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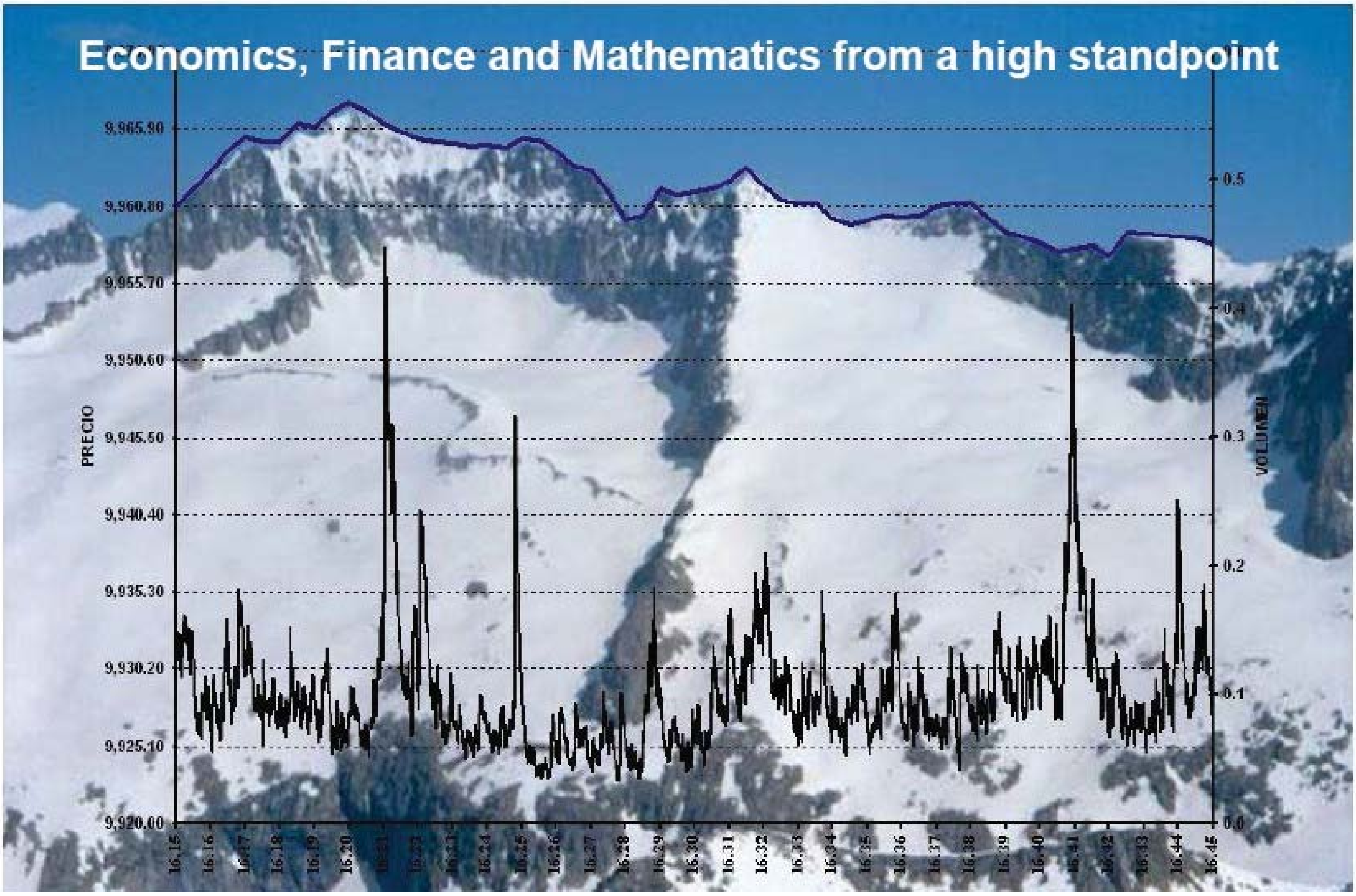

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DT 2018/1

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Edita:
Departamento de Análisis Económico y Finanzas de la UCLM
Teléfono: 34 967 599 200. Extensión 2143
https://www.uclm.es/departamentos/daef/
Depósito Legal: AB-351-2009
ISSN: 1989-4856

Highly Skilled International Migration, STEM Workers, and Innovation*

Anelí Bongers† Carmen Díaz-Roldán‡ José L. Torres§

Abstract

This paper studies the implications of highly skilled labor international migration in a two-country Dynamic Stochastic General Equilibrium model. The model considers three types of workers: STEM workers, non-STEM college educated workers, and non-college educated workers. Only high skilled workers can move internationally from the relative low productivity (sending) country to the high productivity (host) country. Aggregate productivity in each economy is a function of innovations, which can be produced only by STEM workers. The model predicts i) the existence of a wage premium of STEM workers relative to non-STEM college educated workers, ii) this wage premium is higher in the destination country and increases with positive technological shocks, iii) a reduction in migration costs increases output, wages and total labor in the destination country, with opposite effects in the country of origin, and iv) high skilled immigrants reduce skilled native labor and do not affect unskilled labor.

Keywords: STEM workers; Migration; Dynamic Stochastic General Equilibrium models; Innovation.

JEL Classification: F43; J61; O31.

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*Part of this project where developed while Anelí Bongers was visiting the Department of Economics at the Universidad de Castilla-La Mancha, whose hospitality she gratefully acknowledges. Anelí Bongers and José L. Torres acknowledge financial support from the Spanish Ministry of Science, Innovation and Universities through grant ECO-2016-76818-C3-2-P. Carmen Díaz-Roldán acknowledges financial support from the Spanish Ministry of Science, Innovation and Universities through grant ECO-2016-78422-R.

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1 Introduction

Human capital and skill acquisition investment are accepted to be fundamental variables for productivity growth (Lucas, 1988; Jones, 1995, 2002). In a context of international labor mobility, the stock of human capital in any economy does not only depend on investment in skill acquisition by natives but is also affected by the skill embodied in the inflows of workers from abroad. Moreover, human capital and educational attainment by immigrants have not only direct consequences for productivity in the hosting country through increasing the stock of human capital for production, but they also have important implications for the generation of ideas and innovations, which is an additional source of productivity growth. Recent trends in international labor mobility, and in the design of migration policies by high income countries, suggest that migration of some types of high-skilled workers (as scientists and engineers), can be an important factor to promote research, development, and innovation activities.

In the literature, we find two separate branches studying the implications of international flows of workers. The first one, focuses on the effects of immigration on the host countries. A key question in this branch of the literature is how the domestic labor market is affected by the arriving of foreign workers, and which are the implications on wages, employment, occupations, and investment in education by natives. Leading examples can be found in Borjas (1987, 2003), Borjas and Katz (2007), Card (2009), Ottaviano and Peri (2012), among others. A second branch of the literature focuses on the effects of immigration on the country of origin: the outflow of human capital of immigrant workers, a phenomenon known as the "brain drain", as migration of high skilled workers implies a transfers of human capital from the countries of origin to the destination countries. Initial contributions to this literature are those of Grubel and Scott (1966), Johnson (1967), Bhagwati and Hamada (1974), Bhagwati and Rodriguez (1975) and Kwok and Leland (1982), among others. However, a more recent literature, starting with Mountford (1997), Stark, Helmenstein and Prsawetz (1997, 1998), Vidal (1998), Beine, Docquier and Rapoport (2001), Start and Wang (2002), Chen (2006), Docquier and Rapoport (2007), and Dustmann, Fadlon and Weiss (2011), to name a few, show that the effects of high skilled migration can be positive in the sending countries, considering the possibility of a “brain gain”, i.e., the boost of human capital accumulation in the origin countries motivated by the expected returns of education in high income countries, remittances, circular flows, knowledge transfers, etc.

International flows of highly skilled workers do not only have a direct impact on productivity and new technologies adoption, but they can also be a key factor for the generation of ideas, which is an additional factor positively influencing productivity growth. Koser and Salt (1997) pointed the importance of a highly skilled, specialized elite of migrants as crucial element of the spread of expertise. They also addressed that highly skilled migrant labor would transfer expertise through using of new technologies and international networking. In this line, Regets (2007) provides a broad overview of research and policy issues related to international mobility of high skilled migrants, paying special attention to scientists and engineers.

In recent years, the interest of studying the contribution of high-skilled workers to economic growth has been concentrated on those high-skilled workers related with R&D and innovation generating occupations. Namely, workers with an educational background in Science, Technology, Engineering, or Mathematics, the so-called STEM (Science, Technology, Engineering and Mathematics) workers. Employment in STEM occupations has grown 79% since 1990, from 9.7 million to 17.3 million (Graf, Fry and Funk, 2018). In high income countries, as the U.S., immigrants represent a significant fraction of these occupations. According to Hanson and Slaughter (2016), in 2013 in the U.S., foreign-born workers accounted for 19.2 percent of STEM workers with a bachelor's degree, 40.7 percent of those with a master's degree, and more than half (54.5 percent) of those with a Ph.D. As a product of the interest of some countries in welcoming potentially STEM workers specific migration policies have been designed. Examples are the H-1B visa program in the U.S. and the Optional Practical Training program (see Peri, Shih and Sparber, 2015).

Several papers study the effects of STEM migration on innovation and the labor market in the hosting country. Examples are Hunt and Bauthier-Loiselle (2010), Kerr and Lincoln (2010), Lindsay (2010), Peri *et al.* (2015), Jaimovich and Sin (2016) and Picot and Hou (2018). They analyses the contribution of STEM educated immigrants to innovation in the hosting country and the implications for native workers, with mixed results. For instance, Lindsay (2010) found that there is no evidence of the displacement of natives. Kerr and Lincoln (2010) and Peri *et al.* (2015) used changes in the H-1B visa program to study the effects of high-skilled immigrant in the innovation process. Jaimovich and Sin (2016) highlight the role played by high-skilled immigrants in STEM occupations, and their contribution to economic growth through higher productivity steaming from research and innovation areas in the U.S. More recently, Picot and Hou (2018) describe the performance of STEM educated immigrants in the Canadian economy. They studied the contribution to innovation and productivity by STEM educated immigrants working in STEM and in non-STEM occupations.

This paper proposes a theoretical framework to analyze the dynamics of highly skilled international migration on both the origin and the receiving countries, in a unified two-country dynamic general equilibrium model. We assume that only high skilled workers can move internationally from the low productivity (origin) country to the high productivity (host) country. In one hand, following Peri *et al.* (2015), the model considers three types of workers: STEM workers, non-STEM college educated workers, and non- college educated workers. The first two types of workers are high-skill workers, whereas the last one is classified as low-skill. High-skill and low-skill workers are imperfectly substitutable and innovations are is only produced by STEM workers. Accordingly, the Total Factor Productivity (TFP) in each economy is a function of innovations, which can be produced only by STEM workers. On the other hand, the model considers two types of capital assets: structures and equipment. Equipment capital assets and skill workers are complements but equipment and low-skilled workers capital are substitutes. The model also introduces the skill-bias technological hypothesis in which skill workers foster the adoption of skill complementary technologies. In our model the contribution of high-skill workers to economic growth is analyzed from different perspectives. First, STEM workers are modelled as a production factor that contributes exogenously to aggregate productivity by producing innovations (more STEM lead to higher productivity) with positive effects on growth in the short term, since they are a key factor for the development of new technologies and, in this sense, comparable to capital assets in structures. But, in addition, STEM workers also contribute endogenously to the increase of TFP, because they are the only workers able to generate ideas and promote the innovative process (more STEM means an increase of innovation), with positive effects on long-term growth. And, secondly, the model also allows for an additional way of contributing to economic growth, i.e., the complementarity of the high-skill workers (including non-STEM college educated) with equipment.

The model developed here produce a number of results. First, we study the effects of a positive aggregate productivity shock. This shock increases wages for all types of workers, increasing the number of skilled workers but reducing the number of unskilled workers. In the sending country, this shock also provokes a reduction of the incentives to migrate to the destination country. The shock increases the wage differential of STEM workers related to non-STEM college educated workers. The model also produces several results regarding wages. We found the existence of a wage premium to skilled workers related to unskilled workers, but also a wage premium from STEM workers related to non-STEM workers. Additionally, when aggregate productivity differential between the receiving country and the sending country is large enough, it is possible to find situations in which wage for unskilled workers in the destination country is larger than the wage for skilled workers in the sending country. Finally, the model is used to simulate a change in the migration policy implemented by the destination country. A relaxation of the migration policy to allow a larger number of skilled workers increases output in the destination country but has a negative effect on the sending country's output. Total skilled workers increase in the destination country, but there is a partial substitution of native skilled workers, without any effects on the quantity of unskilled workers. Finally, a migration policy to attact foreign STEM workers has similar effects to a positive TFP shock.

The structure of the rest of the paper is as follows. Section 2 introduces a two-country general equilibrium model as a unified theoretical framework to study the effects of several shocks affecting international migration of skilled workers on both sending and hosting countries. Section 3 presents the calibration of the model. In Section 4, the dynamic properties of the model are analyzed by simulating a positive idiosyncratic total factor productivity shock in each country. Section 5 presents the prediction of the model for the wage premium of STEM workers relative to non-STEM college educated workers. Section 6 simulates the effects of changes in the migration policy implemented by the destination country. Finally, Section 7 summarizes the main conclusions.

2 The Model

In this section, we develop a two-country Dynamic Stochastic General Equilibrium (DSGE) model with imperfect international labor mobility. The model is based on previous DSGE models with the possibility of migration developed by Djacic (1987), Canova and Ravn (2000), Klein and Ventura (2009), Mandelman and Zlate (2012), and Hauser (2014). The model considers a world composed by two countries: A country of origin and a destination high-income country. Following Peri *et al.* (2015) the model considers three types of workers: STEM workers, non-STEM college educated workers, and non-college educated workers. These three types of workers are aggregated into low-skilled workers (non-college educated workers) and high-skilled workers (STEM and non-STEM college educated workers). The difference between STEM and non-STEM college educated workers is not in the level of skill but in the occupation. The economy is populated by an infinitely lived representative agent who maximizes the expected value of her lifetime utility. Given a migration policy implemented by the destination country, it is assumed that only high-skill workers are allowed to migrate from the low income country to the high income country. It is assumed that productivity in the destination country is higher than in the sending country, and hence, a wage premium exists. That difference can be explained by total factor productivity differentials (see, for instance, Klenow and Rodriguez-Clare, 1997; Hall and Jones, 1999; etc.), or by differences in the stock of human capital (as in Klenow and Rodriguez-Clare, 1997).

A key point of the model economy is the introduction of a positive externality in the production process, reflecting research and development, and innovations activities, which are connected with the number of STEM workers (Pyo, 2005; and Peri *et al.*, 2015). The importance of STEM workers on economic growth has been highlighted by Griliches (1992) and Jones (1995, 2002). These authors consider that STEM workers is the main input in the idea-production function, and that innovation is the main factor behind productivity growth in the long-run. In our model, the innovation process is based on the production of ideas by STEM workers. The model assumes that aggregate productivity is driven by innovations and that innovations depend on the number of STEM workers. Additionally to the labor inputs, the aggregate production function considers two types of capital assets: structures and equipment, with capital equipment-skill complementarity in the production process.

2.1 Population

We consider a world composed by two countries with international labor mobility: A (relative) low-income country, denoted by o (the country of origin), and a high-income country, denoted by d (the destination country). Differences in income are explained by the fact that productivity in one country is larger than in the other. This introduces the existence of a wage differential and workers in the low productivity country have incentives to move to the high productivity country, depending on migration costs. In both countries exits three types of workers: Low-skilled workers (NS), STEM workers (ST) and non-STEM (NST) college educated workers. Let st_{jj} denotes the proportion of STEM college educated workers born in each economy, nst_{jj}, the proportion of non-STEM college educated workers, and ns_{jj} the proportion of unskilled workers. The total population born in each country is the sum of both skilled and unskilled country born, which it is normalized to 1, $st_{jj} + nst_{jj} + ns_{jj} = 1$. World population is assumed constant, but population in each country can change due to emigration. In particular, population increases in the destination country and reduces in the sending country under the presence of emigration. We assume that, given migration policy implemented by the destination country, only skilled workers, both STEM and non-STEM college educated, can migrate. Therefore, unskilled workers are forced to remain in the born country. Agents are born at time zero and acquire their respective skill endowments, i, at birth, where $i = ns, st, nst$.

With the possibility of migration of skilled workers, population in the destination country, N_d, is defined as:

$$N_d = ns_{dd} + st_{dd} + nst_{dd} + st_{od} + nst_{od} \tag{1}$$

where st_{od} is the proportion of STEM workers born in the sending country that emigrate to the destination country, and nst_{od} is the equivalent for non-STEM college educated workers. By symmetry, population in the origin country, N_o, is defined as:

$$N_o = ns_{oo} + st_{oo} + nst_{oo} - st_{od} - nst_{od} \tag{2}$$

Migration changes the relative proportion of each type of worker over total labor, increasing the proportion of high-skilled workers in the destination country and reducing their proportion in the sending country.

2.2 Innovation process

An important aspect of the proposed model economy is the introduction of a positive externality in the production process, reflecting research, development, and innovations activities. In the literature on economic growth, there are several contributions showing the extent to which Total Factor productivity (TFP) trend depends on the innovation process. Griliches (1992) and Jones (1995) study the relationship between economic growth and ideas production, finding that growth is generated endogenously through R&D spillovers, and economic growth is tied to growth in productivity. On the other hand, Acemoglu and Augrist (2000), Moretti (2004a), Iranzo and Peri (2009) and Peri *et al.* (2015) emphasize the role of human capital externalities associated to innovation. Factors like the number of college graduates, immigration of highly educated workers and the adoption of new technology, among other factors promoting high-skill abilities, generate positive spillover effects on productivity. And, as addressed by Peri *et al.* (2015), STEM workers are fundamental inputs for innovation, and the main driver of productivity growth. Nevertheless, in the empirical literature, there are no clear-cut conclusions. Moretti (2004b) finds large TFP effects of an increase in the share of college graduates in the U.S. cities. However, opposite results are found by Acemoglu and Angrist (2000) and Ciccone and Peri (2006), who do not find any significant effects on TFP of an increase in average schooling across U.S. cities and states. Although those mixed effects could be due to confuse schooling externalities with wage changes due to a downward sloping demand curve for human capital. Trying to solve those opposite results, Iranzo and Peri (2009) by using a simple model and a new empirical strategy, reconcile the mixed findings on human capital externalities previously found in the literature. Kerr and Lincoln (2010) show that immigrant science and engineering employment in the U.S. has a significant effect on patenting without observing negative effect on their native peers.

Having those considerations in mind, we assume that the aggregate production function of the economies includes an additional factor to neutral technology (TFP) representing innovation, which in turn is a function of the number of STEM workers. Following Pyo (2005) and Peri *et al.* (2015), we will assume that aggregate productivity is an increasing function of the number of STEM workers who are the only workers capable of generating ideas and, consequently, innovation. Hence, innovations are considered as a positive externality in the production process, given by.

$$e^{\eta_j L_{j,ST,t}} \tag{3}$$

where $L_{j,ST,t}$ is the number of STEM workers in country j and η_j determines the elasticity of output with respect to the innovations generated by the

STEM workers. The other component of technology, representing neutral technical change, $A_{j,t}$, is assumed to be exogenously determined. We assume that this shocks follows an autoregressive process of order 1:

$$\log A_{j,t} = (1 - \rho_{A,j})\overline{A}_j + \rho_{A,j} \log A_{j,t-1} + \varepsilon^A_{j,t} \tag{4}$$

where $\overline{A}_j$ is the steady state TFP in country j, $\rho_{A,j} < 1$, and $\varepsilon^A_{j,t} \sim N(0, \sigma^2_A)$.

2.3 The technology

The model considers a five-factor production function: Three types of labor (STEM, non-STEM college educated, and non-college educated) and two types of capital assets (structures and equipment). STEM workers are the key inputs in developing new technologies, whereas all high-skill workers, including non-STEM college educated, are key inputs in the adoption of those new technologies given their complementarity with capital equipment.

We assume the following aggregate production function:

$$Y_{j,t} = A_{j,t} e^{\eta_j L_{j,ST,t}} K^{\alpha_j}_{j,s,t} \left[\mu_j L^{\phi_j}_{j,NS,t} + (1 - \mu_j)(\theta_j K^{\rho_j}_{j,e,t} + (1 - \theta_j) L^{\rho_j}_{j,H,t})^{\frac{\phi_j}{\rho_j}} \right]^{\frac{(1-\alpha_j)}{\phi_j}} \tag{5}$$

where $Y_{j,t}$ is final output in country j at time t, $A_{j,i,t}$ is the Total Factor Productivity, $K_{j,s,t}$ is the capital stock in structures, $K_{j,e,t}$ is the capital stock in equipment, $L_{j,NS,t}$ is non-college educated labor, $L_{j,H,t}$ is high-skilled labor, which it is a combination of STEM labor, $L_{j,ST,t}$, and non-STEM college educated labor, $L_{j,NST,t}$. The parameter α_j indicates the elasticity of output with respect to structures. The parameters ρ_j and ϕ_j captures the elasticity of substitution between unskilled labor, capital equipment, and skilled labor. The elasticity of substitution between equipment or skilled labor and unskilled labor is $1/(1 - \phi_j)$, whereas the elasticity of substitution between equipment and skilled labor is $1/(1 - \rho_j)$. Capital skill complementarity requires that $\phi_j > \rho_j$. Finally, μ_j and θ_j are technological parameters that govern income shares.

The skilled labor is an Armington aggregator of STEM and non-STEM college educated labor,

$$L_{j,H,t} = \left[\omega_j L_{j,ST,t}^{\frac{(\sigma_j - 1)}{\sigma_j}} + (1 - \omega_j) L_{j,NST,t}^{\frac{(\sigma_j - 1)}{\sigma_j}} \right]^{\frac{\sigma_j}{\sigma_j - 1}} \tag{6}$$

where the parameter $\sigma_j > 1$ is the elasticity of substitution between STEM and non-STEM college educated workers. Both types of workers are similar in education skills but not in occupation.

The objective of the firms is profit maximization, where profits are defined as:

$$\Pi_{j,t} = Y_{j,t} - \sum W_{j,i,t} L_{j,i,t} - R_{j,e,t} K_{j,e,t} - R_{j,s,t} K_{j,s,t} \tag{7}$$

From the profit maximization problem first order conditions we obtain the following input prices:

$$W_{j,NS,t} = \frac{\mu_j (1 - \alpha_j) Y_{j,t} L_{j,NS,t}^{\phi_j - 1}}{X_{j,t}} \tag{8}$$

$$W_{j,ST,t} = \eta_j Y_{j,t} + \frac{e^{\eta_j L_{j,ST,t}} (1 - \theta_j)(1 - \mu_j) \frac{\omega_j}{\sigma_j} L_{j,ST,t}^{-\frac{1}{\sigma_j}} Y_{j,t} Z_{j,t} L_{j,H,t}^{\rho_j - 1}}{X_t} \tag{9}$$

$$W_{j,NST,t} = \frac{(1 - \theta_j)(1 - \mu_j) \frac{(1 - \omega_j)}{\sigma_j} L_{j,NST,t}^{-\frac{1}{\sigma_j}} Y_{j,t} Z_{j,t} L_{j,H,t}^{\rho_j - 1}}{X_t} \tag{10}$$

$$R_{j,s,t} = \frac{\alpha_j Y_{j,t}}{K_{j,s,t}} \tag{11}$$

$$R_{j,e,t} = \frac{(1 - \alpha_j)(1 - \mu_j) \theta_j K_{j,e,t}^{\rho_j - 1} Y_{j,t} (1 - \mu_j) Z_t}{\left[\mu_j L_{j,NS,t}^{\phi_j} + (1 - \mu_j)(\theta_j K_{j,e,t}^{\rho_j} + (1 - \theta_j) L_{j,t}^{\rho_j})^{\frac{\phi_j}{\rho_j}} \right]} \tag{12}$$

where:

$$X_{j,t} = \mu_j L_{j,NS,t}^{\phi_j} + (1 - \mu_j) \left[\theta_j K_{j,e,t}^{\rho_j} + (1 - \theta_j) L_{j,H,t}^{\rho_j} \right]^{\frac{\phi_j}{\rho_j}}$$

and

$$Z_{j,t} = \left[\theta_j K_{j,e,t}^{\rho_j} + (1-\theta_j) L_{j,H,t}^{\rho_j}\right]^{\frac{\phi_j}{\rho_j}-1}$$

Relative wage for STEM workers versus college non-STEM is given by:

$$\frac{W_{j,ST,t}}{W_{j,NS,t}} = \eta_j Y_{j,t} X_{j,t} + \frac{\omega_j L_{j,ST,t}^{-\frac{1}{\sigma_j}}}{(1-\omega_j) L_{j,NST,t}^{-\frac{1}{\sigma_j}}} \tag{13}$$

As we can observe, the model produces two wage premia. First, there is a wage premium of skilled workers relative to unskilled workers, as it is standard in the literature. Second, we find the existence of a wage premium of STEM workers relative to non-STEM college educated workers, a result supported by the empirical evidence. Therefore, wage inequality is not only generated by the education attainment but by the occupation. In our framework, STEM workers produces innovations which is an additional source of productivity to their skills.

2.4 Host country households

Each economy is populated by an infinity lived representative agent who maximizes the expected value of her lifetime utility. Agents derive utility from consumption and leisure by taking optimal consumption-saving and labor supply decisions. Utility function for the host country households is given by:

$$U_{d,i,t}(C_{d,i,t}, L_{d,i,t}) = \gamma_d \log C_{d,i,t} + (1-\gamma_d)\log(1-L_{d,i,t}) \tag{14}$$

where $C_{d,i,t}$ is consumption by agents born in the destination country, $L_{d,i,t}$ is working hours, and γ_d $(0 < \gamma_d < 1)$ is a parameter determining the weight of consumption in the household's utility. Total available discretionary time has been normalized to one. The household's budget constraint is given by:

$$C_{d,i,t} + I_{d,i,t} = W_{d,i,t} L_{d,i,t} + K_{d,s,i,t} R_{d,s,t} + K_{d,e,i,t} R_{d,e,t} \tag{15}$$

where $I_{d,i,t}$ is investment by agents born in the destination country, $W_{d,i,t}$ is the wage, $K_{d,e,t}$ is the stock of capital equipment and $K_{d,s,t}$, is the stock of structures held by agents born in the destination country, and $R_{d,s,t}$ and $R_{d,e,t}$ are the rental rate of structures and equipment, respectively. Total investment by agents born in the destination country is the sum of investment in structures plus investment in equipment.

$$I_{d,i,t} = I_{d,s,i,t} + I_{d,e,i,t} \tag{16}$$

Accumulation equations for each capital asset is given by:

$$K_{d,e,i,t+1} = (1-\delta_{d,e})K_{d,e,i,t} + I_{d,e,i,t} \tag{17}$$

$$K_{d,s,i,t+1} = (1-\delta_{d,s})K_{d,s,i,t} + I_{d,s,i,t} \tag{18}$$

where $\delta_{d,e}$ and $\delta_{d,s}$ are the depreciation rates for equipment and structures, respectively.

The corresponding Lagrange's auxiliary function is given by:

$$\begin{aligned}\mathcal{L}_d &= \sum_{t=0}^{\infty} \beta_d^t \left[\gamma_d \log C_{d,i,t} + (1-\gamma_d)\log(1-L_{d,i,t})\right] \\ &\quad -\lambda_{d,i,t}\begin{bmatrix} C_{d,i,t} + K_{d,e,i,t+1} - (1-\delta_{d,e})K_{d,e,i,t} \\ +K_{d,s,i,t+1} - (1-\delta_{d,s})K_{d,s,i,t} \\ -W_{d,i,t}L_{d,i,t} + K_{d,s,i,t}R_{d,s,t} + K_{d,e,i,t}R_{d,e,t} \end{bmatrix}\end{aligned} \tag{19}$$

The first order conditions for the consumer maximization problem are:

$$\frac{\partial \mathcal{L}_d}{\partial C_{d,i,t}} \; : \; \frac{\beta_d^t \gamma_d}{C_{d,i,t}} - \lambda_{d,i,t} = 0 \tag{20}$$

$$\frac{\partial \mathcal{L}_d}{\partial L_{d,i,t}} \; : \; -\frac{\beta_d^t(1-\gamma_d)}{(1-L_{d,i,t})} + \lambda_{d,i,t}W_{d,i,t} = 0 \tag{21}$$

$$\frac{\partial \mathcal{L}_d}{\partial K_{d,e,i,t+1}} \; : \; -\lambda_{d,i,t} + \lambda_{d,i,t+1}(R_{d,e,t+1} + 1 - \delta_{d,e}) = 0 \tag{22}$$

$$\frac{\partial \mathcal{L}_d}{\partial K_{d,s,i,t+1}} = -\lambda_{d,i,t} + \lambda_{d,i,t+1}(R_{d,s,t+1} + 1 - \delta_{d,s}) = 0 \tag{23}$$

Solving for the Lagrangian parameter in the first order condition (20) and substituting in (21) we arrive too the equilibrium condition for labor supply is:

$$\frac{(1-\gamma_d)}{(1-L_{d,i,t})} = W_{d,i,t}\frac{\gamma_d}{C_{d,i,t}} \tag{24}$$

The optimal consumption path (investment decisions) is given by the following two equilibrium conditions for equipment and structures, respectively:

$$\frac{C_{H,i,,t+1}}{C_{H,i,t}} = \beta_H (R_{H,e,t+1} + 1 - \delta_{H,e}) \tag{25}$$

$$\frac{C_{H,i,t+1}}{C_{H,i,t}} = \beta_H (R_{H,s,t+1} + 1 - \delta_{H,s}) \tag{26}$$

2.5 Sending country households

Sending country households' utility function presents some differences, as we consider the possibility of migration to the other country. Similar to Borjas (1987), in our model, the resulting emigration rate is: (i) a negative function of mean income in the sending country; (ii) a positive function of mean income in the hosting country; and (iii) a negative function of the costs of emigrating to the hosting country. The utility function for the sending country is given by:

$$U_{o,i,t}(C_{o,t}, L_{o,i,t}, L_{os,i,t}) = \gamma_o \log C_{o,t} + (1 - \gamma_o) \log(1 - L_{o,i,t} - L_{od,i,t}) \tag{27}$$

where C_o is total consumption of agents born in the country of origin, $L_{o,i,t}$ is working time in the origin country and $L_{od,i,t}$ is working time in the destination country, representing the fraction of workers who emigrate to the destination country. The budget constraint is given by

$$C_{o,i,t} + I_{o,i,t} = W_{o,i,t} L_{o,i,t} + (W_{d,i,t} - M_t) L_{od,i,t} + K_{o,s,i,t} R_{o,s,t} + K_{o,e,i,t} R_{o,e,t} \tag{28}$$

where $I_{o,i,t}$ is total investment by agents born in the origin country, $K_{o,s,i,t}$ and $K_{o,e,i,t}$ are the stock of structures and equipment, respectively, $R_{o,s,t}$ and $R_{o,e,t}$ are the rental rate of structures and equipment capital assets, respectively, $W_{o,i,t}$ is the wage in the country of origin, and $W_{d,i,t}$ is the wage in the destination country. M_t represents the cost of emigration.

Capital stock accumulation for equipment and structures is given by:

$$K_{o,e,i,t+1} = (1 - \delta_{o,e}) K_{o,e,i,t} + I_{o,e,i,t} \tag{29}$$

$$K_{o,s,i,t+1} = (1 - \delta_{o,s}) K_{o,s,i,t} + I_{o,s,i,t} \tag{30}$$

where $I_{o,e,i,t}$ is investment in equipment and $I_{o,s,i,t}$ is investment in structures by agents born in the country of origin.

The corresponding Lagrange's auxiliary function is given by:

$$\begin{aligned}\mathcal{L}_o &= \sum_{t=0}^{\infty} \beta_o^t \left[\gamma_o \log C_{o,i,t} + (1-\gamma_o)\log(1 - L_{o,i,t} - L_{od,i,t})\right] \\ & -\lambda_{o,i,t} \left[\begin{array}{c} C_{o,i,t} + K_{o,e,i,t+1} - (1-\delta_{o,e})K_{o,e,i,t} \\ +K_{o,s,i,t+1} - (1-\delta_{o,s})K_{o,s,i,t} \\ -W_{o,i,t}L_{o,i,t} - (W_{d,i,t} - M_t)L_{od,i,t} \\ -K_{o,s,i,t}R_{o,s,t} - K_{o,e,i,t}R_{o,e,t} \end{array}\right] \end{aligned} \tag{31}$$

The first order conditions for the consumer maximization problem are:

$$\frac{\partial \mathcal{L}_o}{\partial C_{o,i,t}} : \frac{\beta_o^t \gamma_o}{C_{o,i,t}} - \lambda_{o,i,t} = 0 \tag{32}$$

$$\frac{\partial \mathcal{L}_o}{\partial L_{o,i,t}} : -\frac{\beta_o^t(1-\gamma_o)}{1 - L_{o,i,t} - L_{od,i,t}} + \lambda_{o,i,t}W_{o,i,t} = 0 \tag{33}$$

$$\frac{\partial \mathcal{L}_o}{\partial L_{od,i,t}} : -\frac{\beta_o^t(1-\gamma_o)}{(1 - L_{o,i,t} - L_{od,i,t})} + \lambda_{o,i,t}(W_{d,i,t} - M_t) = 0 \tag{34}$$

$$\frac{\partial \mathcal{L}_o}{\partial K_{o,e,i,t+1}} : -\lambda_{o,i,t} + \lambda_{o,i,t+1}(R_{o,e,i,t} + 1 - \delta_{o,e}) = 0 \tag{35}$$

$$\frac{\partial \mathcal{L}_o}{\partial K_{o,s,i,t+1}} : -\lambda_{o,i,t} + \lambda_{o,i,t+1}(R_{o,s,i,t} + 1 - \delta_{o,s}) = 0 \tag{36}$$

Equilibrium condition for labor supply in the country of origin is given by:

$$\frac{(1-\gamma_o)}{(1 - L_{o,i,t} - L_{od,i,t})} = W_{o,i,t}\frac{\gamma_o}{C_{o,i,t}} \tag{37}$$

whereas the equilibrium condition for labor supply in the destination country (emigration) is given by:

$$\frac{(1-\gamma_o)}{(1 - L_{o,i,t} - L_{od,i,t})} = (W_{d,i,t} - M_t)\frac{\gamma_o}{C_{o,i,t}} \tag{38}$$

By combining the above two expressions we obtain the equilibrium condition for emigration, given by

$$(W_{d,i,t} - M_t) = W_{o,i,t} \tag{39}$$

Equilibrium conditions for investment in equipment and structures are given by:

$$\frac{C_{o,i,t+1}}{C_{o,i,t}} = \beta_o(R_{o,e,t+1} + 1 - \delta_{o,e}) \tag{40}$$

$$\frac{C_{o,i,t+1}}{C_{o,i,t}} = \beta_o(R_{o,s,t+1} + 1 - \delta_{o,s}) \tag{41}$$

Aggregate values for consumption, investment and capital assets in each country are obtained by assuming that consumption and investment of immigrants are equal to the corresponding values for native in the destination country in per capita terms. That is, we add to the variables of native households in the hosting country the corresponding value from immigrants, and subtract those values for the country of origin.

2.6 Migration policy

In practice, each country choose a particular migration policy. However, in our model economy we assume that only the receiving country implements a migration policy by imposing some restrictions to immigration.[1] These restrictions can be qualitative (depending on the characteristics of immigrants) or quantitative (number of immigrants). We assume that the destination country implements both restrictions: international mobility of low-skill workers is not allowed. Additionally, there is a quantitative restriction by the destination country to the number of high-skill workers that can migrate. Djajic (1989) studied the implications of emigration restrictions. The results vary depending on whether immigration policies limit the quality, or both the quality and the quantity of migrants. But it is shown that qualitative restrictions lower the welfare of the host country, as well as that of the rest of the world.

Migration decision depends on the difference in wages between the origin and the destination countries compared to the cost of migration, as defined above. According to that, the condition for emigrating would be

[1] There is a number of papers that consider migration policies implemented by the countries of origin, as Bhagwati and Hamada (1974), among others.

$$\frac{W_{d,i,t} - M_t}{W_{o,i,t}} > 1 \tag{42}$$

A positive wage gap induces movements of workers from one country to another. However, this emigration process is dampened by the existence of an emigration cost, including both monetary and non-monetary costs incurred by migrant workers seeking jobs abroad. This migration cost is supposed to reflect an heterogeneous set of factors, such as travel and installing costs, adjustment to a new lifestyle and cultural adaptation, cost of searching for employment, family constraints, etc., including migration policy. In the model, $M_t > 0$, represents the cost of migration, and changes in this value is assumed to reflect changes in migration policy, by assuming constant all other factors affecting the cost of migration.

Migration policy is defined as:

$$M_t = \varepsilon_{M,t}\overline{M} \tag{43}$$

where $\overline{M}$ is the steady state value for M_t, and $\varepsilon_{M,t}$ is a shock to the migration policy affecting the value of the emigration cost.

3 Calibration

The model is calibrated for one high income country, and an origin country that can be a developed economy or a developing economy. This is supported by empirical evidence. Only a few countries are net receptors of migration, including the United States, Canada, Australia and the U.K. These are high-income countries in which there exist a wage premium with respect to potential sending countries. In absolute terms, the first destination country of workers migration is the United States. A larger variety is found in the case of sending countries, which includes both developed and developing countries. Therefore, calibration of the model for the country of origin can be done using either a developing country as the reference, or a developed country. However, to isolate the effects of emigration on human capital, we consider that all parameters of the model are the same for both countries, except the steady state value for aggregate productivity. We assume that the steady state value for Total Factor Productivity (TFP) is larger in the destination country with respect to the sending country. In particular, we assume that TFP in the destination country is $\overline{A}_D = 1.50$, and that TFP in the sending country is $\overline{A}_S = 1.00$. This ensures the existence of a wage premium and an incentive to emigrate from the origin country to the destination country.

Calibrated parameter values are shown in Table 1. The discount factor is fixed to be 0.99 (using a quarterly basin), as it is standard in the literature. Depreciation rates for structures and equipment are taken from Greenwood *et al.* (1997) and Krusell *et al.* (2000). Values are 0.05 for structures and 0.125 for equipment, using annual data. For quarterly data, the corresponding values are 0.014 for structures and 0.031 for equipment. The preference parameter representing the weight of consumption in the utility function is fixed to be 0.45.

Technological parameters of the production function are taken mainly from Krusell *et al.* (2000). The elasticity of output with respect to structures is estimated to be 0.117 by Krusell *et al.* (2000), and 0.12 by Greenwood *et al.* (1997). Substitution of low-skill workers by new capital is argued to explain the low demand of non-college educated workers (Autor, Katz and Krueger, 1998; Acemoglu, 1998, 2002; Krusell, Ohanian, Ríos-Rull and Violante, 2000; Beaudry and Green, 2005; Autor, Katz and Kerney, 2007; among others). Johnson (1997) estimated an elasticity of substitution between unskilled and skilled labor of 1.5. Hamermesh (1997) presents similar estimations. Krusell *et al.* (2000) report estimates of 1.67 for the elasticity of substitution between unskilled and skilled labor (or, similarly between unskilled labor and equipment), and a estimated substitution elasticity between skilled labor and equipment of 0.67. These estimates implies that $\rho = -0.495$, and that $\phi = 0.401$.

The weight μ and θ in the CES nestings of the production function are taken from Lindquist (2004) who calibrate these parameters to be $\mu = 0.413$, and $\theta = 0.553$. Peri *et al.* (2015) estimated an elasticity of TFP to the number of STEM workers of 2.75. Based on that estimation, the innovation productivity parameter is fixed to be 0.8. The proportion of STEM workers over total employment is around 6.2% for the U.S., and the total skilled workers represents around 52% of total employment. Combining both figures we obtain that the proportion of STEM workers with respect to skilled workers is 0.117. Finally, the elasticity of substitution between STEM and non-STEM college educated workers, following Peri *et al.* (2015) is fixed to be 1.75, with estimates values in the literature between 1.5 and 2.5.

Table 1: Calibration of the model			
Parameter	**Definition**	**Country D**	**Country S**
β	Discount factor	0.990	0.990
δ_e	Equipment depreciation rate	0.031	0.031
δ_s	Structures depreciation rate	0.014	0.014
γ	Consumption/leisure weight	0.450	0.450
α	Elasticity of output to structures	0.120	0.120
ϕ	Equipment/unskilled substitution	0.401	0.401
ρ	Equipment/skilled substitution	-0.495	-0.495
μ	Unskilled share	0.413	0.413
θ	Equipment share	0.553	0.553
η	Innovation productivity	0.800	0.800
ω	Proportion of STEM workers	0.117	0.117
σ	STEM/non-STEM substitution	1.750	1.750
$\overline{A}$	Steady State TFP	1.500	1.000
ρ_A	Autoregressive parameter TFP	0.950	0.950
σ_A	Standard deviation TFP	0.010	0.010

4 Total Factor Productivity shock

In this section, we present some simulations to show the dynamics of the model economies via impulse-response functions to an aggregate productivity shock. This first exercise considers the case of an exogenous idiosyncratic positive neutral shock to each economy, that is, an increase in Total Factor Productivity, A_t. This standard shock is studied in most real business cycle models and so it is used as a benchmark to test the dynamic properties of the model economy. When studying the dynamics of the response of the economies to technological shocks, we assume that the immigration rate remains constant and that the migration policy is endogenously determined. In this context, a change in the migration cost reflects the pressure of immigration. This is justified by the fact that the number of (legal) immigrants is not endogenous determined by the model, but it is a variable determined by the migration policy. We assume that TFP increases by one standard deviation on impact. As expected, this shock raises output on impact, as more output is produced for given factor inputs. When the shock occurs, private investment also increases in the period, given that the shock reduces the marginal cost of capital accumulation. As a consequence, capital stock also increases in response to the rise in its productivity, increasing the persistence of output to the shock.

These changes in output and physical capital lead to a gradual increase in consumption above its steady state. Thus, the overall effects of this shock in our theoretical framework are the same (from a qualitative point of view) than in the standard real business cycle model, in which would observe a rise on output, investment, consumption and capital stock (both structures and equipment) in response to the shock. Additionally, to the standard results, the model indicates that the demand for unskilled workers reduces and increases the demand for skilled workers in the country hit by the productivity shock. This would justify a relaxation of the migration policy to attract high-skilled workers from abroad.

When looking at migration's decision, additional effects are observed. A positive productivity shock in the sending country reduces the number of native workers that want to emigrate to the destination country. The most important implications can be found in the response of wages, which are assumed to represent labour productivity. The positive aggregate productivity shock has a positive effect on the number of skill workers but reduces the number of unskilled workers. This is due to the assumption of capital-skill complementarity used to model the production function. In this context, there is a reallocation of investment between structures and equipment, which increases the demand of skilled workers and reduces the demand of unskilled workers. On the other hand, the effects of this shock on wages is positive for all types of workers. Finally, the model's dynamic shows that the cost of migration must be increased to maintain constant the proportion of immigrants. This means that migration policy should be reinforced in the case of a rise in productivity, as this shock generates more incentives to emigrate for workers in the origin country.

Figures 1 and 2 plot the effects of a positive productivity shock in the destination country (for the sending country, results are similar, except for migration pressure which it is the opposite). We observe how this positive shock increases skilled labor, both STEM and non-STEM college educated labor. Change in the unskilled labor is not significant. Given the rise in aggregate productivity, all wages for the three types of workers increase in response to the shock, increasing the wage premia of both skilled relative to unskilled labor and STEM versus non-STEM college educated labor. Finally, we obtain a measure of migration pressure, by calculating the change in migration costs to maintain fixed the number of immigrants.

5 STEM versus non-STEM wage premium

An important aspect studied by the literature related to the effects of immigration is its impact on wages and employment conditions for native workers in the destination country. The model presented in this paper produces several results regarding the effects of emigration on labor markets in both, destination and sending countries. The calibrated model can be used to assess how migration affect changes in factor inputs and wage inequality.

First, as expected, all three types of wages (those for STEM, non-STEM college educated, and non-college educated workers) are higher in the destination country than in the country of origin. Since the model assumes that aggregate productivity is higher in the destination country, this also implies that wages in this country for all types of workers, including unskilled workers, are higher than the equivalent wage for each type of worker in the country of origin. This creates an incentive for all types of workers to emigrate from their countries to higher productivity countries. Nevertheless, as it is assumed by the model, the number of immigrants will depend on the migration policy implemented by the destination country. As showed in the previous section, aggregate productivity of each economy affects positively to all types of workers. In the benchmark calibration of the model, wages for unskilled workers in the destination country are lower than wages for the skilled workers in the sending country. However, depending on the calibration of the model it is possible to produce situations in which wages for unskilled workers in the destination country are higher than the wage for skilled workers (both STEM and non-STEM college educated) in the origin country.

Second, the model produces a wage premium for skilled workers with respect to unskilled workers. This is a standard result obtained in the literature, reinforced by the assumption of capital-skill complementarity. As it is pointed out by Krusell *et al.* (2000), skill-biased technological change is the main factor explaining the rise in the skill premium of skilled workers relative to that of unskilled workers. Katz and Murphy (1992), analyzed changes in the US wage structure from 1963 to 1987 and they found that part of the divergence in wage structure changes across countries were due to skill-biased technological changes, since skilled workers become a key factor of technological revolution. Acemoglu (1998) considers that new technologies are not complementary to skills by nature, but by design. In this context, the rise in the supply of skills reduces the skill premium in the short run, but then it induces skill-biased technological change which leads to a rise in the skill premium in the long run. Our model is consistent with those findings when there is a rise in the number of skilled immigrants, as we will show in the next section.

Third, a novel result obtained from the model is that wage differential for skilled workers relative to unskilled workers is larger in the destination country that in the sending country. This implies that wages inequality is a factor driven by aggregate productivity, and hence, productivity growth will increase the skill premium across countries. This result has important implications for the emigration process, as that implies the existence of more incentives to migrate for STEM workers compared to that of non-STEM college educated workers.

Fourth, we obtain that the existence of a wage premium of STEM workers relative to non-STEM college educated workers. This wage premium is given by expression (13), where the wage differential depends on the relative quantity of each type of labour and on the technological parameter of the innovation process and on the parameter representing the elasticity of substitution between STEM and non-STEM college educated workers. That result is consistent with the empirical evidence, where the average wage for STEM workers is larger compared with that of non-STEM workers with similar levels of education. According to the BLS (Bureau of Labor Statistic), for the year 2015, average wage for all STEM occupations in the U.S. was 87,570 dollars, nearly double average wage for non-STEM occupations (45,706). Petroleum engineers (with an annual wage mean of $149,590) and Physicists ($118,500) are among the highest paid STEM occupations. This difference has increased in recent years; for the period 2009-2015, average wage of STEM occupations has increased a 10.5%, whereas the increase for non-STEM occupation has been of 5.2%. Among those with some college education, the typical full-time, year-round STEM worker earns $54,745 while a similarly educated non-STEM worker earns $40,505, or 26% less.

Finally, a major finding is that wage premium for STEM workers relative to non-STEM college educated workers is higher is the destination country that in the country of origin. This result means that the difference in aggregate productivity across countries is an additional factor explaining the wage premium for STEM versus non-STEM college educated workers. This is consistent with the results obtained previously, indicating that the incentives to emigrate to high productivity countries is larger for STEM workers than for non-STEM college educated workers. This results must be taken into account when designing migration policies in both the hosting and the origin countries.

6 Migration policy shocks

In this section, we study the effects of changes in the migration policy implemented by the destination country. We consider that changes in migration policy are represented by changes the migration cost, M_t. The migration cost would capture, both a quantitative migration policy that limits the number of immigrants, but also a qualitative migration policy allowing only skilled workers to migrate. Having those in mind, migration costs are assumed to be exogenously determined, and two types of migration policies can be considered. First, we can consider a relaxation of migration policy that allows the entrance of a great number of high skilled workers, both STEM and non-STEM (quantitative policy). Second, we can study the effects of a migration policy designed to attracting only STEM workers (qualitative policy). The calibrated model can be used to assess the extent to which the changes in the migration policy affect labour markets and productivity in both countries.

We start by studying a relaxation of migration policy for all skilled workers. This will increase the number of skilled immigrant labor force in the destination country, reducing the number of skilled workers (both STEM and non-STEM college educated) in the country of origin. As a first result, we observe a positive effect on final output in the destination country and a negative effect on output in the origin country. This is a direct consequence on the rise in labor inputs in the destination country, whereas this international labor mobility implies a reduction in skilled labor inputs in the sending country. Figures 3 and 4 plot the transition dynamics for the selected variables to a relaxation in the immigration policy implemented by the destination country. As we can observe, there is a sudden drop in output in the sending country and a sudden rise in output in the destination country as the model assumes that migration is an instantaneous process. After this initial adjustment, output converge (increasing in the destination country and reducing in the sending country) to the new steady state. In quantitative terms, the relative gain in output in the destination country is lower than in the origin country. However, the final effect is a net world gain, given that output in the destination country is higher than in the origin country. Therefore, international labor mobility of highly skilled workers increases total world output but at the cost of a reduction of output in the sending country. Nevertheless, this result must be interpreted with caution, as the theoretical framework developed here does not consider other factors, as remittances, circular migration, and knowledge transfers, which are expected to have a positive effect on production in the country of origin.

However, the final effect is a net world gain, given that output in the destination country is higher than in the origin country. Therefore, international labour mobility of highly skilled workers increases total world output but at the cost of a reduction of output in the sending country. However, this result must be interpreted with caution, as the theoretical framework developed here does not consider other factors, as remittances, circular migration, and knowledge spill-overs, which are expected to have a positive effect on production in the country of origin. As a rule, wages increase in the destination country and reduces in the sending country. This is true for all three types of workers and implies that international labour mobility of highly skilled workers also affects wages for unskilled workers. Interestingly, wages for skilled workers reduce in impact in the destination country and increase in impact in the country of origin just reflecting changes in productivity. However, after the initial negative effects, we observe a recovery in wages, increasing in the long-run with respect to the initial steady state in the destination country. In the country of origin, we observe the opposite response. After an initial positive impact, as it is reduced the supply of skilled labour, the response is negative, producing a reduction in wages in the long-run as productivity decreases. An important result is that wages for STEM workers increase more than that of non-STEM college educated workers, enhancing the wage premium between both types of occupations in the destination country. The opposite result is observed in the country of origin. This result indicates that higher the number of STEM workers, higher the level of innovations, which in turn implies higher wages for STEM workers. Therefore, the model predicts not only an increasing in the wage premium of skilled workers related to unskilled workers, as shown by the literature, but also a rise of the wage premium of STEM workers related to non-STEM college educated workers, as innovation is one of the key factors fostering productivity.

On the other hand, total skilled labor in the destination country increases with the relaxation of the migration policy. This is expected, as immigrants are high skilled workers. However, we observe that the response is positive in impact given the instantaneous entry of new workers, but negative subsequently. Nevertheless, the long-run impact is a rise in skilled labor. The negative response of skilled labor after the initial positive impact is related to the response of native skilled labor to the entry of skilled immigrants. In fact, the model, predicts a reduction in the working hours by native workers, an effect also found in some empirical works. Another result is that unskilled labor in not affected in any country. This means that migration of skilled workers does not have consequences, on the quantity of unskilled labor, affecting unskilled wages depending on their impact on aggregate productivity. Therefore, in this case the model predicts a world loss of skilled labor as native skilled workers in the destination country are partially substituted by skilled immigrants from the country of origin.

Finally, we study the effects of a migration policy designed to attract only STEM workers from abroad. In this case, the relaxation in migration policy only affect to foreign STEM workers. This is intended to represent the H-1B visa program specifically designed to allow access to the U.S. of foreign STEM workers. Results are qualitatively similar to the case of a migration policy change affecting all skilled workers, but the quantitative effects are reinforced. Transition dynamics are not shown for this experiment, as they resemble the previous case. However, two important differences can be observed. First, the quantitative impact on all variables is larger than when the migration policy allows to both STEM and non-STEM college educated workers to emigrate. This is a direct consequence of the higher impact of this type of workers on aggregate productivity through the production of innovations. Second, the negative impact on native STEM workers is of similar magnitude to the previous case. This result can be explained by the fact that STEM workers contribute to increase productivity through two channel: a direct channel by increasing the level of skills for production and another channel through the production of innovations, which is an additional factor of aggregate productivity. A conclusion that arises from this result is that a specific migration policy designed to attract STEM workers, does not crowing-out native employment in these occupations in a greater extent than a more general migration policy to attract skilled workers.

7 Conclusions

This paper has studied the implications of high skilled workers migration for both receiving and sending countries, focusing on the role of STEM workers. For this goal, we have developed a two-country DSGE model. Our main concern has not directly focused on the (potentially negative) effects of STEM migration in the sending countries (the so called "brain drain"), neither in the (potentially positive) effects of STEM migration in the hosting countries (the "brain gain"), but on the integrated and global effects on economic growth provoked by a significant increase in international skilled workers movements. In our experiments the number of STEM migrants allowed by a particular immigration policy, should be understood as a proxy of the cumulative effect of an appropriate set of policies (affecting educational, social and inclusion policies, together with labour measures) aimed to encourage the incorporation of high-skilled workers to STEM oriented tasks.

Our results show that specific productivity shocks to each country provokes a change on the incentives to migrate. A positive aggregate shock in the destination country increases the incentive to migrate from the origin country, whereas a positive productivity shock in the origin country reduces those incentives. Additionally, the productivity shock increases the wage differential of STEM workers related to non-STEM college educated workers. We found the existence of a wage premium to skilled workers related to unskilled workers, but also a wage premium from STEM workers related to non-STEM workers. This result can be interpreted as the existence of more incentives for migration for STEM workers than for non-STEM workers. One important property of the model economy developed in the paper is that it can be used to simulate a change in the migration policy implemented by the destination country. A relaxation of the migration policy to allow a larger number of skilled workers increases output in the destination country but has a negative effect on the sending country's output. Total skilled workers increase in the destination country, but there is a partial substitution of native skilled workers, without any effects on the quantity of unskilled workers.

As the most obvious policy implications, we could say that our results would support economic policies recommendations suggesting the promotion of new technologies oriented to favour technological intensive educational policies, immigration policies attracting STEM workers, and a proper combination of investment in equipment and structures compatible with the social capability of population.

References

[1] Acemoglu, D. (1998): Why do new technologies complement skills? Directed technical change and wage inequality. *Quarterly Journal of Economics*, 113(4), 1055-1089.

[2] Acemoglu, D. (2002): Technological change, inequality and the labor market. *Journal of Economic Literature*, 40(1), 7-72.

[3] Acemoglu, D. and Angrist, J. (2000): How large are human capital externalities? Evidence from compulsory schooling laws. *NBER Macroeconomics Annual.*

[4] Autor, D., Katz, L. and Krueger, A. (1998): Computing inequality: Have computers changed the labor markets? *Quarterly Journal of Economics*, 113(4), 1169-1214.

[5] Autor, D., Katz, L. and Kearney, M.S. (2006): The polarization of the U.S. labor market. *American Economic Review*, 96(2), 189-194.

[6] Beaudry, P. and Green, D.A. (2005): Change in U.S. wages, 1976-2000: Ongoing skill bias or major technological change? *Journal of Labor Economics*, 23(3), 609-648.

[7] Beine, M., Docquier, F. and Rapoport, H. (2001): Brain drain and economic growth: theory and evidence. *Journal of Development Economics*, 62(1), 275-289.

[8] Bhagwati, J. N. and Hamada, K. (1974): The brain drain, international integration of markets for professionals and unemployment: a theoretical analysis. *Journal of Development Economics*, 1(1), 19-42.

[9] Bhagwati, J. N. and Hamada, K. (1982): Tax policy in the presence of emigration. *Journal of Public Economics*, 18, 291-317.

[10] Bhagwati, J. N. and Rodríguez, C. (1975): Welfare-theoretical analyses of the brain drain. *Journal of Development Economics*, 2, 295-221.

[11] Borjas, G. (1987): Self selection and the earning of immigrants. *American Economic Review*, 77(4), 531-553.

[12] Borjas, G. (2003): The labor demand curve is downward sloping: Reexamining the impact of immigration of the labor market. *Quarterly Journal of Economics*, 118(4), 1335-1374.

[13] Borjas, G. y Katz, L. (2007): The evolution of the Mexican-born workforce in the United States, in *Mexican Immigration to the United States*, edited by G. Borjas. NBER Conference Report.

[14] Canova, F. and Ravn, M.O. (2000): The macroeconomic effects of German unification: Real adjustments and the welfare state. *Review of Economic Dynamics*, 3, 423-460.

[15] Clemens, M. A. (2017): "Migration is a form of development: The need for innovation to regulate migration for mutual benefit", Center for Global Development and IZA Institute of Labour Economics, December 2017.

[16] Djajic, S. (1989): Skills and the pattern of migration: The role of qualitative and quantitative restrictions on international labor mobility. *International Economic Review*, 30(4), 795-809.

[17] Graf. N., Fry, R. and Funk, C. (2018): 7 facts about the STEM workforce. Pew Research Center, January.

[18] Griliches, Z. (1992): The search for R&D spillovers. *Scandinavian Journal of Economics*, 94(1), 29-47.

[19] Hall, R. and Jones, C. (1999): Why Do Some Countries Produce So Much More Output Per Worker Than Others?. *Quarterly Journal of Economics*, 114(1), 83-116.

[20] Hamermesh, D.S. (1997): *Labor Demand*. Princeton: Princeton University Press.

[21] Hauser, D. (2014): Technology shocks, labour mobility and aggregate fluctuations. Bank of Canada Working Paper, n. 2014-4.

[22] Hunt, J. and Gauthier-Loiselle, M. (2010): How much does immigration boost innovation? *American Economic Journal: Macroeconomics*, 2(1), 31-56.

[23] Iranzo, S. and Peri, G. (2009): Schooling externalities, technology, and productivity: Theory and evidence from U.S. States. *Review of Economics and Statistics*, 91(2), 420-431.

[24] Johnson, H. G. (1967): Some Economic Aspects of the Brain Drain. *Pakistan Development Review* 7(3), 379-411.

[25] Johnson, G.E. (1997): Changes in earnings inequality: The role of demand shifts. *Journal of Economic Perspectives*, 11(1), 41-54.

[26] Jones, C.I. (1995): Time series tests of endogenous growth models. *Quarterly Journal of Economics*, 110, 420-431.

[27] Jones, C.I. (2002): Sources of US economic growth in a world of ideas. *American Economic Review*, 92(1), 220-239.

[28] Katz, L. F. and Murphy, K. M. (1992): Changes in relative wages, 1963-1987: Supply and demand factors. *Quarterly Journal of Economics*, 107, 35-78.

[29] Klein, P. and Ventura, G. (2009): Productivity differences and the dynamic effects of labor movements. *Journal of Monetary Economics*, 56(8): 1059-1073.

[30] Kerr, W. and Lincoln, W. (2010): The supply side of innovation: H-1B visa reforms and the U.S. ethnic invention. *Journal of Labor Economics*, 28(3), 473-508.

[31] Koser, K. and Salt, J. (1997): The geography of highly skilled international migration. *International Journal of Population Geography*, 3, 285-303.

[32] Krusell, P., Ohanian, L. E., Ríos-Rull, J. V. and Violante, G. L. (2000): Capital-skill complementarity and inequality: A macroeconomic analysis. *Econometrica*, 68(5), 2019-1053.

[33] Kwok, V. and Leland, H. (1982): An economic model of the brain drain. *American Economic Review*, 72(1), 91-100.

[34] Lindquist, M. J. (2004): Capital-skill complementarity and inequality over the business cycle. *Review of Economic Dynamics*, 7, 519-540.

[35] Lucas, R.E. (1988). On the mechanisms of economic development. *Journal of Monetary Economics*, 22, 3-42.

[36] Mandelman, F. S. and Zlate, A. (2012): Immigration, remittances and business cycles. *Journal of Monetary Economics*, 59(2): 196-213.

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

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

[39] Ortega, F. and Peri, G. (2009): The causes and effects of international labor mobility: Evidence from OECD countries 1980-2005.

[40] Ottaviano, G. I. P. and Peri, G. (2012): Rethinking the effect of immigration on wages. *Journal of the European Economic Association*, 10(1), 152-197.

[41] Peri, G., Shih, K. and Sparber, C. (2015): STEM workers, H-1B visas and productivity in US cities. *Journal of Labor Economics*, 33(3), S225-S255.

[42] Pyo, H. K. (2005): "A time series test of the endogenous growth model with human capital", Chapter 5 in Takatoshi Ito and Anne O. Krueger (eds.): *Growth theories in light of the East Asian experience*. NBER 4, 229-245. University of Chicago Press.

[43] Regets, M. C. (2007): Research issues in the international migration of highly skilled workers: a perspective with data from the United States. Working paper/SRS 07-203. National Center for Science and Engineering Statistics at the National Science Foundation (Ed.). Arlington, VA, USA.

[44] Stark, O., Helmenstein, C. and Prskawetz, A. (1997): A brain gain with a brain drain. *Economic Letters*, 55(2), 227-234.

[45] Stark, O., Helmenstein, C. and Prskawetz, A. (1998): Human capital depletion, human capital formation, and migration: a blessing or a "curse"? *Economic Letters*, 60(3), 363-367.

[46] Vidal, J. P. (1998): The effect of emigration on human capital formation. *Journal of Population Economics*, 11(4), 586-600.

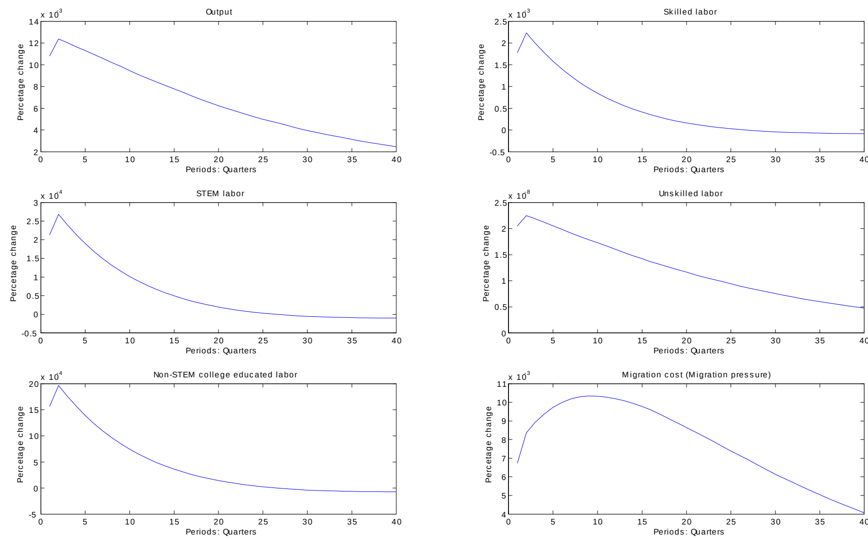

Figure 1: Impulse-responses to a positive aggregate productivity shock (I)

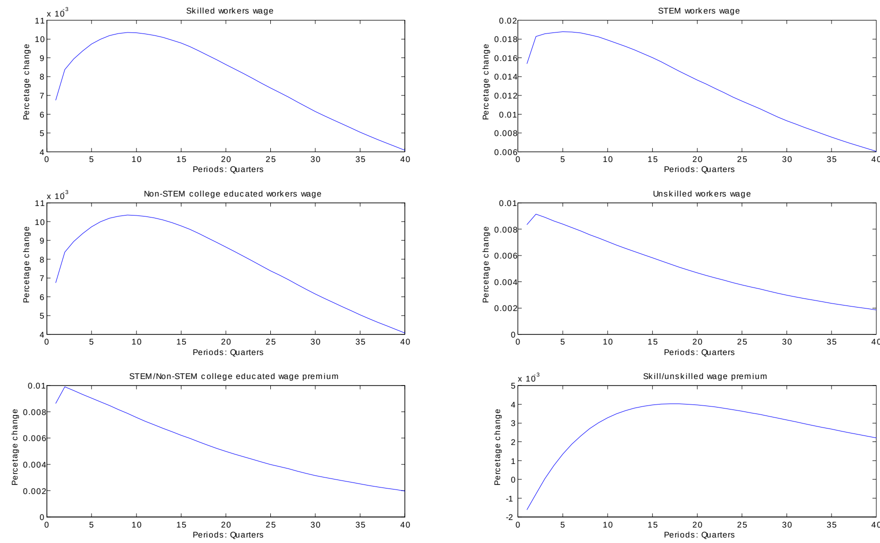

Figure 2: Impulse-responses to a positive aggregate productivity shock (II)

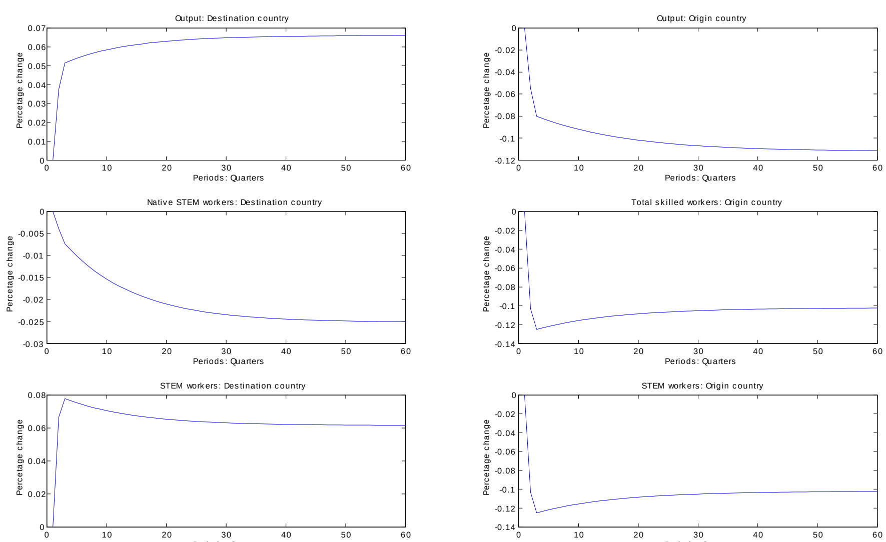

Figure 3: Transition dynamics to a relaxation in migration policy (I)

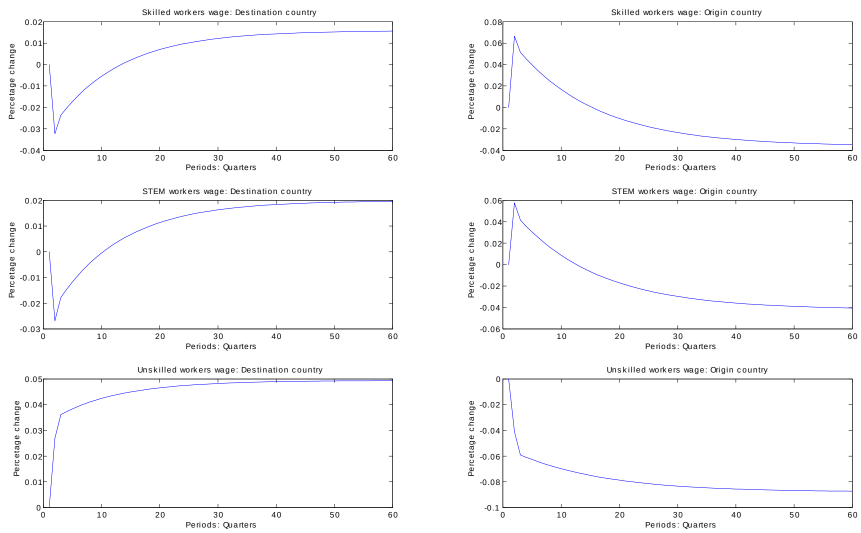

Figure 4: Transition dynamics to a relaxation in migration policy (II)