over the whole 21^{st} century (see figure 1.11), since they accumulate current account deficits over the whole period. Japan is a net creditor at the beginning of the century but becomes a net debtor from 2030 onwards when its current account balance goes into deficit. This is comparable to the findings in Brooks (2003) and to the slowly decreasing pattern in the Japanese current account in Ingenue (2005). China's external position goes the opposite direction. The large current account surpluses at the beginning of the 21^{st} century turn China into the main creditor region with a current account balance converging to the ones of the other developing regions after 2030.

1.5 An increased population scenario in Western Europe

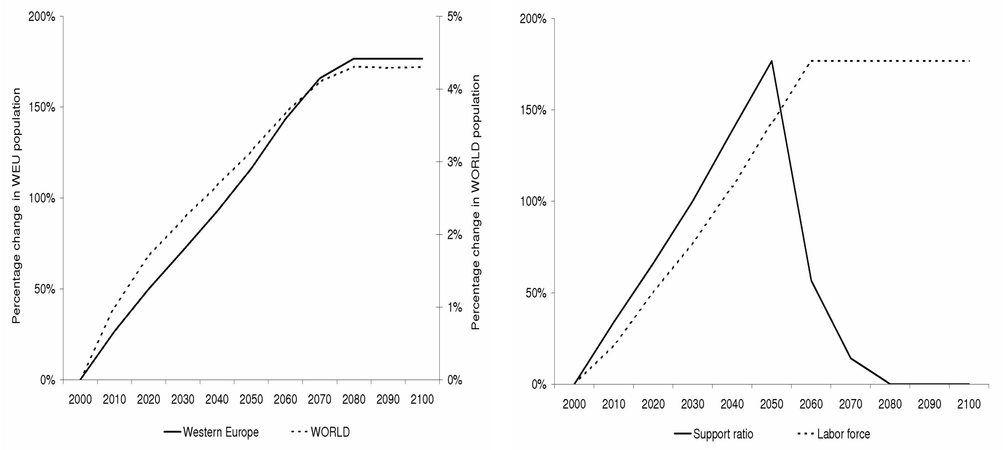
This section aims at demonstrating the importance of endogenizing capital mobility and capital accumulation. To do so, we propose to investigate the implications of a very simple scenario, in which there is a fertility boom in Western Europe in 2010. To show the importance of capital mobility, the consequences of this scenario are analyzed in a framework where the regions are fully financially integrated and in a closed economy environment, where the regions are completely independent of each other. Besides, general equilibrium effects prove to be significant. The population shock arising in a framework where capital accumulation is endogenous is compared with one happening in a partial equilibrium framework where the capital stock is fixed.

The considered scenario assumes that 100 million additional individuals are born in 2010 in Western Europe. These additional individuals are assumed to have the same reproduction rate and probabilities to be alive at each period as individuals living in Western Europe in the baseline. As a consequence, population will be permanently increased compared to the baseline. The number of 15 to 24 years old in Western Europe will augment by 177% leading to a 27% increase in the Western European population in 2010 compared to the baseline (see figure 1.13.a). At the world level, population increases by 1% in 2010 and by 4.3% in the long run.

Even if our scenario consists of enlarging the size of the 15-24 age group only in 2010, the support ratio (ratio of individuals of working age to pensioners) will be improved over a longer time period (see figure 1.12.b). In fact the 100 million persons added in Western Europe in 2010 will augment the population in successive periods since they procreate. Thus Western Europe will face a steady increase in its labor force during the first half of the 21^{st} without experiencing a rise in the number of pensioners. The augmentation in the support ratio will be highest in 2050 with a 177% increase compared to the baseline After 2050, the new-born individuals retire and the support ratio will eventually come back to its baseline value in 2080.

Figure 1.12: Demographic impact of an increased population scenario (% change from the baseline)

a. Population *b. Support ratio and Labor force*



1.5.1 Capital mobility versus no capital mobility

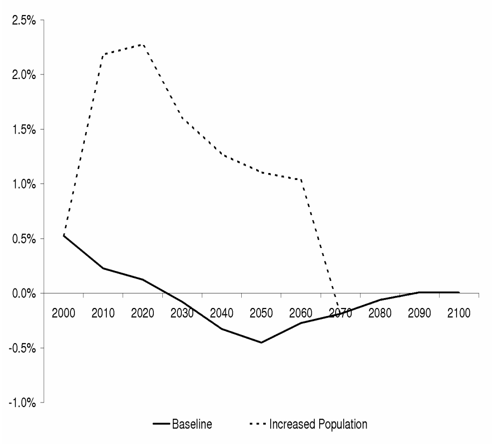
Under our framework, capital is mobile between regions up to a region specific confiscation rate on the returns to capital (π). In the following analysis we compare the effects of an increased population in Western Europe under the MONALISA framework, labeled ‘open economy’, and under no capital mobility, labeled ‘closed economy’. We show that the increased population scenario yields distinct outcomes whether performed in a closed or open economy setting. This confirm the findings of Aglietta et al. (2007) despite the fact that the scenarios they considered are linked to pension reforms. Lastly we also show that consequences on world variables (world GDP and interest rate) may differ depending on the region in which the population increases.

Increased population will lead to a rise in the labor force. Since compared to the baseline the additional-born individuals of 2010 spend time education in their first period of life, the growth rate in the labor force will be highest in 2020 when they fully add to the labor force (figure 1.13.a). From 2030 to 2070, the labor force still continues to increase but at a lower pace.

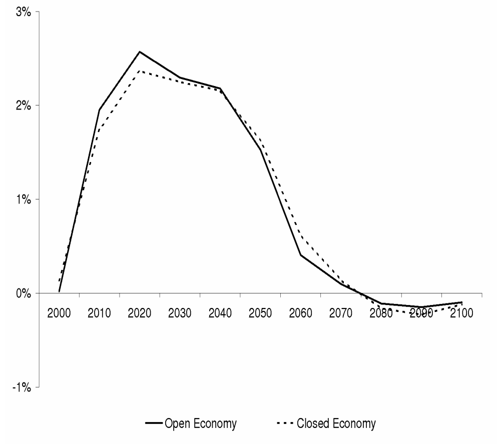
This boost in the labor force will reduce the capital to labor ratio and raise the marginal productivity of capital. The Western European interest rate will increase under the two frameworks, as shown in figure 1.13.c. Under the MONALISA framework, capital markets are fully integrated and the interest rate of Western Europe is equal to the world interest rate. The effects of an increased labor force are diluted on the international capital market and the interest rate reacts less than

Figure 1.13: Impact of an increased population scenario

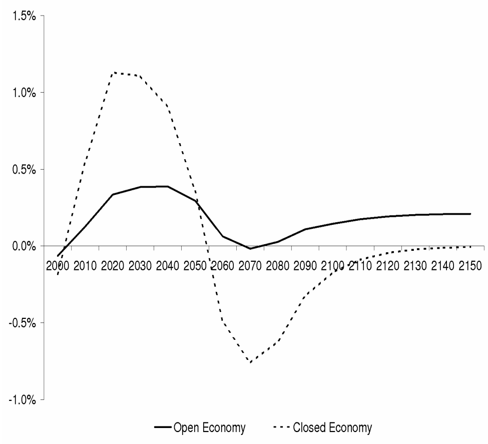
a. Annual growth rate of the workforce



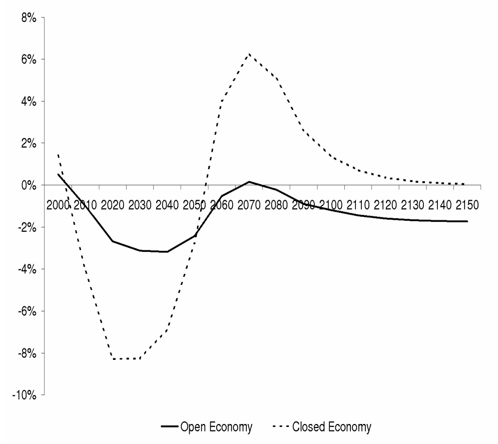
b. Annual growth rate in GNI (% change)



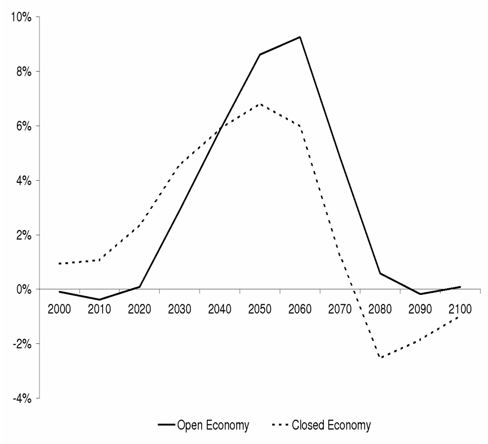
c. Annual interest rate (% deviation)



d. Wage rate (% change)



e. Savings to GNP (% change)



f. Gross Investment to GDP (% change)

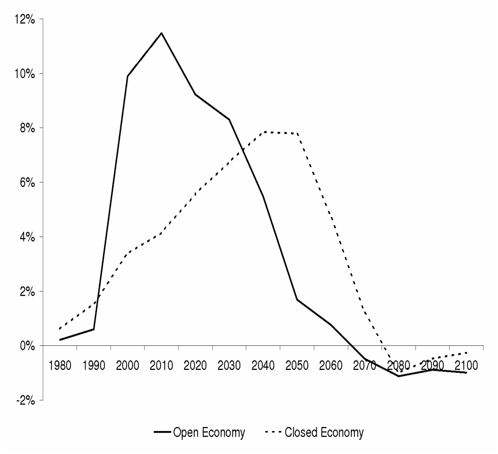
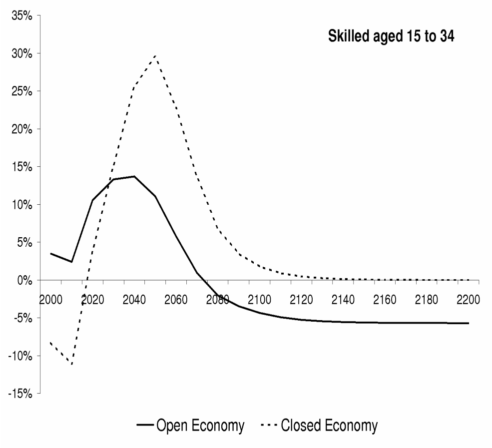
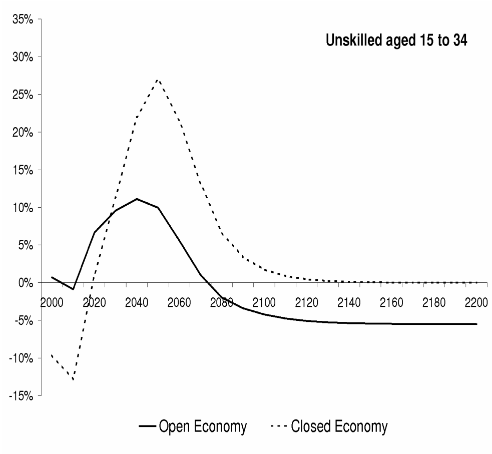


Figure 1.14: Impact on consumption profiles (% change from the baseline)

a. High-skilled aged 15-34

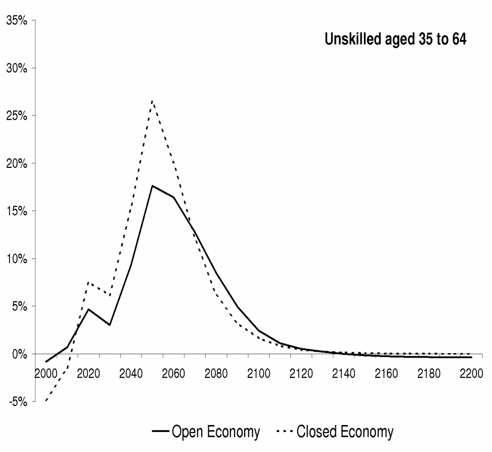


b. Low-skilled aged 15-34

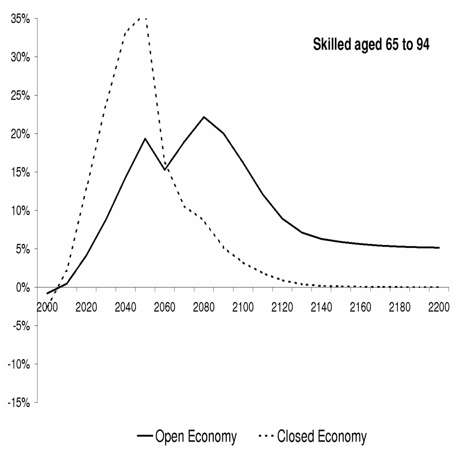


c. High-skilled aged 35-64

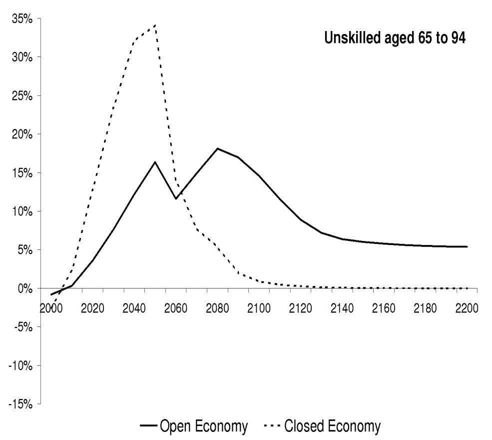
d. Low-skilled aged 35-64



e. High-skilled aged 65-94



f. Low-skilled aged 65-94



in the closed economy framework. In a closed economy, the effects of a rising labor force are totally absorbed on the regional capital market inducing an increase in the interest rate of 1.13 percentage points in 2020.[11] After 2030, the augmentation in the interest rate decelerates and, in the closed economy setting, the interest rate is even reduced compared to the baseline. The reasons are that the growth in the labor force slows down after 2020 and that the additional individuals start to retire after 2050. From 2070 onwards, the population structure stabilizes. In the closed economy, the interest rate goes go back to its baseline value and there will be no change in the long run, since the increased population scenario leads simply to a rescaling of the Western European economy. In the open economy setting, the scenario has a long term impact. Since population is increased in the long term in Western European there will be a higher labor force in a relatively more productive region. A higher long term interest rate is established because regions are interdependent and differ in terms of demography, productivity, pension systems, skills.

Compared to the interest rate, the impact on the wage is reversed (figure 1.13.d).[12] The increase in the workforce leads to a higher saving rate and thus to a higher investment-to-GDP ratio (figures 1.13.e and 1.13.f). In a closed economy framework, the higher demand for capital is provided by domestic savings. In the fully integrated world, the changes in the saving and investment rates are not symmetric. In the first decades of the 21^{st} century, the rise in the labor force of Western Europe leads to capital inflows and to strong increase in the investment rate. Since the interest rate increases less than in the closed economy setting, the change in the domestic saving rate is relatively small.[13] This implies a reduction in the current account balance compared to the baseline. The situation is reversed after 2040 when the increase in the saving rate is more marked than the one in the investment rate (leading to an improvement in the current account compared to the baseline). From this period onwards, the increase in the saving rate is also higher than in the closed economy case because of a higher the interest rate.

The impact on the GNI growth rate is similar under both frameworks figure 1.13.b. In fact, in the closed economy the rise in the labor force leads to higher rise in the interest rate than in an open economy but to also to a higher decrease in wages. Thus changes in the prices of inputs compensate each other.

However, this diverse impact on the returns to production inputs under the two frameworks will affect in a distinct way the consumption profiles of the various age groups (figure 1.14). Let us first notice that average consumption is

[11] The annual interest rate is 5.11% compared to 3.98% in the baseline in 2020.

[12] In the current version of the model, high- and low-skill labor are perfect substitutes and moreover the skill premium is held constant (see sections 1.2.4 and 1.3.2).

[13] The saving rate even decreases in 2010 because the population increase is due to individuals aged 15 to 24 who have negative saving rates.

increased in general for every cohort. In the closed economy framework, average consumption of the different age groups is enhanced with a maximum in 2050. The consumption of the younger cohorts (i.e. the 15-34 years old) is however decreased in 2010 (figures 1.14.a and 1.14.b). These individuals have few assets and do not benefit from the higher interest rate, but suffer from the drop in the wage rate. This also explains the downward peak in the increase in their consumption in 2030 when these individuals are 35-64 years old (figures 1.14.c and 1.14.d). At the time of the introduction of the 100 million additional individuals in 2010, the individuals benefiting most are the pensioners, since they see their wealth enhanced by the higher interest rate (figures 1.14.e and 1.14.f).

In contrast to the closed economy setting, the maximum in the average consumption of the different age groups arises at different moments in time in the open economy framework: the highest increases in consumption happen in 2030 for the 15-34 years old, in 2050 for the 35-64 years old and in 2080 for the +65 years old. This means that the individuals benefiting most from the population increase belong to the *same* cohort, i.e. the one born around 2030. This corresponds to the period where the fiscal effect is largest: the number of contributors is considerably enhanced while the replacement rates and the number of pensioners are constant at the baseline level. In fact, in the fully integrated world, changes in the returns to production inputs play a smaller role that in the closed economy setting and the main force explaining the changes in consumption profiles is the fiscal effect. Nevertheless, as in the closed economy case, the variation in consumption of the cohort born at the time of the “arrival” of the 100 million indivuduals in 2010 experiences a downward peak. Again this can be explained by a lower wage rate for this cohort and which leads to lower asset accumulation than cohort born before or after 2010.

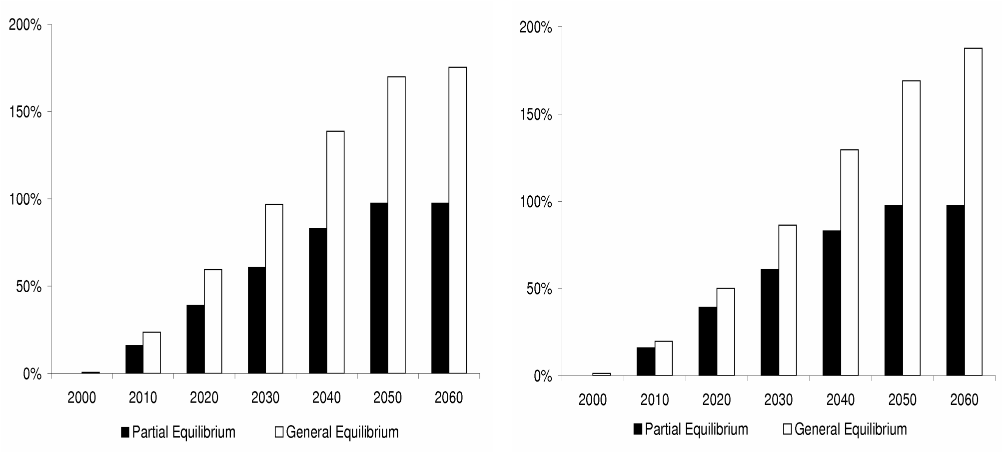
1.5.2 General versus partial equilibrium and geographical differences

In this section we show that taking a general equilibrium approach is important to quantify the exact response of variables that are crucial for policy analysis. Also, the geographic location of a shock matters since regions differ in many aspects, e.g. demography, productivity, welfare state, pension systems etc.

Under a partial equilibrium analysis, the capital stock is kept at its baseline level and an augmentation by 100 million individuals in the population arising in Western Europe leads to a 16% increase in its GDP in 2010 (figure 1.15.a). In the general equilibrium analysis, the response of the GDP differs and output rises by 24%, because the decisions of households and firms matter in terms of capital accumulation. In 2060, output is increased by 98% in a partial equilibrium

Figure 1.15: Partial versus General equilibrium: GDP in WEU (% change from the baseline)

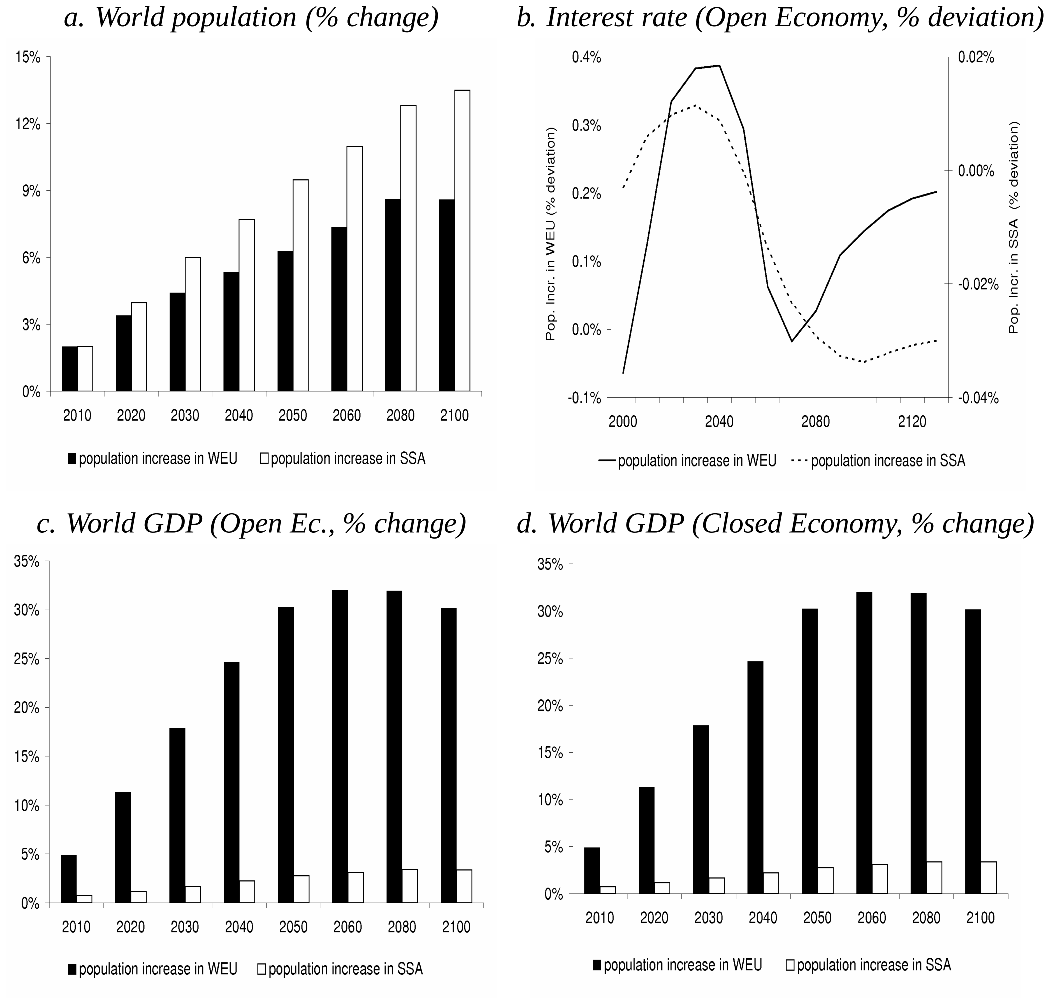
a. Open Economy *b. Closed Economy*



setting and by 176% when general equilibrium effects are taken into account. The difference in output responses between a partial and general equilibrium analysis is not only due to the full integration of the capital markets. In fact, the difference would still subsist within a closed economy framework, showing that domestic supply and demand of capital are important (figure 1.15.b): output is raised by 16% (partial equilibrium) and by 20% (general equilibrium) in 2010.

The consequences of a population increase on aggregate world variables depends also on the region in which such a shock arises. We compare the impact of a similar population increase in Western Europe and Sub-Saharan Africa. Figure 1.16.a shows that, except in 2010, the world population is not affected in a similar way because reproduction rates differ across regions. Introducing 100 million individuals in Western Europe respectively in Sub-Saharan Africa in 2010 raises the world population by 8.6% respectively by 13.5% in 2100. The annual world interest rate will augment in 2020 by 0.38 percentage points compared to the baseline if population increases in Western Europe, but only by 0.01 percentage points if population increases in Sub-Saharan Africa (figure 1.16.b). Since labor is relatively less productive in Sub-Saharan Africa than in Western Europe, the demand for capital will be lower explaining the smaller magnitude in the response of the world interest rate to a population boom in Sub-Saharan Africa. Moreover, in the long run, the world interest rate is enhanced (by 0.21 pp) if population rises in Western Europe and slightly depressed (by 0.03 pp) if Sub-Saharan Africa experiences a population increase. The "arrival" of 100 million additional individuals in a region increases in its population in the long run and gives a higher weight to this

Figure 1.16: Geographical differences: Comparing a population increase in WEU and SSA



region on the international capital market. When population rises in Sub-Saharan Africa, the world demand for capital is relatively less stimulated and the interest rate is negatively impacted in the long run. It matters thus where the population boom happens. Furthermore, the impact on the world aggregate GDP will also differ. In an open economy setting, the world GDP rises by 30.1% in 2100 if population increases in Western Europe compared to 3.4% increase if Sub-Saharan Africa experiences such a demographic shock (figure 1.16.c). In a closed economy variant, world GDP increases by 28.9% (shock in Western Europe) and by 3.4% (shock in Sub-Saharan Africa). The impact on world GDP would be different even in the first period of the shock when the world population increases in the same proportion. In 2010, the world population increases by 2% whether the 100 million individuals are introduced in Western Europe or in Sub-Saharan Africa, but the world GDP will still rise more, increasing by 4.9% (demographic shock arises in Western Europe) compared to 0.7% (demographic shock happens in Sub-Saharan Africa).

1.6 Conclusion

This note introduces a multi-regional overlapping generations computable general equilibrium model of the world economy that takes into account the skill heterogeneity of agents. The model groups the countries of the world into ten regions and their population is calibrated on the data of the United Nations' World Population Prospects, which predict the evolution of the population by country until the year 2050. Based on these projections, the model describes a path of the world economy over the 21^{st} century, in which capital is internationally mobile. In such a framework, differences in the forecasted demographic evolution of each region affect international capital flows. This paper also highlights the importance of endogenizing capital mobility and capital accumulation. For this purpose, the implications of a simple population shock in one region are analyzed. Concerning the integration of capital markets, the population shock leads to different outcomes in a model where capital mobile or immobile between regions. Moreover, the population increase will have a quite different impact when capital accumulation is endogenous or when the capital stock is fixed. Besides, geographical characteristics matter for the implications of such a shock on the world economy: the response of the world aggregate output or the international interest rate will depend on the region in which the population increase arises.

Lastly, this paper validates a model of the world economy, which may serve as the building block for future studies exploiting the 'skill-heterogeneous agents' feature of our framework. Issues that could be addressed comprise an exploration of the consequences of skill-specific pension reforms on the sustainability of the welfare state. The model can also be extended to examine the implications of high skilled emigration on migrants' origin regions.

Chapter 2

Replacement migration, labor market characteristics and pension systems:
North-America versus Europe

Abstract. This paper analyzes the impact of immigration on the contribution rate in North-America and Western Europe, when holding the generosity of the welfare state constant at current levels. This issue is addressed within a calibrated overlapping generations model featuring integrated capital markets. Two immigration policies are considered: a selective one, where the majority of migrants are high-skilled, and a non-selective one, with a majority of low-skilled migrants. It is found that increased immigration yields small fiscal gains and that both the selective and non-selective immigration policies induce similar tax cuts. Increasing immigration flows by 25% between 2010 and 2050, when the majority of the additional migrants are high-skilled (low-skilled) results in a -2.13 (-1.83) percentage points reduction in the contribution rate in Western Europe in 2050 and in a -1.79 (-1.56) percentage points tax cut in North-America. Furthermore, these policies are compared with realistic changes in labor market characteristics. Results show that similar fiscal gains could be achieved as with the immigration policies, simply by postponing the retirement age of low-skilled workers by 2 years from 2010 onwards in Western Europe and by a gradual increase from 1% to 5% between 2010 and 2050 in skill-biased technical change in North-America.

Key words: OLG-CGE Model, pension systems, replacement migration, labor market characteristics.
JEL classification: C68; H55; O30; J26; J61

2.1 Introduction

Population is aging all over the world due to rising life expectancy and declining fertility. During the next 50 years, the number of people of working age for one pensioner will strongly decrease in many countries. In the United States and Europe-15, the average number of working-aged per retiree was equal to 5.2 respectively 4.2 in 2000; this number is expected to reach 2.7 respectively 1.9 in 2050.[1] As public transfers are strongly ascending, such a demographic transition imposes a strong pressure on the fiscal policy. In many developed countries, it will be impossible to maintain current levels of taxes/pension benefits and pay-as-you-go (PAYG) pension systems are thus undergoing several reforms. In this debate, replacement migration is sometimes seen as a possible tool to reduce the burden of aging.

The debate on replacement migration was boosted by the popular report of the United Nations (2007). At first glance, such migration policies seem pertinent. Compared to policies that intend to raise the fertility rates in countries with a projected declining population, replacement migration has the advantage of augmenting immediately the population of working age. Hence, the United Nations evaluated the size of replacement migration that is needed to offset population aging and/or the population decline in many industrialized countries between 1995 and 2050. In one scenario, they determined the number of migrants needed to hold the support ratio (i.e. the number of people of working age for one pensioner) constant at his 1995 level until 2050. The study finds that the numbers of migrants that would be required are extraordinarily large. Thus replacement migration cannot by itself solve the problem of population aging. At most, it can be considered as a solution only *together* with other policies that act upon the age of retirement, labor-force participation, pension benefits and contributions to the social security system. However, only relying on demographic variables, the UN analysis suffers from major shortcomings. It completely abstracts from the skill composition of additional migration flows, from the cross-country differences in welfare programs and labor market institutions, from a range feedback effects on wages, taxes and interest rates, etc.

Hence, macroeconomic models are required to accurately assess the costs and benefits of such policies. Although the implications of globalization on trade, outsourcing and foreign direct investment gave rise to a growing number of studies, the literature on replacement migration has been relatively forsaken. Four strands of literature can be distinguished. The first kind of studies relies upon a generational accounting methodology; a second type of studies uses *theoreti-*

[1] Medium variant of the population prospects of the United Nations (2008) and own computations.

cal OLG models; a third type of papers relies on single-country *closed-economy computable* OLG models; and finally one uses *multi-country* computable OLG models. As the last strand of studies, our analysis is based on an open-economy multi-region CGE-OLG model.

Models using a generational accounting perspective analyze the impact of a change in migration policy on the average fiscal burden endured by different cohorts of individuals. The study of Auerbach & Oreopoulos (1999) for the United States stresses that the net benefit of immigration on the fiscal balance is small relative to the size of the overall imbalance itself.[2] On the other hand, Bonin et al. (2000) for Germany and Collado et al. (2004) for Spain find that immigration has a positive impact on intertemporal public finance. Yet all these studies agree that a policy that acts upon the structure of migration flows (age, skill and gender) has more beneficial effects than one that simply increases the volume of these flows.

The issue if immigration can be a solution to the viability of pension systems in aging countries has also been addressed in theoretical OLG models. The most cited is the two-period open-economy model of Razin & Sadka (1999). Their model suggests that even though migrants may be low-skilled and net beneficiaries of a pension system, they provide a net contribution to public finance in the period they arrive. In addition, all age groups living at the time of the migrants' arrival are better off. As the time horizon of the economy is infinite, the cost of a permanent openness to migration is postponed to the indefinite future. In the closed economy OLG model of Scholten & Thum (1996), migrants have a negative effect on wages. Natives (i.e. the median voter) can choose the immigration policy, the outcome of which will depend upon the age of the natives. Old individuals will choose a high immigration rate, because immigrants improve the situation of the pension system. The younger individuals prefer a restrictive immigration policy as immigrants have a negative impact on wages. In general, the outcome is a too restrictive immigration policy and lifetime income could be increased by fixing a higher but steady immigration rate.

The impact of immigration in mitigating future tax hikes is quantified in *computable* OLG models. One category of such models consists of *closed-economy* computable OLG models. The well-known study of Storesletten (2000) explores the case of the U.S. in a CGE model where agents differ in age, skills and legal status (native, legal immigrant, or illegal immigrant). An important message of this study is that *selective* immigration should be able to alleviate some of the fiscal burden associated with the aging of the population. It might also provide an alternative to a rise in taxes or a reduction in pension benefits (in order to finance fiscal deficits).[3]

[2]Chojnicki (2005) arrives at the conclusion by performing a similar study for France.

[3]In a similar framework, Chojnicki (2005) compares the pension systems of the U.S. and of

The articles presented above were done for single countries in a closed-economy setting. Our paper belongs to the last group of studies, which develop multi-country open-economy CGE-OLG models. Such models have been developed to account for the effects of international capital mobility in mitigating the effects of demographic transition, because capital mobility reduces factor price responses to demographic shocks (see below). These models do not and are not particularly suited to address issues concerning replacement, since they feature skill-homogeneous agents.One exception is the multi-regional model of Fehr et al. (2004), which distinguishes three income classes of agents. analyze the consequences of skill-heterogeneous migration. They find that “increased immigration does very little to mitigate the fiscal stresses facing the developed world". Their finding is similar to the one of Storesletten (2000): while increased immigration does little to reduce the burden of aging in the United States, a rise in the number of skilled immigrants may be beneficial. But, they stress that increasing the number of immigrants is not unproblematic. If high-skilled immigrants come from developed regions, it does not help the public finance of the developed world. If they come from developing regions, it may worsen the brain drain "that is already greatly depleting the human capital of developing regions".

Our analysis builds on a calibrated multi-region computable general equilibrium (CGE) dynamic overlapping generations (OLG) model, with integrated capital markets between the regions. Studies advocating the modeling of capital mobility claim that in a closed economy framework, a demographic transition strongly raises the capital-labor ratio and affects factor prices in a more pronounced way. As a consequence, interest rates are strongly increased and wages are strongly reduced. This reduces the saving rate since young people are the highest net savers and rely mainly on labor income. Capital deepening may then partly mitigate the negative consequences of a demographic transition (Aglietta et al., 2007; Börsch-Supan et al., 2006; Storesletten, 2000, p315). Our model differs from the study of Storesletten (2000) and from Fehr et al. (2004) by different aspects. While closer to the latter study, two differences can be highlightened and may explain somehow different findings. First, our model comprises also developing regions, which are considered as migrants’ regions of origin, while in Fehr et al. (2004), migrants to the developed world originate from outside the model.

France over the 21st century. In his CGE model, agents are either low-, or medium- or skilled. He contrasts a scenario without any immigration at all and a situation with projected immigration flows. The finding is that, in both countries, immigration has only a slight impact on public finance and cannot be considered as a solution to population aging. However, if a more selective immigration policy would be applied, immigration could be beneficial for the pensions systems of both countries at least for the first half of the century. After 2070, the positive effect on public finance will be offset by the increase in the share of the pensions in the GDP as the immigrants get old.

Apart from being more realistic, this feature allows us to assess the impact of labor mobility on migrants' source regions.[4] Moreover, it allows to consider capital mobility between developing and developed regions, and also to account for the non-synchronous aging process in a more global way by letting the demographics of developing regions come into play. Second, compared to Fehr et al. (2004), a more relevant difference for the issue addressed here, hinges on the modeling based on skill-composition of agents. Agents are grouped into skill groups according to existing data on education levels (Barro & Lee, 2001a) and are either high-skilled (post-secondary education) or low-skilled (below secondary education). In Fehr et al. (2004) agents are categorized into three income groups: low-, medium- and high-income according to an arbitrary rule (30%/60%/10%). Thus there is no difference in the skill composition across regions, as it is actually observed between North-America and Western Europe. Moreover in Fehr et al. (2004), agents from the three income groups are perfect substitutes as in Storesletten (2000) implying fixed skill premia. However, according to Acemoglu (2002), low- and high-skilled workers are rather imperfect substitutes in production. We account for this by introducing a constant elasticity of substitution (CES) function for efficient labor.[5]

Our study addresses two main issues. First, is increased immigration be a solution for paying the pensions of the elderly in developed countries? More precisely, building on the immigration forecasts of the United Nations (U.N.) Population Division, we consider two immigration variants in which migration flows to developed countries are doubled between 2000 and 2060 for North-America and for Western Europe. In the first variant, the majority of newcomers are high-skilled; in the second one, the majority of them are low-skilled. We examine the implications of an increase of 25% in immigration flows between the 2010 to 2050 in mitigating the pressure on the contribution rate in both regions in North-America (Canada and the US) and in Western Europe (EU-15) when current generosity of the welfare state is held constant. Two immigration policies are studied: a selective immigration policy and a non-selective immigration policy. In the former 70% of the additional migrants are high-skilled and in the latter 70% are low-skilled. A second objective is to compare the immigration policies to "potential" changes in labor market characteristics. These potential alternative remedies to aging suggested in this study, as well as the considered immigration policies, can be thought of being "realistic" i.e. the magnitude of these policy changes is not excessive. Such policies comprise a postponement of 2 years in the retirement age of either high- or low-skilled workers, a gradual acceleration

[4]This issue is beyond the scope of this paper, but will be addressed in a further study.

[5]Another interesting difference, linked to the skill-type of workers, is the modeling of pension systems that differ in their redistributiveness across regions.

of skill-biased technical change (SBTC) from 1% in 2010 to 5% in 2050 and a 10 percentage points increase in the share of high-educated people. It can be relevant to analyze such policy changes since, in the United States (US) and in many European countries governments plan to or have already delayed mandatory retirement age. Moreover, retirement regimes vary across countries, but also within countries since mandatory retirement age may for example differ across sectors or professions. In fact, high educated workers spend more time in school than low-skill workers and have thus shorter periods of contributions. But when they enter the labor force, they usually contribute by higher amounts to (and also benefit less from) welfare systems. Furthermore, another important labor market characteristic is the demand for skills. In fact, the last decades have been characterized by an increase in skill complementary technologies causing a rise in wage inequality (between high- and low-skill workers) and in overall inequalities Acemoglu (2002, 2003a). An acceleration of SBTC may also have implications for fiscal policy through changes in the wage differential between higher and less educated workers. A modification in the skill premium will affect the tax base and thus the contribution to the welfare state. Lastly, as high-educated workers are contributing relatively more to the welfare in net terms, it could be worthwhile to see how an increase in the proportion of high-skilled affects fiscal pressure. In particular, as the supply of skills is relatively high in the US compared to Europe, it would also be interesting to investigate how pension systems in Europe would be affected when education levels of the European population approach the ones in the US.[6]

Obviously, part of our results is driven by the model assumptions. Three main assumptions characterize the current version of the model. First, the world economy is characterized by free capital mobility. Second, low- and high-skilled workers are imperfect substitutes and policy changes will thus affect skill premia.

Within the limits of these assumptions and as previous studies we find that immigration has only a small impact in mitigating future tax hikes. Another important finding is that of our study is that the impact of immigration in financing pension systems has a similar impact as the other potential remedies in terms of magnitudes. In North-America, a selective (non-selective) immigration policy reduces the tax rate by -1.79 (-1.56) percentage points. A gradual acceleration in skill-biased technical change from 1% in 2010 to 5% in 2050 would do a similar job by cutting the tax rate by -1.78 percentage points in 2050. In Western Europe, a postponement of the retirement age by 2 years from 2010 onwards decreases the tax rate by -2.19 percentage points, while a selective (non-selective) immigration

[6]Following Cheeseman Day and Bauman (2000), who carry out projections of school attendance for the US until 2028, we can consider that the proportion of high-skilled individuals in North-America will not increase in the future, justifying why we do not carry out a simulation of a rise in the educational attainment for the North-American region.

policy entails a -2.13 (-1.83) reduction in the contribution rate. Moreover, both increased immigration policies have a quantitatively similar effect in mitigating the expected fiscal burden of population aging in developed countries. The finding, that a non-selective immigration policy can be beneficial in financing pension systems contrasts with the literature and can only be partly explained by the fact that we do not consider an extreme immigration policy with 100% of additional migrants being low-skilled. Doing so would reduce the fiscal benefits from a non-selective immigration policy, but would not make them vanish. Another explanation hinges on the fact that skill premia are affected by immigration, unlike in Storesletten (2000) and Fehr et al. (2004). A non-selective immigration policy increases skill premium and thus the contributions to the welfare made by main net tax payers: high-skilled workers.

The paper is organized as follows. Section 2.2 introduces the 10 regions of the world and presents the model. The calibration of the baseline scenario is provided in section 2.3. Section 2.4 explains the results of the different scenarios. Section 2.5 concludes.

2.2 The Model

This study builds upon a calibrated overlapping generations model where individuals live for 8 periods each of 10 years. We calibrate the economies of 2 regions: North-America and Western Europe.[7] Age classes go from 15-24 to 85-94 years, implying that individuals are “born" at the age of 15 and die at the age of 95. However there is a probability of being alive at each period, because some individuals are assumed to die before the age of 95. There are moreover two types of individuals, high- and low-skilled individuals. "high-skilled individuals" identify individuals with an education above high-school degree (tertiary education), whereas "low-skilled individuals" comprise individuals having an educational level less than high-school (primary education) and with a high-school degree (secondary education). The educational choice (e) and thus also the proportion of highly educated individuals among one generation (ϕ) is exogenously determined.

As in de la Croix & Docquier (2007), we postulate the existence of an insurance mechanism à la Arrow-Debreu (or à la Yaari (1965)). Each time an individual dies, her/his assets will be equally distributed among individuals belonging to the same age class. In other words, individuals do not leave any bequests to their children (or to next generations). Furthermore, there is only one consumption

[7] North-America contains the United States and Canada, while Western Europe comprises Europe-15 plus Australia and New-Zealand. There are 10 regions in the model, 3 developed and 7 developing, see chapter 1.

good and its price is the numeraire of the model. There is one leading economy (North-America), in the sense that the technological progress (TP) of each region is expressed in terms of the TP of the leading economy. The leader is always ahead in terms of TP compared to the other regions. Besides, the evolution of the TP is exogenous.

The model introduces skill heterogeneity among individuals. A constant elasticity of substitution (CES) function for efficient labor is used to define the mix of high- and low-skilled labor forces in the production process. Moreover, the model is characterized by full-employment. Finally, each economy has three agents: households, a representative firm and a public sector. In the following subsections, we describe the regional decomposition of the world, agents' behavior and the equilibrium of the model.

Demography. At each date, some individuals die and a new generation appears. A cohort of age a and born at time t is denoted by $N_{a,t}$. Since we consider only individuals aged from 15 to 94, households reaching age 15 (labeled as age 0 in our notations) at year t belong to generation t. The size of the young generation increases over time at an exogenous growth rate:

$$N_{0,t} = m_{t-1} N_{0,t-1}, \tag{2.1}$$

where $N_{0,t}$ measures the initial size of generation t and m_{t-1} is one plus the demographic growth rate, including both fertility and migration. Each household lives a maximum of 8 periods ($a = 0, ..., 7$) but faces a cumulative survival probability decreasing with age.[8] The size of each generation declines deterministically through time.

$$N_{a,t+a} = P_{a,t+a} N_{0,t}, \qquad j = h, l \tag{2.2}$$

where $0 \leq P_{a,t+a} \leq 1$ is the fraction of generation t alive at age a (hence, at period $t + a$). Moreover, $P_{0,t} = 1$. Obviously, total population at time t amounts to $N_t = \sum_{a=0}^{7} N_{a,t}$. High- and low-skilled cohort sizes are given by:

$$\begin{aligned} N^h_{0,t} &= \phi^h_t N_{0,t} = \phi_t N_{0,t} \\ N^l_{0,t} &= \phi^l_t N_{0,t} = (1 - \phi_t) N_{0,t} \end{aligned}$$

where ϕ^h_t equals ϕ_t and denotes the proportion of high-skilled (post-secondary educated) individuals among the generation born in t.

[8] To avoid agent heterogeneity, migration flows are allowed only among individuals of the first age class. Population is calibrated to match the population prospects of the United Nations (2008).

Preferences. The expected utility function (U) of high- (upperscript h) and low-skilled (upperscript l) individuals is assumed to be time-separable and logarithmic:

$$E(U_t^j) = \sum_{a=0}^{7} P_{a,t+a} ln(c_{a,t+a}^j), \tag{2.3}$$

where $c_{a,t+a}^j$ is the consumption of age class a at time $t + a$.

The budget constraint of low- (l) and high-skilled (h) individuals requires equality between the expected value of expenditures and the expected value of incomes (I). It writes as follows for $j = h, l$:

$$\sum_{a=0}^{7} \frac{P_{a,t+a}}{\prod_{v=1}^{a} R_{t+v}^*}(1 + \tau_{t+a}^c)c_{a,t+a}^j = \sum_{a=0}^{7} \frac{P_{a,t+a}}{\prod_{v=1}^{a} R_{t+v}^*} I_{a,t+a}^j, \tag{2.4}$$

Incomes consist of labor income (w), pension benefits (b) and other welfare transfers (ζ)

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

where $\lambda_{a,t+a}^j$ is the labor participation rate for a j type individual of age class a, w_t^j is labor income of a j type worker, R_t^* is one plus the international interest rate, τ_t^c is consumption tax, τ_t^w stands for income tax, b_t^j represents (individual) pension benefits, ζ_a^j are other welfare transfers received by an individual of type j and are represented as a time-constant fraction of labor income, and finally ψ_t is the generosity factor, which is the factor by which these other welfare transfers are multiplied at time t. Moreover, education is exogenous and individuals spend a fraction e_t^j of their total time (which is only positive in their first period of life).

Individuals maximize their utility (2.3) subject to their intertemporal budget constraint (2.4) with respect to the levels of consumption. The optimal (contingent) levels of consumption for both types of households $j = h, l$ will then be:

$$c_{a+1,t+a+1}^j = R_{t+a+1}^* c_{a,t+a}^j. \tag{2.5}$$

Equation (2.5) reveals that to know the optimal lifetime consumption (c_0 to c_7) of a cohort born in t can be known once its consumption level at age 0 is identified. The optimal level of consumption in the first period of life can be determined by substituting (2.5) in (2.4).

Moreover, we can also define the implicit asset holdings of each age class. We assume that individuals are born with no assets at time t, or in other words, there are no bequests. At time $t + a$ with $a > 0$, assets of high- and low-skilled individuals ($Z^j_{a,t+a}$) depend on their assets in the previous period ($Z^j_{a,t+a-1}$) plus an interest rate as well as on current expenditures (consumption) and incomes (labor income, pension benefits and other welfare transfers). Formally, at the beginning of their first period of life (when $a = 0$), $Z^j_{0,t} = 0$ for all t. For $a > 0$, aggregated assets, for $j = h, l$, correspond to:

$$Z^j_{a+1,t+a+1} = R^*_{t+a} Z^j_{a,t+a} + \phi^j_t N_{a,t+a}[(1-\tau^w_{t+a})(1-e^j_{t+a})\lambda^j_{a,t+a} w^j_t \\ -(1+\tau^c_{t+a})c^j_{a,t+a} + (1-\lambda^j_{a,t+a})b^j_{t+a} + \psi_t \zeta^j_a w^j_t] \qquad (2.6)$$

where $N_{a,t+a}$ represents the number of individuals of age class a living at time $t + a$, ϕ^j_t is the proportion of individuals of skill type j among generation t.

Firms. At each period of time and in each region, a representative firm uses efficient labor (L_t) and physical capital (K_t) to produce a composite good (Y_t). We assume a Cobb-Douglas production function with constant returns to scale:

$$Y_t = K^\alpha_t (A_t L_t)^{1-\alpha}, \qquad (2.7)$$

where α measures the share of wage income in the national product, and A_t is an exogenous process representing Harrod neutral technological progress.

Total efficient labor force combines the demands of high-skilled (L^h_t) and of low-skill labor (L^l_t) according to the transformation function characterized by a constant elasticity of substitution (CES):

$$L_t = [\upsilon_t (L^h_t)^\sigma + (1-\upsilon_t)(L^l_t)^\sigma]^{1/\sigma}, \qquad (2.8)$$

where υ_t is an exogenous high-skilled biased technological progress (SBTC), and σ is defined as σ=$1 - \frac{1}{\varepsilon}$, with ε being the elasticity of substitution between high- and low-skill labor. The capital share in output α is set to one third, as estimated in the growth accounting literature. We follow Acemoglu (2002) in fixing the elasticity of substitution ε to 1.4 and thus the parameter σ equals to 0.2857 in the CES function. One of our scenarios analyzes the impact of an acceleration in skill-biased technical change, which, in terms of the model, is translated by a gradual increase in the parameter υ.

Government. The government levies taxes on labor earnings (τ^w_t) and consumption expenditures (τ^c_t) to finance general public consumption (c^g_t), pension benefits (b^j_t) and other welfare transfers (ζ^j_{a+1}). The government surplus (S_t) can be written as follows for $j = h, l$:

$$S_t = \tau_t^w \sum_{j=\{h,l\}} L_t^j w_t^j + \tau_t^c \sum_{j=\{h,l\}} \sum_{a=0}^{7} \phi_{t-a}^j N_{a,t} c_{a,t}^j$$
$$- \sum_{j=\{h,l\}} b_t^j \sum_{a=0}^{7} \phi_{t-a}^j N_{a,t} (1 - e_t^j)(1 - \lambda_{a,t}^j)$$
$$-\psi_t \sum_{j=\{h,l\}} w_t^j \sum_{a=0}^{7} \phi_{t-a}^j N_{a,t} (1 - e_t^j) \zeta_a^j - c_t^g Y_t, \tag{2.9}$$

where c_t^g is a part of national income used to finance general public spending.

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

$$d_{t+1} Y_{t+1} = R_t^* d_t Y_t - S_t, \tag{2.10}$$

where d represents the debt-to-GDP ratio, R^* is one plus the international interest rate and S is the government's surplus. Equation (2.10) says that public debt in $t+1$ depends on past debt in t and its interests, minus the government's surplus S. The evolution of the public debt is exogenously given. Since transfers and taxes on consumption are exogenous as well, the wage tax rate will adjust to satisfy the government's budget constraint (2.10).

Finally, in contrast to existing multi-regional models, the modeling of the pension systems should account for the skill-heterogeneous agents feature of our model. In fact, a social security system can be characterized not only by its generosity or size but also by its redistributiveness (Pestieau, 1999). In the following equations, the first characteristic is captured by the replacement rate χ_t and the second one by the parameter ρ, with both parameters comprised between 0 and 1. Pension benefits for low- (b_t^l) and high-skilled (b_t^h) write as follows

$$b_t^l = \chi_t w_t^l, \tag{2.11}$$

$$b_t^h = \chi_t \left[\rho w_t^h + (1 - \rho) w_t^l \right], \tag{2.12}$$

A value for ρ close to 0 implies more redistributive pension systems, since low- and high-skilled would receive similar amounts of benefits when retired. If ρ is close to 1, then pension systems are weakly redistributive with replacement rates that are constant across income levels. This modeling allows regional pension systems to be partly Bismarckian or Beveridgian.[9]

[9] Bismarckian systems can be defined as highly generous and poorly redistributive, while Beveridgian pension systems are small-sized and more redistributive. This remains however a simplistic categorization (Pestieau, 1999).

International capital markets. In an economy with perfect capital mobility, 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:

$$\sum_{x \in X} \Omega_t^x = \sum_{x \in X} (K_t^x + d_t^x Y_t^x), \tag{2.13}$$

where X is the set containing each world region. Moreover, K_t^x is the sum of the capital stock of region x at time t, Ω is the sum of the assets of all the cohorts of region x, $d_t^x Y_t^x$ is the level of region x's debt at time t. An economy with perfect capital mobility is also characterized by the arbitrage condition of the returns to capital which requires the equality between the rates of return to capital in each region.

Definition (Competitive Equilibrium) *Given an initial stock of capital $\{K_t\}_{t=0}$, an exogenous demographic structure summarized by $\{N_{a,t}\}_{a=0..7,t\geq 0}$, an exogenous distribution of high-skilled individuals $\{\phi^j_{a,t-a}\}_{a=0..7,j=h,l,t\geq 0}$ and an initial distribution of wealth $\{Z^j_{a,t+a}\}_{a=1..7,t=0,j=h,l}$ with $\{Z^j_{a,t} = 0\}_{a=0,t\geq 0}$, a competitive equilibrium in an economy with perfect capital mobility, up to a confiscation rate, is*

- ▷ *a vector of individual variables $\{c^j_{a,t}\}_{a=0..7,t\geq 0,j=h,l}$ that are the optimal solutions to the households' maximization problem, i.e. equation (2.3) subject to (2.4);*
- ▷ *a vector of the firm's variables $\{K_t, L^j_t\}_{t\geq 0,j=h,l}$ that maximize the firm's profit subject to technology (2.7);*
- ▷ *a vector of income taxes $\{\tau^w_t\}$ balancing the budget of the government (2.10);*
- ▷ *a vector of wages $\{w^j_t\}_{t\geq 0,j=h,l}$ such that labor markets are in equilibrium ;*
- ▷ *an interest factor $\{R_t\}_{t\geq 0}$ satisfying the no arbitrage condition of the rates of return to capital;*
- ▷ *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, i.e. equation (2.13) holds.*

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

2.3 Parameterization of the model economy

In this section we explain the calibration of the parameters as well as of observed and unobserved exogenous variables. We also define the baseline scenario and the assumptions on the future. Finally we focus on the different scenarios characterized by changes in the retirement age, skill-biased technical progress and education levels.

The model is calibrated in such a way that it matches regional structures and world disparities over the period 1950-2000. We start from an initial steady-state in 1870 and we focus on the transitional path of the world economy until it reaches the final steady-state in 2200. Our period of interest is 2000-2100.

2.3.1 Parameters and exogenous variables

Table 2.1 gives an overview of the values for model's parameter and exogenous variables. The following lines explain the calibration process.[10]

Table 2.1: Overview of main calibrated parameters (for the year 2000)

	ϕ	λ_5^h	λ_5^l	υ	A	c^g	χ	ρ	τ_c
North-America	55%	0.7	0.5	48.1%	1	14.9%	41.5%	0.2	20%
Western Europe	30%	0.7	0.5	73.3%	0.74	19.57%	42.5%	0.6	20%

Various sources are used (see below) and own computations.
The table shows the values for the year 2000.

Population process and individual characteristics. In the baseline, we compute $P_{a,t+a}$, the probability for an individual of generation t of being alive at time $t+a$ and the population growth rate m_t for the period 1950 to 2050 from the United Nations data of World Population Prospects, United Nations (2008). In order to compute the share of high-skill individuals of a generation ϕ_t, we use the Barro-Lee Dataset (2001), which provides data on the educational attainment of individuals aged 25 to 74 for the years 1950 to 2000 per country.[11] In the

[10]The model splits the countries of the word into 10 world regions. Here we focus on the calibration of two of them: Western Europe and North America.

[11]We firstly aggregate this data set by region and then partition it to obtain shares of highly skilled per age group. We proceed as follows in order to dis-aggregate the Barro-Lee data by age group. First, it is reasonable to assume that, at each period, the share of highly skilled individuals is higher for the younger age class. In particular, we assume that the share of highly skilled individuals aged 85 to 94 corresponds arbitrarily to 80% of the share of 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 highly skilled per age class then depend on the share of highly skilled aged 25 to 34, we

future, we assume that the young cohorts are educated as the young one in 2000. Labor participation rates of high- and low-skilled individuals (respectively $\lambda_{a,t}^{h}$ and $\lambda_{a,t}^{l}$) are set to 1 for the age groups 15-24, 25-34, 35-44 and 45-54. The participation rate for the three last age groups equals 0. For the fifth age group, the labor participation is between 0 and 1. Low-skilled individuals work until 60, i.e. the participation rate for individuals aged 55-64 equals 0.5 ($\lambda_{5,t}^{l} = 0.5$), and high-skilled individuals until 62 ($\lambda_{5,t}^{h} = 0.7$). Time spent in education is set to 0.6 for high-skilled individuals (e^h), meaning that they obtain a secondary school diploma (or above) and enter the labor force at the age of 21. For low-skilled, e^l equals 0.2. Finally, the introduction of migrants in the model is explained in appendix.

Technology and skill-biased technical change. First of all, the two parameters δ and α are assumed to be identical for across regions. As Aglietta et al. (2007) we argue that there is no reason to think that these parameters should differ across regions. We use an annual depreciation rate of capital of 5% like in Chojnicki et al. (2005) and de la Croix & Docquier (2007), which implies that δ equals 0.4. The capital share in output α is set to one third, as estimated in the growth accounting literature (see also GTAP, 2008). In our baseline scenario, we use a back-solving calibration method proposed in de la Croix & Docquier (2007) that allows to exactly match the observed world disparities between and within regions, i.e. the distance of a region's GDP to the GDP of the leader (North-America), and the wage differential between the two skill-types of individuals. The method consists of swapping the exogenous variables A_t for the endogenous variables Y_t/Y_t^*, where Y^* is North-American GDP, and then solving the identification step with the Dynare algorithm (Juillard, 1996). Skill-biased technical change υ_t is calibrated in the same manner by targeting the wage differential among skill-type of individuals, i.e. H_t ($= w_t^h/w_t^l$). The ratio of GDP's is computed by employing the data of the GDP per purchasing power parity from the World Bank Development Indicators (WDI, 2007) for the three years 1980, 1990 and 2000.[12] We hold the value of 1980 (respectively 2000) constant for the years preceding 1980 (respectively following 2000). The skill

compute this share in order to matches the total share of 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 highly skilled aged 35 to 44 in 1960 is equal to the share of highly skilled aged 25-34 in 1950, as we assume that the high- and low-skill 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 highly skilled aged 25 to 34 in the same way as for the year 1950. Lastly, the share of highly skilled aged 15 to 24 in 1950 is simply equal to the share of highly skilled aged 25 to 34 in 1960.

[12] We take the 5-year average value for the three time periods 1980, 1990 and 2000: 1978-1982, 1988-1992 and 1998-2002.

premium H_t is fixed at 2.3 for Western Europe and 3 for North-America for the year 2000 and depicts the fact that skill premium is higher in the US than in Europe. These two values reflect the pattern of the US college wage premium in Acemoglu (2003a) during the period 1950-2000. We follow Acemoglu (2002) in fixing the elasticity of substitution ε to 1.4 and thus the parameter in the CES labor demand function, σ, which corresponds to $1-\frac{1}{\varepsilon}$ equals 0.2857. Finally, the technical progress growth of the leader, i.e. North-America, g_t=A^*_{t+1}/A^*_t, where A^* is the leader's technical progress, is calibrated on observations and set to 1.2, which means that the annual growth rate is equal to 1.84%.

Government, transfer profiles and pension systems. Public debt, d_t, and public spending, c^g_t are computed from the World Development Indicators (WDI, 2007) for North-America and from the OECD (2006b) for Western Europe. Social security transfer profiles for each educational group, ζ^j_a, are assumed to be stable over time. The data for the social security transfer profiles (ζ^j_a) come from US and European generational accounting studies (Chojnicki, 2005). For the US, he disaggregates the profiles in the homogeneous agent study of Gokhale et al. (2000) by individuals' education level: below high school, high school and above high school. These profiles are also used in Chojnicki & Docquier (2007) and comprise eight types of transfers: old age security, disability insurance, medicare and medicaid, unemployment insurance, general welfare, aid to families with dependent children, food stamps and finally, educational transfers. In our model we take the average profiles of the two first groups as the profiles of 'low-skilled' individuals for the North American region. For the Western European region, we rely on European data from Chojnicki (2005), which stem from Crettez et al. (1999). The profiles for both regions are shown in table 2.2. The generosity factor of the social

Table 2.2: Time-constant transfer profiles (ζ)

Age groups	**15-24**	**25-64**	**65-74**	**+75**
Western Europe				
High-skilled	3%	6%	10%	15%
Low-skilled	10%	18%	20%	22%
North-America				
High-skilled	0.5%	1%	6%	12%
Low-skilled	7%	12%	20%	25%

Source: Chojnicki (2005) and own computations

security transfers, ψ_t is increasing during the period 1950-2000 and normalized to 1 from 2000 onwards. To parameterize pension systems, we need to set the values of the replacement rate, χ_t and of the time-invariant pension scheme parameter ρ. We calibrate the replacement rate in order to match the share of public pension spending to GDP of the year 1990. The data for this last variable come from Table A.5 of Palacios (1996) and from the World Bank (1994). We assume that the replacement rate of 1950 corresponds to 3/4 of the one of 1990. The replacement rates of 1960, 1970 and 1980 are chosen in order to build an linear upward trend between 1950 and 1990. The ones before 1950 are kept identically to the value of 1950, whereas the replacement rates after 1990 correspond to the value of 1990. The pension scheme parameter, ρ, captures the redistributiveness of the pension system and is specific to each region. We can set ρ by relying on the data on the size and redistributiveness of pension systems for several OECD countries collected by Johnson (1998) and exposed in Pestieau (1999).[13] According to this data, the ratio of replacement rates between the highest and lowest income levels is 0.33 in Canada and 0.5 in the United States. To be precise, this data reports replacement ratios for an average income level and for incomes that are half or twice as large as the average level. We take the ratio of replacement rates between the highest and lowest income levels as a rough approximation of the ratios between high- and low-skilled wages. The ratio of replacement rates for North-America will correspond to the weighted average of the Canadian and US ratios (weighted by the population of both countries in 1990). By using the formulas (2.11) and (2.12) we can write this ratio in the terms of our model as $[\rho + (1 - \rho)/H]$ where $H \equiv w^h/w^l$. Then ρ is set in order to match the ratio of replacement rates between high- and low-skilled individuals (the value of H is given below). We obtain a ρ of 0.2 for North America, and similarly ρ equals to 0.6 for Western Europe.[14]

2.3.2 Baseline and assumptions on the future

In the baseline scenario, the distance of the technical progress of each region to the technical progress of the leading economy is assumed to be constant after 2000. Furthermore, like the policies conducted in many developing countries, the baseline already features less generous pension systems in the near future because of population aging, e.g. a postponement by 1 year of the retirement age of high- and low-skilled individuals between 2000 and 2050. In addition, we hold the

[13] Since data on the size of the pension systems in Johnson (1998) comprises only several developed countries, we prefer to use the more complete data of the World Bank to calibrate χ.

[14] Pension systems differ quite a lot across Western European countries, with the largest countries as Italy, Germany and France being Bismarckian (i.e. with a large percentage of public spending for social security systems to GDP and a less equal redistribution), while smaller countries as the Netherlands being Beveridgian. In contrast, Canada and the United States are clearly more Beveridgian than Western Europe, with a smaller sized welfare system and a more egalitarian distribution of pension benefits across income levels.

proportion of skilled individuals among each new generation constant from 2000 onwards.

- *Population structure:* The main driving force of the model over the 21^{st} century is the evolution of the population structure, since the predictions of the United Nations Population Projections last until 2050. Thus, as said above, the growth rate of the first cohort and the probabilities of being alive are calibrated until 2050.

- *Education:* The proportion of high-skilled individuals among each new generation is held constant from 2000 onwards. As young cohorts are more educated than older cohorts (or in other words, cohorts born before 2000 are less educated than those born born in 2000 and after), it implies that the proportion of educated workers continues to increase after 2000. In the long run, the proportion of educated individuals will equal the proportion of educated among the cohort born in 2000.

- *Pension systems:* In line with the policies conducted in many developed countries, we consider that pension systems will be less generous in the near future because of population aging. To represent these anticipated forthcoming pensions reforms, our baseline scenario for the first half of the 21^{st} century accounts for two changes compared to the year 2000. First, between 2000 and 2040, the retirement age is gradually postponed by 1/4 year for both low- and high-skilled individuals, meaning that the retirement age for low- and high-skilled increases from respectively 60 and 62 in 2000 to respectively 61 and 63 in 2040. Formally, for the age group 55-64, λ_5^l (respectively λ_5^h) passes steadily from 0.5 to 0.6 (respectively from 0.7 to 0.8) over the period 2000-2040 in North-America and Western Europe. Second, the replacement rate is reduced implying lower pension benefits in the next decades. Between 2000 and 2050, the replacement rate in North-America is gradually reduced from 41.5% to 36%, while the one in Western Europe falls from 42.5% to 37%.

2.3.3 Scenarios on labor market characteristics

Table 2.3 presents the "realistic" changes in the various labor market characteristics with the benchmark model. Five scenarios are considered for North-America and six for Western Europe. In the first scenario, retirement age of less educated individuals is postponed by two years beyond the baseline level from 2010 onwards both in Western Europe and in North-America. In a second simulation, the same scenario is run for the retirement age of skilled individuals. In scenario three the firms augment their demand for skilled labor in the production process scenario during the first half of the 21^{st} century. This scenario is characterized by a continuous acceleration in skill-biased technical change with respect to the baseline from 2010 to 2050: from a 1% augmentation in 2010 to reach a 5% increment in 2050 compared to the baseline.[15]

In simulation four we assume that the proportion of educated individuals rises during the first half of the 21^{st} century, but only in Western Europe. The proportion of young educated people augments steadily from 2 percentage points in 2010 to 10 percentage points in 2050 with respect to the baseline scenario. There will be no scenario of increased supply of skills in North-America, because according to Cheeseman Day and Bauman (2000) the proportion of skilled among young skilled individuals may not vary much in the near future in the US. Finally, we consider two policies of increased immigration. We track migration flows from the seven developing regions to North-America and Western Europe.[16] To avoid additional agent heterogeneity, we also assume that migrants enter at the age of 15 when they have no assets (the integration of migration flows in the model is explained more in detail in appendix). In the two immigration scenarios, 25% of additional immigrants (compared to the baseline scenario) arrive to North-America and to Western Europe between 2010 and 2050. When the non-selective immigration policy (scenario 5) is applied, 30% of these additional migrants are highly skilled and 70% low-skilled whereas 70% of these migrants have a higher education level and 30% a lower education level in the selective immigration policy (scenario 6). Table 2.3 shows how the proportion of young high-skilled individuals in the population changes according to these two policies (details about the calibration of the migration scenario can be found in appendix).

The evolution of the parameters in the different scenarios can be justified in the following way. We argue that a prolongation of the working life can be implemented immediately via a public policy and thus the total augmentation in legal retirement age happens in one period. In the scenarios 3 and 4 the changes are progressive (and occur over several periods), because the proportion of highly skilled in a population and skill-biased technical change may not be radically influenced over a short time period.

Moreover, instead of simulating two radical policies of increased immigration (e.g. an arrival of 100% of low-skilled versus 100% of high-skilled immigrants), we prefer to compare the effects of two more "realistic" immigration policies: 70% of high-skilled / 30% of low-skilled versus 30% of high-skilled / 70% of low-skilled migrants. We argue that when a country chooses to adopt a selective

[15] The values of all exogenous variables are fixed after 2050 in each scenario, expect for ν_t, which continues to vary slightly from 2050 to 2100 in the baseline case.

[16] We do not quantify migration flows from the North (developed regions) to the South (developing regions) as well as North-North and South-South migrations, because they are implicitly taken into account in the UN Population data.

immigration policy, it can never "attract" 100% of high-skilled migrants, because a migrant may for example arrive with his family members, who are probably not all highly skilled.

Table 2.3: Simulations for Western Europe and North-America

Scenario 1: Postponement of low-skilled retirement age (increase of 2 years from 2010 onwards)						
	2000	**2010**	**2020**	**2030**	**2040**	**2050**
Both regions: Baseline	60	60.2	60.4	60.6	60.8	61
Both regions: Scenario 1	60	62.2	62.4	62.6	62.8	63

Scenario 2: Postponement of high-skilled retirement age (increase of 2 years from 2010 onwards)						
	2000	2010	2020	2030	2040	2050
Both regions: Baseline	62	62.2	62.4	62.6	62.8	63
Both regions: Scenario 2	62	64.2	64.4	64.6	64.8	65

Scenario 3: Rise in SBTC υ (from a relative change of 1% in 2010 to 5% in 2050)						
	2000	2010	2020	2030	2040	2050
Western Europe: Baseline	48.1%	51.8%	54.2%	55.3%	55.5%	55.5%
Western Europe: Scenario 3	48.1%	52.4%	55.3%	57%	57.8%	58.2%
North-America: Baseline	73.3%	75.3%	76.2%	76.7%	76.9%	76.9%
North-America: Scenario 3	73.3%	76%	77.8%	79%	80%	80.8%

Scenario 4: Increase in the share of young skilled ϕ (from 2 percentage points in 2010 to 10 pp in 2050)						
	2000	2010	2020	2030	2040	2050
Western Europe: Baseline	30%	30%	30%	30%	30%	30%
Western Europe: Scenario 4	30%	32%	34%	36%	38%	40%
North-America: Baseline	55%	55%	55%	55%	55%	55%
North-America: No Scenario 4	—	—	—	—	—	—

Scenario 5 and 6: Share of young skilled (ϕ) when the inflow of migrants increases by 25%						
	2000	2010	2020	2030	2040	2050
WEU: Baseline	30%	30%	30%	30%	30%	30%
WEU: Scenario 5 (Non-selective)	30%	30%	30%	30%	30%	30%
WEU: Scenario 6 (Selective)	30%	30.78%	30.82%	30.85%	30.86%	30.87%
NAM: Baseline	55%	55%	55%	55%	55%	55%
NAM: Scenario 5 (Non-selective)	55%	53.98%	54.04%	54.08%	54.11%	54.15%
NAM: Scenario 6 (Selective)	55%	55.61%	55.58%	55.55%	55.53%	55.51%

Source: Docquier & Marfouk (2006) for scenarios 5 & 6 and own computations; own calibration for scenarios 1-4. ϕ is the proportion of high-skilled among individuals aged 15-24, ν is high-skilled biased technological change

Besides, unlike Ingenue (2005) and Fehr et al. (2004) who double immigration flows to sending countries/regions, the immigration scenarios presented here do only augment by 25% the migrants coming to Western Europe and to North-America. The reason is that we prefer to follow again the aim of more "realistic" changes on the labor supply. Table 2 shows how a prolongation (of two years) in the working life of low- or high-skilled individuals and an increase (by 25%) in high- or low-skilled migration inflows affects the labor supply compared to the baseline. The rise in the labor supply (compared to the baseline) due to a postponement of the legal retirement age is obviously relatively constant (because it is a one-time change in labor supply), while immigration constantly increases

Table 2.4: Labor force increase under retirement age and immigration scenarios

Increase in the labor force compared to the BSL						
Advanced Countries	2010	2030	2050	2060	2080	2100
Scenario 1: postponement of RA-h	0.64%	1.51%	1.47%	1.41%	1.36%	1.36%
Scenario 2: postponement of RA-l	3.69%	3.91%	3.43%	3.28%	3.17%	3.18%
Scenario 5: increase in IMMI-h	0.23%	2.23%	6.39%	8.48%	10.83%	11.15%
Scenario 6: increase in IMMI-l	0.30%	2.31%	6.44%	8.44%	10.79%	11.15%
North-America	2010	2030	2050	2060	2080	2100
Scenario 1: postponement of RA-h	1.94%	2.19%	2.49%	2.42%	2.49%	2.53%
Scenario 2: postponement of RA-l	2.20%	1.98%	2.03%	1.98%	2.03%	2.07%
Scenario 5: increase in IMMI-h	0.62%	4.98%	12.47%	16.08%	20.18%	20.81%
Scenario 6: increase in IMMI-l	0.81%	5.16%	12.56%	16.01%	20.11%	20.81%

Source: Docquier & Marfouk (2006) and own calculations

RA-l and RA-h stand for the postponement in retirement age of low- and high-skilled individuals

IMMI-l and IMMI-h represent the non-selective resp. selective immigration policy.

the labor supply as additional migrants arrive each period to their destination region until 2050. We see that the increase in the labor force due to any of the two immigration policies is more than two (four) times higher than the increase in the labor supply due to a prolongation of the working life in Western Europe (North-America). Thus doubling immigration would have an excessive effect on the labor supply.

2.4 Results

In this section we present the implications of the different potential remedies for the tax-to-GDP ratio and GDP per capita in Western Europe and in North-America. First, we investigate if any of the scenarios can mitigate the old age crisis, by sustaining pension systems. But we will also analyze their consequences on GDP per capita, as they are likely to have an impact on the economic performance of these two regions.

2.4.1 Impact on the tax rate

As mentioned above, the labor income tax rate (or simply 'tax rate' hereafter) balances the government budget. The main driving force of the model over the 21^{st} century is the evolution of the population structure. In particular, aging will put a strong pressure on pension systems which will be reflected by a rising labor income tax rate. This can be clearly seen in figure 2.1. In both regions, the evolution of the support ratio (the share of working age population to pensioners) dictates the financial pressure on pension systems.In Western Europe, the tax rate needs to be multiplied by 1.3 between 2000 and 2050 to maintain the generosity of the welfare state as in 2000 (figure 2.1.c). In the long-run, the fiscal impact is mainly explained by the progressive rise in life expectancy. The peak observed between 2020 and 2060 is due to the graying of baby boom generations. During the first half of the century, North-America is able to keep a younger demographic structure and the demographic transition results in a more gradual increase in the tax rate. North-America is more open to immigration and can thus avoid a dramatic rise in the tax rate caused by the retirement of the baby boomers. Let us observe that Western Europe has the highest social security contribution rate in the world. This is due to its relatively higher dependency ratio and to the relatively high replacement ratio people enjoy at constant policy. In fact, public pension spending to GDP ratio is largest in Western Europe (9.2% in WEU compared to 6.5% in NAM, see Palacios, 1996) and translates into a higher replacement rate.[17]

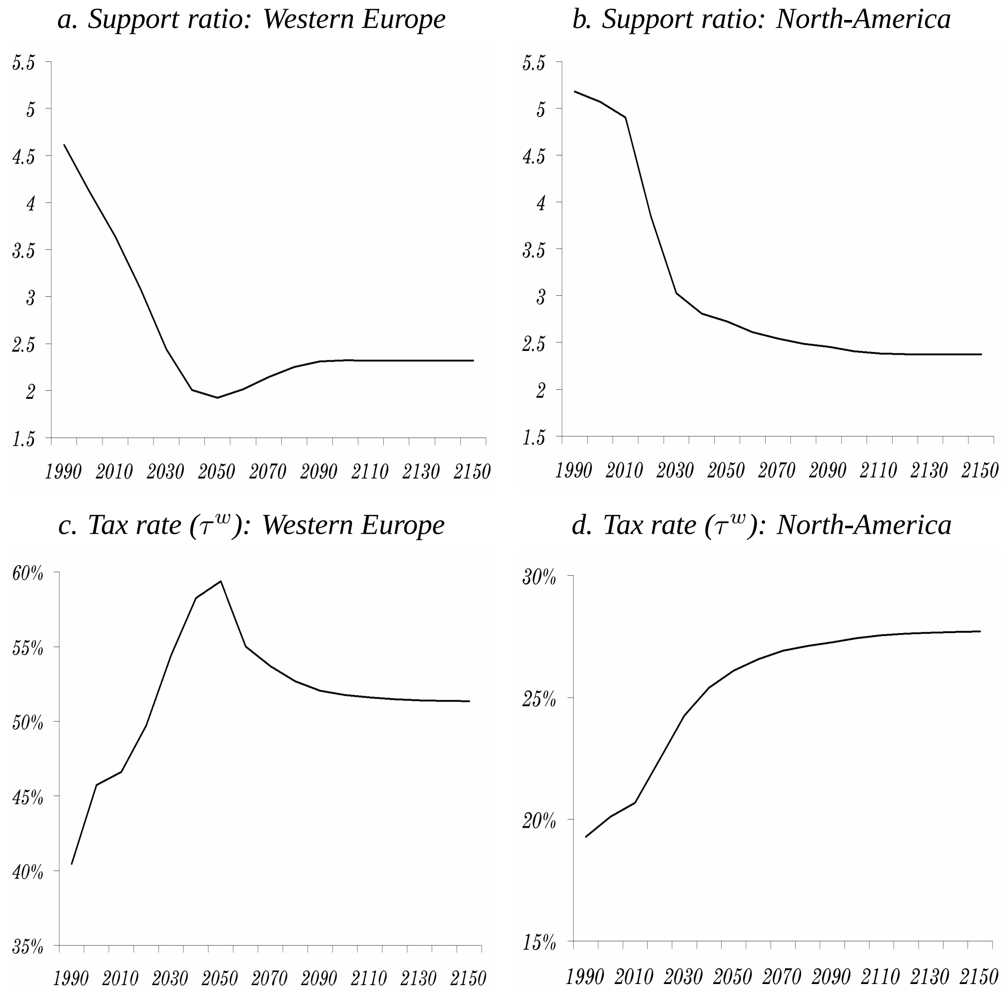
Figure 2.2 displays the impact of the different policy changes on the tax-to-GDP ratio in percentage point changes with respect to the baseline. In the following lines, we explain the impact of all the non-migratory policies (solid lines in the graph), first for Western Europe and then for North-America. The effects of immigration (dashed lines) are described subsequently in a separate paragraph.

Western Europe. Postponing retirement age of low-skilled individuals is the most effective among all policy changes in reducing the fiscal pressure on Western European pension systems. During the 20^{th} century, younger cohorts are more skilled than the previous generations and we assumed that future young cohorts are educated like the 2000 young cohort (see section 2.3), implying that share of high-skilled individuals will be increasing during the 21^{st} century.[18] Delaying retirement of low-skilled induces a relative strong decrease in the tax rate in the first quarter of the 21^{st} century, with a reduction of -1.89 percentage points already in 2010. The reason is that there is still a relative large pool of low-skilled middle aged individuals in the beginning of the century. In contrast, postponing the retirement age of high-skilled individuals, has a smaller initial impact on the tax rate, but becomes more significant during the following decades as the labor force becomes more skilled. Still, in the long run (end of the century), the reduction in the tax rate amounts to -1.3 percentage points with a postponement of low-skilled retirement age and only -0.86 with high-skilled retirement age.

[17] Our labor income tax rates passes from 45.73 in 2000 to 59.37% in 2050 in Western Europe and from 20.10% to 26.10% in North-America. This is comparable with Fehr et al. (2004), where the combined social insurance payroll tax and wage tax rates rise from 40.70% to 69.20% in Europe and from 23.50% to 39.40% in the United States.

[18] The share of high-skilled among a new born generation is 24% in 1980, 27.8% in 1990 and 30% from 2000 onwards. Thus the proportion of highly educated in the population rises steadily in the 21^{st} century and tends to 30% in the long run.

Figure 2.1: Support ratio and labor income tax rate in the baseline



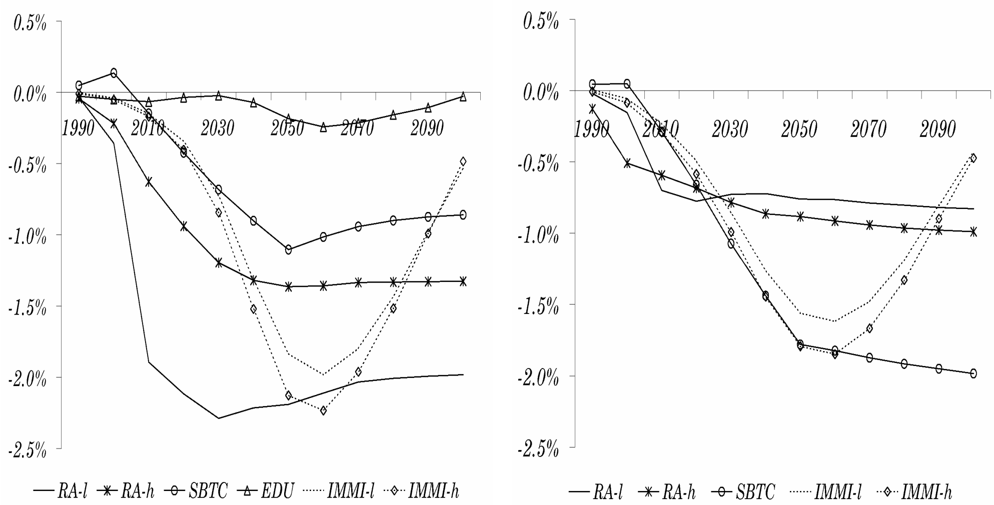
The explanation is that the proportion of low-skill workers remains relatively large enough to dominate the fact that a high-skill worker contributes marginally more to the welfare system than a low-skill one. Nevertheless, because the share of high-skilled individuals increases over the first half of the 21^{st} century, the difference in the reduction of the tax-to-GDP ratio due to both retirement age policies is lower. Our model supports also the magnitudes of the findings in the skill-homogeneous agent model of Aglietta et al. (2007). They obtain that a gradual increase in the retirement age from 60 to 65 years between 2000 and 2020 in Western Europe induces a relative change in the contribution rate of

-22.67% in 2050 (-8.5 percentage points) and of -21.88% in the long run (-7 pp). Transposing their scenario in our framework implies a delay in retirement of both skill groups[19], which induces a relative decrease in the labor income tax rate of 14.27% in 2050 (-8.47 percentage points) and of -15.15% in the long run (-7.84pp). Finally, an acceleration in skill-biased technical change reduces taxes by -0.55 percentage points in the long term (compared to the baseline), while a rise in the proportion of high-skilled has an even smaller impact on taxes.

Figure 2.2: Impact of the different policy changes on the tax rate (τ^w)

(Percentage points change w.r.t. baseline)

a. Western Europe *b. North-America*



RA-l and *RA-h* stand for the postponement in retirement age of low- and high-skilled individuals
SBTC and *EDU* are respectively the scenarios in which skill-biased technical change and education levels increase
IMMI-l and *IMMI-h* represent the non-selective resp. selective immigration policy.

North-America. In North-America, an acceleration in skill-biased technical change has a bigger impact on pension systems than delaying retirement age. In the long run (from 2100 onwards), the cut in the tax rate corresponds to -1.98 percentage points (compared to the baseline). Postponing high-skilled retirement age induces a slightly larger reduction in the tax rate than delaying retirement of low-skilled. In North-America, the proportion of high-skilled leans to 55% in the

[19]To compare to Aglietta et al. (2007), we increase the retirement age for both skill-groups by 4% in 2010 and by 8% from 2020 onwards.

long term.[20] There is thus a more equal number of low- and high-skilled individuals than in Western Europe. But then we could expect a larger gap in the reduction of the tax rate between the two types of policies, since postponing high-skilled retirement age increases the effective labor supply by increasing the number of contributors and their "quality": a high-skilled individual contributes more and benefits less from the welfare system. The explanation hinges on the impact of both policies on the skill premium, which increases by 3.12% and drops by -3.18% in 2050 when retirement age of low-skill respectively high-skill workers is postponed. Since the contribution and the benefits (pension benefits and other welfare transfers) of tax payers are a fraction of the labor income, delaying retirement age of (low-) high-skill workers will (decrease)increase the net contribution of a high-skill worker. As a consequence, there is no reason to advocate a longer working time of one skill-type of workers compared to another in North-America.

Immigration. Finally, the impact of immigration in financing pension systems has a similar impact as the other potential "remedies" in terms of magnitudes. In both regions the reduction in the tax rate is highest in the middle of the century, more precisely in 2060 when the first wave of migrants is fully retired and the last wave fully joins the workforce. The beneficial effect on taxes disappears by the end of the century, when all the additional migrants are retired. This supports the results of the two-period theoretical OLG model of Razin & Sadka (1999), in which individuals work in the first period of their life and are retired in the second period. Razin & Sadka (1999) find that an immigration policy is beneficial to the pension systems of the receiving countries in the period of the migrants' arrival, as they increase the labor force. We also find that the positive effects of immigration last until the immigrants retire. In addition, because our individuals live for eight periods, the beneficial effects of immigration hold several periods after the stop of the increased immigration policy. Even though the labor force remains higher than in the baseline in the long run, the number of pensioners benefiting from contributions will also be higher. Furthermore, in Razin & Sadka (1999), also low-skilled immigrants may contribute to finance the pension systems of developed countries. This corroborates with our result, but contrasts with existing generational accounting studies and with the outcome of Storesletten (2000), who argues that only selective immigration policies may be used to reduce the fiscal pressure on the welfare state. This is also one of the conclusions of Fehr et al. (2004), where a doubling of low-skilled immigration leads to an increase in the tax rate.[21]

[20] In 1980, 50% of the 15 to 24 years old are high-skilled. In 1990, there are 52.5% of the high-skilled among the same age group and 55% from 2000 onwards.

[21] To be precise, in their model, low-skilled migration leads both to a rise in the social insurance tax rate and the wage tax rate.

In fact, figure 2.2 shows that both immigration policies lead to similar cut in the tax rate.[22] Compared to the base case, a selective policy relieves the fiscal pressure by -1.85 in North-America and by -2.23 percentage points in Western Europe in 2060 while a non-selective one induces a decrease in the tax rate of -1.62 in North-America and by -1.98 percentage points in Western Europe . What explains this result? Compared to generational accounting studies, where wages are exogenously given and which predict a negative impact of low-skilled migration in contributing to the welfare state, general equilibrium effects are into play here. An inflow of workers will change the capital-labor ratio and impact on factor prices by lowering wages and increasing the interest rate. However, the frameworks of Storesletten (2000) and Fehr et al. (2004), which can be very roughly defined as an open economy version of the former model, comprise such effects and deliver a pessimistic message concerning the impact of low-skilled migration in sustaining the financing of pension systems. Two reasons are put forward. A first explanation, is that unlike in the two aforementioned studies the skill-composition of our proposed immigration policies is not a "radical" one, in the sense that the selective policy is not composed of 100% of high-skilled migrants, but of 70% of high-skilled and the non-selective one does not comprise 100% of low-skilled migrants, but only 70%. We argue that even if governments wish to attract only high-skilled workers, they may fail to do so, for example because they can not impede that these workers come with their family members, who are less likely to have a higher education level. Nevertheless, in order to confront our model with the aforementioned studies we simulate such the effects of such extreme migration policies on the tax rate. The differential impact between low- and high-skilled immigration would be indeed slightly increased.[23]

Another reason explaining the similar impact of both immigration policies is that when the additional immigrants are high-skilled, the skill premium decreases (a -0.81% relative change compared to the baseline in 2060) and this reduces the average contribution of a high-skill worker in financing pension systems. Conversely, when additional migrants are low-skilled, a high-skilled worker will pay more taxes since the skill premium is enhanced (+2.71% relative change in 2050). In Storesletten (2000) and Fehr et al. (2004) the skill premium are fixed, i.e. work-

[22] When simulating the two immigration policies, general public consumption ($c_t^g Y_t$) is the same in the two scenarios of increased immigration. The government spends more public goods when additional migrants arrive (because Y_t will rise when the labor force increases). However, there is no reason to believe that general public expenditure should change if the composition of these migrants is different.

[23] A very selective migration policy, increasing migration flows by 25% and comprising only high-skilled migrants would reduce the tax rate by -2.41 and -2.01 percentage points in Western Europe respectively North-America in 2060. Its counterpart, all additional immigrants are low-skilled, would lead to a decrease of -1.78 and -1.43 in Western Europe respectively North-America.

ers of different skill-types are perfect substitutes. Finally, we can also make a very rough comparison with Fehr et al. (2004). They obtain that in the United States a 1% increase in low-skilled immigration from 2000 onwards would result in an rise of the combined tax rate by 0.12% in 2050, while a 1% increase in high-skilled immigration would reduce it by -0.56%.[24] Our results suggest that a similar shock i.e. with a 1% increase in low- respectively high-skilled immigration flows between 2010 and 2050 would result in a reduction of the tax rate by -0.21% and by -0.3% in 2050. These results are thus less optimistic with respect to high-skilled immigration and less pessimistic with respect to low-skilled immigration than the findings of Fehr et al. (2004).

Our findings suggest that realistic changes in labor market characteristics are potentially as beneficial in reducing the fiscal pressure on pension systems as an increase in immigration: in North-America (a rise in skill-biased technical change) and in Western Europe (a postponement of low-skilled retirement age). Moreover, our results are less optimistic in advocating high-skilled immigration and less pessimistic in recommending low-skilled immigration to mitigate future tax hikes than the existing literature.

2.4.2 Income per capita

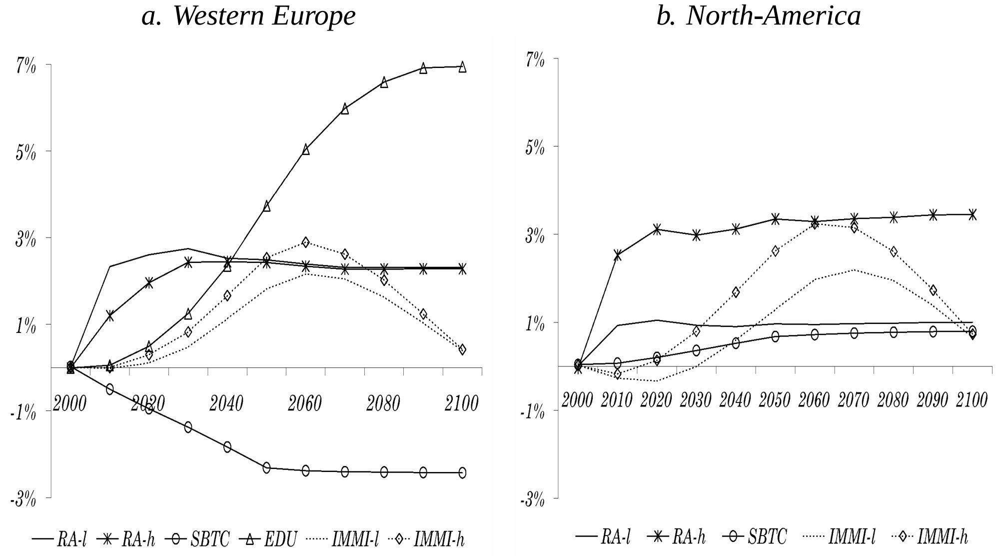
In Western Europe, a progressive increase in the share of high-skilled individuals, up to a level of 40% in 2050, is the scenario that leads to the highest long term increase in per capita GDP of 7% with respect to the baseline scenario (figure 2.3). Postponing retirement age of either high- or low-skilled individuals increases per capita GDP by less than 2.5% compared to the reference case in the long run.

Higher skill-biased technical change leads to a long term decrease in per capita GDP of almost 2.5% compared to the baseline. In North-America, a delay in the retirement age of high-skilled individuals produces the most important increase in per capita GDP among all the scenarios: a 3.5% rise by the end of the 21^{st} century compared to the reference case. high-skilled biased technical change and a delayed low-skilled retirement age increase per capita GDP by around 1%.

[24] These numbers originate from own computations based on the results exposed in Fehr et al. (2004) and the impact on the tax rate is based on the combination between the social insurance and the wage tax rate. The two skill-specific immigration policies they analyze are an yearly increase from 100’000 to 200’000 high-skilled migrants (10% increase in immigration flows) and an increase from 1 to 2 million, where all the additional migrants are low-skilled (this corresponds to a doubling in total immigration flows). While our model differs in many aspects from the one of Fehr et al., it is more reasonable to compare our findings to them rather than to Storesletten (2000). In fact, they also assume that integrated capital markets between the regions of their model while Storesletten employs a closed economy model, implying a larger response of factor prices to labor inflows.

Figure 2.3: Impact of the different policy changes on GDP per capita

(Relative change w.r.t. baseline)



RA-l and *RA-h* stand for the postponement in retirement age of low- and high-skilled individuals
SBTC and *EDU* are respectively the scenarios in which skill-biased technical change and education levels increase
IMMI-l and *IMMI-h* represent the non-selective resp. selective immigration policy.

We notice that an increase in skill-biased technical change has different effects on the economies of North-America and of Western Europe. It increases per capita GDP in the former and decreases it in the latter. This is closely linked to the different education levels in both regions and can be interpreted as follows. A high supply in the high-skill labor force induces North-American firms to apply more advanced technologies in the production process (Acemoglu, 2002, 2003a). Following a reasoning à la Nelson & Phelps (1966a) or à la Benhabib & Spiegel (2005) where a follower imitates the technology of the leader economy, we can argue that the skill-complementary technologies developed in North-America are adopted by Western Europe. Because of lower education levels, the production process in Western Europe is not adapted to use the new technologies. They lead to a higher skill premium and widen the per capita income gap between North-America and Western Europe.

Lastly, immigration has a beneficial impact on per capita GDP but again only as long as the labor force is increased and as long as the number of pensioners does not increase (by too much). In 2050, the increase in per capita GDP is by 51% higher in Western Europe and by 111% in North-America with a selective immigration than with a non-selective immigration policy. The fact that the skill-complementary production process is more important in North-America (higher υ) can explain that a selective immigration policy has a more beneficial effect in North-America.

2.5 Conclusion

This paper analyzes the impact of immigration on the contribution rate in North-America and Western Europe, when holding the generosity of the welfare state constant at current levels. This question is addressed within a calibrated overlapping generations model featuring integrated capital markets. Two immigration policies are considered: a selective one, where the majority of migrants are high-skilled and a non-selective one with a majority of low-skilled migrants. It is found that increased immigration yields small fiscal gains. Moreover, both the selective and non-selective immigration policies result in similar tax cuts. Our findings also suggest that realistic changes in labor market characteristics are potentially as beneficial in reducing the fiscal pressure on pension systems as an increase in immigration: in North-America (a rise in skill-biased technical change) and in Western Europe (a postponement of low-skilled retirement age). Moreover, our results are less optimistic in advocating high-skilled immigration and less pessimistic in recommending low-skilled immigration to mitigate future tax hikes than the existing literature.

Several extensions may undoubtedly enrich the analysis. It would be interesting to see what would be the effects of such scenarios on developing regions. Besides, endogenizing the educational choice (i.e. the time spent in education) of the individuals, could add one more feedback into the model: the formation of human capital. We could then see how the impact of various pension reforms affects the tax rate via changes in the education level of the population. Finally, endogeneizing the labor supply would allow us to have a framework where individuals choose when they want to retire. These issues are left for future research.

Appendix

Appendix A: Calibration of migration

Throughout the paper, migration refers to migrants from the developing regions going or living in the North. In order to calibrate these migration stocks and flows for the baseline, we explicitly track migrants from the seven developing regions into the North-America and Western Europe. North-to-North and South-to-South migrants are implicitly dealt with through the U.N. population data and forecasts. To introduce migration flows in the model, we make 3 assumptions. First, migrants are directly assimilated to natives, i.e. they acquire the same characteristics (e.g. productivity) as natives as soon as they enter the destination region. A second assumption is that there is no return migration. Finally, all the migrants arrive at the age of 15 (i.e. without any assets).[25]

Each of these two receiving regions experiences two different policies of increased immigration between 2010 and 2050. Instead of simulating two radical policies of increased immigration (e.g. an arrival of 100% of low-skilled versus 100% of high-skilled immigrants), we prefer to compare the effects of two more "realistic" immigration policies: 70% of high-skilled / 30% of low-skilled versus 30% of high-skilled / 70% of low-skilled migrants. We argue that when a country chooses to adopt a selective immigration policy, it can never "attract" 100% of high educated migrants, because for example a migrant may arrive with his family members, who are probably not high-skilled.

Table 2.5: Additional Migrants to NAM and WEU by region of origin

Source region	EAS	MEN	LAC	JAP	SSA	RUS	CHI	IND
Host region								
NAM	6.19%	5.03%	53.58%	0%	2.81%	2.97%	21.76%	7.66%
WEU	21.61%	33.10%	8.86%	0%	11.19%	2.90%	9.68%	12.66%

Source: Docquier & Marfouk (2006) and own calculations

Table 2.6: International migrants as a proportion of the population

Region and scenario	2010	2030	2050	2070	2090	2110	2130
WEU: Baseline	6.15%	7.36%	8.33%	9.07%	9.50%	9.66%	9.67%
WEU: +25% of migrants	6.43%	8.15%	9.67%	10.43%	10.44%	10.01%	9.67%
NAM: Baseline	12.39%	14.38%	15.68%	16.41%	16.48%	16.45%	16.45%
NAM: +25% of migrants	13.11%	16.07%	18.21%	18.70%	17.97%	16.99%	16.45%

Source: Docquier & Marfouk (2006) and own calculations

[25]These assumptions are necessary in order not to increase the heterogeneity of agents in the model, which would further complicate the computation of the transitory path. In fact, in our model we have individuals with 2 different educational attainments of 8 different age classes and belonging to 10 different regions. If there was for example return migration in the model (no permanent immigration), migrants would go back to their region(s) of origin after some periods with different characteristics than the individuals that did not emigrate from their home region. Agent heterogeneity in the region(s) of origin would then increase. For the same reason we have to assume that migrants arrive at the age of 15 years. When migrants arrive later, they will come with different characteristics than natives and the heterogeneity of households in the destination country will also change.

In the following step we need to determine the "additional" number of migrants arriving to North-America and to Western Europe between 2010 and 2050. According to the projections of the U.N. Population Division, 64'375 respectively 39'104 thousands of migrants will arrive to North-America respectively to Western Europe between 2010 and 2050. From this number we subtract the number of 0 to 14 years old migrants. In the United States, 8% of the immigrants are aged between 0 to 14 years (U.S. Census Bureau). We apply this share also to the migrants of Western Europe. Next, we only want to consider migrants from the seven developing to North-America and Western Europe. Thus we subtract from the migrants aged 15 and more, all the migrants coming from the countries belonging to these two developed regions and from Japan. Using the data available in the World Bank sponsored study of Docquier & Marfouk (2006), we obtain that 79.02% respectively 58.44% of the total immigrants in NAM respectively WEU come from the 7 developing regions in 2000. We assume that in the periods following 2000 the share of migrants coming from the seven developing regions will be more and more important in NAM and WEU. We assume that the share of migrants coming from the seven developing regions will increase progressively from 79.02% in 2000 to 85% in 2050 in North-America and from 58.44% to 70.13% in Western Europe.[26] To determine from which developing region the additional migrants will arrive we assume that they will be split up according to the region of origin of the 2000 stock of migrants in North-America and in Western Europe again by making use of the data available in the World Bank sponsored study of Docquier & Marfouk (2006). Table 2.5 indicates that the additional migrants to North-America and Western Europe have quite different origins. While most of the additional migrants to North-America originate from Latin America and the Caribbean (54%) and from the Chinese World (22%), Western Europe experiences most of their additional immigration from the Middle East and North Africa (33%) and from the Eastern European Countries (22%).

Table 2.6 shows the evolution in the proportion of international migrants under different scenarios. The share of immigrants is much higher in North-America than in Western Europe. When migration inflows are increased by 25%, there are around 2.5% more migrants in North-America and almost 1.5% in Western Europe in 2050.

[26]The value of 85% for North-America is fixed arbitrarily and 70.13% corresponds to an arbitrary 20% increase in the value of 2000.

Chapter 3

Brain Drain and the World Economy: Lessons from a General Equilibrium Analysis

Abstract. The paper aims to address concerns of brain drain due to high-skill biased immigration policies. The potential impacts of South-North high-skilled migration are simulated on GDP per capita, GNI capita, and the high-to-low skill income inequality at origin. A ten-region CGE-OLG model is built and dynamically calibrated so as to match observations from the world economy. While our results reconfirm the important role of remittances in subsidizing the income of those left behind, they are also robust to different assumptions as to whether the highly skilled remit less or not. Furthermore, the paper assesses the significance of several feedback effects ignored in previous CGE works. First, it is shown that the high-skilled diaspora may greatly benefit domestic production by reducing information-related risks and bringing in more foreign direct investments. Second, the so-called "brain gain" effect acts to reduce the income disparity between workers of different skills. These feedback effects may well outweigh losses of high-skill labor, and they are especially pronounced for regions with low high-skilled emigration rates. In contrast, brain drain indeed poses as a curse for regions already facing severe high-skill outflows, including Eastern Europe, Latin America.

JEL Classifications: F22, J24, O15.

Keywords: Brain drain, Human capital, Remittances, Development.[1]

[1] joint with Frédéric Docquier, Elisabetta Lodigiani and I-ling Shen.

3.1 Introduction

The South-North migration of talented workers is an important component of the globalization process. Although the world proportion of international migrants remained stable over the last decades, the immigration rate in high-income countries has, similarly to the trade-to-GDP ratio, tripled since 1960 and doubled since 1985. Thanks to new harmonized and original data sets on migration stocks and rates by educational attainment, it is today possible to have a more accurate vision of the educational structure of international migration. For instance, Docquier et al. (2009) show that the number of highly educated immigrants living in the OECD countries has increased by 70 percent during the 1990s, against a 30 percent increase only for low-skilled immigrants. Two thirds are due to migration from developing countries. Obviously, such a change partly reflects a general rise in educational attainments in developing countries. It follows that, in proportion of the highly skilled labor force at origin, brain drain rates were relatively stable over time (see **?**). Nevertheless, many developing countries exhibit brain drain rates well above 40 percent, especially sub-Saharan African countries, Central American countries and small states[2]. The brain drain is thus a major source of concern in some developing regions and could become an increasingly important issue if developed countries reinforce the selection of their immigrants (in response to aging, occupational shortage, etc.).

In principle, international migration can generate substantial welfare gains for many parties concerned. One of the most fundamental results in economics is the Arrow-Debreu “first welfare theorem” which states that, under some conditions, a competitive market economy leads to a Pareto efficient general equilibrium. As far as the brain drain is concerned, it typically means that when highly skilled individuals take decisions that are good for them, an efficient allocation of resources is obtained. In particular, if high-skill workers are moving to rich countries, they contribute to increasing the total amount of welfare at the world level: they work in a more productive environment and potentially contribute to higher productivity improvements. The rest is a matter of redistribution.

With appropriate transfers, the brain drain could potentially lead to a Pareto-improving situation in which origin and destination countries would gain. However, in the absence of redistributive transfers, the brain drain is usually considered as a curse for origin countries, especially for developing countries. Indeed, it deprives poor countries of one of their scarcest resources, human capital. In turn, it reduces their capacity to adopt recent technologies and induces a fiscal cost for those left behind. Unsurprisingly, since the 1970s Bhagwati & Hamada (1974); McCulloch & Yellen (1975, 1977), the traditional literature has delivered more or

[2] The high-skilled emigration rate exceeds 70 percent in a dozen countries.

less the following messages: i) the brain drain is a negative externality imposed on those left behind; ii) it is a zero sum game, with the rich countries getting richer and the poor countries getting poorer; and, iii) at a policy level, the international community should implement a mechanism whereby international transfers could compensate the origin countries for the losses incurred, for example in the form of an income 'tax on brains' (or 'Bhagwati Tax') to be redistributed internationally. Modern theories of endogenous growth have considerably renewed the analysis of the relationships between education, migration and growth. The first models to address the issue of the brain drain in an endogenous growth framework also emphasized its negative effects (Miyagiwa, 1991; Haque & jik Kim, 1995, for example).

The recent literature is less pessimistic. While recognizing the importance of human capital for economic development, it stresses a set of feedback effects through which the brain drain positively affects sending economies. As a substitute to official/public redistributive transfers, remittances constitute an important channel through which the brain drain may generate positive effects for origin countries. The new literature also puts forward a range of other "feedback effects" such as return migration after additional knowledge and skills have been acquired abroad, the creation of business and trade networks facilitating foreign direct investments and exports in the South, diaspora externalities on technology diffusion or the effects of migration prospects on human capital formation. Many elasticities have been estimated in the recent literature thanks to the new data sets presented above.

Nevertheless, to the best of our knowledge, there is no study in the literature that analyzes how all these direct and feedback effects interact. It is thus almost impossible to figure out what are the dominant and minor mechanisms at work. It is also difficult to assess the global impact of the brain drain on developing regions. The objective of this paper is to combine the major results of the empirical and theoretical literature in a unified general equilibrium model of the world economy. We use an overlapping generations framework with low- and high-skill workers. We divide the world in ten regions (three developed and seven developing regions) and model the various interdependencies between them. In our baseline scenario, we use an original back-solving calibration method that allows to exactly match the observed world disparities between and within regions. Increasing high-skilled migration has multiple effects on the equilibrium:

- ex-post (i.e. for a given number of educated natives in the South), it reduces human capital in origin regions. This affects their average productivity of labor and capacity to adopt modern technologies;
- the emigration of young individuals deteriorates the dependency ratio in the South;

- high-skilled migration stimulates (resp. deteriorates) the marginal productivity of physical capital in the North (resp. in the South). This leads to a reallocation of physical capital;
- high-skilled migrants abroad generate diaspora externalities in terms of foreign direct investments and diffusion of knowledge;
- new migrants remit a fraction of their income. Their propensity to remit depends on their level of education;
- increased migration prospects for the highly skilled stimulate the expected returns to schooling and generate more human capital formation ex-ante at origin.

Accounting for all these factors, our general equilibrium model allows us to provide a first global evaluation of the brain drain impact on economic activity, income, inequality in source and destination regions. It also allows us to disentangle the relative impact of each specific mechanism and to conduct robustness checks on key assumptions. This is important since there is still a lot of uncertainty about the magnitudes of some feedback effects, an uncertainty arising from the fact that causality is hard to establish using cross-section empirical studies.

A related study is Walmsley & Winters (2003) who used the World Bank's standard global general equilibrium model *LINKAGE* to estimate the gain from international migration. They simulated the impact of a three percent increase in South-North migration flows between 2000 and 2025. Considering that 70 percent of these new migrants are low skilled, the world real income would increase by 1.19 percent in US$ (i.e. a 39 percent elasticity to migration). The gain would be equal to 0.36 percent for natives in high-income countries (who benefit from the immigration surplus, reduced taxation). The gain would amount to 0.86 percent for natives in developing countries, mainly due to remittances. The main winners are new migrants who see their income multiplied by six in US$ and by two in PPP. Correcting for the change in the cost of life for these new migrants, the global increase on the world real income becomes 0.63 percent (i.e. a 20 percent elasticity to migration). The only loss of income is experienced by old migrants. The *LINKAGE* model leaves out many aspects of the brain drain debate. It does not account for the endogeneity of productivity and the links between human capital and technological changes at origin and destination. It disregards the potential of migration to spur higher investments (through diaspora externalities or brain gain effects). Except for remittances, it disregards the ties that migrants keep with their origin countries. Finally, since remittances play a crucial role, nothing guarantees that the same "win-win" outcome would be obtained if additional migrants would have higher skills (since high-skilled individuals are usually considered to remit a lower proportion of their income to their home country).

By incorporating human capital-related externalities and accounting for the various ties between migrants and their origin country, our model refines the World bank study in many ways. Our main results are the following:

- The high-skilled diaspora may contribute greatly to domestic production in the developing regions, as it decreases information-related risks and brings in higher amounts of FDI. However, this positive effect is dominated by the loss of labor force in regions where high-skilled emigration rates are high and/or population aging is acute.

- Remittances receipts play an important role in subsidizing the income of those left behind. Moreover, the magnitudes of their effect on GNI per capita are robust to different assumptions as to whether highly skilled emigrants remit less or not.

- The incentive effect of human capital formation (or the "brain gain" effect) is responsible for changes in the high-to-low skill income inequality. For regions where high-skilled emigration rates are low, while more human capital is formed due to better migration prospect for the highly skilled, more also remains at origin and helps to reduce the disparity between different types of workers. Moreover, in these regions, this compensatory effect also saves GDP per capita from a potentially large adverse impact due to high-skilled emigration.

- If the diaspora externality is weaker (i.e. less FDI) or the incentive effect is absent (i.e. less high-skilled and more low-skill workers), it is observed that the domestic production is adversely affected, which results in more pessimistic effects on GNI per capita. Furthermore, inequality also deteriorates when better migration prospects fail to induce more human capital formation.

- While some empirical studies show that the high-skilled diaspora accelerates technological progress in relatively backward countries, it is found that this effect is rather negligible on domestic production.

The remainder of this paper is organized as follows. Section 3.2 describes the model and its calibration. The analysis of simulated results is presented in Section 3.3. Robustness analyses are provided in Section 3.4. Finally, Section 3.5 concludes.

3.2 The model

We introduce international migration with skill heterogeneity into a general equilibrium model with overlapping generations of individuals. The world is divided into ten regions similarly to Ingenue (2005). We distinguish three developed regions, North America (NAM), Japan (JAP) and other high-income OECD countries (ADV). The latter group is essentially made up of European Union countries but also comprises Australia and New Zealand. We distinguish seven developing regions, Eastern Europe (EAS), Middle East and Northern Africa (MEN), Latin America and the Caribbean (LAC), Sub-Saharan Africa (SSA), the Former Soviet Union (RUS), the Chinese world (CHI) and the Indian world (IND).

Table 1: Regional characteristics in 2000 (in %)

Region	Demog	Human	Average	High-skilled	Low-skilled	Rem/Y
CHI	36.6	3.8	0.5	7.3	0.2	0.8
EAS	3.9	12.4	6.6	11.8	5.3	1.3
IND	30.3	4.5	0.4	5.2	0.2	1.8
LAC	10.2	11.8	4.3	11.0	3.1	2.0
MEN	6.2	8.5	3.5	8.5	2.8	2.8
RUS	3.0	18.9	2.0	2.6	1.8	0.6
SSA	9.7	2.8	0.8	12.9	0.4	2.6

Source: Docquier et al. (2009) and IMF.

Our analysis focuses on developing regions. Table 1 characterizes the demographic patterns of these regions, i.e. their demographic share in the population aged 25+ of the developing world (Demog), the proportion of highly skilled in the resident population (Human), their average emigration rate towards the OECD members (Average), the emigration rates of high- and low-skill workers (High-skilled and Low-skilled) and the ratio of remittances to GDP (Rem/Y). Regarding remittances, the amounts presented in Table 1 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.

Each region has three types of agents: households, firms and the public sector. The adult population is divided into 8 overlapping generations, from age 15-24 to age 85-94. Age is denoted by a=0, ... ,7. Individuals have uncertain lifetime and can die at the end of every period. In each generation, we have time-varying proportions of low-skilled and high-skilled individuals. Due to data availability constraints, the highly skilled are those with post-secondary education completed.

Migration occurs at the first period of life and is permanent. This is a realistic assumption since we focus here on the migration of high-skill workers, who are most likely to emigrate on a more permanent basis with their family members. We only track migrants from the South to the North. Other international migrants are included in the demographic forecasts.

The model has two main blocks with a recursive structure. In order to account for the empirical elasticities estimated in the literature, we build an 'upstream block', calibrated outside the core of the model using data and empirical studies. This block predicts the evolution of demographic variables, human capital and the magnitude of diaspora externalities. Then, these predictions are introduced in a 'micro-founded general equilibrium block' which generates predictions for the world output, prices, remittances, asset accumulation, the geographical allocation of assets, the international flows of capital income and many other endogenous variables. In fact, one may have the feeling that the non-micro founded block is less coherent than the micro-founded one, where variables are generated through the optimization behavior of households and firms. Usually CGE works are criticized because the parameters used are calibrated to match observed values of specific indicators at a given moment and are thus disconnected from the empirical evidence. In the present work, we believe that the non-micro founded block is an improvement upon such criticism since we calibrate some parameters using existing estimations. In the next sub-sections, we describe the structure of these two blocks.

3.2.1 The upstream block

The upstream block is used to predict the evolution of demographic variables, the effect of migration on human capital accumulation and the magnitude of diaspora externalities. Starting from the U.N. forecasts, our shock involves a 10% increase in the flows of emigrants originating from each region between 2000 and 2050. These additional migrants are assumed to be highly skilled. Their allocation by destination region is assumed to be identical to the one observed in 2000. Such a change could be due to increasingly selective immigration policies at destination. Figures 3.3 to 3.6 display the evolution of six indicators/variables under the baseline (left panel, labeled "a") and under the various shocks accompanying high-skilled emigration (right panel, labeled "b"). Each of these figures will be commented successively in this section along with a description of the specific shock corresponding to it.

Population. Individuals reaching age 0 at year t belong to the generation t. The size of the young generation increases over time at an exogenous growth rate:

$$N_{0,t} = m_{t-1} N_{0,t-1},$$

where $N_{0,t}$ measures the initial size of generation t and m_{t-1} is one plus the demographic growth rate, including both fertility and migration.

At every period, agents of the same age class ($a = 0, 1, ..., 7$) face an identical cumulative survival probability, which decreases with age. Hence, the size of each generation declines deterministically over time:

$$N_{a,t+a} = P_{a,t+a} N_{0,t}$$

where $0 \leq P_{a,t+a} \leq 1$ is the fraction of generation t alive at age a (at period $t+a$). Obviously, we have $P_{0,t} = 1$.

Denoting by ϕ_t the proportion of highly skilled (post-secondary educated) among the first cohort, the high- and low-skilled cohort sizes are given by:

$$\begin{aligned} N^h_{0,t} &= \phi_t N_{0,t} \\ N^l_{0,t} &= (1 - \phi_t) N_{0,t} \end{aligned}$$

We assume an exogenous participation profile per age and education group, $\lambda^j_{a,t}$. Hence, labor supply of type j at time t is given by

$$L^j_t = \sum_a \lambda^j_{a,t} N^j_{a,t}, \qquad j = h, l.$$

Specifically, we assume full participation except for the following three groups. First, young highly skilled spend a fraction of their time in obtaining education and do not fully participate in the labor market ($0 < \lambda^h_{0,t} < 1$). Second, part of the population aged 55 to 64 years old are retired ($0 < \lambda^j_{4,t} < 1$). Lastly, all individuals aged above 65 are retired ($\lambda^j_{a,t} = 0$ for all $a > 4$).

Demographic changes affect the economic performances of the economy (GDP or GNI per capita) through the support ratio, defined as the ratio of labor force to population:

$$SR_t = \frac{\sum_a \sum_j \lambda^j_{a,t} N^j_{a,t}}{\sum_a \sum_j N^j_{a,t}}$$

Finally, we define human capital as the proportion of highly skilled in the residents labor force:

$$HC_t = \frac{\sum_a \lambda^h_{a,t} N^h_{a,t}}{\sum_a \sum_j \lambda^j_{a,t} N^j_{a,t}}$$

In the baseline, we compute $P_{a,t+a}$, the probability for an individual of generation t of being alive at time $t + a$ and the population growth rate m_t for the period 1950 to 2050 from the United Nations data of World Population Prospects, the 2000 Revision. In order to compute the share of high-skilled individuals of a generation ϕ_t, we use the Barro-Lee Dataset (2001), which provides data on the educational attainment of individuals aged 25 to 74 for the years 1950 to 2000 per country.[3] In the future, we assume that the young cohorts are educated as the young one in 2000.

As shown in figure 3.3.a the Chinese world (CHI) and the Middle Eastern and North African region (MEN) have the largest high-skilled diaspora, i.e. the number of highly skilled individuals living abroad. One aspect of the demographic evolution in each region is described in figure 3.4.a. While the in some regions, in the Indian world (IND), MEN and Sub-Saharan Africa (SSA), working age population (individuals aged 15 to 64) increases during the 21^{st} century, it decreases in some others as in CHI, the Eastern European countries (EAS) and the Russian world (RUS). This reduction in the labor is one factor contributing to the aging phenomena arising in most regions. The evolution of the support ratio (the proportion of labor force to the total population) is an indicator of the aging pattern of the population and its evolution in the baseline is depicted in figure 3.1.a. We see that, according to the U.N. Population Projections, almost all the developing regions of our model will be affected by the aging process of their populations during the 21^{st} century. The only exception, is Sub-Saharan Africa (SSA) which keeps having the highest proportion of young people among the developing regions. In contrast, the Eastern European countries (EAS) will have to cope with the oldest population among the seven regions.

In the baseline scenario, we assume that future young cohorts are educated like the 2000 young cohort. Since cohorts born before 2000 are less educated than the ones born from 2000 onwards, our assumption induces a progressive rise in the average level of human capital depicted in Figure 3.2.a. The proportion of highly skilled is lowest in SSA.

South-North migration. In order to calibrate migration stocks and flows for the

[3]We firstly aggregate this data set by region and then partition it to obtain shares of highly skilled per age group. We proceed as follows in order to dis-aggregate the Barro-Lee data by age group. First, it is reasonable to assume that, at each period, the share of highly skilled individuals is higher for the younger age class. In particular, we assume that the share of highly skilled individuals aged 85 to 94 corresponds arbitrarily to 80% of the share of 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 highly skilled per age class then depend on the share of highly skilled aged 25 to 34, we compute this share in order to matches the total share of 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 highly skilled aged 35 to 44 in 1960 is equal to the share of highly skilled aged 25-34 in 1950, as we assume that the 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 highly skilled aged 25 to 34 in the same way as for the year 1950. Lastly, the share of highly skilled aged 15 to 24 in 1950 is simply equal to the share of highly skilled aged 25 to 34 in 1960.

baseline, we explicitly track migrants from the seven developing regions into the three developed regions. North-North and South-South migrants are implicitly dealt with through the U.N. population data and forecasts. Our calibration strategy is based on immigrant-to-population ratios, or the proportions of stock of immigrants to total population observed in the three developed regions. To begin with, we use published statistics on the number, age structure and education levels of immigrants in 2000 (combining the U.N. and the Docquier-Marfouk datasets). From the gross number of immigrant stock in each region, we subtract the number of 0 to 14 years old migrants, and then we subtract all North-to-North migrants. Based on the Docquier-Marfouk dataset, we calibrate the shares of immigrants by education level and by region of origin. To construct the number of migrants before 2000, we use survival probabilities as well as the growth rate of the immigrant population. 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 the change in the stock of immigrants follow the UN forecasts (from which we subtract the 0-14 years old and North-to-North migrants using the 2000 proportions). We assume that future migrants are distributed by educational level and by origin as in 2000.

As mentioned above, our shock involves a 10% increase in the flows of emigrants originating from each region between 2000 and 2050. These additional migrants are assumed to be highly skilled. Figure 3.3.b, depicts the change in the high-skilled diaspora compared to the baseline. MEN and LAC will experience the highest increase in their number of highly skilled abroad (>25% in 2050). In all the regions, the increase will be largest in 2050 when all the ‘additional’ high-skilled migrants left their region of origin.[4] Figure 3.4.b represents the change in the working age population due to the migratory shock (compared to the baseline). Increasing emigration by ten percent will obviously reduce the number of people aged 15 to 64, since only the individuals from the youngest cohort are assumed to migrate. Similarly, increased migration will also depress the support ratio as shown in figure 3.1.b. The most serious drops in the working age population and in the support ratio are expected for the Eastern Countries and Latin America.

Brain drain versus brain gain. A recent wave of theoretical contributions demonstrates that high-skilled migration can raise the average of human capital in the sending countries Mountford (1997a); Stark et al. (1997, 1998); Vidal (1998); Beine et al. (2001a); Stark & Wang (2002). These papers assume that the return to education is higher abroad and that high-skill workers have a much higher probability to emigrate than low-skill workers (a hypothesis strongly supported by the

[4]The highest change in the number of high-skilled emigrants occurs at a later period for EAS, because its high-skilled diaspora is expected to fall in the baseline after 2050.

data). Hence, migration prospects raise the expected return to human capital and induce more people to invest in education at origin. Ex-ante, more people opt for education. Ex-post, some of them will be leaving. Under certain conditions detailed in these models, the incentive effect (or brain effect) dominates that of actual emigration (or drain effect), which creates the possibility of a net brain gain for the source country.

Beine et al. (2008) found evidence that the prospect of high-skilled migration is positively associated with gross or ex-ante (pre-migration) human capital levels in cross-country regressions. They used a β-convergence empirical specification:

$$\Delta ln\left(HC_t^a\right) = \alpha - \beta \ln(HC_t^a) + \gamma ln(m_t^h) + \sum \eta_i X_{i,t}$$

where $\Delta ln\left(HC_t^a\right)$ is the growth rate of human capital between t and $t+1$, HC_t^a denotes human capital measured as the proportion of highly skilled among natives at time t (superscript a stands for natives, or human capital ex-ante, before emigration occurs), m_t^h is the high-skilled emigration rate, $X_{i,t}$ is a vector of other control variables, $(\alpha, \beta, \gamma, \eta_i)$ is a set of parameters. The long-run elasticity of natives' human capital to the high-skilled emigration rate is equal to $\frac{\gamma}{\beta}$. It amounts to 9.6 percent in the parsimonious IV model. To perform the above estimation, Beine et al. (2008) use the data on human capital by Barro & Lee (2001b) and on migration by Docquier & Marfouk (2006). Given the availability on migration data by skills in the latter dataset, the growth rate of the ex ante stock of human capital (i.e., including emigrants) is defined between 1990 and 2000, $\Delta ln\left(HC_t^a\right) \equiv ln(HC_{2000}^a) - ln(HC_{1990}^a)$. Their sample comprises 127 developing countries excluding countries from the former USSR, Yugoslavia and Czechoslovakia (for consistency between the 1990 and the 2000 data points) as well as high-income countries, since their study focuses on the brain drain impact on developing countries. To evaluate the incentive hypothesis, they use a β-convergence empirical model and regress the growth rate of the ex ante stock of human capital (i.e., including emigrants) between 1990 and 2000.[5]

[5]Control variables include (i) the log of the initial level of ex ante human capital, $ln(H_{1990}^a)$, to capture potential catching-up effects: a negative sign for the coefficient a1 would indicate convergence in natives (residents plus emigrants) human capital among the countries sampled, (ii) the log of the high-skilled migration rate at the beginning of the period, as a proxy for the migration incentives faced by educated individuals, (iii) interaction terms of this initial high-skilled emigration rate, with dummy variables for whether the country's income per capita was lower than a given threshold at the beginning of the period, (iv) population density in 1990, as a proxy for the cost of acquiring education, (v) workers' remittances as a share of GDP, first because they can relax credit constraints on human capital investment, and second, because in the absence of statistics on return migration, they provide an indirect means of controlling for possible returns in subsequent periods, (vi) regional dummies for sub-Saharan African and Latin American countries.

In our simulations, we build on Docquier et al. (2009)'s data and compute the relative change in high-skilled emigration rates resulting from the rise in emigration flows to the North. We assume that these relative changes are experienced by all the countries belonging to the region. Using the above long-run elasticity, we compute the change in human capital of natives and residents (natives minus migrants). Assuming that the long-run level of human capital is reached in 2050, we compute the proportion of highly skilled among remaining residents, denoted by HC_t. We first do it country by country and then aggregate countries by region. The convergence to the 2050 level of human capital level is linear. Finally, we compute the change in ϕ_t required to obtain the desired levels of human capital. After 2060, the high-skilled emigration rates and the ϕ_t come back to their baseline value.

The effect of increased high-skilled migration may either enhance or deteriorate the level of human capital, depending on the calibrated elasticities of natives' human capital to the high-skilled emigration rate. Figure 3.2.b depicts the change in human capital in percentage points. The brain drain deteriorates the human capital level in SSA, EAS and LAC, while it turns out to be beneficial for IND, CHI and RUS. The effect on MEN is almost nil.

Total Factor Productivity (TFP). Regional output, Y_t, is determined by a Cobb-Douglas production function with two inputs, physical capital, K_t, and labor in efficiency unit, $A_t L_t$. The number of efficiency units of labor that a worker supplies depends on his/her level of education (captured in L_t) and on the aggregate level of technology (denoted by A_t):

$$Y_t = K_t^{\alpha} \left(A_t L_t\right)^{1-\alpha}$$

There is one leading regional economy, North America (NAM), in the sense that the Harrod neutral technological progress of each region is a fraction of A_t^*, namely that the leader is always ahead of other regions in terms of production technology. Exogenous paths for the Harrod neutral technological progress A_t and growth of the leading economy are unobservable and/or must be properly calibrated.

To obtain A_t for non-leading regions, we use the observed paths of GDP ratio, Y_t/Y_t^*, where Y_t^* is the leader's GDP. We proceed as in de la Croix & Docquier (2007), who use a backsolving identification method to calibrate Total Factor Productivity. It consists of swapping the exogenous variables A_t for the endogenous variables Y_t/Y_t^* and then solving the identification step with the Dynare algorithm Juillard (1996). The ratio of GDP's is computed by employing the data of the GDP per purchasing power parity from the World Development Indicators (WDI) for the three years 1980, 1990 and 2000. We adopt the value of 1980 for the years preceding 1980 and the value of 2000 for those following 2000. Finally, the leader's growth of Harrod neutral technological progress, is calibrated on real observations, and for future years, the value is calibrated such that the annual growth rate is equal to 1.84 percent.

Following Benhabib & Spiegel (2005), themselves building on Nelson & Phelps (1966b), we consider an endogenous Harrod-neutral technical progress of the neo Schumpeterian type. Technical changes are determined by the regional capacity to innovate and to adopt modern technologies. Vandenbussche et al. (2006), henceforth VAM, estimated a neo-Schumpeterian model using panel data on OECD countries. More recently, Lodigiani (2008) has extended the framework by adding a diaspora externality: high-skilled emigrants living in rich countries increase the capacity to adopt modern technologies. She re-estimated the model for a larger sample of 92 countries, including high-, middle- as well as low-income countries. Having 276 observations by using data for the years 1980, 1990 and 2000, she obtained the following specification:

$$\begin{aligned}\Delta ln\left(A_t\right) &= .59 - .28\ln\left(\frac{A_t}{A_t^*}\right) + 1.43HC_t - 0.10\ln(M_t^h) \\ &\quad +0.87\ln\left(\frac{A_t}{A_t^*}\right)HC_t - 0.06\ln\left(\frac{A_t}{A_t^*}\right)\ln(M_t^h) + \epsilon_t \qquad (3.1)\end{aligned}$$

where $\Delta ln\left(A_t\right)$ is the rate of technical progress, A_t^* is the technological level of the leader (typically, the NAM region), M_t^h is the stock of high-skilled emigrants living in the leading economy and ϵ_t is an exogenous component.[6] Confirming VAM, the interaction effect between proximity and the proportion of workers with tertiary education is positive, meaning that high-skill workers are more important for growth in economies closer to the frontier. On the contrary, the interaction effect between proximity and the log of high-skilled emigrants is negative, implying that high-skilled emigration has a decreasing effect on growth when a country approaches the frontier, or that migration is more important for countries far from the frontier. Backward countries, that rely more on adoption, can beneficiate more from the high-skilled diaspora as it facilitates technology and knowledge transfer from abroad.

In the baseline, we plug the human capital and migration forecasts in the above equation to predict the evolution of the technology. On the period 1950-2000, we calibrate ϵ_t so that our baseline simulations perfectly match the GDP observations

[6]We transpose this equation also to high-skilled migration to the other two developed regions. Thereby we assume that the diaspora in Japan and the Advanced Countries has a similar impact on the TFP of migrants' origin regions. This is not unreasonable since the total productivity level in these two developed regions is close to the North-American one: the technology levels of the Advanced Countries and of Japan are respectively 96% and 99% of the North-American one in 2000.

(as percentage of the leading economy). The calibrated path for ϵ_t is rather stationary and distributed around zero in all the regions except in the Indian world, the Chinese world and Eastern Europe where a positive trend is observed.

In our baseline forecasts, we consider that ϵ_t is equal to zero everywhere except in India, China and Eastern European countries where ϵ_t remains positive until 2100. Our baseline accounts however for a catch-up of China, India and Eastern Europe to North America. This would be in line with the recent accession of the majority of the Eastern European countries to the European Union and with the last years' increased growth pace of India and China. Likewise the assumptions of Ingenue (2005), the Eastern Countries will have increased their GDP per capita level by 25% compared to North America, while both the Chinese and Indian worlds will have doubled it (compared to the leader) by 2100. It is also assumed that 75% of this catch-up occurs between 2010 and 2050 while the remaining 25% between 2050 and 2100. These catch-ups to North America in the baseline are obtained by calibrating the productivity A of these regions via the backsolving identification approach described in previous paragraphs and represented by the exogenous parameter ϵ in the above 'technology' equation.

Figure 3.5.a depicts the evolution of the technological distance to the frontier in developing regions in the baseline. For IND and CHI the time path is increasing and the regions are approaching to the frontier. For CHI this effect is particularly strong. For EAS, the closest region to the frontier, the time path is first increasing and then slightly decreasing. For all these regions (IND, CHI and EAS), the path is exogenously imposed. For all the other regions (SSA, MEN, RUS and LAC) the time path is quite stable. Since our shock modifies human capital and the number of high-skilled emigrants abroad, it affects the rate of technical progress as well. Given the specification above, $\Delta \ln A_t$ increases in HC_t when $ln\frac{A_t}{A_t^*} \succ -1.64$ ($\frac{A_t}{A_t^*} > 19.4\%$), i.e. the economy is not too far from the frontier. Moreover, $\Delta \ln A_t$ increases in M_t^h if $ln\frac{A_t}{A_t^*} \prec -1.67$ ($\frac{A_t}{A_t^*} < 18.8\%$), i.e. when the economy is far from the frontier.

Figure 3.5.b represents the effect of our migration shock on the level of technology. A positive change is observed for IND and MEN, regions far from the technological frontier. However, albeit being the region farthest from the frontier, SSA suffers from high-skilled emigration because its domestic human capital is so low that technology adoption is very unlikely to occur even with an enlarged high-skilled diaspora. Therefore, the loss of an already scarce high-skilled population imposes a negative effect on SSA's technology. Given the mechanism explained above, a negative effect is instead observed for LAC, CHI and EAS. For RUS the effect is nil.

Confiscation rate. A large sociological literature emphasizes that the creation of migrants' networks facilitates the further movement of persons, the movement of goods, factors, and ideas between the migrants' host and home countries. Several studies investigated whether FDI and migration are substitutes (as one would expect) or complements. Using cross-section data, Docquier & Lodigiani (2009) find evidence of significant network externalities in a dynamic empirical model of FDI-funded capital accumulation. Their analysis confirms that business networks are mostly driven by high-skilled migration. Using bilateral FDI and migration data, Kugler & Rapoport (2007) also found strong evidence of a complementarity between FDI and high-skilled migration with a similar elasticity.

In our model, we assume that physical capital is mobile across regions, the optimal marginal productivity of capital is equal to the international interest rates r_t^* augmented of country-specific confiscation rate π_t reflecting informational costs or risks. The confiscation rate is endogenous and depends on the size of the high-skilled diaspora abroad (M_t^h). We have:

$$\begin{aligned} r_t^*(1+\pi_t) &= \alpha K_t^{\alpha-1}\left(A_t L_t\right)^{1-\alpha} - \delta \\ (1+\pi_t) &= (1+\pi_{0,t})\left(M_t^h\right)^{-\varphi} \end{aligned}$$

where δ is the capital depreciation rate, $\pi_{0,t}$ is an exogenous variables used to calibrate the baseline level of the confiscation rate and -φ is the elasticity of the confiscation rate to the high-skilled diaspora size.

Using panel data, Docquier & Lodigiani (2009) have estimated that the long-run elasticity of foreign direct investments to the high-skilled diaspora is equal to 0.75.More precisely, they use migration data contained in Defoort (2008), which provides high-skilled emigration stocks and rates from 1975 to 2000 (one observation every 5 years). This data focuses on six major destination countries representing 75 percent of the OECD total immigration stock. The study of Docquier & Lodigiani (2009) is based on 83 countries for a total of 332 observations in a balanced panel data set.[7] Using the specifications above and relying on the fact that foreign direct investments represent 12.5 percent of total investments in developing countries, the calibrated value for φ is equal to 0.05.

In the year 2000, we calibrate $\pi_{0,2000}$ in such a way that the regional confiscation rate reflects country risk rating. The confiscation rate is modeled here as governmental tax on investment. In a risky region, a part of an investor's returns

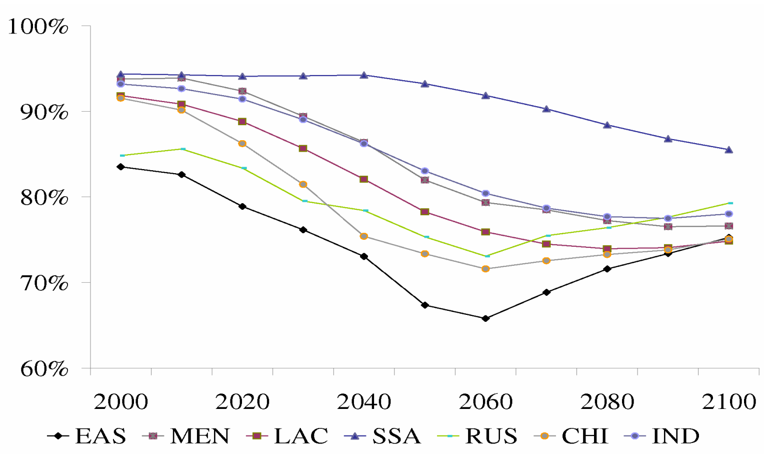
[7]They compute the growth rate of FDI-funded capital stock per worker for 4 sub periods of 5 year each (1980-85, 1985-90, 1990-95, 1995-00) and regress it on (i) total lagged migration stock, (ii) lagged share of high-skilled migrants, (iii) lagged FDI-funded capital (in logs), (iv) lagged GDP per capita (in logs), (v) labor force growth rate, (vi) lagged democracy score, (vii) dummy for high-income country, (viii) interaction term between lagged democracy score and the high-income dummy, (ix) lagged trade costs (in logs, the distance to most important countries) (x) interaction term between lagged trade costs and the high-income dummy (xi) and finally some time dummies.

to capital is collected by the government, who uses it for non productive purposes (e.g. extra-goods consumed by corrupted civil servants). We use data available from the OECD for region specific risk, which in turn rely upon the Knaepen Package methodology. To compute the risk classification per region, we take an arithmetic mean of ratings of the available countries[8].

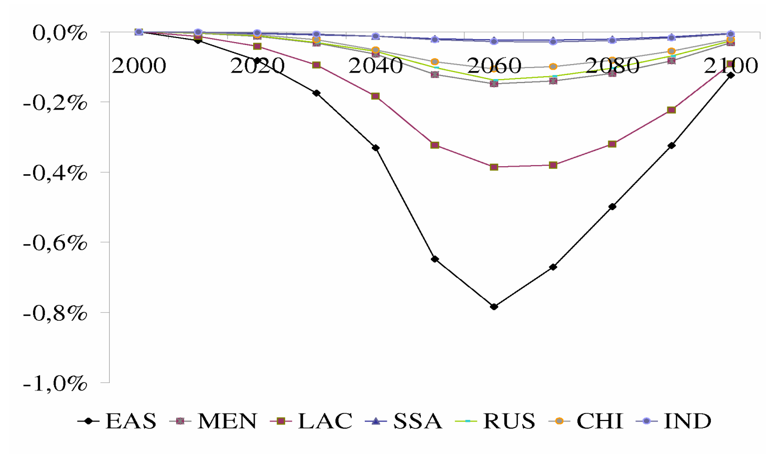
In the baseline scenario, $\pi_{0,t}$ is adjusted to keep the regional confiscation rate constant over time. Figure 3.6.a shows the flat profiles for $(1+\pi_t)$ in the baseline. Then, as our shock increases the size of the high-skilled diaspora abroad, it reduces the confiscation rate and stimulates *ceteris paribus* foreign direct investments at origin. The intuition is as follows. When there are more high-skilled migrants abroad, the information costs or information-related risks will decrease, migrants in fact can provide important information to foreign investors, which may otherwise be difficult or costly to obtain, and they can reduce communication barriers. Therefore, the return to capital increases and so does FDI. Figure 3.6.b shows how $(1+\pi_t)$ varies over time. In particular, the largest change in π occurs in MEN and in LAC. MEN and LAC have the largest increases in high-skilled diaspora, which contributes to the large effect. In contrast, in relative terms, CHI has a very small increase in diaspora, thus the change in π is very small too.

[8]The Knaepen Package is a system for assessing country credit risk and classifies countries into eight country risk categories (0 - 7), from no risk (0) to high risk (7). Basically, it measures the credit risk of a country. In our calibration, there are no risks for the three developed regions whereas the seven developing have risk classifications as follows: CHI (3.2), EAS (3.4), MEN (4.2), IND (4.9), LAC (5.2), RUS (6.2) and SSA (6.4).

Figure 3.1: Support Ratio

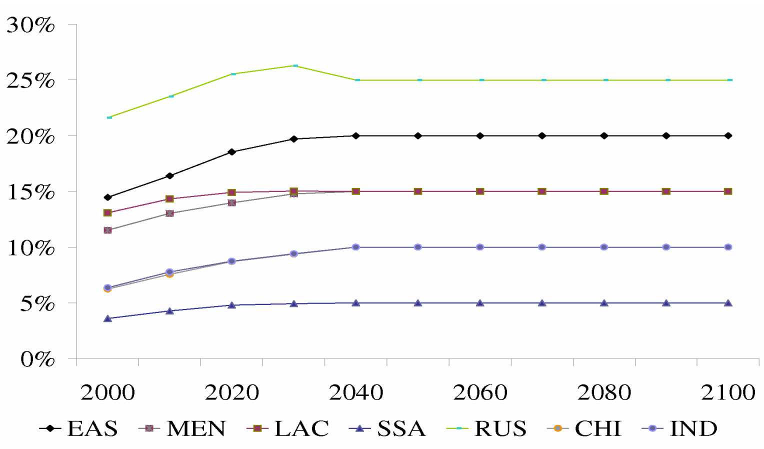


a. Baseline value

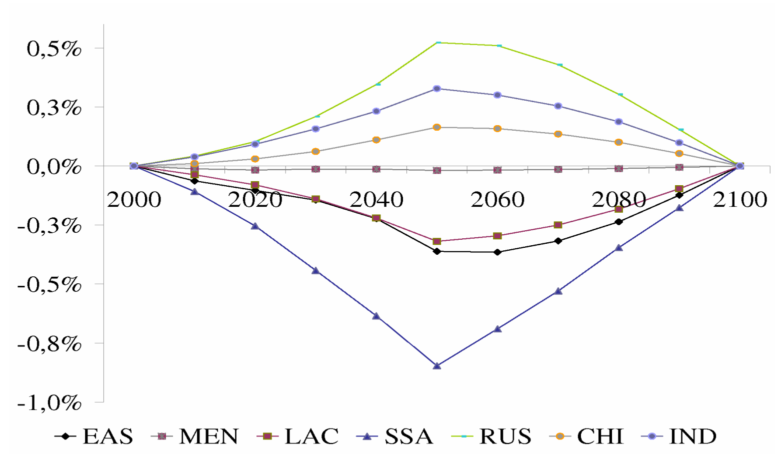


b. After Shocks (change compared to baseline)

Figure 3.2: Human Capital

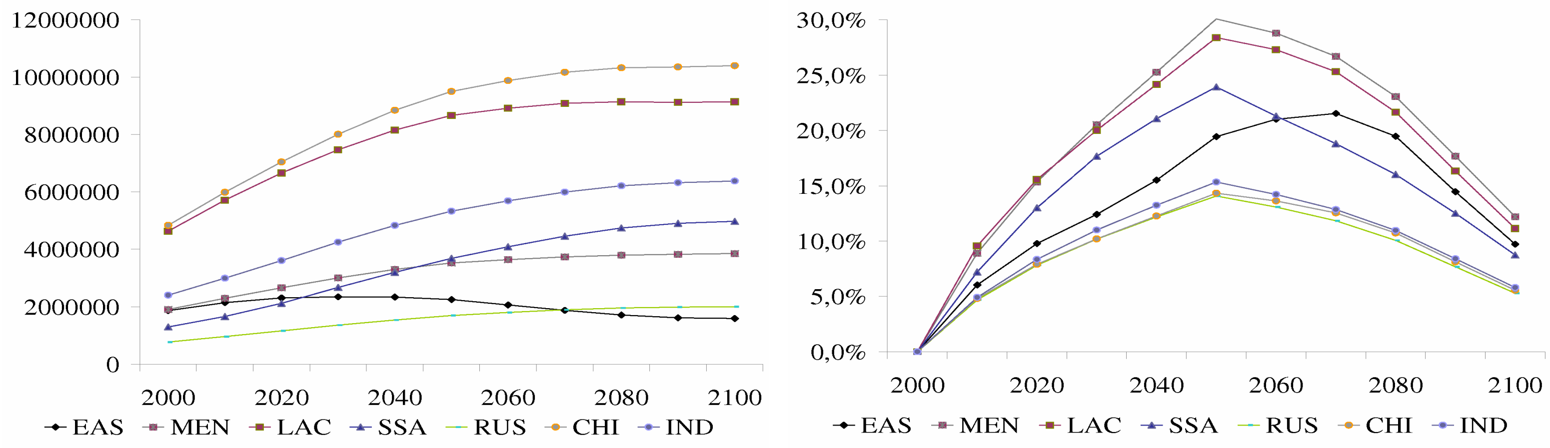


a. Baseline value



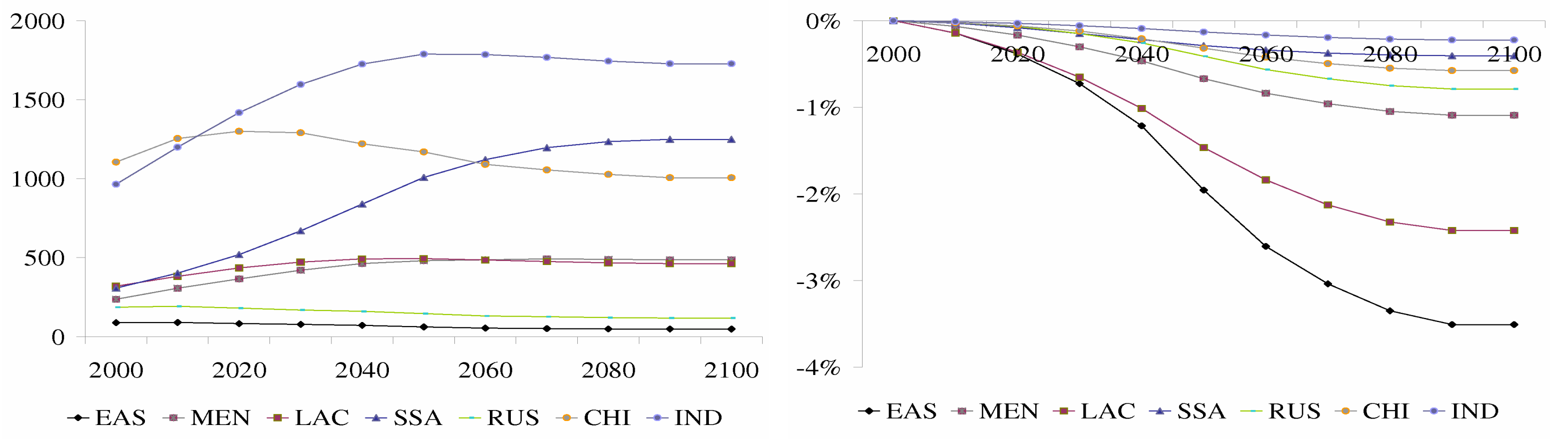
b. After Shocks (change compared to baseline)

Figure 3.3: High-skilled Diaspora (Number of high-skilled individuals living abroad)



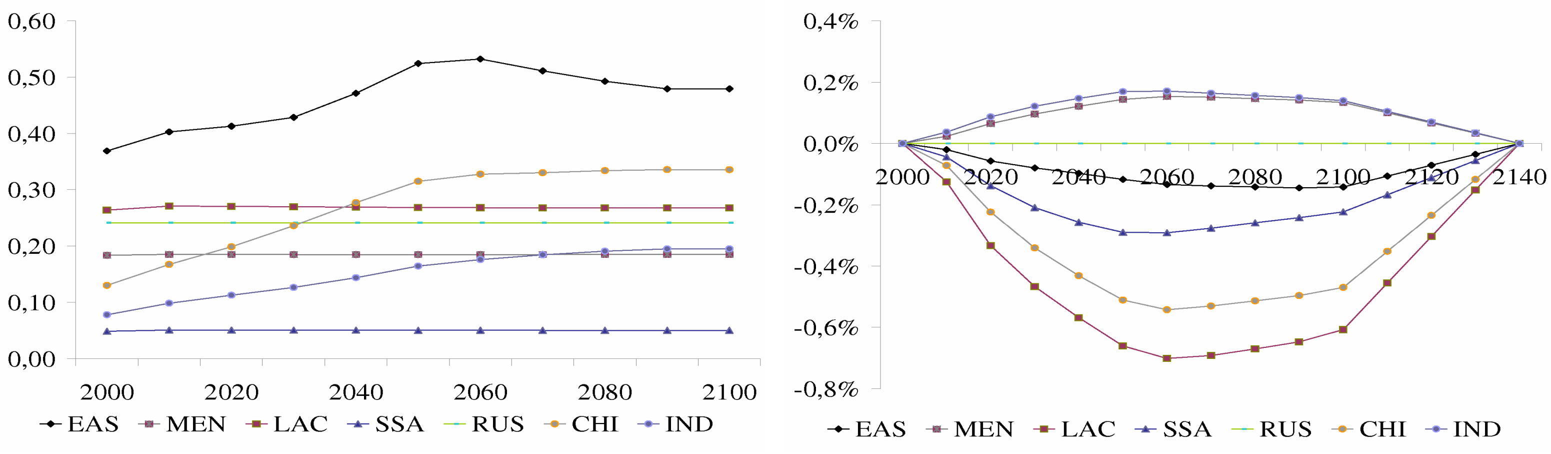
a. Baseline value *b. After Shocks (change compared to baseline)*

Figure 3.4: Working age population (Individuals aged 15 to 64)



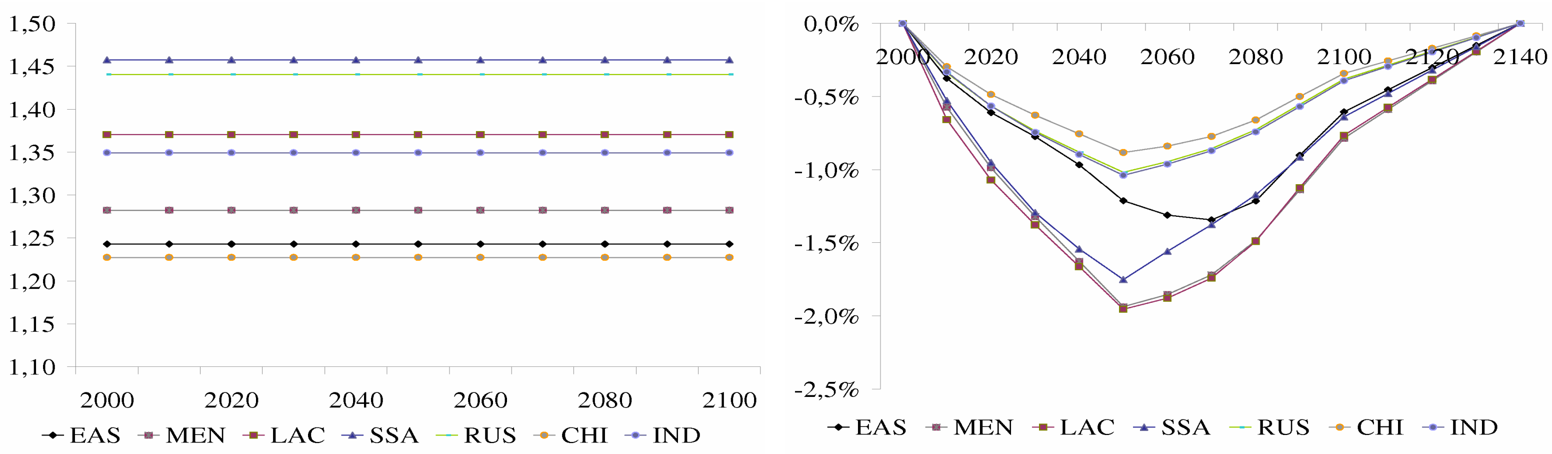
a. Baseline value (in millions) *b. After Shocks (change compared to baseline)*

Figure 3.5: Technological Progress



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

Figure 3.6: Confiscation Rate



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

3.2.2 The micro-founded block

The global impact of the brain drain also depends on its effects on labor and capital income (at destination and origin), on asset accumulation by region, on the amounts remitted by emigrants and on the distribution of these remittances. To simulate these effects, we use a micro-founded block depicting firms', states' and households' behaviors.

Preferences. The expected utility function of our agents 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 $c_{a,t+a}^j$ represents expenditures of age class a at time $t+a$. For natives in both developing and developed regions, $c_{a,t+a}^j$ is equivalent to goods consumption. However, for immigrants in the developed regions, $c_{a,t+a}^j$ is a Cobb-Douglas combination of goods consumption ($c^{M,j}$) and remittances ($RM^{M,j}$)

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

where γ^j is an age-invariant propensity to remit that determines the proportion of expenditures a migrant in the skill group j sends as remittance to his region of origin. This parameter varies with region of origin.[9]

Furthermore, following de la Croix & Docquier (2007), we postulate the existence of an insurance mechanism à la Arrow-Debreu. Each time after an individual dies, her/his assets are equally distributed among individuals belonging to the same age class. Individuals thus maximize their expected utility subject to a budget constraint requiring equality between the discounted expected value of expenditures and the discounted expected value of income, which consists of net labor income, pension benefits, other welfare transfers and/or net remittances. The household optimization problem determines the age profiles for consumption, remittances, saving and asset accumulation.

Controversies on remittances. In the former optimization problem, the only parameters to be calibrated are the propensities to remit of migrants, γ^j $(j = h, l)$. These parameters are assumed to vary by education level and region of origin. Disregarding differences by education level, it would be easy to fix γ so as to perfectly match the remittances/GDP ratios observed in developing regions.

[9] We model remittances in this way so that migrants and natives have identical asset accumulations. The age-invariance of propensity to remit comes from our assumption that there is no remittances decay.

However, it is important to capture the potential heterogeneity in propensities to remit since remittances constitute an important source of income for developing countries (see Table 1).

Although little attention has been paid to the role of migrants' skills, the empirical literature on the determinants of remittances is ambiguous. Ratha (2003) argued that educated migrants earn more and remit more, which suggests that the cost of the brain drain can be offset by migrants' transfers. Using aggregate data, however, Faini (2007) challenged this view with very different results: the amount of remittances increases in the number of migrants but decreases with their average educational attainment. One interpretation is that educated migrants tend to come from better off families who rely less on remittances for their livelihood. Another argument is that educated migrants are more likely to settle permanently and to bring their close family members into the destination country; thus, they have less incentives to remit. The shortcoming of such type of papers is that they rely on cross-country data, and therefore, the causality put forward in their arguments is extremely hard to establish, especially as some papers demonstrate that remittances may alleviate liquidity constraints and allow people to obtain more education in the origin countries (see Cox Edwards & Ureta (2003) and Duryea et al. (2005)). Nimii et al. (2008) recently accounted for such endogeneity problems. Using Instrumental Variable (IV) regressions, they confirm that remittances are negatively correlated with the average level of schooling of migrants, i.e. the highly skilled remits less.

In spite of this evidence, it does not imply that remittances sent by high-skilled migrants are negligible, particularly if the high-skilled proportion of temporary migrants increases. For example, Kangasniemi et al. (2007) show that nearly half of Indian medical doctors working in the United Kingdom send remittances back to India and that these transfer on average represent 16 percent of the remitters' income. In addition, cross-country regressions could suffer from a bias of omitted variable. The average level of schooling of migrants is strongly correlated with the level of schooling of residents: the more educated residents, the higher their income and the less they need remittances.

Another source of uncertainty concerns the distributional effect of remittances in the recipient region. Taylor & Wyatt (1996) find that remittances are distributed rather evenly amongst the sampled income groups in rural Mexico. Moreover, remittances have the highest shadow value for households at the lower end of income distribution since the additional income helps to relax credit and risk constraints. Hence, they conclude that remittances have an equalizing effect on income inequality at origin. In contrast, Barham & Boucher (1998) argue that the equalizing effect is found mainly because remittances are treated as an exogenous transfer. Instead, they construct counterfactuals with no migration and no remittances in order to study how they affect income inequality in Bluefields, Nicaragua. After controlling for self-selection problems, it is found that the potential home earnings of migrants have a more equalizing effect than remittances; in other words, inequality is deepened with migration and remittances. In addition, several studies show that the relationship between remittances and inequality exhibits a Kuznets curve. Stark et al. (1986) and McKenzie & Rapoport (2007) suggest that the network effect lowers migration costs over time and thus gradually facilitates migration from the low-income households. Hence, in the beginning when only the high-income households can afford migration costs, inequality is accentuated because remittances are received at the higher end of income distribution.

Given the controversies above, we simulate our model with three variants of remittances behavior, that will be explained in Section 3.4.

Firms. At each period of time 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). As stated in the previous section, we assume a Cobb-Douglas production function with constant returns to scale,

$$Y_t = K_t^{\alpha}(A_t L_t)^{1-\alpha}, \tag{3.2}$$

where α measures the share of capital returns in the national product, and A_t is an exogenous process representing the Harrod neutral technological progress. Total efficient labor force combines the demands of highly skilled (L_t^h) and of low skilled labor (L_t^l) according to the transformation function characterized by a constant elasticity of substitution (CES):

$$L_t = [\upsilon_t (L_t^h)^{\sigma} + (1-\upsilon_t)(L_t^l)^{\sigma}]^{1/\sigma}, \qquad \sigma < 1 \tag{3.3}$$

where υ_t is an exogenous high-skill biased technological progress, and σ is defined as σ=1 $- \frac{1}{\varepsilon}$, with ε being the elasticity of substitution between high- and low-skill labor. The capital share in output α is set to one third, as estimated in the growth accounting literature. We follow Acemoglu (2002) in fixing the elasticity of substitution ε to 1.4 and thus the parameter σ equals to 0.2857 in the CES function. Regarding the high-skill biased technological change, we apply the same procedures as for TFP (A_t) by using skill wage premiums, $h_t = w_t^h / w_t^l$. The skill premiums for each region in year 2000 are arbitrarily fixed.[10] Then, we let these values vary according to the pattern of the US college wage premium for the period 1950-2000 in Acemoglu (2003b).

[10] h_{2000} are fixed at 3 (NAM), 2.35 (ADV), 3 (EAS), 3 (MEN), 3.15 (LAC), 3 (JAP), 3.5 (SSA), 3.25 (RUS), 3.25 (CHI) and 3.25 (IND).

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.

The pension system is modeled in a way as to allow for different pension systems in each region. The regional pension systems are partly Bismarckian (benefits proportional to wages) and partly Beveridgian (lump-sum benefits). We use a region-specific parameter capturing the wage-related fraction of benefit. The government's budget constraint is satisfied at each period by adjusting the wage tax rate τ_t^W. Public debt d_t is computed from the WDI Database. Exceptions are the public debt of the ADV and the JAP regions, which are obtained from the OECD data on Gross Financial Liabilities.

Equilibrium. A competitive equilibrium of the economy with perfect capital mobility is characterized by (i) households' and firms' 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 arbitrage condition of the rates of return to capital. The equilibrium on the goods market is achieved by Walras' law.

3.3 Interpretation of simulated results

In this section, we interpret the simulated results of a selective immigration policy, which in effect increases by ten percent the outflows of emigrants (all assumed to be highly skilled) from each developing region into the developed world. Our period of interest is 2000-2100, or the year before the first wave of additional migrants in the developed regions to the year when the last wave is entirely retired. We pay special attention to year 2060, or when the first wave of migrants is fully retired and the last wave fully joins the workforce. The development indicators in question are defined as follows.

- **GDP per capita**: total domestic production divided by total population, $\frac{Y_t}{N_t}$.
- **GNI per capita**: GNI, composed of GDP minus consumption taxes plus foreign aid, remittances receipts and net capital inflows, divided by total population.[11]
- **high-skilled/low-skilled inequality**: ratio of high-skilled to low-skilled GNI per capita, $\frac{GNI_t^h/N_t^h}{GNI_t^l/N_t^l}$.

[11] Net capital inflows are calculated as natives' assets minus capital used in domestic production.

A selective immigration policy affects the indicators above through four different channels, including demography, human capital, technological progress, and information costs/confiscation rate. We begin with the discussion with the disentangled effects on GDP per capita, then we turn our analysis to total impacts on GDP and GNI per capita, as well as on high-to-low skill inequality.

3.3.1 Disentangled effects on GDP per capita

The disentangled effects on GDP per capita are depicted in Figure 3.7.

Demography. Increased high-skilled emigration acts to reduce the size of the youngest cohort at origin. While reducing the working age population at origin, migrants settle in the North and add into the work force at destination.[12] This reallocation of labor results in higher returns to capital in the technologically more advanced North, and therefore, labor outflow is accompanied by a more than proportional capital flight to the developed regions. As a consequence, GDP per capita is negatively impacted in the South (see Figure 3.7.a). It is observed that EAS and LAC experience the largest negative impacts, mainly due to their very high emigration rates. Although the shock is the same for each region (ten percent increase in emigration flows), additional outflows triggered by a selective immigration policy result in huge losses in the labor force in regions that experience already large emigration rates. Moreover for EAS, its serious aging problem further exacerbates the impact of losing working-age population.

Human capital. On the one hand, increased high-skilled emigration acts to reduce the average human capital of the youngest cohort, by changing its skill composition. On the other hand, however, it may induce more human capital formation through the so-called brain gain effect. Figure 3.7.b depicts the isolated effect of human capital on GDP per capita. For regions where this incentive effect more than fully compensates for the loss of the high-skilled youngsters, a more skilled working force contributes positively to GDP per capita. For instance in RUS, the effect is always positive. For regions with significant high-skilled emigration rates, however, a selective immigration policy tends to worsen brain drain. EAS experiences the worst impact, and it is closely followed by LAC and SSA.

Technological progress. The distance to the technology frontier is affected by increased high-skilled emigration, as it modifies human capital at origin and the

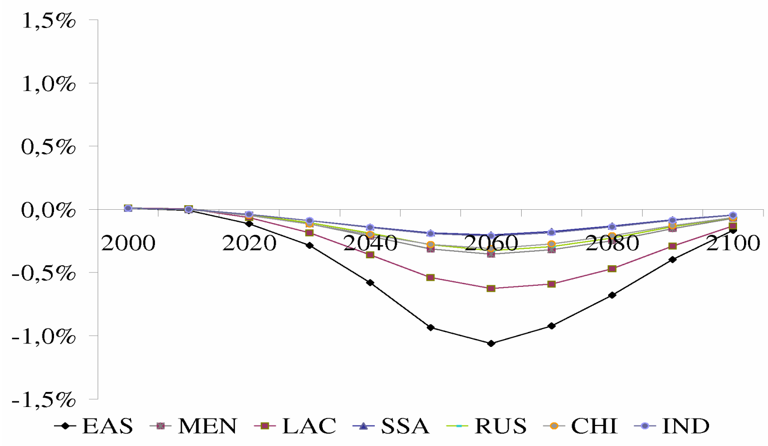
[12] When isolating the effect of m_t, the total amount of remittances receipts are kept constant at the baseline. This means that remittances receipts per capita change since the population at origin is reduced.

size of high-skilled diaspora abroad (and therefore the capacity of a region to innovate or to adopt).

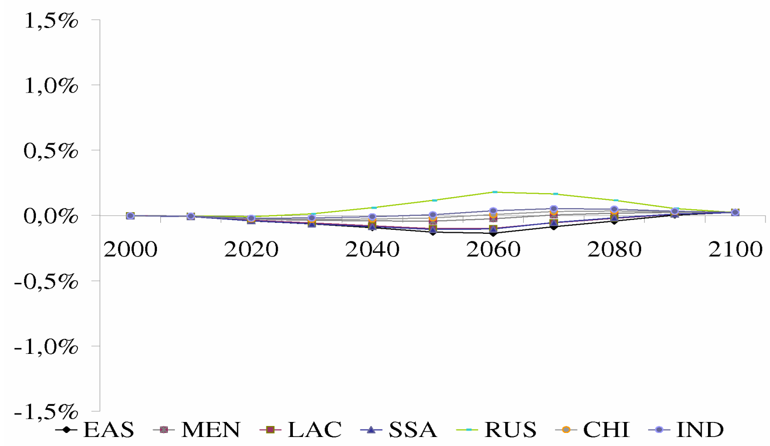
Given this mechanism, it is found that MEN and IND experience positive effects in terms of GDP per capita, thanks to technological progress through adoption, that is enhanced by enlarged high-skilled diaspora. For more advanced regions, however, an increase in the number of emigrants has negative effects on technology, and consequently on GDP per capita, due to loss of high-skill workers who are crucial in terms of innovation. For instance, CHI is close enough to the frontier to experience a negative effect in terms of GDP per capita. In general, for all the regions the effect is relatively small.

Transaction costs. Transaction costs, or the information related confiscation rate, π_t, may be reduced by the high-skilled diaspora externality. As our shock increases the size of the high-skilled diaspora abroad, it reduces the confiscation rate and stimulates *ceteris paribus* foreign direct investments at origin for all the regions. With more FDI, capital inputs are increased and, consequently, total domestic production, thus contributing to positive effects on GDP per capita. The effect is quite important for all the regions. In particular, the largest effects occur in MEN and in LAC, regions with the largest change in high-skilled diaspora. In contrast, as CHI has a small increase in diaspora in relative terms, the change in π is rather small .

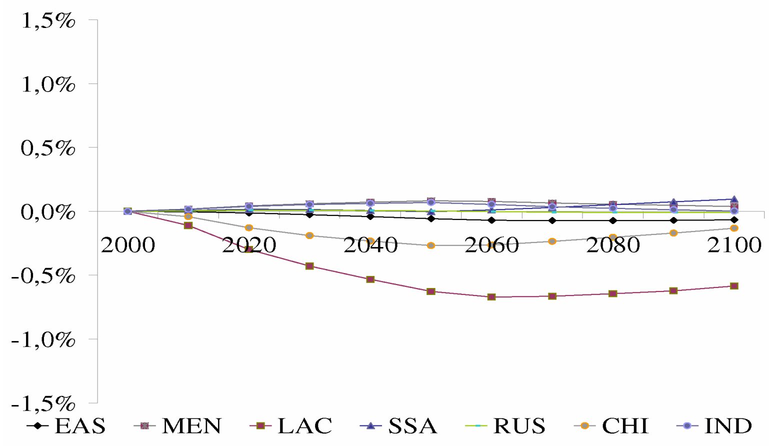
Figure 3.7: Disentangling the change in GDP per capita



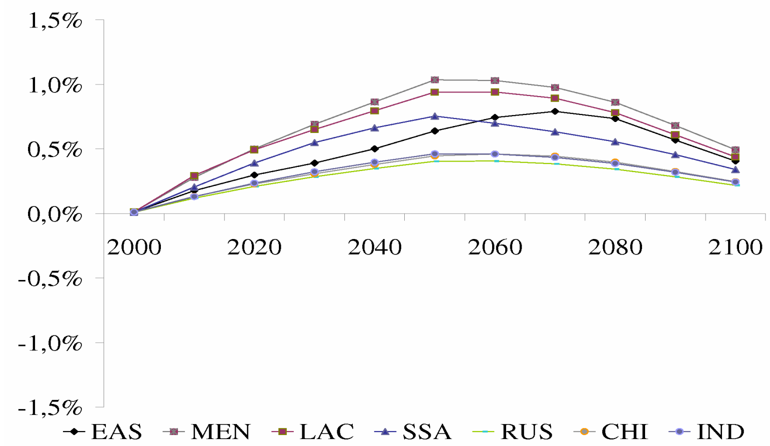
a. Through demography



b. Through human capital



c. Through technological progress



d. Through transaction costs

3.3.2 Total impact

GDP per capita. The total impact of a selective immigration policy on GDP per capita mainly results from the interplay between changes in demography and in transaction costs. The overall effects are positive for MEN, SSA, IND, and RUS, ranging from 0.22% to 0.67% in 2060 (see Figure 3.8.a). The major contributor is the diaspora externality, for that it brings in more FDI due to lower information costs. Moreover, these regions suffer only slightly in terms of working-age population, either because they have a relatively low-skill labor force or their high-skilled emigration rates are not very high. In contrast, despite a decreased confiscation rate, the total effects are negative for EAS and LAC. This is because both regions are encountered with significant high-skill emigration rates, and as already mentioned, there is a serious aging problem occurring in EAS; moreover, LAC experiences very negative changes in terms of technology, which further damage its domestic production. Lastly for CHI, the total impact is slightly negative mainly due to the adverse effect of high-skill emigration on technology innovation.

GNI per capita. In terms of GNI per capita, the channels at work are the same as for GDP per capita, except that remittances also come into play and act to alleviate the negative impact on GDP per capita. In fact, from the perspective of migrant sending regions, the direct impact of an enlarged diaspora is to increase the amount of remittances receipts, and the impact is rather sizable (see Figure 3.8.b). It is the largest in MEN, which is also the region with the largest increase in remittances thanks to a selective immigration policy. Moreover, remittances receipts have a very significant poverty-reducing effect for poorer regions, such as SSA, where even a very small amount of remittances can account for a large part of national income.

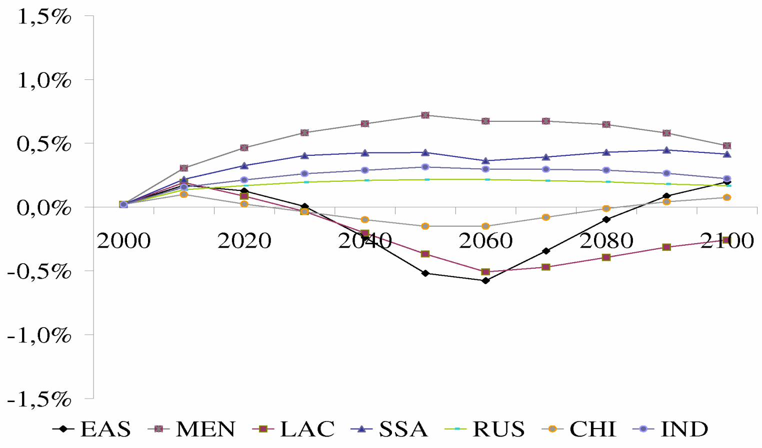
The total impact is generally positive for all regions and at all periods after the shock (see Figure 3.8.c). The optimistic overall effects mainly come from two sources: i) increased GDP per capita through more FDI, and ii) remittances receipts, with the former contributing more to enhancing GNI per capita. The only exception is EAS in 2060, when it experiences the worse impact in terms of domestic demographic structure. This negative demographic effect outweighs its large increases in remittances receipts, which have a less pronounced effect in EAS when compared to more impoverished regions.

Inequality. So far as the high-to-low skill inequality is concerned, the total impact is mostly driven by the effect on skill composition of human capital, which leads to changes in the skill premium. That is to say, inequality falls (rise) in regions with net brain gain (drain).

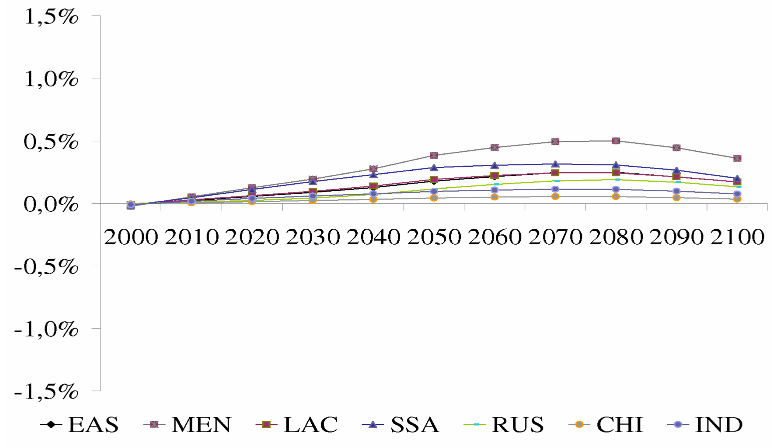
In regions where the brain gain effect is absent, reductions in the size of youngest cohort bring down the average skill level in the source economy since younger cohorts in the model are more skilled than the previous generations (see Section 3.2.1). Hence, when skilled labor becomes scarcer, the skill premium goes up and skilled-to-unskilled income inequality worsens. This is especially the case for SSA, for that it has a very low level of human capital to begin with. MEN and LAC are the two exceptions, however, where remittances increase by the highest degree and contribute the most to inequality reduction, under an equal-sharing scenario for remittances.

Last yet not the least, it follows from Beine et al. (2008) that regions with the largest high-skill emigration rates are those who do not benefit from brain gain but suffer brain drain. In the meantime, they are also the regions that are most seriously impacted, in terms of demography, by the high-skill biased immigration policy. Thus, when a region (e.g. EAS) finds its GDP per capita adversely impacted mainly due to a strong demographic impact, it will also find that it is its low skilled population who disproportionally shares this hardship.

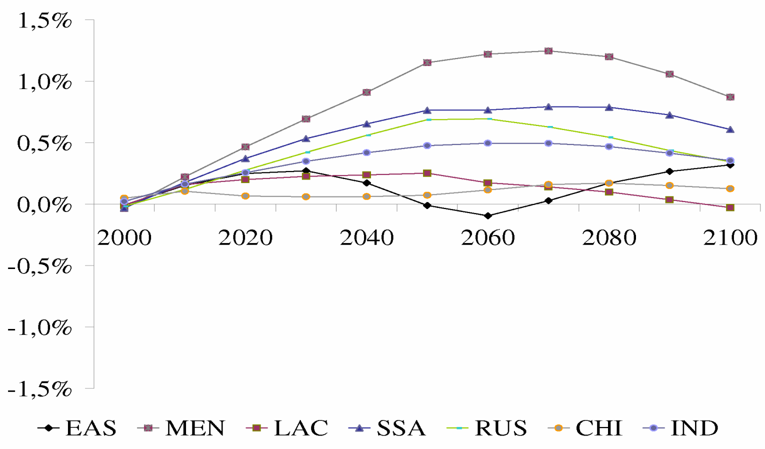
Figure 3.8: Total impact on GDP/GNI per capita and inequality



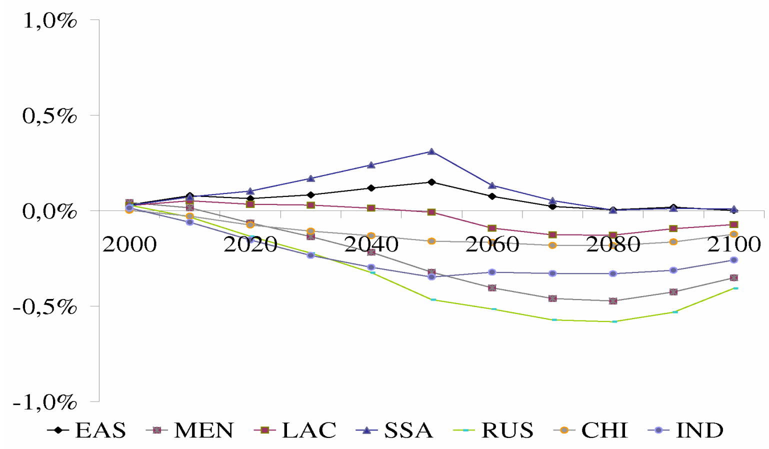
a. Total impact on GDP per capita



b. Effect of remittances on GNI per capita



c. Total impact on GNI per capita



d. Total impact on inequality

3.4 Robustness checks

In this section, several alternative assumptions are introduced as robustness checks to our main results.

Alternative remittances behavior. We denote a migrant's propensity to remit as γ^j, $j = h, l$. We have 3 different alternative remittances behaviors. Scenarios 1 and 2 differ in the ratio of high-to-low skill migrants' propensities to remit. Scenario 1 assumes $\gamma^l = \gamma^h$ and thus fits Ratha (2003) where he argues that high-skill migrants send more remittances due to higher earnings. Scenario 2 corresponds to Faini (2007) and Nimii et al. (2008) and assumes $\gamma^l > \gamma^h = 0.7\gamma^l$: given other things equal, high-skill migrants remit less. On the other hand, Scenarios 2 and 3 distinguish in the ways remittances are distributed. While variant 2 assumes an income equalizing effect of remittances in the same spirit as in Taylor & Wyatt (1996), Scenario 3 considers that (low-) high-skill only remit to (low-) high-skill individuals and thus high-skill households are the major recipients of remittances under brain drain.

Notice that, when calibrated to the official remittances data for the period 2000, it is apparently not viable that high-skill migrants have a much lower propensity to remit when compared to the low skilled. Otherwise, remittances from the low-skilled migrants will have to account for an unreasonably high share of total remittances receipts. It is unreasonable because low-skilled emigrants then remit a very high fraction, even more than 100%, of their total income to their regions of origin.

These alternative remitting behaviors lead to little changes in the impacts on GDP and GNI per capita, while obviously, Scenario 3 strongly exacerbates inequality in each region.

No Remittances. The effects of a brain gain are also analyzed within a variant where migration entails no money transfers back to origin regions. As observed before, remittances do not affect GDP per capita and a brain gain leads to similar results under the 'no remittances' variant as in the central variant when remittances are present. However, the beneficial effect of remittances in terms of GNI per capita and inequality is lost in the 'no remittances' variant. Thus GNI per capita is less improved and inequality less reduced by high-skill emigration. In the case of Latin America, GNI per capita would even be reduced and inequality increased.

Brain drain vs brain gain. In the brain drain (BD) scenario the incentive effect for human capital formation is absent. Thus the impact on GDP per capita and GNI per capita is more pessimistic for all the regions. We saw in the previous section that, under the 'brain gain' scenario, human capital was not the most important factor in explaining the change in GDP per capita. The reason is that the externality of high-skill emigration on human capital formation is important to prevent a huge drop in the level human capital and may even lead to higher level after emigration. In fact, it can be observed that, in the absence of this side-effect of high-skill emigration, GDP per capita is quite negatively impacted. Since the high-to-low skill inequality is largely determined by the skill premium, changes in the average skill level of the labor force are negatively associated with changes in inequality. Therefore, in the brain drain scenario high-skill labor is more scarce, inequality increases in all the regions.

Brain waste. Brain waste implies that additional high-skill migrants are employed as low skilled in the destination regions and impacts negatively all indicators. GDP per capita is depressed since the new migrants do not increase the size of the high-skill diaspora and do thus not contribute to reducing information costs for foreign investors. Additionally, the total amounts of remittances are lower than in the benchmark due to lower earnings of the new migrants. This further depresses GNI per capita and brings about a lower inequality-reducing effect of remittances.

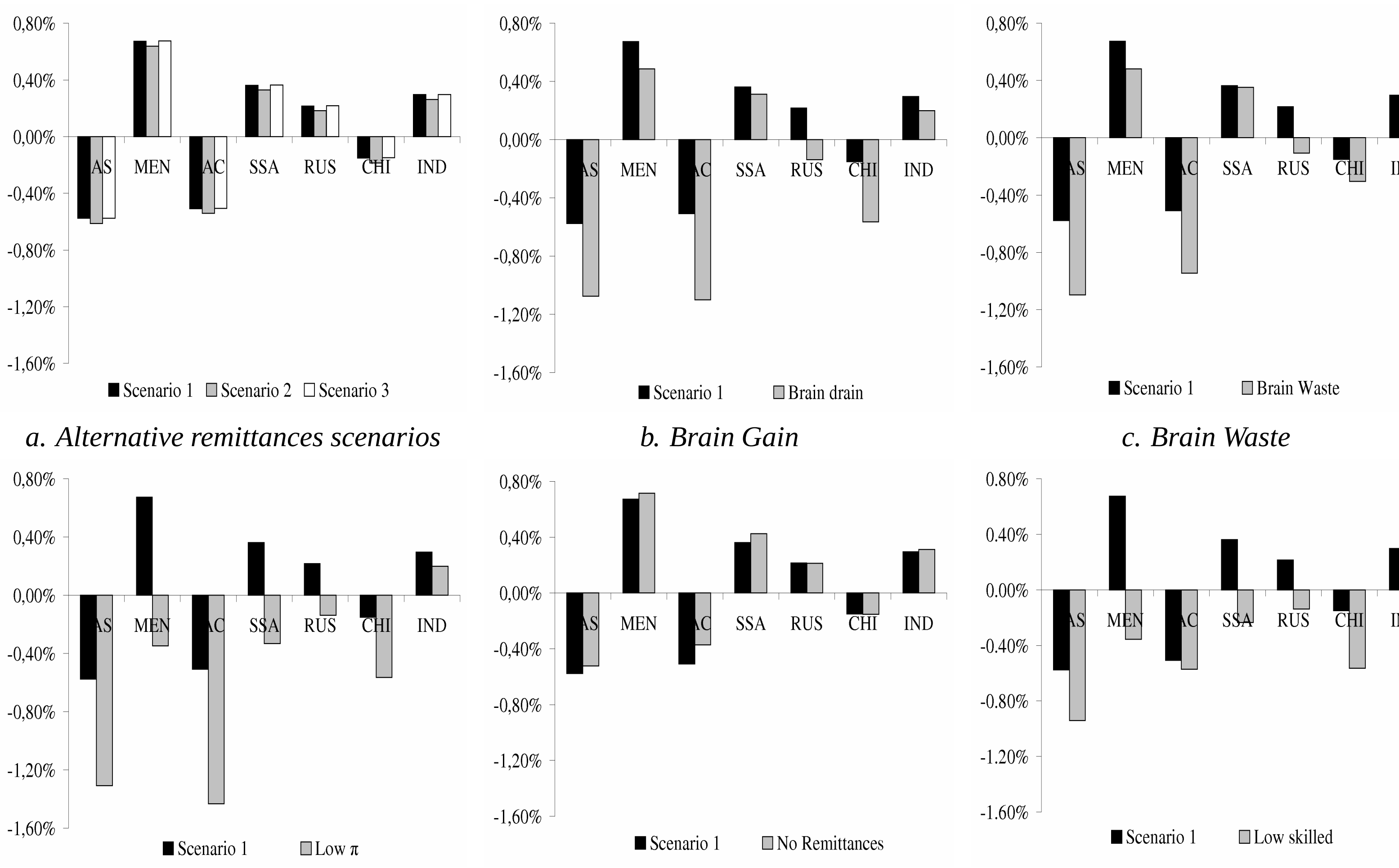
Less optimistic network effects. In this alternative scenario the long-run elasticity of the diaspora effect on the confiscation rate is lower than in the benchmark.[13] Since FDI inflows brought by reduced information costs are very important for GDP and GNI per capita, predictions on both indicators are more pessimistic. The change in inequality is negligible since it does not affect the skill premium.

Low skilled. The 'low-skilled' scenario considers that the additional emigrants are all low skilled and that low-skilled migration entails no externalities on the incentives to educate, technology diffusion and foreign direct investments. Increased low-skilled migration raises the proportion of highly skilled in the sending regions and has a similar negative impact on demography as high-skill migration. The positive effect on human capital is however not sufficient to compensate for the demographic impact and for the fact that low-skilled migrants do stimulate foreign direct investments. low-skilled migration leads thus to more pessimistic results on GDP and GNI per capita. An exception is the Indian world, which sees its GDP per capita enhanced even under low-skilled migration. The reason is that this region suffers relatively little from the negative demographic effects, has a relatively smaller emigration rate and benefits relatively little from the externality of FDI to high-skill migration. Moreover, despite the fact that low-skilled migrants have a higher propensity to remit than high-skill ones, the amounts of remittances will be lower than under high-skill emigration and contribute thus to

[13] It is set to 0.53 as it is obtained from the cross-country regression in Docquier & Lodigiani (2009), compared to scenario 1 where the long-run elasticity is set to 0.75 as it is obtained from the panel regression.

further depress GNI per capita. Finally, inequality may either be exacerbated or reduced compared to a ‘brain gain’ scenario. The harmful effect on inequality due to lower amounts of remittances may be counterbalanced by a reduced skill wage premium due to the departure of unskilled workers.

Figure 3.9: Robustness analysis on GDP



a. Alternative remittances scenarios

b. Brain Gain

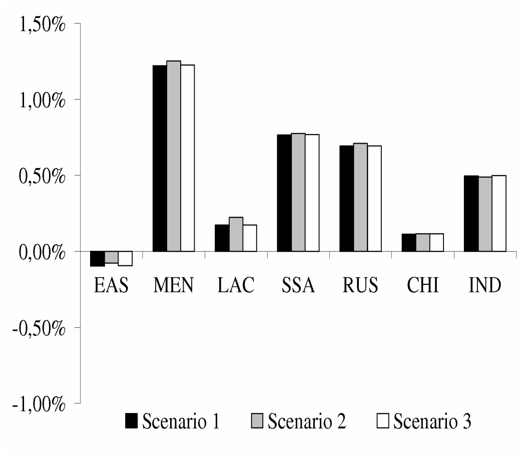
c. Brain Waste

d. Less optimistic network effects

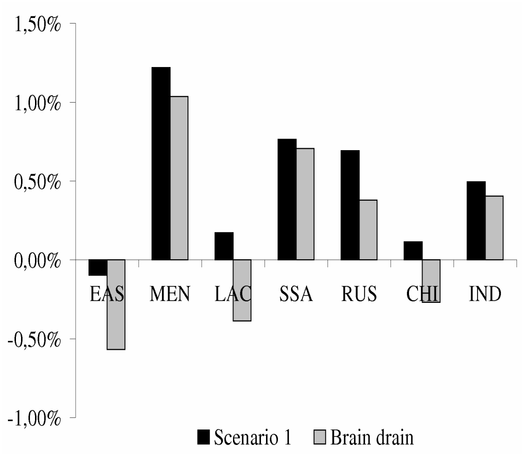
e. No Remittances

f. Low-skilled emigration

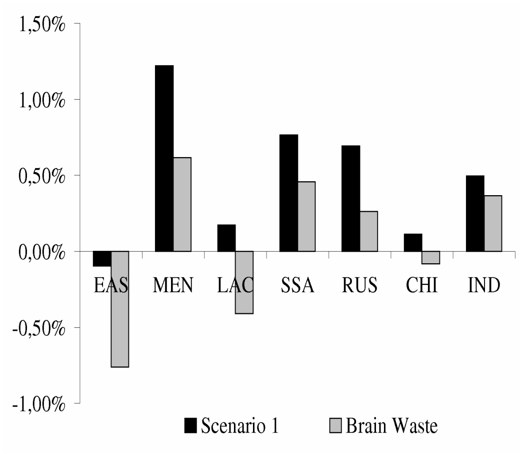
Figure 3.10: Robustness analysis on GNI per capita



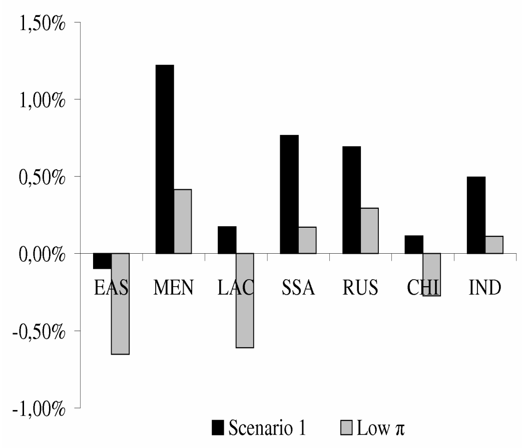
a. Alternative remittances scenarios



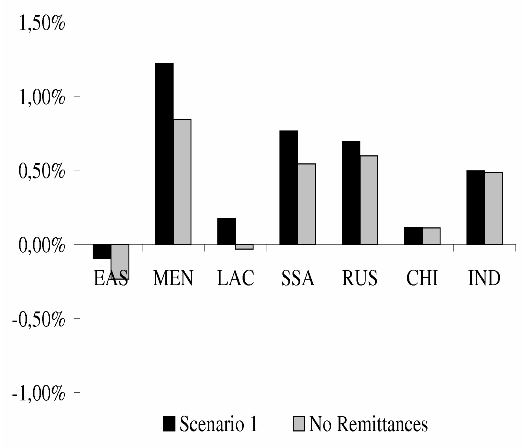
b. Brain Gain



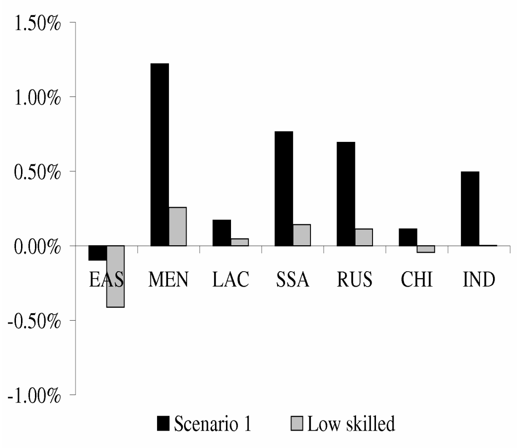
c. Brain Waste



d. Less optimistic network effects

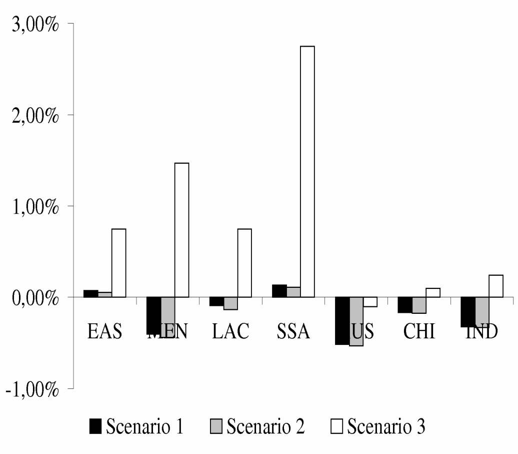


e. No Remittances

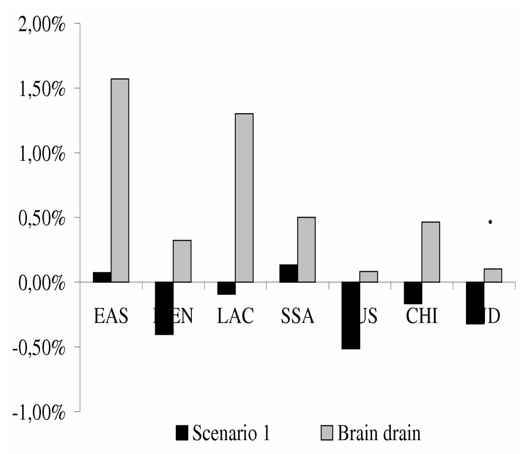


f. Low-skilled emigration

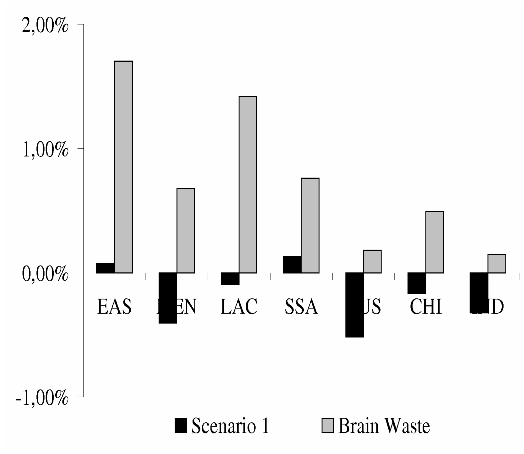
Figure 3.11: Robustness analysis on inequality



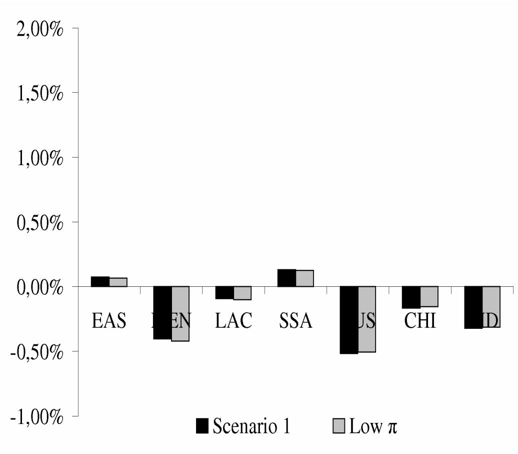
a. Alternative remittances scenarios



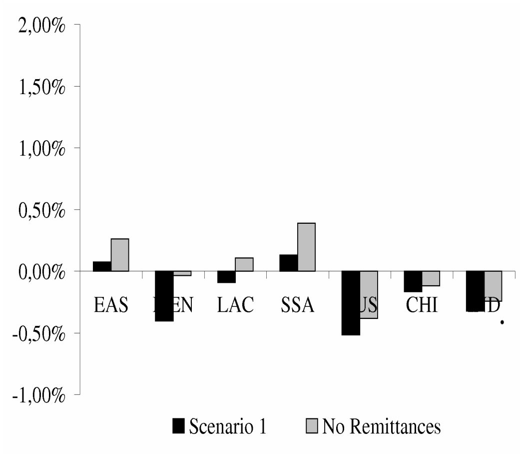
b. Brain Gain



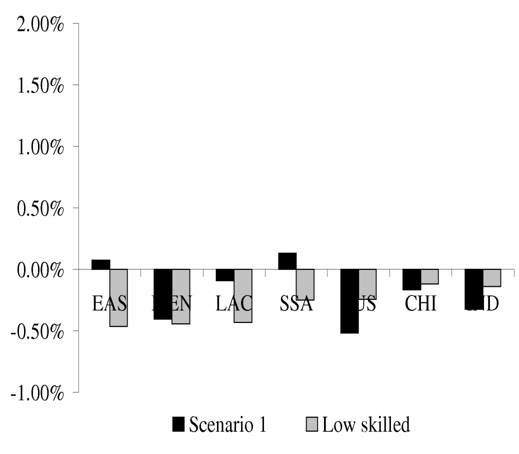
c. Brain Waste



d. Less optimistic network effects



e. No Remittances



f. Low-skilled emigration

3.5 Concluding Remarks

Brain drain has long been a major source of concerns, especially when it involves South-North high-skill migration. By combining major results of existing theoretical and empirical literature in a general equilibrium framework of the world economy, the major contribution of this paper is to provide a more thorough analysis regarding the total effects of high-skilled biased out-migration on the developing countries.

It is found that the empirically observed diaspora externality on FDI inflows may have significant contributions to domestic production at origin, and hence, when this effect is ignored, the negative impacts of brain drain could be overestimated. Similarly, the incentive effect on human capital formation contributes to alleviate the negative impact of a loss in the high-skill labor force on GDP per capita, as it prevents huge drops in the level of human capital. Furthermore it may help to reduce the high-to-low skill inequality in regions experiencing a "brain gain". Moreover, in spite of the concern expressed by many that a more selective immigration policy in the North may do little to enhance the benefits of remittances to the South as some studies show that the highly skilled remit less, it is found in our robustness checks that the total effects on GNI per capita do not vary much with different propensities to remit for the high-skill migrants.

All in all, our paper highlights the significance of the high-skill diaspora in attracting FDI, which enhances GDP and GNI per capita and the importance of the brain gain effect in reducing income inequality. Moreover, it reconfirms the role of remittances in subsidizing the income of those left behind and shows that the effects are robust to different remitting behaviors. However, it also dismisses the relevance of some feedback effects that are argued to enhance domestic production at origin, such as the diaspora externality that promotes technological diffusion. Although our results present a more optimistic picture of brain drain, its destructive impacts on domestic production are still overwhelming in regions already facing large outflows of their highly skilled and talented. Finally, the demographic impact should not be disregarded in aging societies, such as Eastern Europe.

Part II

Theoretical analysis

Chapter 4

When Nature Rebels: International Migration, Climate Change and Inequality

Abstract. We study climate change and international migration in a two-country overlapping generations model with endogenous climate change. Our main findings are that climate change increases migration; small impacts of climate change have significant impacts on the number of migrants; a laxer immigration policy increases long-run migration, aggravates climate change, increases North-South inequality if climate change impacts are not too small; a greener technology reduces long-run migration, provides a double-dividend in favor of the environment, reduces inequality if the migrants' impact to overall climate change is large. The preference over the policies depends on whether the policy maker targets inequality, wealth, the number of migrants or the environment.

JEL Classification: F 22, J 61, O 13
Keywords: climate change, migration, North-South model.[1]

[1]This chapter is a joint work with Ingmar Schumacher.

4.1 Introduction

Without doubt there is a growing concern over how and whether climate change will affect international migration. Although the economic literature has dealt with many aspects of migration, the treatment of the relationship between climate change and migration has not yet been satisfactory. Our focus in this article is to shed some light on the interaction between endogenous climate change, international migration, optimal migratory policies and inequality.

The recently published Stern review on climate change advances an unambiguous message: "An overwhelming body of scientific evidence now clearly indicates that climate change is a serious and urgent issue. The Earth's climate is rapidly changing, mainly as a result of increases in greenhouse gases caused by human activities" (Stern, 2007, p.3). This claim is without a doubt now a widely accepted fact in the scientific community. Another commonly anticipated point is that the "poorest countries will be especially hard hit by climate change, with millions potentially pushed deeper into poverty" (Stern, 2007, p.487). Possible and predicted effects of climate change include land loss due to sea level rise, loss of biodiversity, productivity declines, warmer and drier climates or wetter regions and more extreme weather events, see IPCC (2007).

As some regions are proner to be affected by several of these adverse effects than others, it seems logical that inhabitants of these regions will try to avoid those effects. However, many poor regions either lack finances to abate or they do not emit enough to have any significant impacts from abatement activity. Usually, mitigation or adaptation are then proposed as the only possible ways of dealing with these problems. As ought to be clear however, those regions that are already extremely poor and vulnerable even before climate change impacts them, will be unable to mitigate or adapt in the usual sense. Therefore, very often the only hope left for people is to move away from the inhabitable area to one which might give them better living conditions.

It is this particular setting which shall be investigated in this article. We shall focus on the link from human activity over climate change to international migration. The main questions which we wish to explore are the following: What are the environmental reasons for people to migrate? What are the welfare effects? What could potentially be welfare-improving? Which are the effects of different policies?

It is well-known that the effects of climate change are difficult to measure. The evident lack of strong data thus requires a more thorough theoretical analysis of a kind which we intend to pursue here. The first section shall give an overview of the data which exist on international migration and climate change. We then build upon a model similar of Galor (1986) and investigate, step-by-step, the key issues driving migration in a two-country, overlapping generations world with climate change and migration. As climate change is a long-term phenomenon we shall mainly focus on the steady state perspective, but nevertheless allow for the effects of short-run interactions.

Migration between two countries or regions has traditionally been analyzed within the Harris-Todaro model (Harris & Todaro, 1970), see also Ghatak et al. (1996) for a survey. The model of Harris and Todaro explains rural-urban migration in a general equilibrium model. However, the static framework of the Harris and Todaro model may miss endogenous feedbacks or can only assume these exogenously. Models which are able to analyze these feedbacks are two country models like Galor (1986). He analyzes the welfare effect of migration in a two-country overlapping generations model where he allows for bilateral migration where migration decisions are mainly driven by differences in preferences. Crettez et al. (1996) extend Galor's model to include land as a third production factor.[2] Here we shall focus on climate change as a possible driver behind migration decisions.

Our main findings are as follows: (i) climate change will most likely increase overall migration; (ii) even small impacts of climate change can have significant impacts on the number of migrants; (iii) taking responsibility for its externality a laxer Northern immigration policy will increase world migration and worsen climate change; (iv) North-South inequality may increase or decrease via appropriate green or immigration policy; Finally, the type of policy is crucial for the preference over the one or the other, especially if the North tries to pursue several targets simultaneously. The targets we look at are welfare, the policy's implication for climate change on the effect on North-South inequality.

4.2 Climate change and migration: facts and future

This section is designated to provide an overview of important facts on climate change and migration, as well as to present reasons for the particular assumptions which we use later throughout the article. In the first part we summarize key facts on climate change and in the second part we focus on the environment as a leading cause of migration.

[2]The literature has also focused on the impact of migration on the economy of the destination and origin countries. Migration can affect labor market outcomes such as wages (Borjas, 2003) or unemployment (Bencivenga & Smith, 1997), pension systems (Razin & Sadka, 1999) or human capital formation (Vidal, 1998) and growth (Beine et al., 2001b).

4.2.1 Climate change

The IPCC Third Assessment Report (TAR) concludes that the emission of greenhouse gases from human production activity led to an increase in CO_2 equivalent concentrations from 290 ppm to 440 ppm during the course of the past 150 years. The more greenhouse gases accumulate in the atmosphere the more they will prevent the infrared radiation emitted by the sun to escape the atmosphere of the Earth. This then leads to a warming which is expected to lie anywhere between 2 °C and 6 °C for the next 100 years, depending on the path we humans choose for economic development (see IPCC 2001). Most of these increases in greenhouse gases must be attributed to the rich countries. For example, the estimates provided by Enerdata in its Energy Statistics Yearbook suggest that the European Union, North America and Japan together account for close to 60% of annual world emissions, even though they host only 16% of the world population.

The main reason for this disparity is the use of the amount of primary energy resources in production, which accounts for most of the CO_2 emitted into the atmosphere. According to the International Energy Agency, in 2004 approx. 80% of world total primary energy supply came from oil, coal and gas. The use of these inputs differs drastically between the developed world and the less developed world. Estimates from the International Energy Annual 2004 suggest that Northern America, Europe, Japan and China together account for roughly 65% of the total world primary energy use. In comparison to this, the Least Developed Countries use roughly 5% of total world primary energy (IEA, 2004). Therefore, the developed world is the main emitter of CO_2 and thus responsible for most of the human-induced climate change.

The costs of climate change can vary drastically, depending on the size of the change in temperature. Whereas the IPPC in various publications suggests that an increase of 2°C from pre-industrial levels may lead to economic costs in the range of 2% to 5% of GWP per year, increases above that level may lead to potentially catastrophic costs.

In addition, the distribution of the damages is extremely particular to regions. It is expected that the less developed countries will have to face close to 80% of the world damages from climate change. This is particularly troublesome for several reasons. Most of the developing countries already face the problem of binding income constraints. It is estimated that in 2004 around 800 million people were at risk of hunger (FAO 2004) and malnutrition accounts for approximately four million deaths annually. It is believed that half of those deaths from malnutrition arise in Africa alone. The current estimates suggest that a temperature increase of 2-3°C will potentially raise the number of people at risk of hunger by 30-200 million. If the temperature increases by more than 3°C, which is a likely scenario of the IPCC, then the number of people facing hunger could increase by an additional 250-500 million. It is also believed that most of these will be observed in Africa and Western Asia (Warren et al., 2006). The World Health Organization even estimates that an additional one to three million people will then die from malnutrition, diarrhea or malaria. For example, Swart et al. (1998) estimate that temperate cereals might be faced by yield decreases of up to 22%, thereby substantially increasing food shortages.

Another problem of the effects of climate change concerns the productive capacity of countries. For example, the value added to GDP from agriculture is around 33% for less developed countries, whereas for upper middle income countries only 6.2% (WDI 2007). In addition, around 54% of the developing world's population works in the agricultural sector but only 7% of the developed countries' population. These numbers can be up to 90% high for some of the Sub-Saharan Countries (FAO 2004). The temperature in those countries increased on average by 3°C during the past decade whereas the total amount of rainfall decreased by roughly 4% between 1960 and 2000. Some countries even face decreases up to 20% like Burundi or Rwanda. This suggests that overall these countries have become drier. If they however face binding income constraints, have a high share of agriculture in GDP and in addition if most of the population is rural and works in the agricultural sectors, then these countries will face more severe consequences from climate change than can initially be grasped.

Remark 1 *Two preliminary conclusions can be drawn from the analysis above:*

(1) *Developed countries are the main emitters and therefore the predominant source of human induced climate change,*

(2) *Developing countries are likely to face the strongest impact of climate change.*

4.2.2 Migration

Here we wish to give a list of examples where migration occurred due to environmental factors. We shall then proceed to investigate what several researchers suggest will be the future of migration from climate change in particular.

Examples are, contrary to what some critics might suggest, in fact abundant. A quick reading of the existing literature provides many cases. For example, droughts in the US displaced more than 30,000 people in the 1930s (Rosenzweig & Hillel, 1993); a tsunami in Indonesia in 2004 displaced 500,000 people (FIG 2006); droughts in Burkina Faso or Sudan from 1968-1973 displaced around 1,000,000 people (Afolayan & Adelekan, 1999; Hugo, 1996). For more examples, see e.g. McLeman (2006), Ezra (2001), Morris et al. (2002), Kaye (1994). For a critical opinion see Black (2001).

Several of these cases deserve an additional remark. In Sudan it seems that only a part of the household migrates (the male usually) and then returns after the drought stops. Similar observations hold for Ethiopia where the young generations seem of migration when droughts occur (Afolayan & Adelekan, 1999). This suggests two possibilities: either the costs to migrate are too high for everyone to bear such that only a part of the household is able to leave; or people are particularly attached to their homes and expect better times to come again. However, these droughts usually last a short period of time and are therefore only transitory. One would expect that areas where irreversible changes in the climate lead to a permanently higher level of aridity would not see return migration. This is supported two-folded by Henry et al. (2004). Firstly, for the case of Burkina Faso they show that people from arid regions are more likely to migrate (temporarily and permanently) than those from wetter regions. Secondly they suggest that long-run “migrations are likely to be more influenced by a slow-acting process such as land degradation than by episodic events such as droughts.” A similar conclusion is drawn by Chen et al. (2007), who suggest the population distribution in China depends mainly on the proportion of arable land. Therefore, if that proportion changes due to environmental deterioration one must also expect a change in the population distribution.

Apart from droughts one can observe that extreme weather events also lead to permanent migration. For example, according to Morris et al. (2002), after a strong hurricane in Honduras and Nicaragua in 1998 the amount of migrants to the US and adjacent countries rose sharply. Clearly, economic deprivation thus induces people to migrate, but it can also simply be in order to avoid the same event happening in the future. For example, even one year after the Hurricane Katrina had passed, Louisiana had a 4.87% lower population due to emigration (Christie, 2006).

In Indonesia a tsunami in 2004 displaced around 500,000 people (International Federation of Surveyors (FIG 2006) internally, meaning they did not leave the country. However, one can expect that they increased the economic and social pressures in the areas they moved into and will therefore effect the migration decisions in those places. Thus, people who were before on the brink of migrating might now finally decide to move.

Remark 2 *From this quick overview we can draw a particular conclusion: Permanent migration seems to occur because of irreversible or long-lasting problems like desertification or continuous environmental degradation which removes the subsistence possibility of people; or simply because people expect further extreme events in the future and try to avoid these.*

These results therefore point toward a further analysis of the effects which climate change has on the expected future migration decisions.

It is estimated that the amount of people affected by natural disasters has tripled to a staggering number of 2 billion people over the course of one decade only. Approximately 211 million people are believed to be affected each year. Scientific evidence suggests that this amount is likely to increase the larger the change in temperature from climate change, as this leads to more floods, extreme weather events and desertification (IPCC, Stern review).

Also, as approximately two billion people are living in arid, semi-arid and sub-humid regions, one can expect that only small climatic changes will induce particularly large damages there. For example, it is suggested that the resilience of many arid regions is already weakened. Estimates conclude that up to 20 percent of drylands are degraded, droughts seem to become more frequent ((Millennium Ecosystem Assessment, MA 2003), groundwater depletion intensifies and groundwater quality deteriorates due to increased fertilizer use (Brown, 2000; Brown et al., 1988). It is thus clear that if the temperature and the weather variability increase as is expected, then the resilience of the ecosystems will have difficulties to support further stresses.

Many people will then only have the option to leave their homes in order to find a place which is able to support them. For example, the number of migrants increases annually by approximately three million people, half of which come from Africa. It is believed that most of these come from rural areas with severe land degradation. Estimates suggest that more than 135 million people could be at risk of needing to migrate due to desertification alone (INCCCD, 1994), and roughly 200 million due to sea-level rise (Myers, 1996). If desertification and land degradation thus continues as expected, then the number of migrants will shoot up, too.

Another reason for migration can be the effect of climate change on health and thus working ability. Flavin & Tunali (1998) inform that illnesses like cholera, malaria and others are very likely to spread vastly due to increased temperatures and higher humidity. They inform that an increase of around 3°C can potentially increase mosquito-transmitted diseases by up to two times in tropical regions and by up to 10 times in areas like Europe. Higher water temperatures can increase the production of algae, which again can increase the probability of cholera outbreaks. It is estimated that around 3 million people die from malaria each year with up to 500 million suffering near fatal consequences. Additionally, around 17.3 million deaths worldwide (around 33% of total) are believed to be caused by infectious diseases. These deaths are thought to be caused due to shortages of water which result in more use of contaminated water and lower cleanliness (see WHO, 1996). The dark figures for lost working hours due to illness from infectious diseases should by far exceed the deaths. If we use the same ratio as near fatal consequences to fatalities for malaria (ratio of 170), this leads to a (certainly too large) figure of 3 billion people losing some working hours. This however can provide some estimate for lost working hours or reduction in productivity. If this extrapolation is only marginally correct, then this presumes a strong effect of climate change on productivity.

Faced with these figures one cannot easily reject the need to further investigate the impact of climate change on migration and its feedbacks. We shall therefore develop a theoretical model which incorporates these feedbacks. Through this we expect to add to the understanding of the relationship between the economy, migration and climate change.

4.3 The Model

Here we construct a two-country, general equilibrium, overlapping generations model. As we wish to concentrate on analyzing international migration we shall simply assume that firms are profit maximizers in a perfectly competitive world with international capital mobility. Generations however first analyze how much welfare they are likely to obtain at home and then compare this to the welfare they might get from migrating to another region. In case migration is expected to leave them better off, then they shall migrate. Our approach is designed to understand, step-by-step, the welfare implications from migration when climate change plays a significant role for welfare. Most of the article will concern itself with the steady-state perspective of our dynamic model. In terms of notation we shall denote with small letters per capita, with large letters total population. The first subscript refers to the country, the second to the point in time. We write subscript i to denote a solution which applies to both North and South, such that $i = N, S$. Constant returns to scale will be abbreviated by CRTS, decreasing returns to scale by DRTS and total factor productivity by TFP.

4.3.1 The firm's problem

We assume that in each region there exists a representative firm which produces in a perfectly competitive market using capital and labor as inputs. The production function in each country is of a Cobb-Douglas type where we allow for decreasing returns to scale, such that $Y_{it} = A_{it}K_{it}^{\alpha}L_{it}^{\beta}$, and $\alpha + \beta < 1$.

The discussion on whether production is subject to DRTS or CRTS has been ongoing for quite some while. DRTS have also been used in theoretical models by e.g. Facchini & Willmann (2005) and are empirically supported by the estimations of the Global Trade Analysis Project (GTAP), see Badri Narayanan G. and Terrie L. Walmsley, Editors (2008), as well as by other empirical studies (Basu & Fernald, 1997). On the one hand, DRTS makes one vulnerable to the replication argument, which is solely a theoretical argument suggesting that a firm producing under DRTS can split in two and thereby increase overall output. On the other hand, DRTS seems to be a realistic assumption given the empirical evidence that has accumulated during the recent years (see GTAP dataset). We decided to give up a slight amount of theoretical rigor in favor of what is the apparently more realistic assumption. A partial reconciliation between the use of DRTS and the replication argument is that allowing for DRTS can also imply that one views other unpriced and roughly constant factors (like land or other externalities) as another factor of production. We would then have for example land, Q, such that $Y_{it} = B_{it}K_{it}^{\alpha}L_{it}^{\beta}Q_i^{1-\alpha-\beta}$, and via simplification arrive at $Y_{it} = A_{it}K_{it}^{\alpha}L_{it}^{\beta}$ with $A_{it} = B_{it}Q_i^{1-\alpha-\beta}$ (see also Cigno, 1981, for a model with a three factor CRTS production function and endogenous population).

TFP in the North is constant, $A_{Nt} = A_N$, whereas the one in the South is $A_{St} = A_S(T_t)$, where T_t is the change in temperature at time t from human induced climate change. We view this as a proxy for the effect that climate change bears on production. The assumption of climate change affecting TFP can be rationalized by taking TFP as accounting for any residual factor of production which is unpriced. Firstly, assume TFP accounts for the amount of land used in production, then increases in the sea-level or desertification reduce the amount and productivity of land. Secondly, assume TFP captures health effects, then one can argue that climate change is expected to increase the amount of malaria which has significant impacts on the health and thus productivity of workers. The assumption that climate change only impacts the South derives from the observations presented in the previous section.

Assumption 1 *We assume* $A_S(\underline{T}) \geq A_S(T), \forall T > \underline{T}$.

$\underline{T}$ denotes the level of temperate without human induced climate change. This assumption allows us to compare the different scenarios with and without climate change.

Firms then maximize profits according to $\max_{\{L_{it}\}} \Pi_{it} = A_{it}K_{it}^{\alpha}L_{it}^{\beta} - w_{it}L_{it}$, for $i = N, S$, where equilibrium wages are given by

$$w_{it} = \beta A_{it}K_{it}^{\alpha}L_{it}^{\beta-1}. \tag{4.1}$$

Following Hahn & Solow (1995) we assume that in the case of DRTS the excess profits are distributed to the investors, which is the young generation of the previous period, such that $\Pi_{it} = (1-\beta)A_{it}K_{it}^{\alpha}L_{it}^{\beta}$, which gives a return to a unit of capital of

$$R_{it+1} = (1-\beta)A_{it+1}K_{it+1}^{\alpha-1}L_{it+1}^{\beta}. \tag{4.2}$$

In the case of CRTS, we would have $1 - \beta = \alpha$ and there would not be excess profits.

4.3.2 The generation's problem

Here we shall only analyze migration from the South to the North, in line with empirical observations. The generations in the South choose according to a two-step procedure. In the first step they calculate their maximum utility at home (this step is equivalently done by the North). In the second step they calculate whether it is more profitable for them to migrate or to stay in their home country.

In the first step we thus have

$$\max_{s_{it}} \log(c_{it}) + \rho \log(d_{it+1}) \qquad \text{subject to} \tag{4.3}$$

$$w_{it} = s_{it} + c_{it}, \tag{4.4}$$

$$R_{it+1} s_{it} = d_{it+1}, \tag{4.5}$$

for $i = N, S$, where w_{it} refers to wages in region i at time t, $\log(c_{it}) + \rho \log(d_{it+1})$ is the utility of consuming c_{it} when young and d_{it+1} when old, $\rho \in (0, 1)$ is the discount factor, s_{it} are the savings and R_{it+1} the return on the savings. This gives $s_{it} = \rho w_{it}/(1 + \rho)$. Consumption will thus be $c_{it} = w_{it}/(1 + \rho)$ and $d_{it+1} = \rho w_{it} R_{it+1}/(1 + \rho)$. We write indirect utility in the steady state as

$$\tilde{u}_i = \log\left(\frac{w_i}{1+\rho}\right) + \rho \log\left(\frac{\rho R_i w_i}{1+\rho}\right). \tag{4.6}$$

In the second step the agents from the South compare whether their lifetime utility will be higher when migrating, and if this is the case then they migrate North. If an agent wants to migrate, this will cost him an amount $c_N x$ and $d_N x$, where $x \in (0, 1)$ reflects adaptation costs in various forms. This gives a lifetime utility of $u_{Nm} = \log(x w_{Nt}) + \rho \log(x d_{Nt+1})$ for agents that migrate North. We wish to keep these migration costs as general as possible, allowing for both subjective and financial costs. Our preferred interpretation is subjective costs, which are reflected in the ex ante probability of finding a job or in the welfare loss (expressed in consumption units) of having to adopt to different cultures and circumstances. In this sense, we avoid putting an explicit structure behind the level of migration costs. Government policies obviously also affects migratory costs. Whereas some countries are rather liberal towards the amount of migrants they take, other countries restrict the inflow of migrants and regions like the EU even build migratory camps in Africa to catch potential migrants even before they can attempt to cross the boarder. When agents thus compare indirect utilities, then they calculate

$$\begin{aligned} \Delta &= \tilde{u}_{Nm} - \tilde{u}_S, \qquad \text{if} \quad \tilde{u}_{Nm} > \tilde{u}_S, \\ &= 0 \qquad\qquad\quad\ \ \text{if} \quad \tilde{u}_{Nm} \le \tilde{u}_S. \end{aligned}$$

If this difference is positive, then a proportion of the generation in the South will migrate to the North.[3]

From this we obtain that an agent born in the South is in equilibrium indifferent between living in the South and migrating to the North if

$$\log\left(x\frac{w_N}{w_S}\right) = -\frac{\rho}{1+\rho}\log\left(\frac{R_N}{R_S}\right). \tag{4.7}$$

The population accumulates according to $L_{Nt+1} = L_{Nt} + m_{St+1}L_{St}$ and $L_{St+1} = L_{St} - m_{St+1}L_{St}$, where $m_{St} \geq 0$ refers to the percent of people migrating in that point of time. We denote the total population which has migrated as $\sum_{\tau=1}^{t} m_\tau L_{\tau-1} = M_t$. In the steady state we then have $L_N = \bar{L}_N + M$ and $L_S = \bar{L}_S - M$, where $M \geq 0$.

4.3.3 International capital market

In the framework presented here we can solve for both the case of no trade in capital and for the case of free trade. We assume that capital depreciates fully during the course of one generation. This assumption for example finds support in de la Croix & Michel (2002). No international capital mobility implies that savings s_{it} in one region become the capital $k_{it} = K_{it}/L_{it}$ of that region in the next period, $s_{it} = k_{it+1}$. Free capital mobility requires that total world capital stock is equal to total world savings, such that $L_{Nt+1}k_{Nt+1} + L_{St+1}k_{St+1} = L_{Nt}s_{Nt} + L_{St}s_{St}$, and perfect competition on the international capital market implies $R_N = R_S, \forall t$.

Henceforth we shall denote frictionless international capital markets as integrated and the case of no international capital mobility shall be called autarky. We already start with a first important result which we provide in the subsequent proposition.

Proposition 1 *Given the optimization problem of the firm and the problem of the generations, the long-run results of the integrated case are equivalent to those of the autarky case.*

Proof 1 In the autarky case the interest rate is given by $R_i = \frac{(1-\beta)(1+\rho)}{\beta\rho}$. As both β and ρ are the same for North and South this implies that both interests rates are the same. As $R_N = R_S$ by assumption in the integrated case, we can solve for $K_S = \left[\frac{A_N}{A_S}\left(\frac{L_N}{L_S}\right)^{\beta}\right]^{\frac{1}{\alpha-1}} K_N$, which together with the clearing of the world capital

[3] Modeling migration decisions in this way is common in the literature and implies that a decline in Southern income stimulates migration pressure. However it is important to have in mind that a decreasing income in low-income countries may also lead to a reduction in the number of emigrants if liquidity constraints become more binding.

market implies that the long-run capital stock is the same in both the integrated and autarky cases.■

This proposition therefore allows us to derive the results without having to subsequently compare both the integrated and the autarky case.[4] We remind the reader that this result only holds in the long-run at the steady state. Whether one allows for autarky or integrated markets will nevertheless have a significant impact on the transition period with the main impact being on the speed of convergence. In the following sections we therefore focus on the long-run steady state and assume integrated markets.

4.3.4 The climate sector

The climate sector is as follows: The total stock of North's capital drives the amount of emissions of CO_2 equivalent gases, denoted E_t. CO_2 equivalent concentrations Z_t are increased by emissions and reduced by a natural decay. The resulting temperature is non-linearly increased by CO_2 equivalent concentrations.

$$\begin{aligned} E_t &= \mu K_{Nt} \\ Z_t &= (1-\delta)Z_{t-1} + \gamma E_t, \\ \Delta T_t &= g(Z_t), \end{aligned} \tag{4.8}$$

with $g'(Z) > 0$ and $g''(Z) < 0$ and initial condition $T_0 = \underline{T}$. Then, the temperature change from human production activities affects the productivity in the South, such that $A_{St} = A_S(T_t)$. Our interpretation of the temperature change is that it measures the deviation from the pre-industrial climate level caused by productive activity.

As observed in the previous section, we assume that emissions from the South are negligible. This assumption is even strengthened if we were to consider the South as being composed of small developing countries only. We know that large emerging economies like China or India represent 18.4% and 4.9% of the world's CO_2 emissions in 2004, while Western Europe, United States, Canada and Japan contribute together 46% of total emissions. African countries and other developing countries like Bangladesh or small Pacific Islands represent negligible amounts of the world's CO_2 emissions.

[4]It should be clear that this result only holds if preference and production parameters are the same and in the absence of any taxation or subsidy.

4.4 Solving the model

To summarize, we have the following equations at steady state:

$$
\begin{aligned}
w_i &= \beta A_i K_i^{\alpha} L_i^{\beta-1}, \text{ where } A_S = A_S(K_N) && (4.9)\\
R_i &= (1-\beta) A_i K_i^{\alpha-1} L_i^{\beta}, && (4.10)\\
K_S &= \left[\frac{A_N}{A_S}\left(\frac{L_N}{L_S}\right)^{\beta}\right]^{\frac{1}{\alpha-1}} K_N, && (4.11)\\
K_N + K_S &= L_N s_N + L_S s_S, && (4.12)\\
s_i &= \frac{\rho w_i}{1+\rho}, && (4.13)\\
\log\left(x\frac{w_j}{w_i}\right) &= -\frac{\rho}{1+\rho}\log\left(\frac{R_j}{R_i}\right), && (4.14)\\
\Delta T &= g\big(\frac{\gamma\mu}{\delta} K_N\big). && (4.15)\\
L_N + L_S &= \bar{L}_N + \bar{L}_S. && (4.16)
\end{aligned}
$$

To remind, we have $A_S = A_S(T)$ with $A_S'(T) < 0$. At steady state we know that temperature is a function of the capital stock in the North and with some abuse of notation we shall denote $A_S(T)$ simply as $A_S(K_N)$. Equation (4.9) gives wages in each country, (4.10) the interest obtained on investing a unit of capital, (4.11) is equality of interest rates on the international market, (4.12) is the market clearing condition for capital due to international capital mobility, (4.13) gives optimal savings in each country, (4.14) holds if no one from country i wants to migrate to country j, and (4.15) is the steady state temperature, a proxy for climate change. For the moment we shall not introduce any policy considerations yet.

The following assumption is based on empirical evidence and helps us to focus our analysis.

Assumption 2 *Throughout the article we assume that $A_{N0} > A_{S0}$, meaning that TFP in the North is higher at $t = 0$ than in the South. Furthermore, in accordance with the data, we have $\bar{L}_N < \bar{L}_S$.*

Though the model implicitly allows for two-way migration, the conditions given in Assumption 2, which are easily verified through data, will imply that in the long-run only one way migration will occur.

Proposition 2 summarizes the results in section 4.

Proposition 2 *Given the problem as described in equations* (4.9) *to* (4.16) *we find that endogenous climate change is a significant propagator of world migration and reduces per capita welfare in both the North and the South.*

Due to the various feedbacks involved we shall derive these results step-by-step, where we firstly allow for no feedbacks and then switch them on one after the other.

4.4.1 Benchmark case

Firstly we assume no climate change effect on total factor productivity and no labor mobility but international capital mobility. The steady state capital stock will then be given by $K_i = \left[\frac{\rho}{1+\rho}\beta A_i L_i^{\beta}\right]^{\frac{1}{1-\alpha}}$. This leads to $w_i = \left[\beta A_i\left(\frac{\rho}{1+\rho}\right)^{\alpha} L^{\alpha+\beta-1}\right]^{\frac{1}{1-\alpha}}$ and $R_i = \frac{(1-\beta)(1+\rho)}{\beta\rho}$. We denote indirect utility in the benchmark case by $\tilde{u}^a$ and it will be given by

$$\tilde{u}_i^a = \Phi + \frac{1+\rho}{1-\alpha}\log\left(\beta A_i L_i^{\alpha+\beta-1}\right), \tag{4.17}$$

where $\Phi = \frac{\alpha(1+\rho)}{1-\alpha}\log\left(\frac{\rho}{1+\rho}\right) + \log\left(\frac{1}{1+\rho}\right) + \rho\log\left(\frac{1-\beta}{\beta}\right)$. Given the utility and production functions are the same, then in the case of CRTS the only difference between indirect utility of the two countries comes from the TFP. By Assumption 2 we thus know that $\tilde{u}_N^a > \tilde{u}_S^a$. Under DRTS a larger L_i implies a smaller $\tilde{u}_i^a$.

In this benchmark case we obtain a temperature of

$$T^a = g\left(\frac{\gamma\mu}{\delta}\left[\frac{\rho}{1+\rho}\beta A_N L_N^{\beta}\right]^{\frac{1}{1-\alpha}}\right).$$

The steady state change in temperature is increased by the productivity in the North, i.e. the more productive the North is the more it may produce and therefore we would expect a stronger climate change. Similarly, the less patient agents are (a lower ρ) the more they will consume when young and therefore the lower will be the polluting capital stock, which reduces long-run climate change. The more people live in the North the more they will produce overall and therefore the stronger will be climate change. This also suggests that a larger migration to the North should impact climate change, an intuition which we confirm later. The dirtier the production technology (higher μ) and the stronger emissions impact CO2 concentrations (e.g. emissions made higher up, for example from airplanes, impact CO2 stocks longer and worse than emissions on the ground) the higher will be the long-run temperature.

4.4.2 Benchmark and migration

We now move to the case of benchmark with migration. The equilibrium condition for migration from the South to the North then implies $xw_N = w_S$. Rewritten, we obtain the condition that no one moves from the South to the North if

$$x^{1-\alpha}A_N L_N^{\alpha+\beta-1} = A_S L_S^{\alpha+\beta-1}. \tag{4.18}$$

A steady state in migration from the South to the North then exists[5], where we denote the steady state level of M as M^{am}, if $x^{1-\alpha}A_N \bar{L}_N^{\alpha+\beta-1} > A_S \bar{L}_S^{\alpha+\beta-1}$. Intuitively, this condition requires that, at the initial point in time, agents from the South have an incentive to migrate North. We can solve for the total amount of migrants in the steady state[6], given by

$$M^{am} = \frac{(A_S)^{\frac{1}{\alpha+\beta-1}}\bar{L}_S - (x^{1-\alpha}A_N)^{\frac{1}{\alpha+\beta-1}}\bar{L}_N}{(A_S)^{\frac{1}{\alpha+\beta-1}} + (x^{1-\alpha}A_N)^{\frac{1}{\alpha+\beta-1}}}. \tag{4.19}$$

A larger stock of population in the North reduces the incentives to migrate due to the DRTS. On the other hand, the larger the population in the South the more migrants would we expect since per capita welfare in the South is lower the larger the population in the South. Moreover, if its productivity is enhanced (increase in A_N), the North will become more attractive leading to more migration

$$\frac{dM^{am}}{dA_N} = \frac{1}{1-\alpha-\beta}\,\frac{1}{A_N}\,\frac{(A_S A_N x^{1-\alpha})^{\frac{1}{\alpha+\beta-1}}(\bar{L}_N + \bar{L}_S)}{\left[A_S^{\frac{1}{\alpha+\beta-1}} + (x^{1-\alpha}A_N)^{\frac{1}{\alpha+\beta-1}}\right]^2} > 0 \tag{4.20}$$

Moreover, if globalization is associated with lower transportation, migration costs would be reduced (i.e. a higher x) and more people will find it profitable to migrate. This can be seen from the following

$$\frac{dM^{am}}{dx} = \frac{1-\alpha}{1-\alpha-\beta}\,\frac{1}{x}\,\frac{(A_S A_N x^{1-\alpha})^{\frac{1}{\alpha+\beta-1}}(\bar{L}_N + \bar{L}_S)}{\left[A_S^{\frac{1}{\alpha+\beta-1}} + (x^{1-\alpha}A_N)^{\frac{1}{\alpha+\beta-1}}\right]^2} > 0 \tag{4.21}$$

We denote indirect utility in this case by $\tilde{u}_i^{am}$ and it will be given by

$$\tilde{u}_S^{am} = \Phi + \frac{1+\rho}{1-\alpha}\log\left(\beta A_S(\bar{L}_S - M^{am})^{\alpha+\beta-1}\right), \tag{4.22}$$

$$\tilde{u}_N^{am} = \Phi + \frac{1+\rho}{1-\alpha}\log\left(\beta A_N(\bar{L}_N + M^{am})^{\alpha+\beta-1}\right) \tag{4.23}$$

[5]Proof: We check whether the equilibrium condition can exist by varying M along its domain $[0, \bar{L}_S]$. We get $\lim_{M\to 0} x^{1-\alpha}A_N L_N^{\alpha+\beta-1} > \lim_{M\to 0} A_S L_S^{\alpha+\beta-1} > 0$, and $\lim_{M\to \bar{L}_S} x^{1-\alpha}A_N L_N^{\alpha+\beta-1} < \lim_{M\to \bar{L}_S} A_S L_S^{\alpha+\beta-1}$. Since $x^{1-\alpha}A_N L_N^{\alpha+\beta-1}$ is a monotonically decreasing function of M and since $A_S L_S^{\alpha+\beta-1}$ is a monotonically increasing function of M from a positive number to infinity we conclude that a unique steady state exists if $x^{1-\alpha}A_N \bar{L}_N^{\alpha+\beta-1} > A_S \bar{L}_S^{\alpha+\beta-1}$.

[6]Under CRTS no non-trivial steady state exists since $x^{1-\alpha}A_N = A_S$ is a knife-edge condition. Thus, we have either no migration or complete migration.

Thus we obtain that if one allows for migration, then $\tilde{u}_S^{am} > \tilde{u}_S^a$, whereas $\tilde{u}_N^{am} < \tilde{u}_N^a$. Therefore, the South benefits from international migration whereas the North loses. This result is attributable to the decreasing returns in production. If the North is initially better off, then people from the South migrate North until the per capita utility in the North decreases to such a level that migration does not pay any longer. Since fewer people in the South now share the same (or more) capital, this raises the average wage in the South and therefore utility increases.

Steady state temperature is then

$$T^{am} = g\left(\frac{\gamma\mu}{\delta}\left[\frac{\rho}{1+\rho}\beta A_N(\bar{L}_N + M^{am})^{\beta}\right]^{\frac{1}{1-\alpha}}\right).$$

Since there are now more people living in the North which all pollute according to the Northern living standards, this will unambiguously lead to an increase in emissions and therefore long-run temperature. A current estimate by the UN of the amount of migrants in the North is around 10%. Assuming that they lead the same lifestyle as the Northern population, this may work as a significant propagator of climate change. By reducing migration costs and raising the number of migrants, increased globalization would raise temperature. A rise in Northern productivity would directly exacerbate climate change by increasing the productive capacity of the North, but also indirectly affect temperature by making the North more attractive and leading to more migration.

4.4.3 Benchmark with climate

Here we shall assume that there is a climate change effect on total factor productivity in the South but no migration possibilities. We denote indirect utility by $\tilde{u}_i^{ac}$. In this case the North will grow to the same long-run level of capital as in the benchmark case and end up with the same indirect utility, such that $\tilde{u}_N^{ac} = \tilde{u}_N^a$.

The steady state capital stock of the South is however depending on the amount of climate change induced by the production of the North. The productivity in the South can then be written $A_S = A_S(K_N)$, with $K_N = \left[\frac{\rho}{1+\rho}\beta A_N L_N^{\beta}\right]^{\frac{1}{1-\alpha}}$. Therefore, the indirect utility of the South at steady state will be given by

$$\tilde{u}_S^{ac} = \Phi + \frac{1+\rho}{1-\alpha}\log\left(\beta A_S(K_N) L_S^{\alpha+\beta-1}\right), \tag{4.24}$$

which implies that $\tilde{u}_S^{ac} < \tilde{u}_S^a < \tilde{u}_N^{ac} = \tilde{u}_N^a$. As expected, the externality imposed by the North on the production capacity of the South reduces total welfare in the South. The indirect utility in the South is a decreasing function of emissions in the North (since $A_S'(K_N) < 0$). The stronger the effect of climate change on TFP, i.e.

the larger the slope of $A_S(K_N)$ for a given K_N, the lower will be indirect utility. Conclusively, the worse the impact of climate change the less will each person in the South produce which will lead to a lower average income. For example, a likely scenario for temperature increases is 3°C, which could imply an at least doubling of malaria victims in the South (Flavin & Tunali, 1998). With currently 3 million death annually and 500 million near fatalities (and consequently many lost working hours), the productivity decreases in the regions which see a doubling of malaria victims can be enormous.

Since there are no migrants in this scenario and since the integrated case is equivalent to the autarky case, we observe no change in production in the North, and therefore no divergence from the total emissions in the benchmark case.

4.4.4 Benchmark with climate and migration

We now extend the previous case by allowing for migration. A steady state in migration from the South to the North then exists[7], where we denote the steady state level of M as M^{acm}, given that $x^{1-\alpha}A_N\bar{L}_N^{\alpha+\beta-1} > A_S(K_N)\bar{L}_S^{\alpha+\beta-1}$. This requires that at some point in time, be it at $t = 0$ or when climate change has sufficiently reduced TFP in the South, there exists an incentive to migrate North. The total amount of migrants in the steady state is then given by

$$M^{acm} = \frac{(A_S(K_N))^{\frac{1}{\alpha+\beta-1}}\bar{L}_S - (x^{1-\alpha}A_N)^{\frac{1}{\alpha+\beta-1}}\bar{L}_N}{(A_S(K_N))^{\frac{1}{\alpha+\beta-1}} + (x^{1-\alpha}A_N)^{\frac{1}{\alpha+\beta-1}}}. \tag{4.25}$$

We know that $\frac{\partial K_N}{\partial M} > 0$. This implies more climate change and therefore TFP in the South with migration is lower than if one does not allow for migration. In terms of indirect utility we can then conclude that $\tilde{u}_S^{acm} < \tilde{u}_S^{am}$ iff $M^{acm} \geq M^{am}$. The denominator of equation (4.25) is increasing when $\Delta A_S < 0$ and the nominator is increasing when $\Delta A_S < 0$. This comes about because migration implies two things: Firstly, more migration means more climate change which reduces income in the South; secondly, more migration implies a higher per capita steady state income in the South. It is this cumulative effect where more migration implies further climate change which leads to $M^{acm} > M^{am}$. We can therefore conclude that $\tilde{u}_S^{acm} < \tilde{u}_S^{am}$. Let us observe that increased globalization translated by an increase in x would now have the following effect

$$\frac{dM^{acm}}{dx} = \frac{\frac{\partial M^{am}}{\partial x}}{1 - \frac{\partial M^{acm}}{\partial A_S}\frac{\partial A_S}{\partial K_N}\frac{\partial K_N}{\partial L_N}}. \tag{4.26}$$

[7] Proof: $\lim_{M\to 0} LHS > \lim_{M\to 0} RHS > 0$, and $\lim_{M\to \bar{L}_S} LHS < \lim_{M\to \bar{L}_S} RHS$.

The nominator is positive and the sign of the denominator is ambiguous because $\frac{\partial M^{acm}}{\partial A_S} < 0$.[8] A necessary condition for an interior solution to M^{acm} requires $\frac{\partial M^{acm}}{\partial A_S}\frac{\partial A_S}{\partial K_N}\frac{\partial K_N}{\partial L_N} < 1$. This condition holds only if changes in A_S have small impacts on the number of migrants or if climate change has minimal impacts on TFP in the South. Put differently, if the migration costs change, then the impacts unfold subsequently as follows. Initially, more people wish to migrate since the costs are lower, and thus the perceived benefit of moving to the North is higher. The secondary effect of this is, however, that more migrants pollute more and therefore induce a further decrease in the productivity of the South. If migrants have only a small impact on climate change, then M^{acm} will be insignificantly higher than M^{am}. However, if the impact of migrants on total climate change is large enough and climate change impacts the migration decisions strongly, then this could potentially lead to a corner solution: All inhabitants from the South wish to migrate to the North. In any case we can conclude that $dM^{acm}/(dx) > dM^{am}/(dx)$.

Similarly, higher productivity in the North would now not only make the North more attractive but also impact on Southern productivity

$$\frac{dM^{acm}}{dA_N} = \frac{\frac{\partial M^{am}}{\partial A_N} + \frac{\partial M^{acm}}{\partial A_S}\frac{\partial A_S}{\partial K_N}\frac{\partial K_N}{\partial A_N}}{1 - \frac{\partial M^{acm}}{\partial A_S}\frac{\partial A_S}{\partial K_N}\frac{\partial K_N}{\partial L_N}}. \tag{4.27}$$

The nominator is positive while the a necessary condition for an interior solution to M^{acm} requires again $\frac{\partial M^{acm}}{\partial A_S}\frac{\partial A_S}{\partial K_N}\frac{\partial K_N}{\partial L_N} < 1$. As for a change in x, this condition is satisfied when changes in Southern productivity have small effects on migration or when climate change does not impact too much on Southern productivity. As in the benchmark case with migration, an increase in Northern productivity will raise Northern income per capita and make the North more attractive to migration (first term on the nominator). Moreover, a higher TFP in the North will raise its productive capacity and induce a decrease in Southern productivity via climate change (second term on the nominator). Increased migration will have an indirect impact on climate change and further reduce Southern productivity (second term in the denominator).

The strength of climate change will be given by

$$T^{acm} = g\left(\frac{\gamma\mu}{\delta}\left[\frac{\rho}{1+\rho}\beta A_N(\bar{L}_N + M^{acm})^{\beta}\right]^{\frac{1}{1-\alpha}}\right).$$

Therefore, $T^{acm} > T^{am}$. In this scenario therefore, not only the direct migration incentives play a vital role, but also the cumulative effects of more migrants. If

[8] In fact, we have $\frac{\partial M^{acm}}{\partial A_S} = -\frac{1}{1-\alpha-\beta} A_S^{\frac{2-\alpha-\beta}{\alpha+\beta-1}} (x^{1-\alpha}A_N)^{\frac{1}{\alpha+\beta-1}} \frac{\bar{L}_S+\bar{L}_N}{\left(A_S^{\frac{1}{\alpha+\beta-1}} + (x^{1-\alpha}A_N)^{\frac{1}{\alpha+\beta-1}}\right)^2} < 0$.

more migrants also increase emissions in the North and therefore further reduce income in the South, this can imply a strengthening of the migration incentive and will increase climate change further. Since approximately 10% of all the Northern population is made up of migrants, this snowball effect may be substantial and should not be neglected in policy decisions. An intensification of globalization or higher Northern productivity may in fact be the causes of a reinforcement of climate change via the migration they induce.

4.4.5 A Data Experiment

Our objective is to give some numbers to these otherwise analytical results. This is supposed to be viewed as a rough exercise which allows us to extrapolate some numerical implications of the model. We take data from today, extrapolate into the future (year 2050), and then use these estimates as an approximation for the steady state values.

GTAP data suggests that World GDP in the year 2000 is 31.278 billion US $, of which the US, Western Europe and Japan have 70%. We assume those will be the migrants destination countries (North). The South is then composed of most of the remaining countries of the world (we do not consider Australia and New-Zealand in our calculations). Assuming a growth rate of 1% for the North and 2% for the South, we calculate GDP in 2050 to be 36 bn for the North and 25 bn for the South. Total world population is 6.6 billion, of which US, Western Europe, Japan currently hold 17%. In the year 2050, the estimates of the World Population Prospects of the United Nations (2008) are 1.1bn for Europe plus Northern America, and 8bn for the rest of the world. In the year 2000, 52.5 million migrants born in the South live in the North (UN data and Docquier & Marfouk, 2006). We take this as the baseline case with migration but without climate change. The average sources of GDP worldwide are: skilled plus unskilled labor, giving $\beta = 0.44$, and capital, giving $\alpha = 0.37$, which suggests significant decreasing returns.

Knowing Y, α, L, β, we can use our Cobb-Douglas functional form $Y = AK^{\alpha}L^{\beta}$ to calculate K_i as follows: take the interest rate $r_i = \alpha A_i K_i^{\alpha-1} L^{\beta}$, then divide by Y, gives $r/Y = \alpha/K$. Solve for K, gives $K = \alpha Y/r$. We know α and Y, assume $r = 1.02$, then we can calculate K_N and K_S. We then calculate A_i from solving the income equation for A, giving $A = Y/(K^{\alpha}L^{\beta})$. Independent of the scaling, the ratio $\sigma \equiv A_S/A_N$ is always the same. Rewriting equation (4.25) as $x = \sigma^{1/(1-\alpha)}(L_N/L_S)^{(1-\alpha-\beta)/(1-\alpha)}$, we obtain the x that matches the value of migrants in 2000, namely $x = 0.27$.

Having now constructed the variables that we need, we proceed to calculate the effects of climate change on steady state migration. Since there exists barely any data or knowledge of the consequences of climate change on the productive capacity, we take a shortcut and assume that climate change visualizes as a percentage decline in σ. Table 3 shows that the proportion of migrants in the North, $M/(\bar{L}_N + M)$, will change from 9% to up to 35% if the ratio of productivity σ (=A_S/A_N) drops by up to 5%. This suggests that even small impacts of climate change can lead to significant changes in the number of migrants.

Table 4.1: Effect of climate change on migration

decrease in σ	0	-1%	-2%	-3%	-4%	-5%
Migrants in 2050, (in millions)	98.77	150.95	205.80	263.45	324.02	387.64
change in migrants' stock	0.00%	52.84%	108.38%	166.74%	228.07%	292.49%
share of migrants (North)	8.98%	13.72%	18.71%	23.95%	29.46%	35.24%
share of migrants (Sorth)	1.23%	1.89%	2.57%	3.29%	4.05%	4.85%
share of migrants (World)	1.50%	2.29%	3.12%	3.99%	4.91%	5.87%

Source: GTAP, UN Population Division and own computations

The results in this section immediately raise questions of various concerns: Empirically, how can we differ between incentives for migration, namely purely utilitarian incentives and forced migration? Ethically, what value do we give to space and place (or origin) and is someone responsible for taking the migrants? Politically, how are we to deal with possible migration of up to 35% of Northern country's population? Economically, what is the effect of various policies on the number of migrants, on the inequality between North and South, as well as on the amount of climate change?

Though each of the above questions poses challenging problems, we are only going to deal with the economic ones here. In the subsequent section 4.5 we deal with policies of the North.

4.5 Northern Policies

We shall now investigate the effects of several possible policies undertaken by the North. The first policy is an immigration policy whereas the second one leads to greener production. In the last part of this section we calibrate whether the US or Europe would, in the long-run, invest more in green technology or immigration policy. In the subsequent propositions, whenever we refer to 'abstracting from climate change', we mean $A_S(T_t) = A_S(\underline{T})$, $\forall T$.

The following analysis considers that policies are costly in the long-run. Let τ be a production tax paid by firms in the North per unit of output produced and let τ_x and τ_μ be amounts per unit of output produced invested by the government in respectively border controls and green technology. Since the government taxes production, it adheres to the polluter pays principle. The government's budget constraint is then given by

$$\tau Y_N = (\tau_x + \tau_\mu) Y_N \tag{4.28}$$

Let us observe that the following analysis would not lead to different implications in terms of migration, climate change and inequality in case of long-run costliness of these policies. The results would just be simplified by the fact that there is no taxation and thus an absence of the impact of taxes on production.[9] The only effect that we see is a level effect, but not a qualitative change in the results. We now assume that the immigration costs (x) and the impact of the Northern production on emissions (μ) are both a function of government expenditure. We therefore have that $x(\tau_x Y_N)$ and $\mu(\tau_\mu Y_N)$, where both functions are decreasing in their respective arguments. In the previous analysis higher production had a negative effect on climate change via the generated pollution and attracted more migrants because of a higher North-South indirect utility gap. Through the mechanisms in $x(\tau_x Y_N)$ and $\mu(\tau_\mu Y_N)$, higher production will also generate higher tax revenues which strengthen immigration controls and amplify the amounts invested in green technologies. As a consequence, increased migration will not only have a negative feedback effect on climate change but also a positive feedback effect via an increase in tax revenues.

In the presence of such a tax scheme, firms must solve the problem $\max_{\{L_{it}\}} \Pi_{it} = (1-\tau) A_{it} K_{it}^{\alpha} L_{it}^{\beta} - w_{it} L_{it}$, for $i = N, S$, where optimal wages are given by

$$w_{it} = \beta(1-\tau) A_{it} K_{it}^{\alpha} L_{it}^{\beta-1}. \tag{4.29}$$

Again excess profits are distributed to the investors (the young generation of the previous period) such that $\Pi_{it} = (1-\beta)(1-\tau) A_{it} K_{it}^{\alpha} L_{it}^{\beta}$, which gives a return to a unit of capital of

$$R_{it+1} = (1-\beta)(1-\tau) A_{it+1} K_{it+1}^{\alpha-1} L_{it+1}^{\beta}. \tag{4.30}$$

Following the analysis in section 3, the capital stock in the steady state will be $K_i = \left[\frac{\rho}{1+\rho} \beta (1-\tau) A_i L_i^{\beta}\right]^{\frac{1}{1-\alpha}}$.

The steady state utility in the North is

$$\tilde{u}_N = \Phi + \frac{1+\rho}{1-\alpha} \log \left(\beta (1-\tau) A_N L_N^{\alpha+\beta-1} \right). \tag{4.31}$$

[9] While policies may certainly bear costs at the time they are implemented, it could be argued that these costs will be zero in the long-run. This could be the case if one considers for example R&D expenditure in emission reductions: If a greener technology is developed once, then it is clear that further R&D expenditure is not necessary in the long-run. Similarly, immigration policy which leads to a higher probability of obtaining a job for the migrants only requires a discussion in the parliament. The long-run costliness of policies will however not change the results. A formal demonstration is available on request from the authors.

while steady state migration changes to

$$M = \frac{A_S^{\frac{1}{\alpha+\beta-1}} \bar{L}_S - (x^{1-\alpha}(1-\tau)A_N)^{\frac{1}{\alpha+\beta-1}} \bar{L}_N}{A_S^{\frac{1}{\alpha+\beta-1}} + (x^{1-\alpha}(1-\tau)A_N)^{\frac{1}{\alpha+\beta-1}}}. \tag{4.32}$$

We now derive the direct impact of taxes on the stock of steady state migrants. It is straightforward to calculate that $dM^{am}/d\tau < 0$. Since taxes reduce the total capital stock in the North they provide less incentive for part of the Southern population to migrate North. Allowing for climate change to affect migration leads to $dM^{acm}/d\tau < 0$ if $A_S > -(1-\tau)A_S'(K_N)(\partial K_N/\partial\tau + \partial K_N/\partial M^{acm}\partial M^{acm}/\partial\tau)$. If the number of migrants are very responsive to increases in taxes and if climate change bears a significant impact on the productivity in the South, then a small increase in taxes has the potential to reduce the stock of migrants.

In the next two sections we analyze how the North should optimally allocate its tax revenues between border controls and clean technologies.[10] The government maximizes (4.31) subject to $\tau = \tau_j$, where $j = x, \mu$. From equation (4.31) we know that the Northern government will raise taxes iff

$$L_N < -(1-\alpha-\beta)(1-\tau_j)\frac{dM^i}{d\tau_j} \quad j = x, \mu, \quad i = am, acm. \tag{4.33}$$

A necessary condition is that $\frac{dM^i}{d\tau_j} < 0$. The intuition is that an increase in taxes, which reduces per capita income in the North, has to lead to a sufficiently strong reduction in migration to increase Northern utility. The following assumption insures that the North sets positive taxes.

Assumption 3 *In the subsequent analysis, we assume that condition* (4.33) *is always satisfied.*

4.5.1 Investment in border controls

We assume here that all the government's tax revenues are invested in border controls only. The following proposition summarizes the results of this section.

Proposition 3 *Abstracting from climate change, a higher investment in border controls leads to a reduction in the Southern utility and an increase in the Northern one; to a reduction in steady state temperature and to an increase in North-South inequality. In presence of climate change, investments in border controls will decrease further the long-run number of migrants, improve the environment and decrease or increase North-South inequality.*

[10] We neglect the fact that the government may wish to raise taxes but not invest everything in border controls respectively green technologies, an assumption equivalent to the no-Ponzi scheme assumption.

Abstracting from climate change, taxes affect migration as follows

$$\frac{dM^{am}}{d\tau_x} = \frac{\frac{\partial M^{am}}{\partial \tau_x} + \frac{\partial M^{am}}{\partial x}\left(\frac{\partial x}{\partial \tau_x} + \frac{\partial x}{\partial Y_N}\frac{\partial Y_N}{\partial K_N}\frac{\partial K_N}{\partial \tau_x}\right)}{1 - \frac{\partial M^{am}}{\partial x}\frac{\partial x}{\partial Y_N}\frac{\partial Y_N}{\partial K_N}\frac{\partial K_N}{\partial L_N}} \tag{4.34}$$

For an interior solution in migration we require that the denominator of (4.34) is positive. As $\frac{\partial M^{am}}{\partial \tau_x} < 0$ and $\frac{\partial M^{am}}{\partial x} > 0$, the sign of $\frac{dM^{am}}{d\tau_x}$ depends on the terms inside the parentheses. An increase in taxes reduces migration if

$$\frac{dM^{am}}{d\tau_x} < 0 \Longleftarrow \frac{\partial x}{\partial \tau_x} < -\frac{\partial x}{\partial Y_N}\frac{\partial Y_N}{\partial K_N}\frac{\partial K_N}{\partial \tau_x} \tag{4.35}$$

Since immigration costs depend on the tax rate and on production, a higher tax rate may either increase or decrease the amounts spend on border controls. In fact, an increase in the tax rate implies an increase in the proportion of production allocated to border controls (term on LHS) but also a reduction in steady state production leading to a reduction in tax revenues.[11] We can show that the former effect will dominate the latter if taxes are not too high such that production is not reduced too much.[12] If the level of the tax rate is initially low, then an increase will lead to higher tax revenues. On the contrary, if tax levels are already high at the beginning, a further increase in the tax rate will decrease tax revenues. In effect, this result points in the direction of a Laffer curve.

What happens in the South? If condition (4.35) holds, we know that the utility in the South will decrease, because $\frac{d\tilde{u}_S^{am}}{d\tau_x} = \frac{1+\rho}{1-\alpha}(1-\alpha-\beta)\frac{1}{L_S}\frac{\partial M}{\partial \tau_x} < 0$. If we assume that the government increases taxes only if it leads to an increase in the Northern utility, i.e. the increase in taxes leads to a sufficiently high decrease in migrants to induce $\frac{d\tilde{u}_N^{am}}{d\tau_x} > 0$, then North-South inequality will increase.

Allowing for climate change, we obtain the following result.

$$\frac{dM^{acm}}{d\tau_x} = \frac{\frac{\partial M^{acm}}{\partial \tau_x} + \frac{\partial M^{acm}}{\partial x}\left(\frac{\partial x}{\partial \tau_x} + \frac{\partial x}{\partial Y_N}\frac{\partial Y_N}{\partial K_N}\frac{\partial K_N}{\partial \tau_x}\right) + \frac{\partial M^{acm}}{\partial A_S}\frac{\partial A_S}{\partial K_N}\frac{\partial K_N}{\partial \tau_x}}{1 - \frac{\partial K_N}{\partial L_N}\left(\frac{\partial M^{acm}}{\partial x}\frac{\partial x}{\partial Y_N}\frac{\partial Y_N}{\partial K_N} + \frac{\partial M^{acm}}{\partial A_S}\frac{\partial A_S}{\partial K_N}\right)} \tag{4.36}$$

The numerator is negative if condition (4.35) holds. The denominator is positive for an interior M^{acm}, which implies $|\frac{dM^{acm}}{d\tau_x}| > |\frac{dM^{am}}{d\tau_x}|$.[13] Similar to section 4.4.4,

[11] It is straightforward to see that the direct impact of taxes on steady-state production is negative, since $Y_N = \left[\left(\frac{\rho}{1+\rho}\beta\right)^{\alpha}(1-\tau)^{\alpha}A_N L_N^{\beta}\right]^{\frac{1}{1-\alpha}}$.

[12] Imagine the following functional form for the immigration costs $x(\tau_x Y_N)$: $x = \frac{\bar{x}}{1+a\tau_x Y_N}$, where $a > 0$ is a parameter and $\bar{x}$ are immigration costs without government intervention. Then condition (4.35) drops down to $\tau_x < 1-\alpha$. Thus the Northern government can improve the welfare of its citizens if taxes on production are not larger than the share of non-capital revenues in production.

[13] If we take the same functional form as in footnote 12 for the immigration costs, then it is easy to show that a *sufficient* condition for $\frac{dM^{acm}}{d\tau_x} < 0$ is $\tau_x < 1-\alpha$.

the denominator is positive if changes in A_S have small impacts on the number of migrants or if climate change has small impacts on TFP in the South. If the deterioration of the climate impacts the migration decisions strongly, then this could lead to a corner solution where no inhabitants of the South wish to migrate to the North.

Condition (4.35) is also sufficient for taxes to improve the environment. Temperature in the steady state is a function $T = g(\frac{\gamma\mu}{\delta}K_N)$,

$$\frac{dT^{acm}}{d\tau_x} = \frac{\partial T^{acm}}{\partial K_N}\left(\frac{\partial K_N}{\partial \tau_x} + \frac{\partial K_N}{\partial L_N}\frac{dM^{acm}}{d\tau_x}\right)$$

Because $\frac{\partial K_N}{\partial \tau_x} < 0$ and $\frac{\partial K_N}{\partial L_N} > 0$, the effect of taxes on temperature will depend on $\frac{dM^{acm}}{d\tau_x}$, which one would expect to be negative given the previous analysis. Taxes will improve TFP in the South not only by diminishing the productive capacity in the North but also by reducing the number of migrants and thus their effect on climate change (the second term inside the parentheses). In such a case the indirect utility in the South might increase, if DRTS are dominated by the positive effect of taxes on Southern TFP

$$\frac{d\tilde{u}_S^{acm}}{d\tau_x} = \frac{1+\rho}{1-\alpha}\left[\frac{1-\alpha-\beta}{L_S}\frac{dM^{acm}}{d\tau_x} + \frac{1}{A_S}A_S'(K_N)\left(\frac{\partial K_N}{\partial \tau_x} + \frac{\partial K_N}{\partial M^{acm}}\frac{dM^{acm}}{d\tau_x}\right)\right] \quad (4.37)$$

The first term in equation (4.37) captures the effect of DRTS: a reduction in the number of migrants implies that more people have to share the same pie. The second term acts in the opposite direction: less migrants leads to less climate change, then this allows for a higher per capita production in the South.

The effect on inequality is as follows. A reduction in inequality from the immigration policy requires $d(\tilde{u}_N/\tilde{u}_S)/(d\tau_x) < 0$. This is equivalent to the condition

$$\frac{1+\rho}{1-\alpha}\left[-(1-\alpha-\beta)\left(\frac{\tilde{u}_S}{L_N}+\frac{\tilde{u}_N}{L_S}\right)\frac{dM^{acm}}{d\tau_x} - \frac{\tilde{u}_S}{1-\tau_x} - \tilde{u}_N\frac{A_S'(K_N)}{A_S}\left(\frac{\partial K_N}{\partial \tau_x}+\frac{\partial K_N}{\partial L_N}\frac{dM^{acm}}{d\tau_x}\right)\right] < 0$$

The first term inside the square brackets is positive and represents DRTS. A decline in migration lowers Southern utility because due to DRTS more people have to share less wealth. The indirect effect of less migration on inequality is given by the two other terms, which are negative. The second term inside the square brackets shows that higher taxation has a (direct) negative impact on Northern utility ($\tilde{u}_N \downarrow$ if $\tau_x \uparrow$). The third term indicates that higher taxation also acts upon the Southern productivity via a direct decrease on the Northern productive capacity ($\frac{\partial K_N}{\partial \tau_x} < 0$) and via an indirect decrease in K_N through a reduction in the feedback effect of migrants on climate change ($\frac{\partial K_N}{\partial L_N}\frac{\partial M}{\partial \tau_x} < 0$). In short without DRTS, higher taxation will reduce inequality provided condition (4.35) holds, while the two other effects work in favour of equality. We can therefore conclude that North-South inequality will increase or diminish depending on which of the terms is stronger.

Finally, it is certainly true that many Northern governments undertake immigration policies in order to regulate the amount of migrants. Here one could also imagine that the North is more concerned with aftercare measures e.g. by taking responsibility for inducing climate change on the South and therefore takes care of the forced migrants, then it might adopt a more relaxed immigration policy. Such an aftercare policy would reverse the above results: a reduction of taxation would increase the number of migrants (if it leads to lower tax revenues i.e. equation (4.35) is satisfied), worsen climate change and have an ambiguous effect on North-South inequality. Alternatively, investing in greener technology may be understood as a precautionary or preventive policy. Such a policy is analyzed in the following section.

4.5.2 Investment in clean technologies

When the government decides to invest all its tax revenues in green technologies, then we obtain the following.

Proposition 4 *More taxes directed towards a greener technology will reduce the number of migrants, improve the environment and either increase or decrease North-South inequality.*

We can calculate the effect of τ_μ on M^{acm} as

$$\frac{dM^{acm}}{d\tau_\mu} = \frac{\frac{dM^{am}}{d\tau_\mu} + \frac{\partial M^{acm}}{\partial A_S}\left[\frac{\partial A_S}{\partial \mu}\left(\frac{\partial \mu}{\partial \tau_\mu} + \frac{\partial \mu}{\partial Y_N}\frac{\partial Y_N}{\partial \tau_\mu}\right) + \frac{\partial A_S}{\partial K_N}\frac{\partial K_N}{\partial \tau_\mu}\right]}{1 - \left(\frac{\partial A_S}{\partial \mu}\frac{\partial \mu}{\partial Y_N}\frac{\partial Y_N}{\partial L_N} + \frac{\partial A_S}{\partial K_N}\frac{\partial K_N}{\partial L_N}\right)\frac{\partial M^{acm}}{\partial A_S}} \tag{4.38}$$

The first term in the numerator is the direct effect of taxes: less income in the North makes is less attractive to migrate from the South. The second part in the numerator describes the marginal impact of climate change (brought about by changes in taxes) on the motivation to migrate. These terms include the direct effect of higher better green technology from higher taxes; the impact of lower income due to higher taxes on climate change; the impact of a lower production level due to higher taxes. The denominator in (4.38) is governed by two opposite feedback effects of migrants on climate change. When higher taxation induces less migration, then the tax base will be reduced and less resources will be allocated to green technologies. The second term inside the brackets corresponds to the ‘traditional’ feedback effect: more migration means more productive capacity in the North and thus more pollution. Provided that the denominator is positive, then a sufficient condition for $\frac{dM^{acm}}{d\tau_\mu} < 0$ is given by

$$\frac{\partial \mu}{\partial \tau_\mu} + \frac{\partial \mu}{\partial Y_N}\frac{\partial Y_N}{\partial \tau_\mu} < 0.$$

An increase in investments in green technologies has the following effect on Southern productivity

$$\frac{dA_S^{acm}}{d\tau_\mu} = \frac{\frac{\partial A_S^{acm}}{\partial \mu}\left(\frac{\partial \mu}{\partial \tau_\mu} + \frac{\partial \mu}{\partial Y_N}\frac{\partial Y_N}{\partial \tau_\mu}\right) + \frac{\partial A_S^{acm}}{\partial K_N}\frac{\partial K_N}{\partial \tau_\mu} + \left(\frac{\partial A_S^{acm}}{\partial \mu}\frac{\partial \mu}{\partial Y_N}\frac{\partial Y_N}{\partial L_N} + \frac{\partial A_S^{acm}}{\partial K_N}\frac{\partial K_N}{\partial L_N}\right)\frac{\partial M}{\partial \tau_\mu}}{1 - \left(\frac{\partial A_S^{acm}}{\partial \mu}\frac{\partial \mu}{\partial Y_N}\frac{\partial Y_N}{\partial L_N} + \frac{\partial A_S^{acm}}{\partial K_N}\frac{\partial K_N}{\partial L_N}\right)\frac{\partial M}{\partial A_S}} \tag{4.39}$$

The denominator is the same as the denominator in (4.38) and the same reasoning applies concerning its sign. If the 'traditional' feedback effect of migrants on climate change is not too strong then the denominator is positive and we have an interior solution for A_S^{acm}. In this case the numerator will be positive as well and $\frac{dA_S^{acm}}{d\tau_\mu} > 0$. Lower migration decreases pollution by decreasing Northern production (direct effect) but may increase pollution via a reduction in tax revenues (indirect effect). Since $\frac{\partial M}{\partial \tau_\mu} < 0$ and $\frac{\partial M}{\partial A_S} < 0$, if the direct impact of migrants on pollution is stronger than the indirect impact then this is a sufficient condition for $\frac{dA_S^{acm}}{d\tau_\mu} > 0$.

The effect of higher investments in green technologies on Southern utility will be

$$\frac{d\tilde{u}_S^{acm}}{d\tau_\mu} = \frac{1+\rho}{1-\alpha}\left[\frac{1-\alpha-\beta}{L_S}\frac{dM^{acm}}{d\tau_\mu} + \frac{1}{A_S}\frac{dA_S^{acm}}{d\tau_\mu}\right] \tag{4.40}$$

Higher investments in green technologies have a negative effect on utility in the South due to DRTS ($\frac{dM^{acm}}{d\tau_\mu} < 0$) and a positive effect on $\tilde{u}_S$ via improvements in Southern productivity ($\frac{dA_S^{acm}}{d\tau_\mu} > 0$). The effect of higher investments on Southern utility will depend on which of the effects dominate.

The effect on inequality is as follows. A reduction in inequality from the immigration policy requires $d(\tilde{u}_N/\tilde{u}_S)/(d\tau_x) < 0$. This is equivalent to the condition

$$\frac{1+\rho}{1-\alpha}\left[-(1-\alpha-\beta)\left(\frac{\tilde{u}_S}{L_N} + \frac{\tilde{u}_N}{L_S}\right)\frac{dM^{acm}}{d\tau_\mu} - \frac{\tilde{u}_S}{1-\tau_\mu} - \tilde{u}_N\frac{1}{A_S}\frac{dA_S^{acm}}{d\tau_\mu}\right] < 0 \tag{4.41}$$

If DRTS are not too strong then inequality decreases provided $\frac{dA_S^{acm}}{d\tau_\mu} > 0$.

4.5.3 Investment in clean technologies or in border controls

Should a Northern government, that maximizes the utility of a Northern citizen, invest in greener technology or in immigration controls? Assume the government has a fixed amount of resources $\tau = \bar{\tau}$, then the budget constraint can be written as $\tau_\mu = \bar{\tau} - \tau_x$. The Northern government will choose the optimal share of tax revenues for border controls by maximizing the utility of a Northern citizen subject to τ_x.

$$\frac{d\tilde{u}_N}{d\tau_x} = \frac{\partial u_N}{\partial M}\frac{dM}{d\tau_x}$$

The sign of $\frac{d\tilde{u}_N}{d\tau_x}$ will determine if the government should spend more on border controls or more on green technologies. When $\frac{d\tilde{u}_N}{d\tau_x} > 0$, the government will raise τ_x and indirectly reduce τ_μ such that the tax rate remains fixed at $\bar{\tau}$. The reverse is true if $\frac{d\tilde{u}_N}{d\tau_x} < 0$. Since $\frac{\partial u_N}{\partial M} < 0$ the government's decisions will depend on the sign of $\frac{\partial M}{\partial \tau_x}$. Thus for a given tax rate $\bar{\tau}$, if $\frac{dM}{d\tau_x} < 0$, then the government will invest more in border controls while reducing its investments in green technologies. A change in τ_x will have the following impact on the number of migrants

$$\frac{dM}{d\tau_x} = \frac{\frac{\partial M}{\partial \tau_x}\frac{\partial x}{\partial \tau_x} + \frac{\partial M}{\partial A_S}\frac{\partial A_S}{\partial \mu}\frac{\partial \mu}{\partial \tau_\mu}\frac{\partial \tau_\mu}{\partial \tau_x}}{1 - \frac{\partial M}{\partial A_S}\frac{\partial A_S}{\partial K_N}\frac{\partial K_N}{\partial M} - \frac{\partial M}{\partial A_S}\frac{\partial A_S}{\partial \mu}\frac{\partial \mu}{\partial Y_N}\frac{\partial Y_N}{\partial M} - \frac{\partial M}{\partial x}\frac{\partial x}{\partial Y_N}\frac{\partial Y_N}{\partial M}}, \tag{4.42}$$

The numerator of (4.42) depicts the impact of the policy mix. For a fixed tax rate, an increase in τ_x allocates more resources to border controls, which directly reduce migration (first term). At the same time, a rise in τ_x deprives the production sector of subsidies for green technologies, which induces an exacerbation of climate change and more migration (second term). The denominator shows the multiple feedback effects of migration on climate change (second term) and on the tax base (third and fourth terms). These different feedback effects have different impacts on migration. The first effect states that the migration induced climate change will generate further migration, the two other terms suggest that migration will increase production and thus the tax base, which allocates more resources to the government to reduce migration indirectly via green technologies or directly via border controls. A sufficient condition to have an interior solution for M requires then $\frac{\partial M}{\partial A_S}\frac{\partial A_S}{\partial K_N}\frac{\partial K_N}{\partial M} < 1$. This condition holds only if changes in A_S have small impacts on the number of migrants or if climate change has minimal impacts on TFP in the South. Under this condition, the optimal policy mix $\{\tau_x^*; \tau_\mu^*\}$ will be determined by the following equation:

$$\frac{dM}{d\tau_x} = 0 \quad \Leftrightarrow \quad -\frac{\partial M}{\partial \tau_x}\frac{\partial x}{\partial \tau_x} = \frac{\partial M}{\partial A_S}\frac{\partial A_S}{\partial \mu}\frac{\partial \mu}{\partial \tau_\mu}\frac{\partial \tau_\mu}{\partial \tau_x} \tag{4.43}$$

Condition (4.43) states that the optimal policy mix $\{\tau_x^*; \tau_\mu^*\}$ is achieved when a change in migration due to subsidies in border controls (LHS) is exactly compensated by an opposite change in migration via foregone investments in green technologies.

4.5.4 A numerical illustration

In the following we shall give a numerical illustration by comparing the situation of two developed regions. Consider the North to be either EU-15 (EU) or North-America (NAM), which comprises United States and Canada. Will each of these two regions should spend more on green technologies or on border controls? In order to address this issue we do a similar extrapolation exercise as before and choose the following functional forms: $A_S(K_N) = \frac{A_S}{1+\omega T}$, $T = \mu K_N$, $x = \frac{\bar{x}}{1+a\tau_x Y_N}$, $\mu = \frac{\bar{\mu}}{1+b\tau_\mu Y_N}$. Condition (4.43) can then be rewritten as

$$\frac{\omega\mu K_N}{1+\omega\mu K_N}\frac{b}{a}\frac{1+a\tau_x Y_N}{1+b\tau_\mu Y_N} = 1-\alpha \tag{4.44}$$

The aim of the following illustration is to find a tax scheme $\{\tau_x; \tau_\mu\}$ satisfying condition (4.44). This exercise is performed twice, that is for the cases where the North is represented by either Europe-15 or by North-America, and subsequently we compare the so obtained tax schemes of either region.

Calibration of $\bar{L}_N$, $\bar{L}_S$, and A_N. As in section 4.4.5, the structural parameters α, β and ρ are respectively equal to 0.37, 0.44 and 0.9. The unknown parameters ω, a and b are set (subject to subsequent sensivity analysis) respectively to 0.045, 0.01 and 0.5. In condition (4.44) the variables μ, K_N and Y_N, are endogenous while the following variables need to be calibrated: $\bar{L}_S$, $\bar{L}_N$, $\bar{L}_N$, $\bar{A}_S$, $\bar{\mu}$ and $\bar{x}$. Table 4.5.4 summarizes the values for these variables, which take on different values whether the North is considered as being Europe-15 (EU) or North-America (NAM). Knowing total population in the South and the number of Southern migrants in Europe and North-America from the data of Docquier & Marfouk (2006), it is easy to compute the population originating from the South $\bar{L}_S$. According to Docquier & Marfouk (2006), the share of migrants from developing countries in EU and NAM corresponds to 10.13% and 4.9% in 2000. We can thus compute the number of migrants in Europe and North-America as well as $\bar{L}_{EU}$ and $\bar{L}_{NAM}$. Then, $\bar{L}_S$ equals to around 5.75 bn in 2000 in both cases.The next step is to compute the technology level in the North, A_N. Using the data from the WDI (2007), GDP PPP equals to $Y_{NAM} = 10.43$ and $Y_{EU} = 9.27$ thousands bn in 2000. Following the procedures described in section 4.4.5, we obtain $K_{NAM} = 3.78$ and $K_{EU} = 3.36$,

$A_{NAM} = 10.6$ and $A_{EU} = 8.96$ as well as the TFP in the South, which is calculated in the same way, giving $A_S = 4.429$. In the following we explain the calibration of the last parameters for Europe and North-America: $\bar{\mu}$, $\bar{x}$ and $\bar{A}_S$.

Calibration of $\bar{\mu}$, $\bar{x}$ and $\bar{A}_S$. First, we set $\bar{\mu}_{NAM}$ and $\bar{\mu}_{EU}$ equal to the observed values for μ. It can be observed that total emissions in North-America are twice as much as in EU-15 with respectively $E_{NAM} = 6.32$ compared to $E_{EU} = 3.06$ thousand bn tons in 2000. Knowing from equation (4.8) that $\mu = \frac{E}{K_N}$, we obtain the emissions per productive capital ratio $\mu_{NAM} = 1.67$ and $\mu_{EU} = 0.91$ for 2000. The parameters $\bar{\mu}_{NAM}$ and $\bar{\mu}_{EU}$ are set equal to those values. We thereby assume that these observed values for μ correspond to a situation without taxes on production ($\tau = 0$). Our analysis will then consist in exploring how the introduction of a tax rate of $\tau > 0$ should be allocated between green technologies and border controls.[14] The observed values for μ indicate that the production of the EU-15 is much more emissions-saving than the one of NAM. The reason is largely due to the North American climate policy. In fact, it is well-known that the United States and Canada are ranked behind Western European countries in terms of emissions to GDP ratio to carbon dioxide ratio, which is an indicator that represents a very specific aspect of a composite environmental performance index developed by the CIESIN center of the Yale university, see CIESIN (2006). Second, knowing $\bar{L}_N$, $\bar{L}_S$, A_N and M for Europe and North-America as well as A_S, we can compute migration costs as in section 4.4.5: $x_{EU} = 0.2197$ and $x_{NAM} = 0.1744$. These values indicate that migrants face higher migration costs when migrating to North America than to Europe. Again, considering that these values correspond to a situation without taxes or where existing taxes are implicitly taken into account, we apply these values to $\bar{x}_{EU}$ and $\bar{x}_{NAM}$. Finally, since we have ω, $\bar{\mu}$, K_N and A_S, we can calculate $\bar{A}_S$ for Europe and North-America.

Table 4.2: Calibration of exogenous variables

	$\bar{L}_N$	$\bar{L}_S$	A_N	$\bar{\mu}$	$\bar{x}$	$\bar{A}_S$
North=Europe-15	0.39	5.74	8.69	0.91	0.2197	5.04
North=North-America	0.31	5.75	10.60	1.67	0.1744	5.69

Results. Given the proposed functional forms for x, μ and A_S, the calibrated values for the parameters, and the equations of section 4.5 for the endogenous variables K_N, M, Y_N, the resulting steady-state of the model with a production

[14] Alternatively, imposing $\bar{\mu}_{NAM}$ and $\bar{\mu}_{EU}$ to be equal to what the data suggest for μ could be interpreted to reflect a situation where existing taxes on production are implicitly taken into account in the data. Our analysis would then be to focus on how the introduction of an additional tax rate on production should be allocated between border controls and clean technologies.

tax rate of 10% will give us the policy mix $\{\tau_x; \tau_\mu\}$ satisfying condition (4.44) for the Europe-15 and North-America. The so obtained tax scheme corresponds to the decision rule of a Northern government, which maximizes the utility of Northern citizens and which does not internalize the feedback effects of migration on climate change and on the tax base. We obtain that Europe should invest a larger share of its tax revenue in immigration costs than North- America ($\tau_x^{EU} = 67.4\%$ compared to $\tau_x^{NAM} = 50.16\%$), and correspondingly invest less in green technologies than North America ($\tau_\mu^{EU} = 32.6\%$ compared to $\tau_\mu^{NAM} = 49.84\%$). An explanation of these findings is that North-America has a more emission-intensive production and higher border controls than Europe. Thus compared to Europe, it would be optimal to invest a larger share of its revenue in green technologies and less in border controls.

The results of this exercise should obviously - like any calibration exercise with unknown parameters - be approached with care. The conclusions rest solely on a per capita utilitarian approach, neglecting any other ethical or political dimensions. We used a rather stylized model and did not account for other reasons to migrate (like wars) which could lead to different policy decisions. However, our findings are informative about how a region should choose its optimal tax revenues when needing to allocate these between green technologies and border controls (or anything else which affects subjective migration costs).

4.6 Conclusion

In this article we investigate the relationship between climate change and international migration. We make use of a two-regions overlapping generations model similar to Galor (1986) but allow for climate change to affect the productivity in the South.

Our main findings are that climate change will most likely increase world migration and that even small changes in its impact can imply significant changes in the amount of migrants in the long-run. A simple calibration exercise suggests that the number of migrants increases by a factor of four if climate change reduces Southern productivity by approximately 5 percent. However, from our empirical overview in the first part of this paper it is very likely that the reduction in Southern productivity exceeds 5 percent in the future. Thus, it goes without saying that migration is expected to re-shape world orders if it is not properly guided by international policies.

We then analyze what effect a softer immigration policy and investment in greener technology might have on the long-run number of migrants, on the environment and North-South inequality. Both policies could be undertaken for different reasons. Whereas we interpret the softer immigration policy as an aftercare policy which makes the North take responsibility for the effects of climate change which it itself imposed upon the South, the investment in greener technology may be understood as a precautionary or preventive policy. We show that the immigration policy clearly increases the number of migrants but worsens climate change and has an ambiguous effect on North-South inequality. On the contrary, the investment in greener technology leads to fewer long-run migrants, a better environment, but again an ambiguous sign for the inequality measure. It is therefore clear that any policy undertaken by the North will depend on the importance which the North places upon displacement of people, climate change or inequality. Importantly, the qualitative results do not depend on whether the costs of the policies are sunk in the future or whether the policies incur continuous costs. With a numerical example we show that the US should invest more of its tax revenues in green technologies than the EU and less in border controls than the EU, a result which stems from the differences in production technologies and in existing immigration policies.

There are many extensions which this model could see. Firstly, it should be interesting to analyze the short-run migration decisions and compare these to the long-run choices. Since we know that a policy which has positive effects in the long-run might have significant costs in the short-run, it can be important to compare the costs and benefits of both. Furthermore, though in the long-run this is clearly unimportant, in the short-run we could see significant impacts of population growth. Including this in this model is however a challenging task.

Chapter 5

Migration and Human Capital in an endogenous fertility model

Abstract. How does high- and low-skilled migration affect fertility and human capital in migrants' origin countries? This question is analyzed within an overlapping generations model where parents choose the number of high- and low-skilled children they would like to have. Individuals migrate with a certain probability and remit to their parents. It is shown that a brain drain induces parents to have more high and less low educated children. Under certain conditions fertility may either rise or decline due to a brain drain. Low-skilled emigration leads to reversed results, while the overall impact on human capital of either type of migration remains ambiguous. Subsequently, the model is calibrated on a developing economy. It is found that increased emigration of the high-skilled reduces fertility and fosters human capital accumulation, while low-skilled emigration induces a rise in population growth and a reduction in the proportion of high educated individuals.

Keywords: Migration, human capital, fertility.
JEL Classification: F22, J13, J24.[1]

[1] This chapter is co-authored with Patrice Pieretti and Benteng Zou.

5.1 Introduction

At the world level, the number of international migrants rose from 76 million in 1960 to 175 million in 2000, but considering population growth the world share of migrants remained quite stable (2.5% in 1960 to 2.9% in 2000). Nevertheless, by making countries increasingly interdependent, globalization, rising income inequality, enhanced transportation technology, decreasing transportation costs, and stronger demographic disparities between developed and developing countries play in favor of a reinforcement of international migration in the next decades. Moreover, the fact that developed countries are ever more attractive for workers from developing regions is documented by the share of international migrants in developed countries that rose from 4% in 1970 to 8% in 2000 (see UN 2003 and IOM 2005). This is even more true for high-skilled emigration (i.e. emigration of post-secondary educated individuals), which is expected to be increasingly important since immigration policies in migrants' host countries tend to be more and more skilled-biased. Docquier & Marfouk (2006) report that between 1990 and 2000, the augmentation in the number of high-skilled immigrants in OECD countries was about 64%, while it was only about half as much for low-skilled immigrants. Moreover, most of these additional migrants originated from developing countries. The exodus of high-skill workers from developing countries is however feared to have severe consequences on already poor economies, since it deprives them from their most talented labor force.

While the early theoretical literature of the 60s pointed out that a brain drain has basically no impact on migrants' origin countries and should not be a cause for worry (Grubel & Scott, 1966), during the 70s economists, and foremost Bhagwati & Hamada (1974), stressed that high-skilled emigration induces a negative externality on sending countries and that “there *is* a loss to those left behind". In recent years, economists took a fresh look at the issue and highlighted a range of positive side-effects of high-skilled emigration. One major beneficial externality of a brain drain is that it induces greater incentives for individuals to educate because of a higher expected skill premium. Then, if the newly educated individuals outweigh the ones leaving the country, human capital at origin is enhanced compared to a situation without a brain drain (Mountford, 1997b; Stark et al., 1997; Beine et al., 2001b), which may act as a substitute for educational subsidies (Stark & Wang, 2002).[2] However these migration models take population as constant and do not analyze fertility decisions. In fact, an important literature shows that the decisions parents face in terms of fertility and of investment in the education of their children are central for a country's economic development, see for instance Becker &

[2] In an extensive survey, Docquier (2006) describes the different positive externalities linked to high-skilled emigration.

Barro (1988) as well as de la Croix & Doepke (2003). Since the quality-quantity trade-off in terms of children influences human capital formation, it is crucial for a country's economic growth and it seems straightforward to study the impact of emigration within an endogenous fertility model. To our knowledge, only the migration model of Chen (2006) features endogenous fertility, but restricted to the brain drain issue. He analyzes the difference between public and private funded education systems in a model where agents have an average human capital level and a stochastic probability to emigrate. Our study differs in terms of the aim and of the framework used.

This paper analyzes how high- and low-skilled emigration shape parents' fertility choices and thus human capital formation. Contrarily to most endogenous fertility models, individuals do not decide upon the total number of their children and their education level (or investment in their education), but directly about how many low- and high-skilled children they would like to have. This is also a major contrast to Chen (2006) and allows us to explicitly introduce skill heterogeneity among agents in our overlapping generations (OLG) model. Also the end of their childhood, individuals migrate with a certain probability and remit to their retired parents. This is another distinct feature from Chen, since remitting behavior may influence the expected return of raising and/or educating children and thus adults' fertility decisions. It is shown that a brain drain induces parents to have more high and less low educated children, but may either raise or reduce fertility (total number of their offspring). A *sufficient* condition to experience a rise in fertility due to high-skilled emigration is that the relative cost from raising a high compared to a low educated child must be lower than its relative expected gain. In contrast, when the reversed inequality is a *necessary* condition to have a reduction in fertility due to a brain drain is i.e. the relative cost of raising a high educated child is larger than the gain. Low-skilled emigration leads to reversed results: parents choose to have less high- and more low-skilled children. Finally, the impact of migration on human capital is ambiguous.

To provide more concrete findings, the model is calibrated on the Philippines, which is an economy open to migration and experiencing large inflows of remittances. It is found that increased high-skilled emigration reduces fertility and fosters human capital accumulation, while low-skilled emigration induces higher population growth and a lower level of education. More precisely, a permanent increase of 10% in emigration flows is simulated. When the additional emigrants are high-skilled (low-skilled), the share of high-skilled in the work force changes from 22.2% to 28.4% (to 21.2%) and the annual population growth from 1.98% to 1.36% (to 2.1%).

The paper is organized as follows. Section 5.2 introduces the model and explains the theoretical effects of increased emigration. The illustration on the

Philippines economy is presented in section 5.3. Section 5.4 concludes.

5.2 The Economic Model

We consider an overlapping generation economy where individuals live for 3 periods: childhood, adulthood and old age. Each individual has one parent, which creates the connection between generations. Individuals have either a low (superscript l) or a high education level (superscript h). Higher education is costly, while lower education is offered for free by the society.[3]. During their childhood, individuals who attend school do not work, whether they obtain higher education or not. Also, agents work only in their adulthood and earn a wage that depends on their education level. High-skilled adults earn a wage w^h, while low-skilled ones a wage w^l with $w^h > w^l$.

We consider a small open economy where capital is perfectly mobile, which implies a fixed international interest rate R^*. Also, both high- and low-skilled wages are exogenous and constant. Both low- and high-skill labor in this small open economy can emigrate to an advanced economy and earn a higher salary, w^{*i} ($i = h, l$), which is exogenously given with $w^{*i} > w^i$. Finally, we assume that emigration is not large enough to affect the economy of the destination country.

5.2.1 Individual behavior

All decisions are made by the individual during her adulthood. Thus at time t, each adult with education level i cares about her own old age consumption D^i_{t+1} and about the expected income of her children, V^i_{t+1}. It is assumed that individuals consume only when old. Thus there is no arbitrage opportunity for consumption, which is purchased through savings and remittances. The individual also cares about the return from her “education investment", that is, the expected income of her children V^i_{t+1}, which represents the altruistic component in the utility. Moreover, an adult chooses how many low- (n^i_t) and high-skilled children (m^i_t) she would like to have.

At the beginning of their adulthood, individuals with education level i can emigrate with a probability p^i, $i = h, l$ to a more advanced economy. Hence the expected income of a child with education level $i = h, l$ is

$$\overline{w}^i = (1 - p^i)w^i + p^i w^{*i},\ i = h, l. \tag{5.1}$$

[3]For instance, individuals with a college degree could be considered as high-skilled and individuals without a college degree as low-skilled. Then education after high school would be costly, while education below college level would be free.

The probability to emigrate p^i is exogenous and will serve as a policy variable in the comparative statics as well as in the numerical example. A rise in p^i can either be associated with a more liberal immigration policy of a destination country, such as, for example, a reduction of the entry barriers, or with more liberal emigration policies in the origin country, such as larger exit quotas.

Raising one child takes time fraction $\phi \in (0,1)$ of an adult's time and high-skilled children induce an additional cost for their education x. Therefore savings, S^i_{t+1}, result from an adult's labor earnings minus raising and educational costs of her children,

$$S^i_{t+1} = R^*[w^i(1-\phi(n^i_t + m^i_t))] - xm^i_t, \tag{5.2}$$

where in the following we normalize the fixed constant interest rate R^* to 1.

It is assumed that all children care about their parents and remit a proportion of their (foreign) income to their parents. Therefore for a parent of education i expected transfers, Ω^i, from her high- and low-skilled children are given by

$$\Omega^i_{t+1} = T^i_{t+1} + Z^i_{t+1} = \theta^h \overline{w}^h m^i_t + \theta^l \overline{w}^l n^i_t, \tag{5.3}$$

which comprise not only money transmitted by adults staying in the home country to their parents, $T^i_t = (1-p^l)\theta^l w^l n^i + (1-p^h)\theta^h w^h m^i$, but also remittances, Z, defined as $Z^i_t = p^l \theta^l w^{*l} n^i + p^h \theta^h w^{*h} m^i$. Then $\theta^i (> 0)$ is the propensity to transfer money to her parents for an individual with education level i (or to remit for a migrant with education level i).

Lifetime consumption writes as follows

$$D^i_{t+1} = S^i_{t+1} + \Omega^i_{t+1}. \tag{5.4}$$

The utility function of an individual who is an adult with education level i at time t is then given by:

$$U(D^i_{t+1}, V^i_{t+1}) = \ln(D^i_{t+1}) + \ \ln(V^i_{t+1}), \tag{5.5}$$

and

$$V^i_{t+1} = \alpha(n^i)^\epsilon \overline{w}^l + (1-\alpha)(m^i)^\epsilon \overline{w}^h.$$

A part from the fact that we explicitly introduce heterogeneity among the types of children, the non-linear term in V^i_{t+1} is similar to Becker & Barro (1988); Barro & Becker (1989); Doepke (2005), with $\alpha \in (0,1)$ measuring the weight given to low-skilled children and $\epsilon \in (0,1)$ playing the role of the elasticity of the utility to any type of children. As mentioned by Barro & Becker (1989), this form of the altruism term means that, for a given expected income per child $\overline{w}^i$, "parental utility $U(\cdot)$ increases, but at a diminishing rate, with the number of children" (here n^i and m^i).

Thus, combining the above ideas, each adult is facing the following problem

$$\max_{n^i,m^i} U^i = \max_{n^i,m^i}\{\ln(D^i_{t+1}) + \ln(V^i_{t+1})\}, \qquad i = l, h, \tag{5.6}$$

subject to (5.4) and which consists into the maximization of her lifetime utility by choosing the number of low- (n^i) and high-skilled children (m^i).

5.2.2 Solving the individual problem

In appendix, we show that the first order condition of U^i with respect to n^i_t is

$$\frac{\phi w^i_t - \theta^l \overline{w}^l_{t+1}}{D^i_{t+1}} = \frac{\alpha \overline{w}^l_{t+1} \epsilon (n^i_t)^{\epsilon-1}}{V^i_{t+1}}, \tag{5.7}$$

which states that the net marginal cost of raising a low-skilled child, $\phi w^i_t - \theta^l \overline{w}^l_{t+1}$ (cost minus expected transfers), in terms of consumption, should equal the marginal utility gain from a low-skilled child's expected income, in terms of the future value of total children (V). If this equality does not hold, raising children is either too costly (it is then optimal to have no children), or not costly enough (then individuals choose to have more and more children).

Similarly, the first order condition of U^i with respect to m^i_t shows that

$$\frac{\phi w^i_t + x - \theta^h \overline{w}^h_{t+1}}{D^i_{t+1}} = \frac{(1-\alpha) \overline{w}^h_{t+1} \epsilon (m^i_t)^{\epsilon-1}}{V^i_{t+1}}, \tag{5.8}$$

which reads that the net marginal cost of educating one child in terms of consumption (left hand side) should be equal to the marginal benefit from educating a child.

The second order conditions of the agents' maximization problem are satisfied. Therefore the solutions from (5.7) and (5.8) are optimal for the household problem.

It is easy to see that in (5.7) and (5.8), both the right hand sides are positive, implying that the left hand sides are positive also. These are necessary conditions for the existence of interior solutions and it is assumed that, in what follows, these conditions always hold.

Assumption 4 *The following conditions are supposed to always hold (for $i = l, h$ and $\forall t$),*

$$\phi w^i_t > \theta^l \overline{w}^l_{t+1},$$

$$\phi w^i_t + x > \theta^h \overline{w}^h_{t+1}.$$

Assumption 1 guarantees that raising children is expensive, otherwise parents will have as many children as they can; at the same time, educating children is also costly, otherwise all children will get higher education.

Combining these two equations (see appendix), we obtain explicit solutions for m and n, which are put forward in the following proposition.

Proposition 1 *Under Assumption 1 we have*

$$m_t^i = \frac{\epsilon(1-\alpha)\overline{w}_{t+1}^h w_t^i}{(1+\epsilon)\left[\phi w_t^i + x - \theta^h \overline{w}_{t+1}^h\right]\left[\alpha \overline{w}_{t+1}^l \sigma_{n,m}^i + (1-\alpha)\overline{w}_{t+1}^h\right]} \tag{5.9}$$

and

$$n_t^i = (\sigma_{n,m}^i)^{\frac{1}{\epsilon}} m_t^i, \tag{5.10}$$

where

$$\sigma_{n,m}^i = \left(\frac{B_t}{A_t^i}\right)^{\frac{\epsilon}{1-\epsilon}}, \text{ with } A_t^i = \frac{\phi w_t^i - \theta^l \overline{w}_{t+1}^l}{\phi w_t^i + x - \theta^h \overline{w}_{t+1}^h}, \quad B_t = \frac{\alpha \overline{w}_{t+1}^l}{(1-\alpha)\overline{w}_{t+1}^h}. \tag{5.11}$$

In fact A_t^i represents the ratio of net costs of raising a low to a high educated child (see (5.7) and (5.8)), while B_t is the ratio of the contribution of a low educated child to a high educated child in parental utility. Also, if ϵ is the elasticity of the utility to any type of children, then $\sigma_{n,m}^i$ can be considered as the elasticity of substitution between high and low educated children in each household.

Given the explicit expression of m^i and n^i, we can study the change in these two choice variables with respect to a change in p^h. In the appendix we prove the following proposition.

Proposition 2 *Under assumption 1 the number of high educated children is an increasing function of the emigration probability of high-skilled p^h, while number of low educated children is a decreasing function of p^h. Mathematically, we have*

$$\frac{\partial m_t^i}{\partial p^h} > 0, \quad \frac{\partial n_t^i}{\partial p^h} < 0, \quad \forall t, \ i = l, h.$$

The intuition of this proposition is very clear: a brain drain would lead to a trade-off between high- and low-skilled children which is in favor of an increase in the number of the former. However, the impact of a rise in p^h on the total number of children, $n_t^i + m_t^i$, is not so clear. Nevertheless, we have the following results by combining equations (5.28), (5.29), and (5.30) in appendix.

Proposition 3 *Assume Assumption 1 holds.*

(i) The effect of p^h *on fertility,* $n_t^i + m_t^i$*, is ambiguous.*

(ii) A sufficient condition for a rise in fertility following a rise in p^h*,* $\partial(n_t^i + m_t^i)/\partial p^h > 0$*, is*

$$\frac{(1-\alpha)\,\overline{w}^h}{\alpha\,\overline{w}^l} > \frac{\phi w^i + x - \theta^h \overline{w}^h}{\phi w^i - \theta^l \overline{w}^l}\;\overline{\epsilon} \tag{5.12}$$

where $\overline{\epsilon} = \left(\frac{1-\epsilon}{\epsilon}\right)^{1-\epsilon}$ *and the right hand side is increasing in* $\overline{w}^h$*.*

(iii) Furthermore, the other direction of the above inequality offers a necessary condition to have a reduction in the total number of children following a rise in p^h*.*

(iv) Finally, the effect of p^h *on average fertility and on the fertility differential between high- and low-skilled parents is ambiguous, even if we impose condition* (5.12)*.*

The above proposition can be commented as follows. A rise in the probability for high-skilled to emigrate p^h leads to an ambiguous effect on the total number of children since the number of low educated children decreases and the one of high educated children increases (point (i) in proposition 3).

However, through the sufficient condition (5.12), we get some insights on the mechanisms that lead parents to have more children as after a brain drain. Condition (5.12) can be interpreted in the following way. A brain drain induces a rise in fertility when the relative gain of having a high compared to a low-skilled child is larger than its relative net cost (up to a term comprising the elasticity of the utility to any type of child, $\overline{\epsilon}$). In fact, the left hand side in (5.12) is a parent's utility value from a high-skilled child's expected income, $(1-\alpha)\overline{w}^h$, to a parent's utility from a low-skilled child, $\alpha\overline{w}^l$. The right hand side comprises a discounted (by an elasticity term $\overline{\epsilon}$) ratio of the raising and education costs of a high educated child ($\phi w^i + x$) net of expected remittances from this child ($\theta^h\overline{w}^h$) to the raising costs of a low educated child net of expected remittances.

The interpretation of the necessary condition in point (iii) is now straightforward. If the relative gain from having a high-skilled child is lower than its relative net cost, then the reduction in the number of low educated children following a brain drain dominates the additional high-skilled children. Thus fertility decreases after a rise in p^h.

The effect of p^h on average fertility and on the fertility differential between high- and low-skilled parents is unclear (point iv of the proposition). Average fertility may decrease even when condition (5.12) holds, i.e. both types of parents have more children. This would be the case when many high-skilled individuals left the country and raise their children abroad. Furthermore, if condition (5.12) holds, the effect of a brain drain on the fertility differential between low- and high-skilled, i.e. the difference between the total number of children from low- and high-skilled parents divided by the total number of parents, is unclear. Intuitively, a rise in p^h *in period* t leads to a decrease in the fertility differential only if the increase in fertility of high-skilled parents dominates the increase in fertility of low-skilled parents and the decrease *in period* t in the share of high-skilled parents. This is shown in appendix.

Finally, due to the symmetry of the effects of p^l and p^h on n^i and m^i, the same calculations lead us to the following corollary

Corollary 1 *Assume Assumption 1 holds. Then m_t^i is decreasing and n_t^i is increasing in p^l, while the effect on the total number of children is ambiguous.*

5.2.3 The impact of a brain drain on human capital

In the following analysis, we study the dynamic impact of an increase in p^h on human capital. But let us first look at the long-run behavior of the economy. Let N_t^h and N_t^l be respectively high- and low-skill active labor forces at time t, i.e. the stock of high- respectively low-skilled individuals born at time $t-1$ from both low- and high-skilled families and staying in their home country

$$N_t^l = (1-p^l)(N_{t-1}^l n_{t-1}^l + N_{t-1}^h n_{t-1}^h), \qquad (5.13)$$
$$N_t^h = (1-p^h)(N_{t-1}^l m_{t-1}^l + N_{t-1}^h m_{t-1}^h). \qquad (5.14)$$

The growth rates of both labor forces are defined as $g_t^h = \frac{N_{t+1}^h}{N_t^h}$ and $g_t^l = \frac{N_{t+1}^l}{N_t^l}$, while the ratio of the high to low-skill labor force as $q_t = \frac{N_t^h}{N_t^l}$.

Definition 1 *Along the balanced growth path of our economy, both working populations grow at the same rate i.e. $g^h = g^l = g$ and thus ratio of the high- to low-skill labor force is constant $q_{t+1} = q_t = q$.*

The following proposition summarizes the behavior of the economy in the long run

Proposition 4 *If parameters and constants check* (5.37) *then the system globally converges to its unique steady state $\overline{q}$, where $q = \frac{N^h}{N^l} = \overline{q}$ and $g^l = g^h = (1-p^l)(n^l + n^h\overline{q})$.*

The proof of this proposition is given in the appendix.

From the previous section, we know that parents choose to have more high- and less low-skilled children, which acts positively on the formation of human capital. However, a brain drain means also that more high-skilled people leave. Thus which effect dominates? Human capital at time t, denoted by H_t, can be defined as the share of high educated labor in the total active labor force. That is

$$H_t = \frac{N_t^h}{N_t^h + N_t^l}, \tag{5.15}$$

where N_t^h and N_t^l are respectively the high- and low-skill active labor forces at time t, defined as Thus $N_t^l(N_t^h)$ are the low- (high-) skill individuals born at time $t-1$ from both low- and high-skilled families and staying in their home country.

Therefore in order to study the effect of a change of p^h on human capital, that is $\frac{\partial H_t}{\partial p^h}$, we only need to study the effect of p^h on $\frac{1}{H_t} = 1 + \frac{N_t^l}{N_t^h}$.

Case I. If p^h varies at time t and this change in p^h is not anticipated by the individuals, then all N_{t-1}^l, n_{t-1}^l, N_{t-1}^h, n_{t-1}^h, m_{t-1}^l and m_{t-1}^h are independent of a change in p^h. Therefore, it follows that

$$\frac{\partial}{\partial p^h}\left(\frac{N_t^l}{N_t^h}\right) = \left(\frac{N_t^l}{N_t^h}\right)\frac{1}{(1-p^h)} > 0,$$

that is,

$$\frac{\partial}{\partial p^h}\left(\frac{1}{H_t}\right) > 0.$$

As a result, we have

$$\frac{\partial H_t}{\partial p^h} < 0, \tag{5.16}$$

which means that if there is no information about a policy change concerning in p^h, then parents are not prepared for it and will not send more children to obtain higher education following a brain drain. The result is that more high-skill workers emigrate without inducing any additional formation of human capital.

Case II. There is perfect foresight and parents are prepared for the change in p^h that happens in the next period. Imagine that at time $t+1$, p^h increases. Direct calculation shows

$$\frac{\partial}{\partial p^h}\left(\frac{N_{t+1}^l}{N_{t+1}^h}\right) = G(n,m)\frac{(1-p^l)}{(1-p^h)^2} + \frac{(1-p^l)}{(1-p^h)}\frac{\partial G(n,m)}{\partial p^h}, \tag{5.17}$$

where

$$G(n,m) = \frac{N_t^l n_t^l + N_t^h n_t^h}{N_t^l m_t^l + N_t^h m_t^h}.$$

We know that both m^l and m^h (n^l and n^h) are increasing (decreasing) in terms of p^h. Thus a higher p^h will lead to a rise in the denominator and to a reduction in the numerator, while N_t^l and N_t^h are decided at time $t-1$ and will thus not be affected by a change in p^h happening at time $t+1$. Hence we obtain

$$\frac{\partial G(n,m)}{\partial p^h} < 0.$$

To conclude, the first term on the right hand side of (5.17) is positive and represents the ex post loss of human capital due to a brain drain, while the second term on the RHS stands for the ex ante stimulation of human capital due to a brain drain. Since these two effects also depend on the population size N_t^l and N_t^h, it is open to question whether at the end a brain drain results in a brain loss or in a brain gain within our endogenous fertility model.[4] A calibration of our model on a situation of a typical developing country open to labor mobility may give us a specific answer.

5.3 Numerical Analysis

In this section we provide a numerical illustration to analyze the effects of increased emigration on fertility and human capital. Higher migration can be due to the fact that destination countries adopt more liberal immigration policies. Since immigration policies tend to be more and more skilled-biased, we first focus on the effects of higher *high*-skilled emigration. Consecutively, we compare the findings with a situation of increased *low*-skilled migration. Moreover, we focus upon the long term impact of changes in p^h and p^l.

5.3.1 Calibration

Our model is calibrated to depict a typical situation of South-North migration and as such the parameter of our model are adjusted to match the economy of the Philippines (to be the migrants' origin country). This choice seems appropriate since international migration and large flows of remittances are notorious characteristics of the Philippine economy for several decades now (see the IMF study of Burgess and Haksar, 2005). The foreign country of the model, is represented by a combination of OECD countries, where the importance of each of them is weighted by the share of Filipino emigrants they host (see below). The initial steady state is assumed to correspond to 2000 data. The values of parameters and exogenous variables are reported in table 5.1 and chosen as follows.

According to Haveman & Wolfe (1995) parents spend around 15% of their time raising children, which enables us to set the raising cost parameter ϕ to 0.15.

[4]It is also theoretically unclear whether a brain drain will increase or decrease human capital in the steady state.

Table 5.1: Parameter values for the Philippines

$\phi = 0.15$	$\epsilon = 0.5$	$w^l = 1$	$w^h = 2.54$	$p^h = 0.086$	$p^l = 0.043$
$\alpha = 0.62$	$\theta^l = 0.1$	$w^{*l} = 4.74$	$w^{*h} = 9.29$	$x_t^l = 0.92$	$R^* = 1.806$

Also, following the wage of a high-skill worker in the Philippines is 2.54 times larger than the one of a low-skilled.[5] Thus if w^l is set to 1, w^h equals 2.54. Since one period is considered to be 20 years, the interest factor is set to $R^* = 1.806$ which corresponds to an annual interest rate of 3%.

A next step is to choose the probabilities to emigrate, p^h and p^l, which are not directly observable. However, Docquier & Marfouk (2006) document that 67% of the Filipinos living in OECD in 2000 are high-skilled (i.e. post-secondary education), thus we can set $p^h = 2\ p^l$. Also, since one period lasts 20 years, it can be considered that the number of migrants in the OECD in 2000 reported by these authors represents the number of emigrants during one period in our model, meaning that 1'678'735 Filipinos go abroad. [6]. If the number of migrants can be written as $p^l N^l + p^h N^h$ then taking N^l and N^h from Docquier and Marfouk, we have that $p^l = 0.043094295$ and $p^h = 0.08618859$.

For the remaining exogenous variables no data are available. To start with, the parameter ϵ in the "altruistic" argument of the utility function is set to 0.5, but will be subject to several robustness checks in a later section. Remaining variables are set in order to match four main characteristics of the Philippine economy. Let us now describe this procedure. First, we know from Docquier & Marfouk (2006), which themselves rely on the data of Barro & Lee (2001a), that in 2000 the ratio of the low-to-high skill labor force, $1/h$ ($= N^l/N^h$), amounts to 3.5045. This value is met by fixing the education costs of a child to $x_t^l = 0.917045$ and by the plausible assumption that $x^h = x^l$. Second, if we consider one period to be 20 years, then population growth in our model equals $g = 1.481$, implying that $\alpha = 0.621093$. Moreover, we can consider the wage differential between the Philippines and the OECD to be similar to the per capita GDP differential. According to the World Development Indicators WDI (2007), average per capita GDP between 1999-2004 was \$3'991 in the Philippines and \$34'268 in the OECD

[5]The data is originally collected by the United Nations, *General Industrial Statistics* and corresponds to the skill premium in the manufacturing sector for the year 2000, see also Zhu (2005).

[6]This number is not exaggerated, because when considering also temporary residents (42%) and irregular migrants (21%) together with permanent residents (37%), the number of Filipinos living and working overseas was estimated to be around 7.58 million in 2002 with an increase of 1 million since 1996. This number is equivalent to almost one quarter of the domestic labor force (Burgess & Haksar, 2005; Castro, 2006)

(PPP, constant 2000 international \$), thus 7.98 times higher in the OECD.[7] If average domestic wage is defined as $\widehat{w} = (w^h + 1/hw^l)/(1 + 1/h)$ and average foreign wage $\widehat{w}^* = (w^{*h} + 1/h^* w^{*l})/(1 + 1/h^*)$, then the average wage difference $\omega = \widehat{w}^*/\widehat{w}$ equals 7.98. Relying on the same sources as for the domestic economy and applying the same weights for the distribution of migrants among OECD countries as for GDP per capita, the average ratio of low-to-high skill labor force in the OECD, $1/h^*$, was 1.096703272 and the skill premium, w^{*h}/w^{*l}, 1.96.[8] Then to match the average wage difference, w^{*h} is required to be 9.2902, while $w^{*l} = w^{*h}/1.96$. Finally, we need to set the propensities to remit θ^l and θ^h. While high-skilled migrants remit a larger amount than low educated migrants, recent research claims that their propensity to remit is lower than the one of low-skilled migrants, see Faini (2007) and Nimii et al. (2008). In our central scenario it is assumed that the propensity to remit of the high-skilled is 50% as much as the low-skilled one and thus $\theta^h = 0.5\ \theta^l$. This assumption will be subject to robustness checks. Based on Fund staff estimates and on the World Bank, indicate that remittances in percentage of GDP amount to 9.4%. If we define GDP, Y, by the sum of incomes from labor and savings, then $Y_t = N_t^h w_t^h + N^l w_t^l + (R^* - 1)(N_{t-1}^h s_{t-1}^h + N_{t-1}^l s_{t-1}^l)$ and the total amount of remittances in one period, Λ, by $\Lambda_t = N_{t-1}^h Z_t^h + N_{t-1}^l Z_t^l$. Then $\Lambda_t / Y_t = 0.094$ implies that $\theta^l = 0.103657$.[9]

5.3.2 Results

We analyze the effects of a permanent increase of 10% in emigration flows, which means that more people leave the Philippines at each period with respect to the baseline. For instance, in the first period of the shock, the additional migrants amount to 164 thousand. Two scenarios are compared. Under the *high*-skilled emigration scenario, additional migrants are all high-skilled and thus p^h rises from 0.086 to 0.109. Conversely, under the *low*-skilled emigration, additional migrants are low-skilled and p^l changes from 0.043 to 0.05. Moreover, we focus

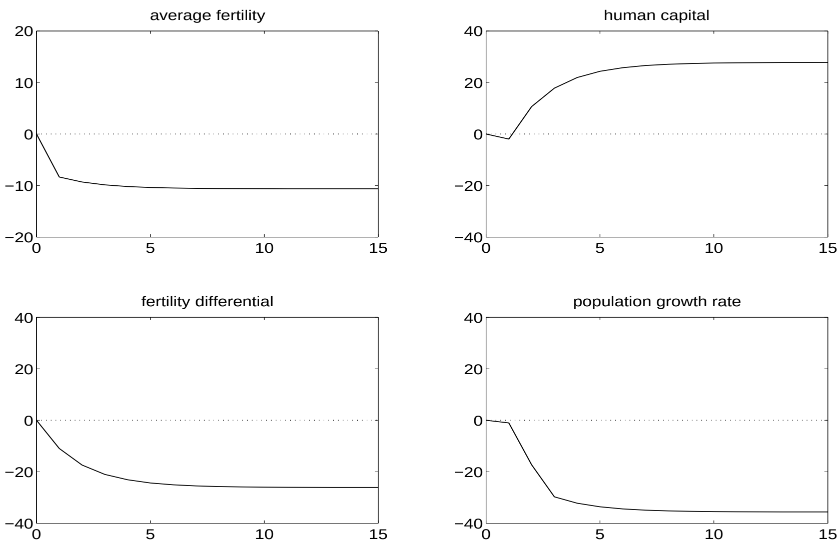
[7] According to Docquier and Marfouk, migrants from the Philippines living in the OECD in 2000 were distributed as follows: United States (69.31%), Canada (11.41%), Australia (4.65%), Japan (4.56%), Italy (2.44%), United Kingdom (2.07%), Germany (0.75%), Korea (0.72%), Spain (0.67%), New Zealand (0.51%), Austria (0.45%), Switzerland (0.43%), Netherlands (0.34%), Greece (0.29%), France (0.28%), Norway (0.25%), Sweden (0.23%), Ireland (0.21%), Denmark (0.15%), Belgium (0.13%), Iceland (0.04%), Mexico (0.04%), Finland (0.037%), Czech Republic (0.0014%), Hungary (0.001%), Slovakia (0.0001%).

[8] The same data source as for the skill premium in the Philippines is used.

[9] According to aggregate data on remittances from the International Monetary Fund (IMF 2007) remittances amount to \$7876 million in 2003. Moreover a more recent report of the World Bank (2006) indicates that the remittances share of GDP in the Philippines would even amount to 13.5% (see World Bank, 2006, p.90, Figure 4.1).

on the long-run impact of such policies, and therefore tables 5.2 and table 5.3 in appendix will refer to long-run changes in main variables (period 10).

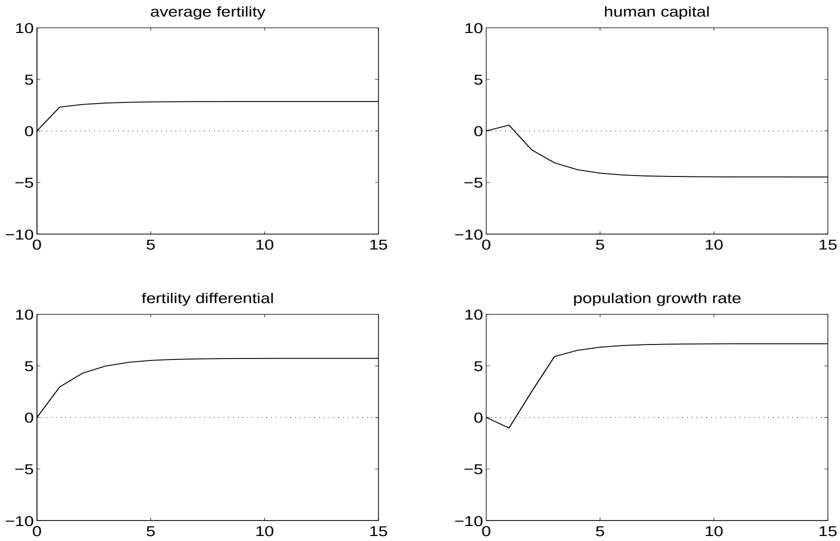
Figure 5.1: Impact of increased *high*-skilled emigration



Values display percentage changes with respect to the baseline.

The long run impact of increased high-skilled emigration is reported in appendix (table 5.2, column 'benchmark'), but can be summarized as follows. Both types of parents choose, as expected from our theoretical results, to finance higher education to a larger number of children and to raise less low-skilled children. While theoretically the effect of p^h on total children was ambiguous, low-skilled parents would prefer to have less children, while high-skilled raise slighty more children. On average, fertility decreases as shown in figure 5.1. Moreover, the fertility differential between low- and high-skilled, i.e. the difference between the total number of children from low- and high-skilled parents divided by the total number of parents, is reduced as well. What about human capital? In the framework of de la Croix & Doepke (2003), a high fertility differential leads to lower human capital accumulation. One of the reasons is that poor families have more children than rich families and their children have a lower human capital. Then for a given initial level of human capital, an economy with a high fertility differential generates a lower future human capital. In our model, there is no explicit link, a lower fertility differential is associated with a higher human capital. The effect of a brain drain on human capital H is (slightly) negative in the short run (when the policy is adopted). This is because the shock is not anticipated

Figure 5.2: Impact of increased *low*-skilled emigration



Values display percentage changes with respect to the baseline.

and more high-skilled individuals leave the country in period 1. In the meantime, parents decide to have more high-skilled children. When these additional high-skilled children, having obtained higher education thanks to the new policy, add to the high-skill labor force in period 2, they will more than compensate for the high educated workers that have left. Moreover, we can see that the growth rate of the population declines slightly in the first period, because of the departure of additional migrants. In the following period, population growth declines compared to the baseline, also because of fertility choices. A 10% rise in emigration flows, where all additional emigrants are highly educated leads, in the long run (period 10), to a 27.80% rise in human capital (i.e. the proportion of high-skilled within a generation H rises from 22.2% to 28.4%) and to a 8.47% decrease in population growth rate (which means that the annual population growth rate declines from 1.98% to 1.36%).

Under the low-skilled emigration scenario, all additional migrants have lower education. From the theoretical analysis, we know that the choices on the number of high- and low-skilled children are upturned compared to a brain drain (see also table 5.2, column 'benchmark'). Such a policy will lead to an increase in average fertility and in the fertility differential between low- and high-skilled parents (figure 5.2). Moreover, the impact on fertility, population growth and human capital is not only reversed, but also of much smaller magnitude than under high-skilled emigration. Increased low-skilled emigration induces, in the long run, a drop of 4.46% in human capital (H goes from 22.2% to 21.2%) and a rise of 7.15% in population growth (the annual growth rate changes from 1.98 to 2.1%).Finally the impact of both migration policies on welfare indicators is discussed in the appendix.

5.3.3 Robustness

Are the above findings consistent with migrants' remittances behavior and with the choice of ϵ? Figure 5.3 reports the impact of high-skilled emigration on human capital formation and population growth when low-skilled migrants have a higher propensity to remit (i.e. the 'benchmark' case when $\theta^h = 0.5\theta^l$), when both types of individuals have equal propensities to remit ($\theta^h = \theta^l$) and when no remittances are sent back ($\Lambda = 0$).[10] The effects on human capital and population growth are robust under these different scenarios. When high-skilled remit in the same propensity as low-skilled, more remittances are sent back (see table 5.2, column '$\theta^h = \theta^l$') and thus the incentives to send more children to get education are higher. It results that human capital is more improved than in the benchmark. However, in the absence of remittances, human capital is nevertheless enhanced (even though less than in the other two scenarios), because parents are altruistic and prefer having more high-skilled children who are expected to earn a higher wage. In terms of population growth, the scenario in which both high- and low-skilled remit in the same way has a less reducing impact than the benchmark. The reason is that since high-skilled migrants remit more, the number of high-skilled children is further stimulated and the decrease in population growth is dampened (see table 5.2). In the absence of remittances, there is no purpose to raise high-skilled children only to obtain additional remittances and low-skilled children are then relatively more interesting in the 'no remittances' scenario than in the other two scenarios. Then the decline in the number of low-skilled children is less important and the effect on population growth reduced.

Figure 5.4 shows the consequences of increased low-skilled emigration. The scenario with the same remitting behavior for high- and low-skilled leads to an inferior reduction in human capital than the benchmark. Under the latter scenario low-skilled remit more than in the case where $\theta^h = \theta^l$, and thus parents react in a stronger way to a rise in p^l. This also explains the higher increase in population growth. The absence of remittances leads to a slight reduction in population growth, because low-skilled parents do not choose to considerably increase the

[10]For each alternative scenarios, the different exogenous variables are recalibrated to meet the characteristics of the Philippine economy in the baseline. Thus, among other features, we always have that human capital is equal to 22.2% and the annual population growth rate 1.98% in the baseline.

Figure 5.3: Impact of *high*-skilled emigration under alternative behaviors to remit

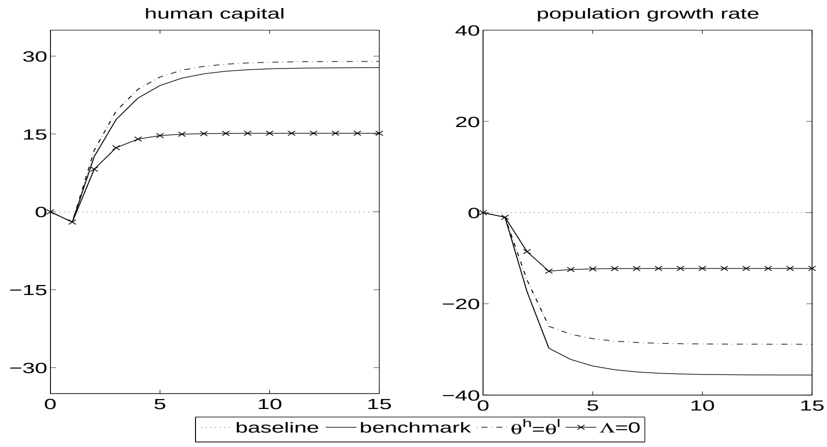
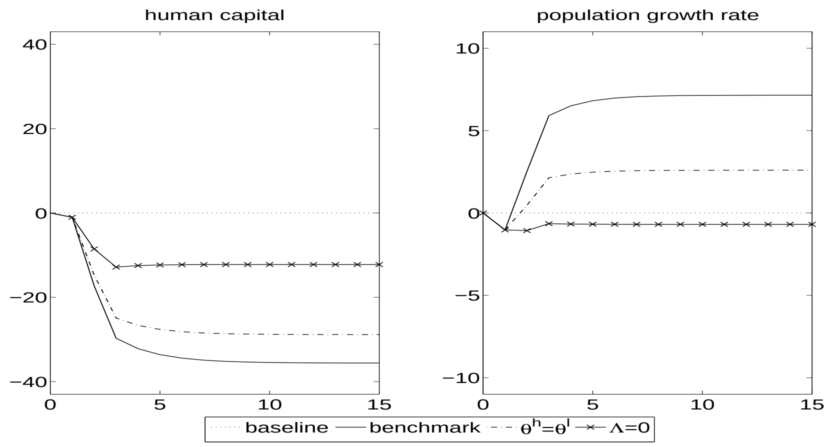


Figure 5.4: Impact of *low*-skilled emigration under alternative behaviors to remit



number of low-skilled children, since these ones do not repay them with any remittances. Ultimately, the implications of larger emigration on human capital formation and population growth are robust to a choice of ϵ (see tables 5.2 and 5.3).

5.4 Conclusion

An endogenous fertility model with overlapping generations is introduced, where parents choose the number of low- and high-educated children they would like to raise. We analyze the impact of high- and low-skilled emigration on parents' fertility choices and on human capital. It is shown that a brain drain induces parents to support higher education to a larger number of their children and to raise less low-skilled ones. Moreover, we find that a sufficient condition to see a rise in the total number of children is that the relative cost of raising a high- compared to a low-skilled child is smaller than its expected gain. Besides, low-skilled emigration leads to contrary results. However, the impact of either type of emigration on human capital is ambiguous.

Finally, the model is calibrated on the Philippines to provide some quantitative results. We examine the consequences of an increase of 10% in emigration flows. When these additional migrants are high-skilled, human capital is enhanced in the long run (the share of high-skilled individuals rises from 22.2% to 28.4%) and population growth experiences a slow down (annual population growth rate falls from 1.98% to 1.36%). Alternatively, when the additional emigrants are low-skilled, the impact is reversed and of a lower magnitude: the level of human capital is exacerbated (the share of high-skilled drops from 22.2% to 21.2%) and population growth is stimulated (from 1.98% to 2.1%).

Appendix A: Proof of Proposition 1

The explicit solutions for n^i and m^i are obtained in two steps. We first compute the linear relationship between n^i and m^i, and find the explicit solution m^i.

Step 1. The relationship between n^i and m^i

By substituting teh equation of $\overline{w}^i$ into the utility function and the ones of S^i_{t+1} and Ω^i_{t+1} into D^i_{t+1}, we are facing the following optimization problem

$$\max_{n^i,m^i} U^i_t = \max_{n^i,m^i} \left[\ln(D^i_{t+1}) + \ln(V^i_{t+1})\right],$$

with

$$D^i_{t+1} = \left[w^i_t\left(1-\phi(n^i_t+m^i_t)\right) - xm^i_t\right] + \left[\overline{w}^h_{t+1}\theta^h m^i_t + \overline{w}^l_{t+1}\theta^l n^i_t\right], \qquad (5.18)$$

and

$$V_{t+1}^i = \overline{w}_{t+1}^l \alpha (n_t^i)^\epsilon + \overline{w}_{t+1}^h (1-\alpha)(m_t^i)^\epsilon, \tag{5.19}$$

First order condition of U^i with respect to n_t^i reads

$$\frac{-\phi w_t^i + \theta^l \overline{w}_{t+1}^l}{D_{t+1}^i} + \frac{\alpha \overline{w}_{t+1}^l \epsilon (n_t^i)^{\epsilon-1}}{V_{t+1}^i} = 0,$$

which is equivalent to

$$\frac{\phi w_t^i - \theta^l \overline{w}_{t+1}^l}{D_{t+1}^i} = \frac{\alpha \overline{w}_{t+1}^l \epsilon (n_t^i)^{\epsilon-1}}{V_{t+1}^i}. \tag{5.20}$$

Similarly, the first order condition of U^i with respect to m_t^i shows

$$\frac{-\phi w_t^i - x + \theta^h \overline{w}_{t+1}^h}{D_{t+1}^i} + \frac{(1-\alpha) \overline{w}_{t+1}^h \epsilon (m_t^i)^{\epsilon-1}}{V_{t+1}^i} = 0,$$

which is the same as

$$\frac{\phi w_t^i + x - \theta^h \overline{w}_{t+1}^h}{D_{t+1}^i} = \frac{(1-\alpha) \overline{w}_{t+1}^h \epsilon (m_t^i)^{\epsilon-1}}{V_{t+1}^i}. \tag{5.21}$$

Dividing (5.7) by (5.8), we obtain

$$\frac{\phi w_t^i - \theta^l \overline{w}_{t+1}^l}{\phi w_t^i + x - \theta^h \overline{w}_{t+1}^h} = \frac{\alpha \overline{w}_{t+1}^l (n_t^i)^{\epsilon-1}}{(1-\alpha) \overline{w}_{t+1}^h (m_t^i)^{\epsilon-1}}.$$

Denote

$$A_t^i = \frac{\phi w_t^i - \theta^l \overline{w}_{t+1}^l}{\phi w_t^i + x - \theta^h \overline{w}_{t+1}^h}, \quad B_t = \frac{\alpha \overline{w}_{t+1}^l}{(1-\alpha) \overline{w}_{t+1}^h}.$$

Hence, we obtain

$$n_t^i = \left(\frac{B_t}{A_t^i} \right)^{\frac{1}{1-\epsilon}} m_t^i, \quad \text{or} \quad (n_t^i)^{\epsilon-1} = \left(\frac{A_t^i}{B_t} \right) (m_t^i)^{\epsilon-1}. \tag{5.22}$$

Step 2. Obtaining m^i

By rewriting (5.7) as follows

$$\left(\phi w_t^i - \theta^l \overline{w}_{t+1}^l \right) V_{t+1}^i = \alpha \epsilon \overline{w}_{t+1}^l (n_t^i)^{\epsilon-1} D_{t+1}^i,$$

using (5.18) and (5.19), and rearranging the terms, yields

$$\lambda \alpha (1+\epsilon) \overline{w}_{t+1}^l (n_t^i)^\epsilon = \alpha \epsilon \overline{w}_{t+1}^l (n_t^i)^{\epsilon-1} \left[w_t^i - \Gamma_1^i m_t^i \right] - \lambda (1-\alpha) \overline{w}_{t+1}^h (m_t^i)^\epsilon. \tag{5.23}$$

with $\lambda = \phi w_t^i - \theta^l \overline{w}_{t+1}^l$ and $\Gamma_1^i = \phi w_t^i + x - \theta^h \overline{w}_{t+1}^h$.

When substituting (5.22) into the right hand side of (5.23) and after rearranging the terms, we obtain

$$\alpha(1+\epsilon)\overline{w}_{t+1}^l (n_t^i)^\epsilon = \frac{(1-\alpha)\epsilon \overline{w}_{t+1}^h}{\phi w_t^i + x - \theta^h \overline{w}_{t+1}^h} w_t^i (m_t^i)^{\epsilon-1} - (1-\alpha)(1+\epsilon)\overline{w}_{t+1}^h (m_t^i)^\epsilon. \tag{5.24}$$

Using (5.22) again and rearranging terms, yields

$$(1+\epsilon)\left(\alpha \overline{w}_{t+1}^l \sigma_{n,m}^i + (1-\alpha)\overline{w}_{t+1}^h\right) m_t^i \overline{w}_{t+1}^h = \frac{\epsilon(1-\alpha)\overline{w}_{t+1}^h}{\phi w_t^i + x - \theta^h \overline{w}_{t+1}^h} w_t^i, \tag{5.25}$$

where $\sigma_{n,m}^i = \left(\frac{B_t}{A_t^i}\right)^{\frac{\epsilon}{1-\epsilon}}$.

Hence m_t^i can be explicitly rewritten as

$$m_t^i = \frac{\epsilon(1-\alpha)\overline{w}_{t+1}^h w_t^i}{(1+\epsilon)\left[\phi w_t^i + x - \theta^h \overline{w}_{t+1}^h\right]\left[\alpha \overline{w}_{t+1}^l \sigma_{n,m}^i + (1-\alpha)\overline{w}_{t+1}^h\right]}.$$

Finally, due to (5.22) and (5.9), we have

$$n_t^i = (\sigma_{n,m}^i)^{\frac{1}{\epsilon}} m_t^i.$$

Appendix B: Proof of Proposition 2

This proof can be established in three steps. In step 1, the effect of p^h on the elasticity of substitution $\sigma_{n,m}^i$ is computed. Step 2 shows that m^i is an increasing function of p^h, while step 3 demonstrates that n^i is decreasing in p^h.

Step 1. Elasticity $\sigma_{n,m}^i$ is decreasing in p^h.

Taking logarithm of $\sigma_{n,m}^i = \left(\frac{B_t}{A_t^i}\right)^{\frac{\epsilon}{1-\epsilon}}$, it follows

$$\ln(\sigma_{n,m}^i) = \frac{\epsilon}{1-\epsilon} \ln\left(\frac{B_t}{A_t^i}\right).$$

Thus

$$\frac{1}{\sigma_{n,m}^i}\frac{\partial \sigma_{n,m}^i}{\partial p^h} = \frac{\epsilon}{1-\epsilon}\frac{A_t^i}{B_t}\frac{\partial}{\partial p^h}\left(\frac{B_t}{A_t^i}\right),$$

and

$$sign\left(\frac{\partial \sigma_{n,m}^i}{\partial p^h}\right) = sign\left(\frac{\partial}{\partial p^h}\left(\frac{B_t}{A_t^i}\right)\right),$$

due to the fact that $\frac{\epsilon}{1-\epsilon} > 0$ and $\frac{A_t^i}{B_t} > 0$.

From the definition of B_t and A_t^i, we have that

$$\frac{B_t}{A_t^i} = \frac{\alpha \overline{w}_{t+1}^l}{(1-\alpha)(\phi w_t^i - \theta^l \overline{w}_{t+1}^l)} \left(\frac{\phi w_t^i + x}{\overline{w}_{t+1}^h} - \theta^h \right).$$

By the definition of $\overline{w}_{t+1}^h$, it follows

$$\frac{\partial}{\partial p^h} \left(\frac{B_t}{A_t^i} \right) = \frac{\alpha \overline{w}_{t+1}^l}{(1-\alpha)(\phi w_t^i - \theta^l \overline{w}_{t+1}^l)} \left[-\frac{\phi w_t^i + x}{(\overline{w}_{t+1}^h)^2} \left(w^{*h} - w^h \right) \right] < 0,$$

where we use the first order condition (or **Assumption 1**)

$$\phi w_t^i + x > \overline{w}_{t+1}^h, \quad \phi w_t^i > \overline{w}_{t+1}^l.$$

Therefore $\sigma_{n,m}^i$ is decreasing in terms of p^h, or

$$\frac{\partial \sigma_{n,m}^i}{\partial p^h} < 0.$$

Step 2. m^i is increasing in p^h.
Denoting

$$\Gamma_1^i = \phi w_t^i + x - \theta^h \overline{w}_{t+1}^h, \quad \Gamma_2^i = \alpha \overline{w}_{t+1}^l \sigma_{n,m}^i + (1-\alpha) \overline{w}_{t+1}^h, \quad \Gamma^i = \Gamma_1^i \Gamma_2^i,$$

and directly taking the derivative of (5.9) with respect to p^h, yields

$$\begin{aligned} \frac{\partial m_t^i}{\partial p^h} &= \frac{\epsilon(1-\alpha) w_t^i}{(1+\epsilon)\Gamma^2} \left[\Gamma^i \frac{\partial \overline{w}_{t+1}^h}{\partial p^h} - \Gamma_2^i \overline{w}_{t+1}^h (-\theta^h) \frac{\partial \overline{w}_{t+1}^h}{\partial p^h} \right. \\ & \left. - \Gamma_1^i \overline{w}_{t+1}^h \left(\alpha \overline{w}_{t+1}^l \frac{\partial \sigma_{n,m}^i}{\partial p^h} + (1-\alpha) \frac{\partial \overline{w}_{t+1}^h}{\partial p^h} \right) \right]. \end{aligned}$$

Define

$$M^i = \Gamma^i + \Gamma_2^i \theta^h \overline{w}_{t+1}^h - \Gamma_1^i (1-\alpha) \overline{w}_{t+1}^h,$$

then $\frac{\partial m_t^i}{\partial p^h}$ can be rewritten as

$$\frac{\partial m_t^i}{\partial p^h} = \frac{\epsilon(1-\alpha) w_t^i}{(1+\epsilon)\Gamma^2} \left(M^i \frac{\partial \overline{w}_{t+1}^h}{\partial p^h} - \alpha \Gamma_1^i \overline{w}_{t+1}^h \overline{w}_{t+1}^l \frac{\partial \sigma_{n,m}^i}{\partial p^h} \right).$$

In step 1, we prove that $\frac{\partial \sigma_{n,m}^i}{\partial p^h} < 0$, so the second terms in the right hand side is positive, and $\frac{\partial \overline{w}_{t+1}^h}{\partial p^h} = w^{*h} - w^h > 0$. Therefore, we only need to study the sign of M^i.

From the above definition, it follows

$$\begin{aligned}
M^i &= \left(\phi w^i + x - \theta^h \overline{w}^h_{t+1}\right)\left(\alpha \overline{w}^l_{t+1}\sigma^i_{n,m} + (1-\alpha)\overline{w}^h_{t+1}\right) \\
&\quad + \theta^h \overline{w}^h_{t+1}\left(\alpha \overline{w}^l_{t+1}\sigma^i_{n,m} + (1-\alpha)\overline{w}^h_{t+1}\right) \\
&\quad - (1-\alpha)\overline{w}^h_{t+1}\left(\phi w^i + x - \theta^h \overline{w}^h_{t+1}\right) \\
&= \left(\phi w^i + x - \theta^h \overline{w}^h_{t+1}\right)\alpha \overline{w}^l_{t+1}\sigma^i_{n,m} + \theta^h \overline{w}^h_{t+1}\left(\alpha \overline{w}^l_{t+1}\sigma^i_{n,m} + (1-\alpha)\overline{w}^h_{t+1}\right) \\
&> 0.
\end{aligned}$$

Therefore, we obtain

$$\frac{\partial m^i_t}{\partial p^h} > 0, \quad \forall t, \quad i = l, h. \tag{5.26}$$

Step 3. n^i_t **is decreasing in** p^h

(In the following, we omit the time subscript t.) Taking logarithm in (5.10), yields

$$\ln(n^i) = \frac{1}{\epsilon}\ln(\sigma^i_{n,m}) + \ln(m^i).$$

Hence direct calculation shows

$$\frac{1}{n^i}\frac{\partial n^i}{\partial p^h} = \frac{1}{\epsilon \sigma^i_{n,m}}\frac{\partial \sigma^i_{n,m}}{\partial p^h} + \frac{1}{m^i}\frac{\partial m^i}{\partial p^h}, \tag{5.27}$$

where the fist term is negative and the second term is positive, therefore we continue the analysis study to see which term dominates and determines the sign of $\frac{\partial n^i}{\partial p^h}$.

It is easy to check that

$$\begin{aligned}
\frac{1}{m^i}\frac{\partial m^i}{\partial p^h} &= \frac{1}{\Gamma^i \overline{w^h}}\left[M^i(w^{*h} - w^h) - \Gamma^i_1 \alpha \overline{w^h w^l}\frac{\partial \sigma^i_{n,m}}{\partial p^h}\right] \\
&= \frac{M^i(w^{*h} - w^h)}{\Gamma^i \overline{w^h}} - \frac{\alpha \overline{w^l}}{\Gamma^i_2}\frac{\partial \sigma^i_{n,m}}{\partial p^h}.
\end{aligned} \tag{5.28}$$

Substituting (5.28) into (5.27), yields

$$\frac{1}{n^i}\frac{\partial n^i}{\partial p^h} = \left(\frac{1}{\epsilon \sigma^i_{n,m}} - \frac{\alpha \overline{w^l}}{\Gamma^i_2}\right)\frac{\partial \sigma^i_{n,m}}{\partial p^h} + \frac{M^i(w^{*h} - w^h)}{\Gamma^i \overline{w^h}}. \tag{5.29}$$

Denote

$$\begin{aligned}\Phi^i &= \frac{1}{\epsilon\sigma^i_{n,m}} - \frac{\alpha\overline{w^l}}{\Gamma^i_2} \\ &= \frac{1}{\epsilon\sigma^i_{n,m}\Gamma^i_2}\left(\Gamma^i_2 - \alpha\epsilon\overline{w^l}\sigma^i_{n,m}\right) \\ &= \frac{1}{\epsilon\sigma^i_{n,m}\Gamma^i_2}\left((1-\epsilon)\alpha\overline{w^l}\sigma^i_{n,m} + (1-\alpha)\overline{w^h}\right) \\ &> 0.\end{aligned}$$

Recall that

$$\begin{aligned}\frac{1}{\sigma^i_{n,m}}\frac{\partial\sigma^i_{n,m}}{\partial p^h} &= \frac{\epsilon}{(1-\epsilon)}\frac{A^i}{B}\frac{\partial}{\partial p^h}\left(\frac{B}{A^i}\right) \\ &= \frac{\epsilon}{(1-\epsilon)}\frac{A^i}{B}\frac{\alpha}{(1-\alpha)}\frac{\overline{w}^l}{(\phi w^i - \theta^l\overline{w}^l)}(-1)\frac{(\phi w^i + x)(w^{*h} - w^h)}{(\overline{w}^h)^2},\end{aligned}$$

where

$$\frac{A^i}{B} = \frac{(\phi w^i - \theta^l\overline{w}^l)}{(\phi w^i + x - \theta^h\overline{w}^h)}\frac{(1-\alpha)\overline{w}^h}{\alpha\overline{w}^l}.$$

Hence

$$\frac{1}{\sigma^i_{n,m}}\frac{\partial\sigma^i_{n,m}}{\partial p^h} = -\frac{\epsilon}{(1-\epsilon)}\frac{(\phi w^i + x)(w^{*h} - w^h)}{(\phi w^i + x - \theta^h\overline{w}^h)\overline{w}^h}. \tag{5.30}$$

Substituting (5.30) into (5.29), it follows

$$\begin{aligned}\frac{1}{n^i}\frac{\partial n^i}{\partial p^h} &= -\frac{(\phi w^i + x)(w^{*h} - w^h)(\Gamma^i_2 - \alpha\epsilon\sigma^i_{n,m}\overline{w^l})}{(1-\epsilon)\Gamma^i\overline{w^h}} + \frac{M^i(w^{*h} - w^h)}{\Gamma^i\overline{w^h}} \\ &= \frac{(w^{*h} - w^h)}{(1-\epsilon)\Gamma^i\overline{w^h}}\left[(1-\epsilon)M^i - (\phi w^i + x)(\Gamma^i_2 - \alpha\epsilon\sigma^i_{n,m}\overline{w^l})\right],\end{aligned} \tag{5.31}$$

where

$$\begin{aligned}(\phi w^i + x)(\alpha\epsilon\sigma^i_{n,m}\overline{w^l} - \Gamma^i_2) &= (\phi w^i + x)\left(\alpha\epsilon\sigma^i_{n,m}\overline{w^l} - \alpha\sigma^i_{n,m} - (1-\alpha)\overline{w^h}\right) \\ &= -(\phi w^i + x)(1-\epsilon)\alpha\sigma^i_{n,m}\overline{w^l} \\ &\quad -(\phi w^i + x)(1-\alpha)\overline{w^h},\end{aligned}$$

and

$$
\begin{aligned}
(1-\epsilon)M^i &= (1-\epsilon)\left[\Gamma_2^i + \theta^h\Gamma_2^i\overline{w^h} - (1-\alpha)\Gamma_1^i\overline{w^h}\right] \\
&= (1-\epsilon)\alpha\sigma_{n,m}^i\Gamma_1^i\overline{w^l} + (1-\epsilon)\Gamma_2^i\theta^h\overline{w^h} \\
&= (1-\epsilon)\alpha\sigma_{n,m}^i\overline{w}^l\left[(\phi w^i + x) - \theta^h\overline{w^h}\right] + (1-\epsilon)\theta^h\overline{w^h}(\alpha\overline{w^l}\sigma_{n,m}^i \\
&\quad +(1-\alpha)\overline{w^h}) \\
&= (\phi w^i + x)(1-\epsilon)\alpha\sigma_{n,m}^i\overline{w^l} + (1-\epsilon)(1-\alpha)\theta^h(\overline{w^h})^2.
\end{aligned}
$$

Hence,

$$
\begin{aligned}
\frac{1}{n^i}\frac{\partial n^i}{\partial p^h} &= \frac{(1-\alpha)(w^{*h}-w^h)}{(1-\epsilon)\Gamma^i}\left[(1-\epsilon)\theta^h w^h - (\phi w^i + x)\right] \\
&\begin{cases} > 0, & \text{if } (1-\epsilon)\theta^h w^h > (\phi w^i + x), \\ = 0, & \text{if } (1-\epsilon)\theta^h w^h = (\phi w^i + x), \\ < 0, & \text{if } (1-\epsilon)\theta^h w^h < (\phi w^i + x). \end{cases}
\end{aligned} \tag{5.32}
$$

However, if Assumption 1 holds (i.e. the first order condition), then the first two cases in (5.32) are not possible, and as a result, we have

$$
\frac{\partial n_t^i}{\partial p^h} < 0, \quad \forall t, \quad i = l, h. \tag{5.33}
$$

This finishes the proof.

Appendix C: Proof of Proposition 3

Dropping the time subscripts for simplicity, a sufficient condition to have a rise in fertility, $\partial(n^i + m^i)/\partial p^h > 0$, is

$$
\frac{m_t^i\left(\phi w^i + x - \theta^h\overline{w}^h\right)}{(m_t^i + n_t^i)\left(\phi w^i - \theta^l\overline{w}^l\right)} < \frac{\epsilon(1-\alpha)\overline{w}^h}{\alpha\overline{w}^l\sigma_{n,m}^i + (1-\alpha)\overline{w}^h}, \tag{5.34}
$$

which is equivalent to (5.12). Before proving proposition 3, let us first show how to rewrite (5.34) into (5.12). Using (5.10) and the results in (5.11), condition (5.34) can be rewritten as

$$
\frac{1}{\left(1 + \left(\frac{B}{A^i}\right)^{\frac{\epsilon}{1-\epsilon}}\right)A^i} < \frac{\epsilon}{1 + B\sigma_{n,m}^i}
$$

Knowing that $B\sigma^i_{n,m} = \frac{B^{\frac{1}{1-\epsilon}}}{(A^i)^{\frac{\epsilon}{1-\epsilon}}}$, the above condition can be rearranged in the following way

$$A^i + \frac{B^{\frac{1}{1-\epsilon}}}{(A^i)^{\frac{\epsilon}{1-\epsilon}}} > \frac{B^{\frac{1}{1-\epsilon}}}{\epsilon(A^i)^{\frac{\epsilon}{1-\epsilon}}}$$

Simplifying further yields,

$$\frac{\epsilon}{1-\epsilon} > \left(\frac{B}{A^i}\right)^{\frac{1}{1-\epsilon}} = \left(\sigma^i_{n,m}\right)^{\frac{1}{\epsilon}}$$

By the definitions of A^i and B we obtain condition (5.12). Proving that condtion (5.12) is sufficient for $\partial(n^i + m^i)/\partial p^h > 0$ is thus equivalent to prove that condtion (5.12) is sufficient for $\partial(n^i + m^i)/\partial p^h > 0$.
This finishes the proof.

Proof of case (ii) of Proposition 3
Denote the right hand side of (5.34) as

$$F(\overline{w}^h) = \frac{\epsilon(1-\alpha)\overline{w}^h}{\alpha\overline{w}^l\sigma^i_{n,m} + (1-\alpha)\overline{w}^h}.$$

And hence

$$\frac{1}{F(\overline{w}^h)} = \frac{\alpha\overline{w}^l\sigma^i_{n,m}}{\epsilon(1-\alpha)\overline{w}^h} + \frac{1}{\epsilon}.$$

Moreover

$$\begin{aligned}\frac{d}{d\overline{w}^h}\left(\frac{1}{F(\overline{w}^h)}\right) &= -\frac{1}{F^2(\overline{w}^h)}\frac{dF(\overline{w}^h)}{d\overline{w}^h} \\ &= \frac{\alpha\overline{w}^l}{\epsilon(1-\alpha)}\frac{\left(\overline{w}^h\frac{\partial\sigma^i_{n,m}}{\partial\overline{w}^h} - \sigma^i_{n,m}\right)}{\left(\overline{w}^h\right)^2},\end{aligned}$$

where, by the definition of $\sigma^i_{n,m}$ and by omitting subscript t for simplicity, leads to

$$\begin{aligned}\frac{\partial\sigma^i_{n,m}}{\partial\overline{w}^h} &= \frac{\epsilon}{1-\epsilon}\left(\frac{B}{A}\right)^{\frac{\epsilon}{1-\epsilon}-1}\frac{1}{A}\left[-\frac{B}{\overline{w}^h} - \frac{B\theta^h}{\phi w^i + x - \theta^h\overline{w}^h}\right] \\ &= -\frac{\epsilon}{1-\epsilon}\sigma^i_{n,m}\frac{\phi w^i + x}{(\phi w^i + x - \theta^h\overline{w}^h)\overline{w}^h} \\ &< 0,\end{aligned}$$

due to Assumption 1 and $0 < \epsilon < 1$.

Hence

$$\frac{d}{d\overline{w}^h}\left(\frac{1}{F(\overline{w}^h)}\right) < 0,$$

and

$$\frac{dF(\overline{w}^h)}{d\overline{w}^h} > 0.$$

The proof is finished.

Proof of case (iv) of Proposition 3

In the following we define average fertility and the fertility differential between high- and low-skilled parents in terms of our model and look the impact of p^h on these two indicators. Average fertility $\overline{F}$ can be defined as

$$\overline{F}_t = \frac{N_t^h(m_t^h + n_t^h) + N_t^l(m_t^l + n_t^l)}{N_t^h + N_t^l} = \frac{q_t(m_t^h + n_t^h) + (m_t^l + n_t^l)}{q_t + 1}$$

Then the impact of a change in p^h on $\overline{F}$ happening at time t can be written as follows

$$\frac{\partial \overline{F}_t}{\partial p^h} = \frac{q_t}{1+q_t}\frac{\partial(m_t^h + n_t^h)}{\partial p^h} + \frac{1}{1+q_t}\frac{\partial(m_t^l + n_t^l)}{\partial p^h} + \frac{(m_t^h + n_t^h)}{(1+q_t)^2}\frac{\partial q_t}{\partial p^h} \tag{5.35}$$

The sign of $\frac{\partial \overline{F}_t}{\partial p^h}$ is unclear. Under condition (5.12) the first two terms are positive, and the sign on $\frac{\partial q_t}{\partial p^h}$ is negative. In fact, q_t is a function of p^h, p^l, N_{t-1}^i, n_{t-1}^i and m_{t-1}^i. Then p^h has a direct negative impact on q_t through the additional high-skilled that emigrate in t but does not affect the choices in terms of children made by parents at $t-1$. Thus the total effect of p^h on average fertility is ambiguous even if we impose condition (5.12).

The fertility differential between high- and low-skilled parents F^d can be defined as

$$F_t^d = \frac{N_t^l}{N_t^l + N_t^h}(m_t^l + n_t^l) - \frac{N_t^h}{N_t^l + N_t^h}(m_t^h + n_t^h) = \frac{1}{1+q_t}\left[(m_t^l + n_t^l) - q_t(m_t^h + n_t^h)\right]$$

The impact of a brain drain on the fertility differential between high- and low-skilled parents will be ambiguous.

$$\frac{\partial F_t^d}{\partial p^h} = \frac{\partial\left(\frac{1}{1+q_t}\right)}{\partial p^h}\left[(m_t^l + n_t^l) - q_t(m_t^h + n_t^h)\right]$$
$$+\frac{1}{1+q_t}\left[\frac{\partial(m^l + n^l)}{\partial p^h} - (m^h + n^h)\frac{\partial q_t}{\partial p^h} - q_t\frac{\partial(m_t^h + n_t^h)}{\partial p^h}\right]$$

Again, even if we impose condition (5.12), then the first three terms on the right hand side of the above equation will have a positive impact on F_t^d while the last term will contribute to decrease F_t^d. This finishes the proof.

Appendix D: Proof of Proposition 4

At the steady state, $q_{t+1} = q_t = q$ and thus we have that

$$q = \frac{N^h}{N^l} = \widetilde{p}\,\frac{m^l + qm^h}{n^l + qn^h}$$

where $\widetilde{p} = \frac{1-p^h}{1-p^l}$. The above equality can be rewritten as

$$n^h q^2 + (n^l - \widetilde{p}m^h)q - \widetilde{p}m^l = 0 \tag{5.36}$$

There exist two solutions to the above equation

$$q = \frac{-(n^l - \widetilde{p}m^h) \pm \sqrt{(n^l - \widetilde{p}m^h)^2 + 4\widetilde{p}n^h m^l}}{2n^h}$$

Since the term in the square root is larger than $n^l - \widetilde{p}m^h$, there exist one unique positive solution to equation (5.36), which is the steady-state value of q

$$\overline{q} = \frac{-(n^l - \widetilde{p}m^h) + \sqrt{(n^l - \widetilde{p}m^h)^2 + 4\widetilde{p}n^h m^l}}{2n^h}$$

Define the function $J(q)$ as

$$J(q) = q_{t+1} = \widetilde{p}\,\frac{m_t^l + q_t m_t^h}{n_t^l + q_t n_t^h}$$

The first derivative of this function with respect to q gives

$$J'(q) = \widetilde{p}\,\frac{\left[m_t^h(n_t^l + q_t n_t^h) - n_t^h(m_t^l + q_t m_t^h)\right]}{(n_t^l + q_t n_t^h)^2} = \widetilde{p}\,\frac{\left[m_t^h n_t^l - n_t^h m_t^l\right]}{(n_t^l + q_t n_t^h)^2}$$

Our economy converges to its steady state, if and only if

$$\text{convergence} \quad \text{iff} \quad J'(\overline{q}) < 1$$

which is equivalent to

$$J'(\overline{q}) < 1 \Leftrightarrow \widetilde{p}\left[m^h n^l - n^h m^l\right] < (n^l + \overline{q}n^h)^2$$

After dividing both sides by n^h, using $m^i = n^i[(\sigma_{n,m}^i)^{\frac{1}{\epsilon}}]^{-1}$ and rearranging, we obtain the following condition

$$\widetilde{p}\left[\frac{1}{(\sigma_{n,m}^h)^{\frac{1}{\epsilon}}} - \frac{1}{(\sigma_{n,m}^l)^{\frac{1}{\epsilon}}}\right] < \frac{n^h}{n^l}\left(\frac{n^l}{n^h} + \overline{q}\right)^2 \tag{5.37}$$

The proof is finished.

Appendix E: Additional indicators, figures and tables

Additional indicators

This section shows the impact of the two migration policies on welfare indicators. Remittances per high- (Z^h) and per low-skilled parent/receiver (Z^l), total remittances (Λ) and average remittances per receiver ($\overline{Z}$) can be written as

$$\Lambda_t = N^h_{t-1} Z^h_t + N^l_{t-1} Z^l_t,$$

$$\overline{\Omega}_t = \frac{\Lambda_t}{(N^h_{t-1} + N^l_{t-1})}.$$

We also look at the impact on average utility ($\overline{U}$) and average utility from consumption ($\overline{\Psi}$):

$$\overline{U}_t = \frac{N^h_{t-1} U^h_t + N^l_{t-1} U^l_t}{N^h_{t-1} + N^l_{t-1}},$$

$$\overline{\Psi}_t = \frac{N^h_{t-1} ln(D^h_t) + N^l_{t-1} ln(D^l_t)}{N^h_{t-1} + N^l_{t-1}}.$$

Moreover, the ratio of the high-to-low skill utilities (Ξ) or of high-to-low skill utilities from consumption (Π) can be considered as indicators of inter-household inequality:

$$\Xi_t = \frac{U^h_t}{U^l_t},$$

$$\Pi_t = \frac{ln(D^h_t)}{ln(D^l_t)}.$$

Average fertility $\overline{F}$ can be defined as

$$\overline{F}_t = \frac{N^l_t}{N^l_t + N^h_t}(m^l_t + n^l_t) + \frac{N^h_t}{N^l_t + N^h_t}(m^h_t + n^h_t)$$

The fertility differential between high- and low-skilled parents F^d can be defined as

$$F^d_t = \frac{N^l_t}{N^l_t + N^h_t}(m^l_t + n^l_t) - \frac{N^h_t}{N^l_t + N^h_t}(m^h_t + n^h_t)$$

The average human capital, is defined as the average proportion of high educated children $\overline{m}$

$$\overline{m}_t = \frac{N^h_t}{N^h_t + N^l_t}\frac{m^h_t}{m^h_t + n^h_t} + \frac{N^l_t}{N^h_t + N^l_t}\frac{m^l_t}{m^l_t + n^l_t}$$

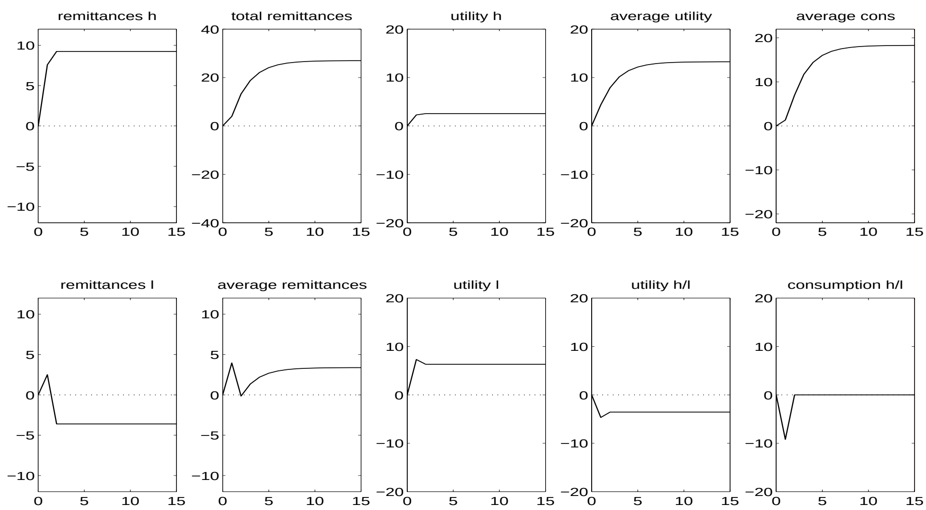
The differential in the proportion of high educated children between high- and low-skilled parents is defined as the human capital differential, m^d

$$m_t^d = \frac{N_t^h}{N_t^h + N_t^l}\frac{m_t^h}{m_t^h + n_t^h} - \frac{N_t^l}{N_t^h + N_t^l}\frac{m_t^l}{m_t^l + n_t^l}$$

The long run impact of the different migration scenarios on all these indicators is shown in tables 5.2 and 5.3.

Impact on welfare

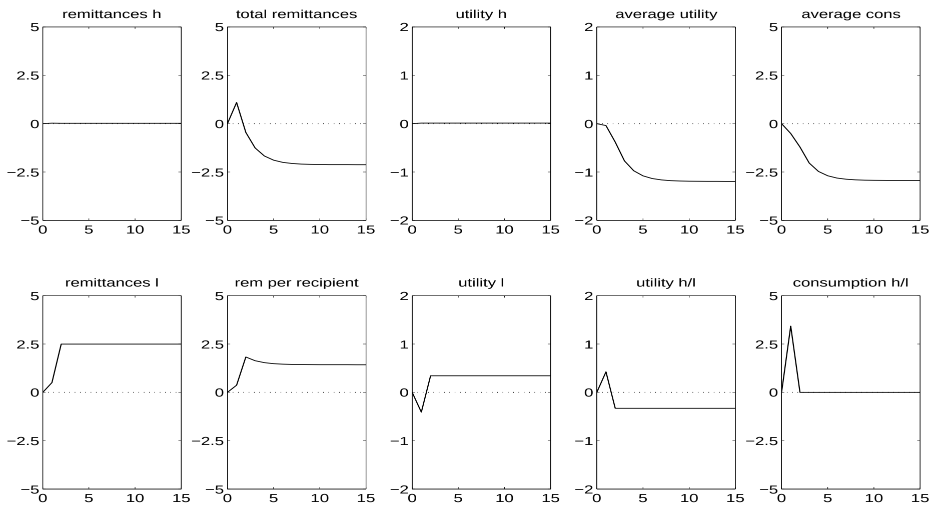
Figure 5.5: Impact of increased *high*-skilled emigration on welfare



Values display percentage changes with respect to the baseline.
“l" refers to low- and “h" to high-skilled individuals.

Figure 5.5 points at the impact of high-skilled emigration on other economic indicators, and more specifically at some welfare indicators. While total remittances and average remittances received rise in the long run (column 2), average remittances received by each skill group behave differently (column 1). Obviously in the first period average remittances for both skill groups rise when more individuals leave the country. However, in the long run remittances for low-skilled individuals are decreased, because the remittances received from their additional high-skilled children do not compensate for the remittances foregone by raising less low-skilled children. In contrast, high-skilled parents benefit from higher per capita remittances. In column 3, high-skilled emigration has only a slight impact on average utility of high-skilled individuals but raises considerably the utility of low-skilled ones. Then average per capita utility will rise and the welfare of low compared to high-skilled individuals will improve (column 4).

Figure 5.6: Impact of increased *low*-skilled emigration on welfare



Values display percentage changes with respect to the baseline.
“l" refers to low- and “h" to high-skilled individuals.

These latter results are explained by the “altruistic” component of the utility. In fact, if we consider welfare to be measured only by the consumption part of the utility, $ln(D^i)$, then average utility per skill group will have only a temporary impact. The ratio of high-to-low skill utilities from consumption, Π_t, will decline in the first period (bottom graph in column 5) because utility from consumption of a high-skilled individual, $ln(D^h)$, decreases more than the utility from consumption of low-skilled individuals. Finally, average utility from consumption, $\overline{\Psi}_t$, rises also in the long run because more and more people become high-skilled and enjoy a higher utility.

Figure 5.6 shows the impact on welfare indicators under increased low-skilled migration. Similarly to a brain drain, higher low-skilled emigration leads to more remittances in the short run (column 2) because more people migrate. In the long run, total remittances decrease, because the number of migrants remitting higher amounts (i.e. the high-skilled migrants) decrease. The reason is that the low-skill biased emigration policy leads parents to finance higher education to a smaller number of children leading to fewer high-skilled emigrants. It can also be observed that in contrast to the brain drain scenario, low-skilled parents benefit on average from higher remittances (bottom graph in column 2). In both scenarios, the utility of low-skilled individuals rises in absolute terms (bottom graph in column 3) and relatively to high-skilled individuals (bottom graph in column 4).

Table 5.2: Long run impact of an increase in p^h under different variants

Impact on household decisions	**Var**	**Bmk**	$\gamma^h = \gamma^l$	$\Lambda = 0$	$\epsilon = 0.25$	$\epsilon = 0.75$
HS children of HS parents	m^h	2.09	3.96	5.36	5.10	1.04
HS children of LS parents	m^l	6.53	10.60	9.09	10.28	8.54
LS children of HS parents	n^h	-14.65	-14.23	-9.44	-8.07	-28.33
LS children of LS parents	n^l	-12.20	-11.00	-6.23	-7.51	-24.12
TOT children of HS parents	$m^h + n^h$	0.22	-0.28	-1.77	0.57	0.98
TOT children of LS parents	$m^l + n^l$	-9.95	-8.40	-4.08	-4.77	-20.46
Savings of HS parents	s^h	-0.88	-1.49	0.00	-0.77	-0.82
Savings of LS parents	s^l	1.61	-1.27	0.00	-1.07	-0.02
Human capital	H	27.79	28.98	15.14	17.06	18.68
Population growth rate	g	-35.62	-28.87	-12.24	-18.81	-23.53
Impact on welfare						
Remittances per HS receiver	Z^h	9.23	11.01	0.00	10.50	8.96
Remittances per LS receiver	Z^l	-3.61	3.59	0.00	2.59	0.06
TOT remittances	Λ	26.98	37.22	0.00	18.20	19.49
AVG remittances	$\overline{Z}$	3.38	14.07	0.00	5.58	4.47
AVG U	$\overline{U}$	13.26	14.49	9.15	7.90	8.79
Ratio of U (HS/LS)	Ξ	-3.56	-3.69	-2.71	-2.60	-2.72
AVG U from consumption	$\overline{\Psi}$	18.31	19.09	9.97	8.42	10.08
Ratio of U from consumption	Π	0.00	0.00	0.00	0.00	0.00

Values display percentage changes with respect to the baseline.

Var stands for 'variables', *Bmk* is the benchmark case, *HS* and LS stand for 'high-skilled' and 'low-skilled', *U* is 'utility', *AVG* means 'average' and *TOT* is 'total'.

Summary of results and robustness

The long run impact of sustained high- and low-skilled migration is summarized in tables 5.2 and 5.3.

Table 5.3: Long run impact of an increase in p^l under different variants

Impact on household decisions	**Var.**	**Bmk**	$\gamma^h = \gamma^l$	$\Lambda = 0$	$\epsilon = 0.25$	$\epsilon = 0.75$
HS children of HS parents	m^h	-0.07	-0.18	-0.53	-0.24	0.00
HS children of LS parents	m^l	-0.70	-0.78	-0.87	-0.53	-1.39
LS children of HS parents	n^h	1.62	1.44	0.94	0.89	3.39
LS children of LS parents	n^l	3.21	1.74	0.60	2.46	5.85
TOT children of HS parents	$m^h + n^h$	0.12	0.20	0.18	0.15	0.01
TOT children of LS parents	$m^l + n^l$	2.74	1.44	0.39	2.00	5.04
Savings of HS parents	s^h	0.00	0.01	0.00	0.00	0.00
Savings of LS parents	s^l	-1.11	-0.33	0.00	-0.73	-0.83
Human capital	H	-4.46	-2.26	-0.78	-2.44	-2.95
Population growth rate	g	7.15	2.60	-0.69	4.32	4.95
Impact on welfare						
Remittances per HS receiver	Z^h	0.02	-0.08	0.00	0.01	0.00
Remittances per LS receiver	Z^l	2.49	0.92	0.00	1.78	2.00
TOT remittances	Λ	-2.12	-1.45	0.00	-0.84	-1.16
AVG remittances	$\overline{Z}$	1.43	0.02	0.00	1.26	1.27
AVG U	$\overline{U}$	-1.19	-0.51	0.07	-0.36	-0.55
Ratio of U (HS/LS)	Ξ	-0.33	-0.41	-0.54	-0.27	-0.28
AVG U from consumption	$\overline{\Psi}$	-2.94	-1.49	-0.51	-1.20	-1.59
Ratio of U from consumption	Π	0.00	0.00	0.00	0.00	0.00

Values display percentage changes with respect to the baseline.

Var stands for 'variables', *Bmk* is the benchmark case, *HS* and LS stand for 'high-skilled' and 'low-skilled', *U* is 'utility', *AVG* means 'average' and *TOT* is 'total'.

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