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Global Migration in the 20th and 21st Centuries: the Unstoppable Force of Demography

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Abstract

This paper sheds light on the global migration patterns of the past 40 years, and produces migration projections for the 21st century, for two skill groups, and for all relevant pairs of countries. To do this, we build a simple model of the world economy, and we parameterize it to match the economic and socio-demographic characteristics of the world in the year 2010.

... / ...

Keywords: international migration, migration prospects, world economy, inequality.

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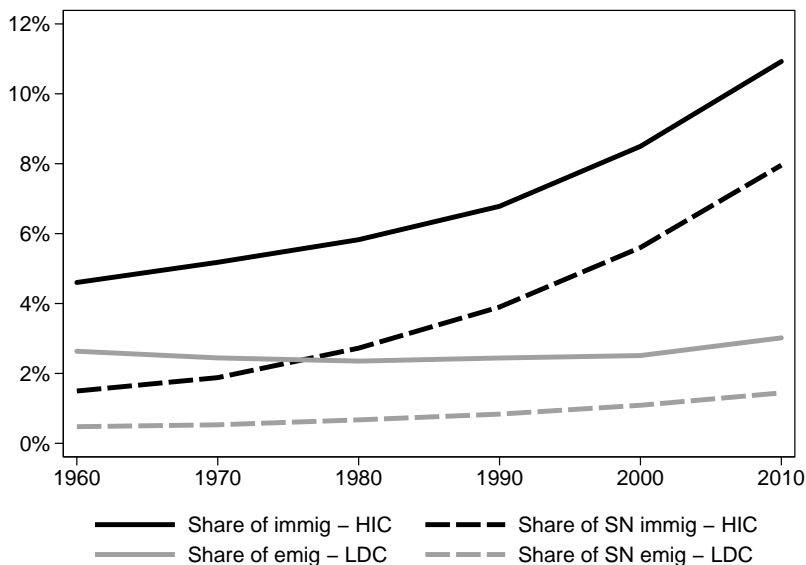
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We conduct a backcasting exercise which demonstrates that our model fits the past trends in international migration very well, and that historical trends were mostly governed by demographic changes. We then describe a set of migration projections for the 21st century. In line with backcasts, our world migration prospects and emigration rates from developing countries are mainly governed by socio-demographic changes: they are virtually insensitive to the technological environment. As far as OECD countries are concerned, we predict a highly robust increase in immigration pressures in general (from 12 in 2010 to 17-19% in 2050 and 25-28% in 2100), and in European immigration in particular (from 15% in 2010 to 23-25% in 2050 and 36-39% in 2100). Using development policies to curb these pressures requires triggering unprecedented economic takeoffs in migrants countries of origin. Increasing migration is therefore a likely phenomenon for the 21st century, and this raises societal and political challenges for most industrialized countries.

1 Introduction

Between 1960 and 2010, the worldwide stock of international migrants increased from 92 to 211 million, at the same pace as the world population, i.e. the worldwide share of migrants fluctuated around 3%. This average share masks comparatively significant differences between regions, as illustrated on Figure 1. In high-income countries (HICs), the foreign-born population increased more rapidly than the total population, boosting the average proportion of foreigners from 4.5 to 11.0% (+6.5%). A remarkable fact is that this change is totally explained by the inflow of immigrants from developing countries, whose share in the total population increased from 1.5 to 8.0% (once again, +6.5%). By comparison, the share of North-North migrants has been fairly stable.¹ In less developed countries (LDCs), the total stock of emigrants increased at the same pace as the total population, leading to small fluctuations of the emigration rate between 2.6 and 3.0%. As part of this emigration process, the share of emigrants to HICs in the population increased from 0.5 to 1.4%. Hence, the average propensity to emigrate from LDCs to HICs has increased by less than one percentage point over half a century.²

Figure 1. Long-run trends in international migration, 1960-2010



The underlying root causes of these trends are known (demographic imbalances, economic inequality, increased globalization, political instability, etc.). However, quantitatively speaking, little is known about their relative importance and about the changing educational

¹Similar patterns were observed in the 15 member states of the European Union (henceforth, EU15). The EU15 average proportion of foreigners increased from 3.9 to 12.2% (+8.2%) between 1960 and 2010. Although intra-European movements have been spurred by the Schengen agreement, the EU15 proportion of immigrants originating from LDCs also increased dramatically, from 1.2 to 7.5% (+6.3%).

²Demographic imbalances allow reconciling emigration and immigration patterns. Over the last 50 years, population growth has been systematically greater in developing countries. The population ratio between LDCs and HICs increased from 3.1 in 1960 to 5.5 in 2010. This explains why a 0.9% increase in emigration rate from LDCs translated into a 6.5% increase in the share of immigrants to HICs.

structure of past migration flows. Furthermore, the very same root causes are all projected to exert a strong influence in the coming decades, and little is known about the predictability of future migration flows. This paper sheds light on these issues, addressing key questions such as: How have past income disparities, educational changes and demographic imbalances shaped past migration flows? What are the pairs of countries responsible for large variations in low-skilled and high-skilled migration? How many potential migrants can be expected for the 21st century? How will future changes in education and productivity affect migration flows in general, and migration pressures to HIC in particular? Can development policies be implemented to limit these flows?

To do so, we develop a simple, abstract economic model of the world economy that highlights the major mechanisms underlying migration decisions and wage inequality in the long term. It builds on a migration technology and a production technology, uses consensus specifications, and includes a limited number of parameters that can be calibrated to match the economic and socio-demographic characteristics of the world in the year 2010. We first conduct a set of backcasting experiments, which consists in using the model to simulate bilateral migration stocks retrospectively, and in comparing the backcasts with observed migration stocks. We show that our backcasts fit very well the historical trends in the worldwide aggregate stock of migrants, in immigration stocks to all destination countries, and in emigration stocks from all origin countries. This demonstrates the capacity of the model to identify the main sources of variation and to predict long-run migration trends. Simulating counterfactual historical trends with constant distributions of income, education level or population, we show that most of the historical changes in international migration are explained by demographic changes. In particular, the world migration stocks would have virtually been constant if the population size of developing countries had not changed. Solving a *Max-Sum Submatrix* problem, we identify the clusters of origins and destinations that caused the greatest variations in global migration. These include important South-North, North-North and South-South corridors for the low-skilled, and North-North and South-North corridors for the highly skilled.

We then enter exogenous socio-demographic scenarios into the calibrated model, and produce micro-founded projections of migration stocks by education level for the 21st century. The interdependencies between migration, population and income have rarely been accounted for in projection exercises. The demographic projections of the United Nations do not anticipate the economic forces and policy reforms that shape migration flows. In the medium variant, they assume long-run convergence towards low fertility and high life expectancy across countries, and constant immigration flows. The Wittgenstein projections rely on a more complex methodology (see Lutz et al., 2014). Depending on the scenario, they consist of a set of probabilities to emigrate (or to immigrate) multiplied by the native population levels in the origin countries (or in the rest of the world). The size of net immigration flows varies over time and are computed by sex, age and education level. Future migration flows reflect expert opinion about future socio-political and economic trends that could affect migration. From 2060 onwards, it is assumed that net migration flows converge to zero (zero is attained in the 2095-2100 period). As regards to the skill structure, it is assumed to be proportional to that of the origin (or destination) country, implying that skill-selection patterns in migration are disregarded. In contrast, our migration projections are demographically and economically rooted. They result from a micro-founded migration technology and are totally

compatible with the endogenous evolution of income disparities.

The economic literature records a limited number of studies that focus on long-run migration trends and on projections of future migration. Hatton and Williamson (2003) examine the determinants of net emigration from Africa using a panel of 21 countries between 1977 and 1995, then subsequently use the regression estimates to predict African emigration pressure until 2025. They allow demography to influence emigration directly (via its impact on the youth share) and indirectly (via its impact on domestic wages). They predict an intensification of migration from Africa by the year 2025. The main reasons lie in the rapid growth of young cohort who has greater potential to migrate, and in the poor economic performance of source countries as a result of demographic pressures. Focusing on the receiving countries' perspective, Hatton and Williamson (2011) identify the various drivers of emigration rates from developing countries to the United States from 1970 to 2004, and then predict immigration trends up to the year 2034. The study reveals abating signs of migration from Latin America and Asia to the United States while rising trend will continue in Africa. The authors conclude that US immigrants will be more African and much less Hispanic. Similar conclusions are obtained in Hanson and McIntosh (2016), who show that the African migration pressures will mostly affect European countries until the mid-21st century. They compare the expanding migration pressure out of sub-Saharan Africa to Europe to that between Latin America and the United States during the second half of the 20th century.

The common features of our present study as compared to these aforementioned papers are the use of past observations and exogenous demographic forecasts to project future migration. However, our contribution is threefold. First, in terms of modeling, our paper builds on a general equilibrium framework to account for the interactions between labor and wage. As a consequence, labor absorption capacity of each economy is not disregarded in the face of demographic shock. A similar approach is used in Mountford and Rapoport (2014) or in Docquier and Machado (2017). Second, the use of a random utility specification allows to allocate the world labor across multiple corridors as a function of the relative attractiveness of all destinations. Third, in terms of country coverage, our world-economy model includes the majority of countries in the world (i.e., 180 countries). The simulation results therefore offer a better overview of future global migration, although we acknowledge that migrant concentrate in a small number of corridors.

Our general equilibrium projection model produces striking results. In line with the back-casting exercise, we find that the future trends in international migration are hardly affected by the technological environment; they are mostly governed by socio-demographic changes (i.e., changes in population size and in educational attainment). Focusing on OECD member states, we predict a highly robust increase in their proportion of immigrants. The magnitude of the change is highly insensitive to the technological environment, and to the education scenario. In particular, a rise in schooling in developing countries increases the average propensity to emigrate but also reduces population growth rates; as far as migrant stocks are concerned, these effects are balancing each other. Overall, under constant immigration policies, the average immigration rate of OECD countries increases from 12 to 25-28% during the 21st century. Given their magnitude, expected changes in immigration are henceforth referred to as *migration pressures*, although we do not make any value judgments about their desirability or about their welfare effects within the sending and receiving countries. The *Max-Sum Submatrix* reveals that this surge is mostly due to rising migration flows from sub-

Saharan Africa, from the Middle East, and from a few Asian countries. In line with Hanson and McIntosh (2016) or with Docquier and Machado (2007), expected immigration pressures are greater in European countries (+21.2 percentage points) than in the United States (+14.3 percentage points). The greatest variations in immigration rates are observed in the United Kingdom, France, Spain; Canada is also strongly affected. Curbing such migration pressures is difficult. For the 20 countries inducing the greatest migration pressures on the EU15 by the year 2060 or for the combined geographic region of Middle-East and sub-Saharan Africa, we show that keeping their total emigration stock constant requires triggering unprecedented economic takeoffs.

The remainder of the paper is organized as follows. Section 2 describes the model, defines its competitive equilibrium, and discusses its parameterization. Section 3 presents the results of the backcasting exercise. Forecasts are then provided in Section 4. Finally, Section 5 concludes.

2 Model

The model distinguishes between two classes of workers and J countries ($j = 1, \dots, J$). The skill type s is equal to h for college graduates, and to l for the less educated. We first describe the migration technology, which determines the condition under which migration to a destination country j is profitable for type- s workers born in country i . This condition depends on wage disparities, differences in amenities and migration costs between the source and destination countries. We then describe the production technology, which determines wage disparities. The latter are affected by the allocation of labor which itself depends on the size and structure of migration flows. The combination of endogenous migration decisions and equilibrium wages jointly determines the world distribution of income and the allocation of the world population.

Migration technology. – At each period t , the number of working age natives of type s and originating from country i is denoted by $N_{i,s,t}$. Each native decides whether to emigrate to another country or to stay in their home country; the number of migrants from i to j is denoted by $M_{ij,s,t}$ (hence, $M_{ii,s,t}$ represents the number of non-migrants). After migration, the resident labor force of type s in country j is given by $L_{j,s,t}$.

For simplicity, we assume a "drawing-with-replacement" migration process. Although one period is meant to represent 10 years, we ignore path dependency in migration decisions (i.e., having migrated to country j at time t influences the individual location at time $t + 1$). In addition, by considering the population aged 15 to 64 as a homogenous group, our model abstracts from the heterogeneity in the propensity to migrate across age groups, i.e. ignoring the effect of age on migration.³ Individual decisions to emigrate result from the comparison of discrete alternatives. To model them, we use a standard Random Utility Model (RUM) with a deterministic and a random component. The deterministic component is assumed to be logarithmic in income and to include an exogenous dyadic component.⁴ At time t , the

³It is often shown that individual aged 15 to 34 are more migratory than older age groups (Hatton and Williamson, 1998; UNDESA, 2013) due to higher present values of migration in intertemporal utility function (Hatton and Williamson, 2011; Djajic et al., 2016).

⁴Although Grogger and Hanson (2011) find that a linear utility specification fits the patterns of positive

utility of a type- s individual born in country i and living in country j is given by:

$$u_{ij,s,t} = \tilde{\gamma} \ln w_{j,s,t} + \ln v_{ij,s,t} + \varepsilon_{ij,s,t},$$

where $w_{j,s,t}$ denotes the wage rate attainable in the destination country j ; $\tilde{\gamma}$ is a parameter governing the marginal utility of income; $v_{ij,s,t}$ stands for the non-wage income and amenities in country j (public goods and transfers minus taxes and non-monetary amenities) and is netted from the legal and private costs of moving from i to j ; $\varepsilon_{ij,s,t}$ is the random taste component capturing heterogeneity in the preferences for alternative locations, in mobility costs, in assimilation costs, etc.

The utility obtained when the same individual stays in his origin country is given by

$$u_{ii,s,t} = \tilde{\gamma} \ln w_{i,s,t} + \ln v_{ii,s,t} + \varepsilon_{ii,s,t}.$$

The random term $\varepsilon_{ij,s,t}$ is assumed to follow an iid extreme-value distribution of type I with scale parameter μ .⁵ Under this hypothesis, the probability that a type- s individual born in country i moving to country j is given by the following logit expression (McFadden, 1984):

$$\frac{M_{ij,s,t}}{N_{i,s,t}} = \Pr \left[u_{ij,s,t} = \max_k u_{ik,s,t} \right] = \frac{\exp \left(\frac{\tilde{\gamma} \ln w_{j,s,t} + \ln v_{ij,s,t}}{\mu} \right)}{\sum_k \exp \left(\frac{\tilde{\gamma} \ln w_{k,s,t} + \ln v_{ik,s,t}}{\mu} \right)}.$$

Hence, the emigration rate from i to j depends on the characteristics of all potential destinations k (i.e., a crisis in Greece affects the emigration rate from Romania to Germany). The staying rates ($M_{ii,s,t}/N_{i,s,t}$) are governed by the same logit model. It follows that the emigrant-to-stayer ratio is given by:

$$m_{ij,s,t} \equiv \frac{M_{ij,s,t}}{M_{ii,s,t}} = \left(\frac{w_{j,s,t}}{w_{i,s,t}} \right)^\gamma V_{ij,s,t}, \quad (1)$$

where $\gamma \equiv \tilde{\gamma}/\mu$, the elasticity of migration choices to wage disparities, is a combination of preference and distribution parameters, and $V_{ij,s,t} \equiv v_{ij,s,t}/(\mu v_{ii,s,t})$ is a scale factor of the migration technology.⁶ Hence, the ratio of emigrants from i to j to stayers only depends on the characteristics of the two countries.

Production technology. – Income is determined based on an aggregate production function. Each country has a large number of competitive firms characterized by the same

selection and sorting in the migration data well, most studies rely on a concave (logarithmic) utility function (Bertoli and Fernandez-Huertas Moraga, 2013; Beine et al., 2013a; Beine and Parsons, 2015; Ortega and Peri, 2013).

⁵Bertoli and Fernandez-Huertas Moraga (2012, 2013), or Ortega and Peri (2012) used more general distributions, allowing for a positive correlation in the application of shocks across similar countries.

⁶The model will be calibrated using migration stock data, which are assumed to reflect the long-run migration equilibrium. We thus consider that $V_{ij,s,t}$ accounts for network effects (i.e., effect of past migration stocks on migration flows). Additionally, $V_{ij,s,t}$ embeds migration costs. They represent monetary moving costs, utility-loss equivalents of migration quotas (similar to tariff equivalent of non-tariff barriers in trade), etc. Migration costs in this study are treated as exogenous. However in practice, visa restrictions depend on the intensity of immigration pressures as well as on origin and/or destination countries' characteristics.

production technology and producing a homogenous good. The output in country j , $Y_{j,t}$, is a multiplicative function of total factor productivity (TFP), $A_{j,t}$,⁷ and the total quantity of labor in efficiency units, denoted by $L_{j,T,t}$, supplied by low-skilled and high-skilled workers. Such a model without physical capital features a globalized economy with a common international interest rate. This hypothesis is in line with Kennan (2013) or Klein and Ventura (2009) who assume that capital "chases" labor.⁸ Following the recent literature on labor markets, immigration and growth,⁹ we assume that labor in efficiency units is a CES function of the number of college-educated and less educated workers employed. We have:

$$Y_{j,t} = A_{j,t}L_{j,T,t} = A_{j,t} \left[\theta_{j,h,t}L_{j,h,t}^{\frac{\sigma-1}{\sigma}} + \theta_{j,l,t}L_{j,l,t}^{\frac{\sigma-1}{\sigma}} \right]^{\frac{\sigma}{\sigma-1}}, \quad (2)$$

where $\theta_{j,s,t}$ is the country and time-specific value share parameter for workers of type s (such that $\theta_{j,h,t} + \theta_{j,l,t} = 1$), and σ is the common elasticity of substitution between the two groups of workers.

Firms maximize profits and the labor market is competitive. The equilibrium wage rate for type- s workers in country j is equal to the marginal productivity of labor:

$$w_{j,s,t} = \theta_{j,s,t}A_{j,t} \left(\frac{L_{j,T,t}}{L_{j,s,t}} \right)^{1/\sigma}. \quad (3)$$

Hence, the wage ratio between college graduates and less educated workers is given by:

$$\frac{w_{j,h,t}}{w_{j,l,t}} = \frac{\theta_{j,h,t}}{\theta_{j,l,t}} \left(\frac{L_{j,h,t}}{L_{j,l,t}} \right)^{-1/\sigma} \quad (4)$$

As long as this ratio is greater than one, a rise in human capital increases the average productivity of workers. Furthermore, greater contributions of human capital to productivity can be obtained by assuming technological externalities. Two types of technological externality are factored in. First, we consider a simple Lucas-type, aggregate externality (see Lucas, 1988) and assume that the TFP scale factor in each sector is a concave function of the skill-ratio in the resident labor force. This externality captures the fact that educated workers facilitate innovation and the adoption of advanced technologies. Its size has been the focus of many recent articles and has generated a certain level of debate. Using data from US cities (Moretti, 2004) or US states (Acemoglu and Angrist, 2001; Iranzo and Peri, 2009), some instrumental-variable approaches give substantial externalities (Moretti, 2004) while others do not (Acemoglu and Angrist, 2001). In the empirical growth literature, there is evidence of a positive effect of schooling on innovation and technology diffusion (see Benhabib and Spiegel, 1994; Caselli and Coleman, 2006; Ciccone and Papaioannou, 2009). In

⁷In fact, there is a slight abuse of terms here as $A_{j,t}$ implicitly includes capital in supplement to the usual TFP, which is by definition the residual that explains a country's output level apart from capital and labor. Therefore, $A_{j,t}$ is rather a "modified TFP."

⁸Interestingly, Ortega and Peri (2009) find that capital adjustments are rapid in open economies: an inflow of immigrants increases one-for-one employment and capital stocks in the short term (i.e. within one year), leaving the capital/labor ratio unchanged.

⁹See Katz and Murphy (1992), Card and Lemieux (2001), Caselli and Coleman (2006), Borjas (2003, 2009), Card (2009), or Ottaviano and Peri (2012), Docquier and Machado (2015) among others.

parallel, another set of contributions highlights the effect of human capital on the quality of institutions (Castello-Climente, 2008; Bobba and Coviello, 2007; Murtin and Wacziarg, 2014). We write:

$$A_{j,t} = \lambda_t \bar{A}_j \left(\frac{L_{j,h,t}}{L_{j,l,t}} \right)^\epsilon, \quad (5)$$

where λ_t captures the worldwide time variations in productivity (common to all countries), \bar{A}_j is the exogenous country-specific component of TFP in country j (reflecting exogenous factors such as arable land, climate, geography, etc.), and ϵ is the elasticity of TFP to the skill ratio.

Second, we assume skill-biased technical change. As technology improves, the relative productivity of high-skilled workers increases (Acemoglu, 2002; Restuccia and Vandenbroucke, 2013). For example, Autor et al. (2003) show that computerization is associated with a declining relative demand in industry for routine manual and cognitive tasks, and increased relative demand for non-routine cognitive tasks. The observed relative demand shift favors college versus non-college labor. We write:

$$\frac{\theta_{j,h,t}}{\theta_{j,l,t}} = \bar{Q}_j \left(\frac{L_{j,h,t}}{L_{j,l,t}} \right)^\kappa, \quad (6)$$

where \bar{Q}_j is the exogenous country-specific component of the skill bias in productivity in country j , and κ is the elasticity of the skill bias to the skill ratio.

Competitive equilibrium. – The link between the native and resident population is tautological:

$$\sum_j N_{j,s,t} = \sum_j L_{j,s,t} = \sum_i \sum_j m_{ij,s,t} M_{ii,s,t} \quad (7)$$

Given our "drawing-with-replacement" migration hypothesis and given the absence of any accumulated production factor, the dynamics of the world economy is governed by a succession of temporary equilibria defined as:

Definition 1 For a set $\{\gamma, \sigma, \epsilon, \kappa, \lambda_t\}$ of common parameters, a set $\{\bar{A}_j, \bar{Q}_j\}_{\forall j}$ of country-specific parameters, a set $\{V_{ij,s,t}\}_{\forall i,j,s}$ of bilateral (net) migration costs, and for given distribution of the native population $\{N_{j,s,t}\}_{\forall j,s}$, a temporary competitive equilibrium for period t is an allocation of labor $\{M_{ij,s,t}\}_{\forall i,j,s}$ and a vector of wages $\{w_{j,s,t}\}_{\forall j,s}$ satisfying (i) utility maximization conditions, Eq. (1), (ii) profit maximization conditions, Eq. (3), (iii) technological constraints, Eqs. (5) and (6), and (iv) the aggregation constraints, Eq. (7).

A temporary equilibrium allocation of labor is characterized by a system of $2 \times J \times (J+1)$ i.e., $2 \times J \times (J-1)$ bilateral ratio of migrants to stayers, $2 \times J$ wage rates, and $2 \times J$ aggregation constraints. In the next sub-sections, we use data for 180 countries (developed and developing independent territories) and explain how we parameterize our system of 65,160 simultaneous equations per period. Once properly calibrated, this model can be used to conduct a large variety of numerical experiments.

Parameterization for the year 2010. – The model can be calibrated to match the economic and socio-demographic characteristics of 180 countries as well as skill-specific matrices of 180×180 bilateral migration stocks in the year 2010.

Regarding production technology, on the basis of GDP in PPP values ($Y_{j,2010}$) from the *Maddison's project* described in Bolt and Van Zanden (2014), we collect data on the size and structure of the labor force from the *Wittgenstein Centre for Demography and Global Human Capital* ($L_{j,s,2010}$), and data on the wage ratio between college graduates and less educated workers, $w_{j,h,2010}/w_{j,l,2010}$, from Hendriks (2004). When missing, the latter are supplemented using the estimates of Docquier and Machado (2015). We assume the labor force corresponds to the population aged 25 to 64.

Using these data, we proceed in three steps to calibrate the production technology. First, in line with the labor market literature (e.g., Ottaviano and Peri, 2012), we assume that the elasticity of substitution between college-educated and less educated workers, σ , is equal to 2. This level fits well labor market interactions in developed countries. Greater levels have been identified in developing countries (e.g., Angrist, 1995). Therefore, we also consider a scenario with $\sigma = 3$. Second, for a given σ , we calibrate the ratio of value shares, $\theta_{j,h,2010}/\theta_{j,l,2010}$, as a residual from Eq. (4) to match the observed wage ratio. Since $\theta_{j,h} + \theta_{j,l} = 1$, this determines both $\theta_{j,h,2010}$ and $\theta_{j,l,2010}$ as well as the quantity of labor per efficiency unit, $L_{j,T,2010}$, defined in Eq. (2). Third, we use Eq. (2) and calibrate the TFP level, $A_{j,2010}$, to match the observed GDP and we normalize λ_{2010} to unity (without loss of generality). When all technological parameters are calibrated, we use Eq. (3) to proxy the wage rates for each skill group.

With regards to the migration technology, we use the DIOC-E database of the OECD. DIOC-E builds on the *Database on Immigrants in OECD countries* (DIOC) described in Arslan et al. (2015). The data are collected by country of destination and are mainly based on population censuses or administrative registers. The DIOC database provides detailed information on the country of origin, demographic characteristics and level of education of the population of 34 OECD member states. DIOC-E extends the latter by characterizing the structure of the population of 86 non-OECD destination countries. Focusing on the populations aged 25 to 64, we thus end up with matrices of bilateral migration from 180 origin countries to 120 destination countries (34 OECD + 86 non-OECD countries) by education level, as well as proxies for the native population ($N_{i,s,2010}$). We assume that immigration stocks in the 60 missing countries are zero, which allows us to compute comprehensive migration matrices.

Regarding the elasticity of bilateral migration to the wage ratio, γ , we follow Bertoli and Fernandez-Huertas Moraga (2013) who find a value between 0.6 and 0.7. We use 0.7. Finally, we calibrate $V_{ij,s,2010}$ as a residual of Eq. (1) to match the observed ratio of bilateral migrants to stayers. In sum, the migration and technology parameters are such that our model perfectly matches the world distribution of income, the world population allocation and skill structure as well as bilateral migration stocks as of the year 2010.

3 Backcasting

Our first objective is to gauge the ability of our parameterized model to replicate aggregate historical data, and to backcast the educational structure of these flows. Our backcasting exercise consists in using the model to simulate retrospectively bilateral migration stocks by education level, and comparing the backcasts with proxies for observed migration stocks for the years 1970, 1980, 1990 and 2000. This exercise can also shed light on the relevance of

technological hypotheses (i.e. what value for σ , κ or ϵ should be favored?), and on the role of socio-demographic and technological changes in explaining the aggregate variations in past migration.

There is no database documenting past migration stocks by education level and by age group. Nonetheless, Özden et al. (2011) provides decadal data on bilateral migration stocks from 1960 to 2000 with no disaggregation between age and skill groups, which can be supplemented by the matrix of the United Nations for the year 2010 (UNPOP division). To enable comparisons, we rescale these bilateral matrices using the destination-specific ratios of the immigration stock aged 25 to 64 (from DIOC-E) to total immigration (from the United Nations) observed in 2010. We then apply these ratios to the decadal years 1970 to 2000, and construct proxies for the stocks of the total stock of working-age migrants, $\widehat{M}_{ij,T,t}$.¹⁰ We then use the model to predict past stocks of migrants by education level, and aggregate them $M_{ij,T,t} = M_{ij,h,t} + M_{ij,l,t}$. To assess the predictive performance of the model, we compare the (rescaled) worldwide numbers of international migrants with the simulated ones; coefficients of correlation between $M_{ij,T,t}$ and $\widehat{M}_{ij,T,t}$ can be computed for each period t .

Backcasting methodology. – Historical data allow us to document the size and structure of the resident population ($L_{j,s,t}$) and the level GDP ($Y_{j,t}$) of each country from 1970 to 2010. However, data on within-country wage disparities and bilateral migration are missing prior to 2010. The model is used to predict these missing variables.

We begin by predicting past wage ratios between college graduates and less-educated workers. Eq. (4) governs the evolution of these ratios. It depends on the (observed) skill ratio, $L_{j,h,t}/L_{j,l,t}$, on the elasticity of substitution σ , and on the ratio of value share parameters, $\theta_{j,h,t}/\theta_{j,l,t}$. We consider two possible values for σ (2 or 3). For a given σ , it should be recalled that we identified the ratio $\theta_{j,h,2010}/\theta_{j,l,2010}$ which matches wage disparities in 2010. In line with Eq. (6), regressing the log of this ratio on the log of the skill ratio gives an estimate for κ , the skill biased externality. We obtain $\kappa = 0.214$ when $\sigma = 2$, and $\kappa = 0.048$ when $\sigma = 3$.¹¹ Given the bidirectional causation relationship between the skill bias and education decisions (i.e. incentives to educate increase when the skill bias is greater), we consider these estimates as an upper bound for the skill biased externality.¹²

Our backcasting exercise distinguishes between six technological scenarios:

- Elasticity of substitution $\sigma = 2$
 - No skill biased externality: $\kappa = 0.000$
 - Skill biased externality equal to 50% of the correlation: $\kappa = 0.107$
 - Skill biased externality equal to 100% of the correlation: $\kappa = 0.214$

¹⁰We assume rescaled immigration stocks are zero for the destination countries that are unavailable in the DIOC-E database.

¹¹The regression lines are $\log(R_j) = 0.214 \cdot \log(L_{j,h}/L_{j,l}) + 0.540$ with $\sigma = 2$, and $\log(R_j) = 0.048 \cdot \log(L_{j,h}/L_{j,l}) + 0.540$ with $\sigma = 3$.

¹²Estimated κ is needed because we do not observe the past levels of the skill premium. On the contrary, our backcasting methodology ignores the elasticity of TFP to the skill ratio ϵ . From Eq. 2, the TFP levels, $A_{j,t}$, are calibrated to match the observed levels of GDP, $Y_{j,t}$, using data for $L_{j,s,t}$ and the estimated level of $\theta_{j,s,t}$.

- Elasticity of substitution $\sigma = 3$
 - No skill biased externality: $\kappa = 0.000$
 - Skill biased externality equal to 50% of the correlation: $\kappa = 0.024$
 - Skill biased externality equal to 100% of the correlation: $\kappa = 0.048$

For each level of κ , we calibrate the scale parameter \bar{Q}_j to match exactly the wage ratio in 2010. Then, for each year prior to 2010, we retrospectively predict $\theta_{j,h,t}$ and $\theta_{j,l,t}$ using Eq. (6), and calibrate the TFP level $A_{j,t}$ that matches the observed GDP level using Eq. (2). Finally, we use Eq. (3) to proxy the wage rates of each skill group.

Turning to the migration backcasts, we assume constant scale factors in the migration technology ($V_{ij,s,t} = V_{ij,s,2010} \forall t$). We thus assume constant net migration costs. Plugging $V_{ij,s,t}$ and wage proxies into Eq. (1), we obtain estimates for $m_{ij,s,t}$, the ratio of bilateral migrants to stayers, for all years. We then rewrite Eq. (7) in a matrix format:

$$\left(\begin{array}{cccc} M_{11,s,t} & M_{22,s,t} & \dots & M_{JJ,s,t} \end{array} \right) \left(\begin{array}{cccc} m_{11,s,t} & m_{12,s,t} & \dots & m_{1J,s,t} \\ m_{21,s,t} & m_{22,s,t} & \dots & m_{2J,s,t} \\ \dots & \dots & \dots & \dots \\ m_{J1,s,t} & m_{J2,s,t} & \dots & m_{JJ,s,t} \end{array} \right) = \left(\begin{array}{cccc} L_{1,s,t} & L_{2,s,t} & \dots & L_{J,s,t} \end{array} \right).$$

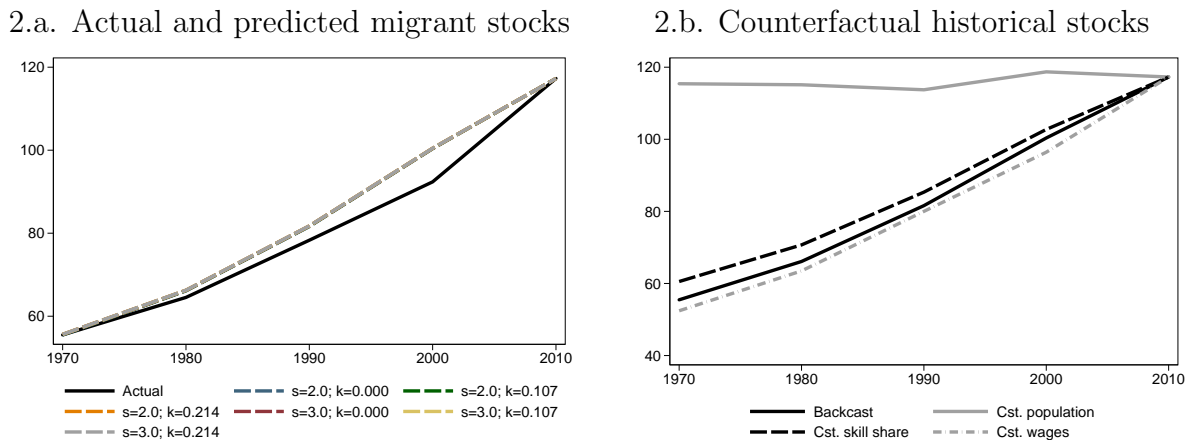
The matrices $m_{ij,s,t}$ and $L_{j,s,t}$ are known. The latter observations of past resident populations from 1970 to 2000 are collected from the Wittgenstein database. The only unknown matrix is that of non-migrant populations, $M_{jj,s,t}$. We identify it by multiplying the matrix of $L_{j,s,t}$ by the inverse of the matrix of $m_{ij,s,t}$. Finally, when $M_{jj,s,t}$ and $m_{ij,s,t}$ are known, we use Eq. (1) to predict bilateral migration stocks by education level.

Worldwide migration backcasts. – Aggregate backcasts are depicted in Figure 2. Figure 2.a compares the evolution of actual and predicted worldwide migration stocks by decade. For the 180×120 corridors, the (rescaled) data gives a stock of 55 million migrants aged 25 to 64 in 1970, and of 120 million migrants in 2010. The model almost exactly matches this evolution whatever the technological scenario (by definition, the model perfectly matches the 2010 data). The six variants of the model cannot be visually distinguished, as the lines almost perfectly coincide. Although technological variants drastically affect within-country income disparities (in particular, the wage rate of college graduates), they have negligible effects on aggregate migration stocks. This is due to the fact that income disparities are mostly governed by between-country inequality (i.e., by the TFP levels, which are calibrated under each scenario to match the average levels of income per worker), and that the worldwide proportion of college graduates is so small that changes in their migration propensity have negligible effects on the aggregate.

Considering the scenario with $\sigma = 2$ and $\kappa = 0.214$, Figure 2.b compares our backcasts with counterfactual retrospective simulations. The first counterfactual neutralizes demographic changes that occurred between 1970 and 2010; it assumes that the size of the working age population is kept constant at the 2010 level in all countries. The second counterfactual neutralizes the changes in education; it assumes that the share of college graduates is kept constant in all countries. The third counterfactual neutralizes the changes in income disparities; it assumes constant wage rates in all countries.

On the one hand, the simulations reveal that past changes/rises in education marginally increased the worldwide migration stock, while the past changes/decreases in income inequality marginally reduced it. These effects are quantitatively small. This is because the rise in human capital has been limited in poor countries, and income disparities have been stable for the last fifty years (with the exception of emerging countries). On the other hand, Figure 2.b shows that demographic changes explain a large amount of the variability in migration stocks. The stock of worldwide migrants in 1970 would have almost been equal to the current stocks (in fact, it would have been 2% smaller only) if the population size of each country had been identical to the current level. This confirms that past changes in aggregate migrant stocks were predominantly governed by population growth and demographic imbalances: the population ratio between developing and high-income countries increased from 3.5 in 1970 to 5.5 in 2010.

Figure 2. Actual and predicted migrant stocks, 1970-2010 (in million)



Bilateral migration backcasts. – We now investigate the capacity of the model to match the decadal distributions of immigrant stocks by destination, and the decadal distributions of emigrant stocks by origin. Table 1 provides the coefficient of correlation between our backcasts and the actual observations aggregate at country level for each scenario and for each decade. Figure 3 provides a graphical visualization of the goodness of fit by comparing the observed and simulated bilateral stocks of immigrants and emigrants for each decade. By definition, as the observed past immigration stocks of all ages are scaled to match the working-age ones in 2010, the predicted immigrant stocks are perfectly matched in that year. Predicted emigrant stocks for 2010 do not perfectly match observations but the correlation with observations is above 0.99. For previous years, the correlation is unsurprisingly smaller; it decreases with the distance from the year 2010. This is because our model does neither identify past variations in migration policies (e.g. the Schengen agreement in the European Union, changes in the H1B visa policy in the US, the points-system schemes in Canada, Australia, New Zealand, guest worker programs in the Persian Gulf, etc.) nor past changes in net amenities and non-pecuniary push/pull factors (e.g., conflicts, political unrest, etc.). The biggest gaps between the observed and predicted migration stocks recorded in our data come from the non-consideration of the partition of Pakistan from India, the collapse of

the Soviet Union, the end of the French-Algerian war and of the Vietnam war, the conflict between Cuba and the US. In addition, the model imperfectly predicts the evolution of intra-EU migration, the evolution of labor mobility to Persian Gulf countries, the evolution of migrant stocks from developing countries to the US, Canada and Australia, and the evolution of immigration to Israel (especially the flows of Russian Jews after the late 1980 - the so-called Post-Soviet aliyah). Nevertheless, the scatterplots on Figure 3 show high correlations between the observed and predicted bilateral migration volumes throughout all decades. The lowest reported R-squared are 0.76 for immigrant stocks and 0.69 for emigrant stocks in 1970. These numbers reach 0.93 and 0.90 respectively in 2000. This demonstrates that the constant V_{ij} hypothesis does a good job on average despite big changes in immigration policies in the past whose restrictiveness was either increasing or decreasing.¹³ In the former case, it may be that stricter entry policies have been balanced by increasing network effects.

Table 1. Correlation between backcasts and actual migrant stocks
(Results by year, destination vs origin)

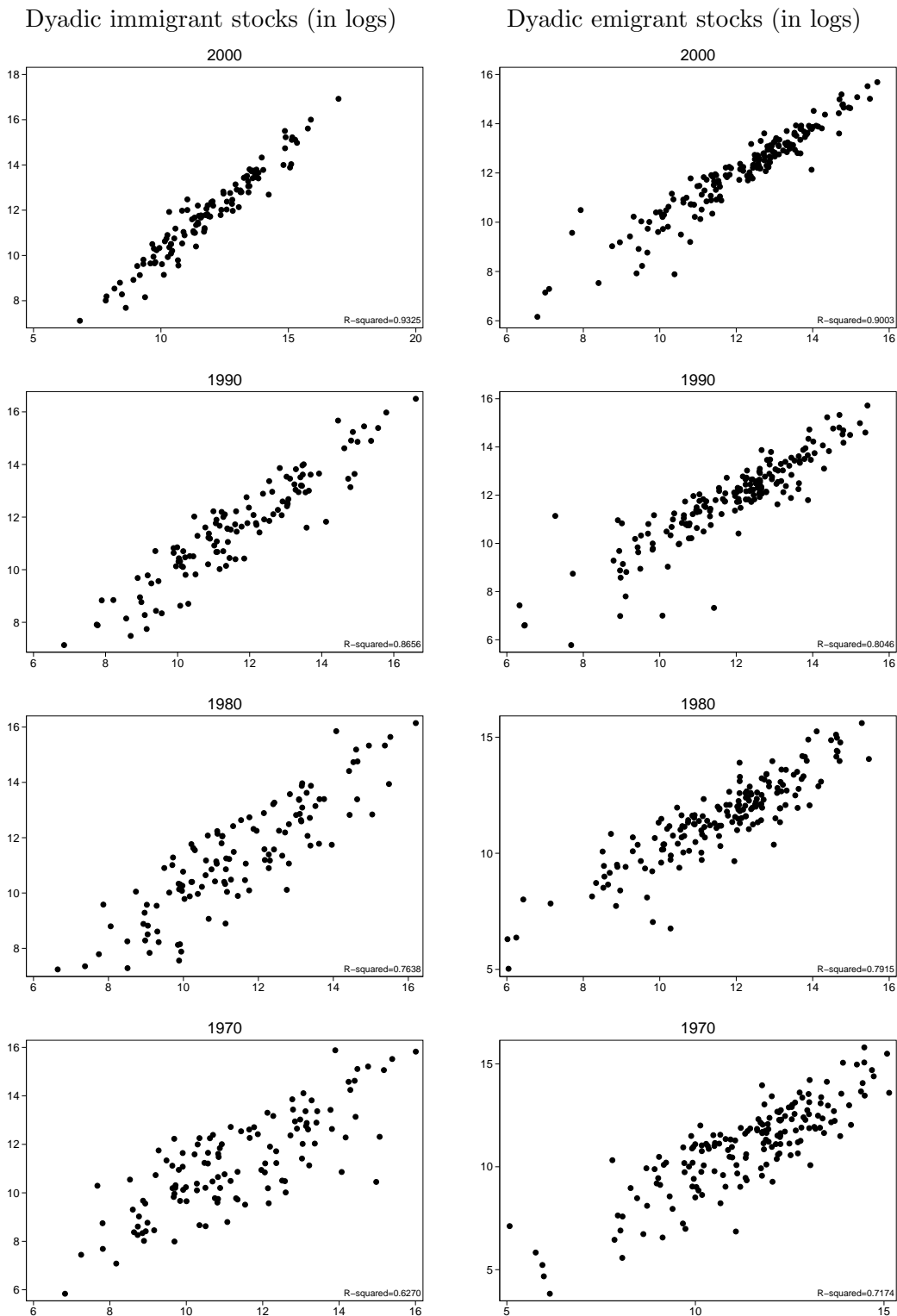
Techn. variants	1970	1980	1990	2000	2010
	Immigration stock by destination				
$\sigma = 2, \kappa = 0.000$	0.7653	0.8365	0.9409	0.9801	1.0000
$\sigma = 2, \kappa = 0.107$	0.7650	0.8360	0.9407	0.9801	1.0000
$\sigma = 2, \kappa = 0.214$	0.7649	0.8358	0.9405	0.9800	1.0000
$\sigma = 3, \kappa = 0.000$	0.7649	0.8359	0.9406	0.9801	1.0000
$\sigma = 3, \kappa = 0.107$	0.7649	0.8358	0.9406	0.9800	1.0000
$\sigma = 3, \kappa = 0.214$	0.7649	0.8358	0.9405	0.9800	1.0000
	1970	1980	1990	2000	2010
	Emigration stock by origin				
$\sigma = 2, \kappa = 0.000$	0.6904	0.7716	0.8616	0.9505	0.9904
$\sigma = 2, \kappa = 0.107$	0.6920	0.7714	0.8612	0.9502	0.9904
$\sigma = 2, \kappa = 0.214$	0.6934	0.7713	0.8608	0.9498	0.9904
$\sigma = 3, \kappa = 0.000$	0.6928	0.7713	0.8610	0.9500	0.9904
$\sigma = 3, \kappa = 0.107$	0.6931	0.7713	0.8609	0.9499	0.9904
$\sigma = 3, \kappa = 0.214$	0.6934	0.7713	0.8608	0.9498	0.9904

As far as the technological variants are concerned, Table 1 confirms that they play a negligible role. The correlation between variants is always around 0.99. The variant with $\sigma = 2$ and no skill-biased externality marginally outperforms the others in replicating immigrant stocks; the one with $\sigma = 3$ and with skill biased externalities does a slightly better job in matching emigrant stocks. Hence, the backcasting exercise shows that our model does a very

¹³In the late 20th century from 1970 to 2000, we document both forms of tighter and loosened immigration policies in major receiving countries. In Western Europe, the Guest Worker program came to an end following the 1973-4's oil crisis. While in the US, a serie of immigration acts were introduced allowing more entry of family immigrants (the 1990 Immigration Act), legalization of illegal immigrants (the 1986 Reform and Control Act) (see Clark et al. (2007) for an overview) before immigration policies became restrictive again after the September 11 attacks in 2001. The third wave of immigration to the Gulf region also took place during this period after 1971 - year of official independence of GCC countries from the United Kingdom. Mass industrialization and modernization have led to large importation of foreign workers.

good job in explaining the long term evolution of migration stocks; however, it does not help eliminating irrelevant technological scenarios.

Figure 3. Comparison between actual and predicted migrant stocks, 1970-2010
(Technological variant with $\sigma = 2$ and with skill biased externality)



Backcasts by skill group. – As historical migration data by skill group do not exist, we use our model to backcast the global net flows of college-educated and less educated workers between regions. We use the scenario with $\sigma = 2$ and with full skill-biased externalities. Assuming κ is large, we may overestimate the causal effect of the skill ratio on the skill bias. However, disregarding causation issues, this technological scenario is the most compatible with the cross-country correlation between human capital and the wage structure: it fits the cross-country correlation between the skill bias and the skill ratio in the year 2010.

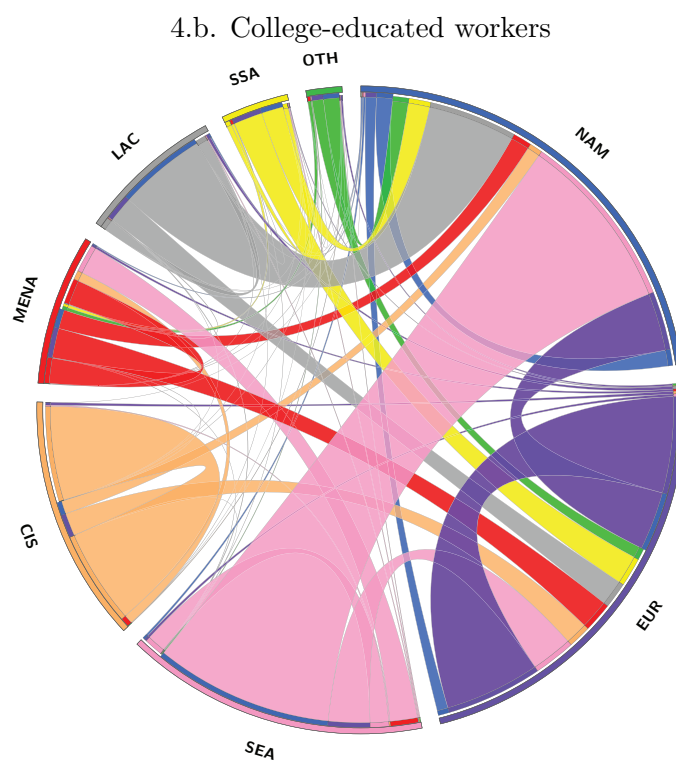
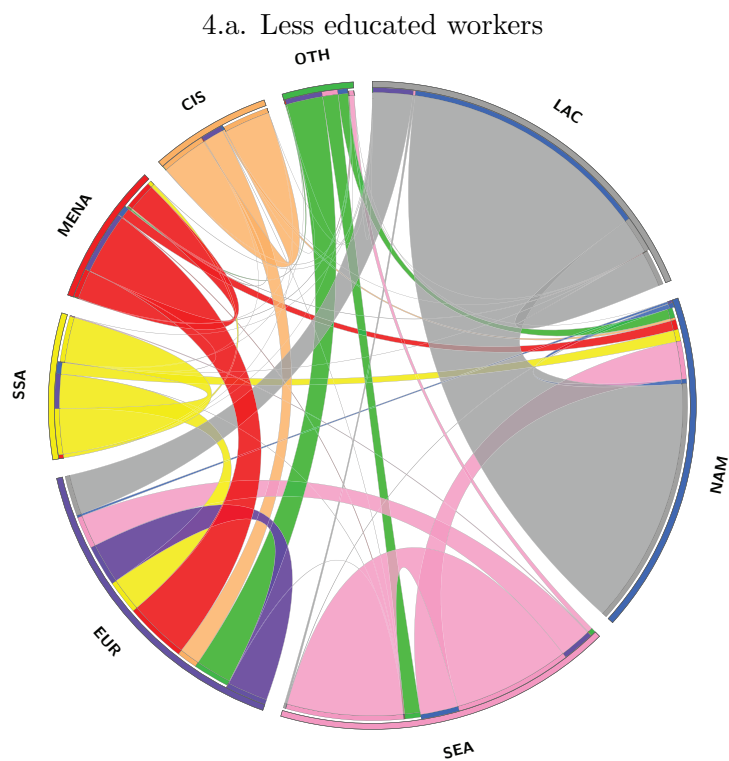
For each pair of countries, we compute the net flow as the difference between the stock of migrants in 2010 and that of 1970, $\Delta M_{ij,s} \equiv M_{ij,s,2010} - M_{ij,s,1970}$. These net flows form the matrix \mathcal{M} . On Figure 4, we group countries into eight regions and use circular ideograms following Kzrywinski et al. (2009) to highlight the major components of \mathcal{M} . We distinguish between Europe (in dark blue), Western offshoots (NAM in light blue),¹⁴ the Middle East and Northern Africa (MENA in red), sub-Saharan Africa (SSA in yellow), South and East Asia including South and South-East Asia (SEA in pink), the former Soviet countries (CIS in orange), Latin America and the Caribbean (LAC in grey), and Others (OTH in green). Net flows are colored according to their origin, and their width is proportional to their size. The direction of the flow is captured by the colors of the outside (i.e., country of origin) and inside (i.e., country of destination) borders of the circle.

Figure 4.a focuses on the net flows of less educated workers. The net flow of low-skilled immigrants equals 35.2 million over the 1970-2010 period. The ten main regional corridors account for 79% of the total, and industrialized regions appear 6 times as a main destination. By decreasing the order of magnitude, they include Latin America to North America (27.6%), migration within the South and East Asian region (13%), from MENA to Europe (6.8%), migration between former Soviet countries (5.2%), migration within sub-Saharan Africa (5.1%), intra-European movements (4.5%), Latin America to Europe (4.4%), South and East Asia to Western offshoots (4.2%), Others to Europe (4.0%), and migration between Latin American countries (4.0%). It is worth noting the low-skilled mobility from sub-Saharan Africa to Europe is not part of the top ten: it only represents 3.8% of the total (the 11th largest regional corridor).

Figure 4.b represents the net flows of college graduates. The net flow of high-skilled immigrants equals 27.6 million over the 1970-2010 period. The ten main regional corridors account for 74% of the total. A major difference with the low-skilled is that industrialized regions appear 9 times as a main destination, at least if we treat the Persian Gulf countries (as part of the MENA region) as industrialized. By decreasing order of magnitude, the top-10 includes South and East Asia to Western offshoots (19.8% of the total), intra-European movements (10.7%), migration between former Soviet countries (10.5%), Latin America to Western offshoots (9.7%), Europe to Western offshoots (6.5%), South and East Asia to Europe (4.6%), MENA to Europe (3.3%), sub-Saharan Africa to Europe (3.2%), South and East Asia to the MENA (3.1%), and Latin America to Europe (2.9%).

¹⁴These include the United States, Canada, Australia and New Zealand.

Figure 4. Global migration net flows, 1970-2010
(Technological variant with $\sigma = 2$ and with skill biased externality)



Major corridors by skill group. – We now characterize the clusters of origins and destinations that caused the greatest variations in global migration between 1970 and 2010. Using the same matrix of migration net flows as above (denoted by \mathcal{M} and including the $J \times J$ net flows between 1970 and 2010, $\Delta M_{i,j,s}$), our objective is to identify a sub-matrix with a fixed dimension $o \times d$ that maximizes the total migration net flows (i.e., that captures the greatest fraction of the worldwide variations in migration stocks). The *Max-Sum Submatrix* problem can be defined as:

Definition 2 *Given the squared matrix $\mathcal{M} \in \mathbb{R}^{J \times J}$ of net migration flows between J origin and J destination countries, and given two numbers o and d (the dimensions of the submatrix), the Max-Sum submatrix is a submatrix (O^*, D^*) of maximal sum, with $O^* \subseteq \mathcal{J}$ and $D^* \subseteq \mathcal{J}$, such that:*

$$(O^*, D^*) =_{O \subseteq \mathcal{J}, D \subseteq \mathcal{J}} \sum_{i \in O, j \in D} \mathcal{M}_{ij} . \quad (8)$$

$$|O| = o \quad \text{and} \quad |D| = d \quad (9)$$

where $\mathcal{J} = \{1, \dots, J\}$.

This problem is a variant of the one introduced in Dupont et al. (2017) or Le Van et al. (2014). The difference is that we fix the dimension of the submatrix. It also has some similarity with the bi-clustering class of problems for which a comprehensive review is provided in Madeira and Oliveira (2004). To solve the *Max-Sum Submatrix* problem, we formulate it as a Mixed Integer Linear Program (MILP):¹⁵

$$\text{maximize} \quad \sum_{i \in \mathcal{O}, j \in \mathcal{D}} \mathcal{M}_{ij} \times X_{ij} , \quad (10)$$

$$\text{s.t.} \quad X_{ij} \leq R_i, \quad \forall i \in \mathcal{O}, \forall j \in \mathcal{D} , \quad (11)$$

$$X_{ij} \leq C_j, \quad \forall i \in \mathcal{O}, \forall j \in \mathcal{D} , \quad (12)$$

$$X_{ij} \geq R_i + C_j - 1, \quad \forall i \in \mathcal{O}, \forall j \in \mathcal{D} , \quad (13)$$

$$\sum_{i \in \mathcal{O}} R_i = o , \quad (14)$$

$$\sum_{j \in \mathcal{D}} C_j = d , \quad (15)$$

$$X_{ij} \in \{0, 1\}, \quad \forall i \in \mathcal{O}, \forall j \in \mathcal{D} , \quad (16)$$

$$C_i \in \{0, 1\}, \quad \forall i \in \mathcal{O} , \quad (17)$$

$$R_j \in \{0, 1\}, \quad \forall j \in \mathcal{D} . \quad (18)$$

A binary decision variable is associated to each origin-row R_i , and to each destination-column C_j , and to each matrix entry X_{ij} . The objective function is computed as the sum of matrix entries whose decision variable is set to one. Eqs. (11) to (13) enforce that variable $X_{i,j} = 1$ if and only both the row i and column j are selected ($R_i = 1$ and $C_j = 1$). This formulation is the standard linearization of the constraint $X_{ij} = R_i \cdot C_j$. Constraints (14) and (15) enforce the $o \times d$ dimension of the submatrix to identify.

Applying the *Max-Sum problem* to the net flows of low-skilled migrants, we can identify the 25 origins and the 25 destinations of the *Max-Sum submatrix*. These 625 entries of the submatrix account for 64% of the worldwide net flows of low-skilled migrants between 1970 and 2010.

¹⁵See Nemhauser and Wolsey (1988) for an introduction to MILP.

- The main destinations (in alphabetical order) are: Australia, Austria, Belarus, Belgium, Canada, Dominican Republic, France, Germany, Greece, Hong Kong, India, Israel, Italy, Kazakhstan, Malaysia, Nepal, the Netherlands, Oman, Russia, Saudi Arabia, Spain, Thailand, the United Kingdom, the United States, and Venezuela.
- The main origins (in alphabetical order) are: Albania, Algeria, Bangladesh, Colombia, the Dominican Republic, Ecuador, Guatemala, Haiti, India, Indonesia, Jamaica, Kazakhstan, Mexico, Morocco, Myanmar, Pakistan, the Philippines, Poland, Romania, Russia, Slovenia, Turkey, Ukraine, Uzbekistan, and Vietnam.

As far as high-skilled migrants are concerned, the set of main destinations mostly includes high-income countries. The 625 entries of the submatrix account for 55% of the worldwide net flow of college-educated migrants between 1970 and 2010.

- The 25 main destinations (in alphabetical order) are: Australia, Austria, Belarus, Canada, France, Germany, India, Ireland, Israel, Italy, Japan, Kazakhstan, the Netherlands, New Zealand, Oman, Russia, Saudi Arabia, Spain, Sweden, Switzerland, Thailand, Ukraine, the United Arab Emirates, the United Kingdom, and the United States.
- The 25 main origins (in alphabetical order) are: Algeria, Bangladesh, Canada, China, Colombia, Egypt, France, Germany, India, Iran, Japan, Kazakhstan, Mexico, Morocco, Pakistan, the Philippines, Poland, Romania, Russia, South Korea, Ukraine, the United Kingdom, the United States, Uzbekistan, and Vietnam.

Aggregate TFP externalities. – Finally, the backcasting exercise allows calibration of the TFP level ($A_{j,t}$) for each country, for each decadal year, and for each pair (σ, κ) . We can use these calibrated TFP levels to estimate the size of the aggregate TFP externality, ϵ . In line with Eq. (5), we regress the log of TFP on the log of the skill ratio, controlling for time fixed effects (capturing λ_t) and for country fixed effects (capturing \bar{A}_j). Identifying the size of the TFP externality is important for conducting the forecasting exercise. Results are reported in Table 2. We identify a significant and positive effect when the skill biased externality operates fully; the greatest level (0.207) is obtained in column 1, when $\sigma = 2$ and $\kappa = 0.214$. Lower levels of ϵ are obtained when $\sigma = 3$ (0.105) and/or when κ increases.

Table 2. Estimating ϵ using panel regressions, 1970-2010
(*Dependent* = $\log A_{j,t}$)

	(1)	(2)	(3)	(4)	(5)	(6)
	$\sigma = 2$	$\sigma = 2$	$\sigma = 2$	$\sigma = 3$	$\sigma = 3$	$\sigma = 3$
	$\kappa = 0.000$	$\kappa = 0.107$	$\kappa = 0.214$	$\kappa = 0.000$	$\kappa = 0.024$	$\kappa = 0.048$
$\log(L_{j,h,t}/L_{j,l,t})$	0.041	0.132***	0.207***	0.063	0.085**	0.105**
	(0.043)	(0.043)	(0.044)	(0.043)	(0.043)	(0.043)
Constant	8.055***	8.493***	8.865***	8.392***	8.490***	8.568***
	(0.260)	(0.254)	(0.252)	(0.257)	(0.256)	(0.255)
Time FE	yes	yes	yes	yes	yes	yes
Country FE	yes	yes	yes	yes	yes	yes
R-squared	0.912	0.915	0.918	0.899	0.900	0.901
Nb. obs.	900	900	900	900	900	900

4 Forecasting

We now use the parameterized model to produce projections of migration stocks and income disparities for the 21st century. Availability of population projection until the end of the century allows us to systematically predict migration for that entire period. Nonetheless since the accuracy of prediction decreases with time, we will mainly focus on interpreting results of the medium-term forecasts (up to 2050). We first define the two socio-demographic scenarios that feed our model; one has optimistic predictions for human capital while the other is more pessimistic. We then describe the global trends in international migration and income inequality involved in these two scenarios, with a special focus on migration flows to OECD countries. We finally discuss the policy options than can be used to curb future migration pressures.

Socio-demographic scenarios. – Our socio-demographic scenarios are drawn from Lutz et al. (2014), who produce projections by age, sex and education levels for all countries of the world. As human capital changes affect the distribution of productive capacities, income inequality and the propensity to migrate of people, we distinguish between an optimistic and a pessimistic scenario (labeled as SSP2 and SSP3, respectively). The authors define SSP2 as a *Continuation/Medium Population* scenario, which is described as follows: “*this is the middle-of-the-road scenario in which trends typical of recent decades continue, with some progress towards achieving development goals, reductions in resource and energy intensity, and slowly decreasing fossil fuel dependency. Development of low income countries is uneven, with some countries making good progress, while others make less.*” As for SSP3, it is defined as the *Fragmentation/Stalled Social Development* scenario, which is described as follows: “*this scenario portrays a world separated into regions characterized by extreme poverty, pockets of moderate wealth, and many countries struggling to maintain living standards for rapidly growing populations. The emphasis is on security at the expense of international development.*”

The SSP2 and SSP3 scenarios involve international migration hypotheses, which are not in line with our migration technology. To neutralize these migration hypotheses, we use the scenario-specific projections of net immigration flows ($I_{i,s,t}$) from Lutz et al. (2014), and we proxy the evolution of the native population ($N_{i,s,t}$) by education level from 2010 to 2100. In practice, the dynamics of the resident population is governed by:

$$\Delta L_{i,s,t} = \Delta M_{ii,s,t} + I_{i,s,t},$$

where $\Delta L_{i,s,t} = L_{i,s,t} - L_{i,s,t-1}$ is the change in the level of the resident, working-age population (available at each period), $I_{i,s,t}$ stands for the net inflow of working-age immigrants (i.e. immigrants minus emigrants) to country i and for the education level s , and $\Delta M_{ii,s,t} = M_{ii,s,t} - M_{ii,s,t-1}$ stands for the change in the number of native non-migrants.

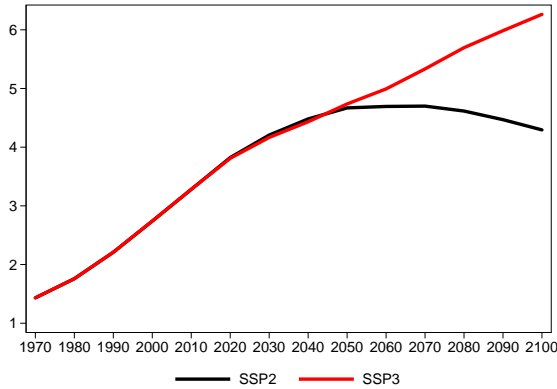
Using official projections for $\Delta L_{i,s,t}$ and $I_{i,s,t}$, we extract $\Delta M_{ii,s,t}$ from this equation. Remember that the DIOC-E database of the OECD allows us to estimate the size of the native population, $N_{i,s,2010}$, and of the native non-migrant population, $M_{ii,s,2010}$, for the year 2010. We can thus recursively compute $\Delta M_{ii,s,t}/M_{ii,s,t-1}$ and the level of $M_{ii,s,t}$ for all years after 2010. Assuming that $\Delta N_{i,s,t}/N_{i,s,t-1} = \Delta M_{ii,s,t}/M_{ii,s,t-1}$ (i.e. the growth rate of the native population equals the growth rate of the native non-migrant population), we then proxy the evolution of the native population for all years after 2010.

Figure 5 describes the two socio-demographic scenarios. Figure 5.a compares the trajectories of the worldwide population aged 25 to 64 over the 21st century. In the SSP2 scenario, the working-age population increases by 31%, from 3.28 billion in 2010 to 4.29 billion in 2100. Figure 5.c illustrates the evolution of the regional shares in the world population. The breakdown by region and the choice of colors are similar to Figure 4, albeit slightly less detailed for expositional convenience. The demographic share of OECD member states decreases from 19.2 to 14.8% (-4.4 percentage points), and that of Asia decreases from 54.6 to 40.0% (-14.6 percentage points). By contrast, the share of sub-Saharan Africa drastically increases from 8.4 to 28.5% (+20.1 percentage points). The shares of MENA countries (+2.3 percentage points), of Latin American countries (-1.1 percentage points), and of the rest of the world (-2.2 percentage points) exhibit smaller variations. In the SSP3 scenario, the working-age population increases by 90% and reaches 6.26 billion in 2100. Figure 5.d shows that the demographic share of OECD member states decreases from 19.2 to 8.8% (-10.4 percentage points), and that of Asia decreases from 54.6 to 45.8% (-8.8 percentage points). The share of sub-Saharan Africa increases from 8.4 to 27.0% (+18.6 percentage points). Demographically speaking, the difference between these two scenarios is mainly perceptible after the year 2050, and concerns the shares of OECD and Asian countries.

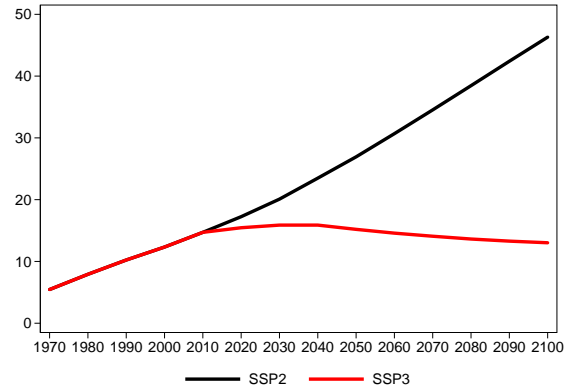
Figure 5.b compares the trajectories of the worldwide proportion of college graduates in the working-age population. In the SSP2 scenario, this proportion increases by 31.6 percentage points, from 14.7% in 2010 to 46.3% in 2100. Between 1970 and 2010, the worldwide share of college graduates increased by 2.3 percentage point per year under the impetus of high-income countries; it increased by 1.9 percentage points per year in developing countries, and by 2.1 percentage points per year in sub-Saharan Africa. For the years 2010 to 2100, SSP2 predicts a rise of 3.5 percentage point per year for the world and for the set of developing countries, against +0.5 percentage points in Africa. By contrast, SSP3 predicts a slight decrease in human capital for the world and for the set of developing countries, and +1.2 per year in Africa. Figure 5.e illustrates the evolution of the regional shares in the world stock of human capital. In 2100, 40.1 % of college graduates are living in the OECD member states; this share decreases by 17.9 percentage points between 2010 and 2100. The share of Asia increases from 36.9 to 39.9% (+3.0 percentage points), and the share of sub-Saharan Africa drastically increases from 3.1 to 18.4% (+15.3 percentage points); the latter change is due to the rising demographic share of Africa. In the SSP3 scenario, the proportion of college graduates decreases slightly, from 14.7% in 2010 to 13.0% in 2100. Figure 5.f shows that the human capital share of OECD member states decreases from 40.2 to 20.4% (-19.8 percentage points). The share of Asia increases from 36.9 to 42.2% (+5.3 percentage points). The share of sub-Saharan Africa increases from 3.1 to 13.5% (+10.4 percentage points). As far as education is concerned, the major difference between these two scenarios is the evolution of human capital in low-income countries in general, and in sub-Saharan Africa in particular.

Figure 5. Socio-demographic scenarios, 2010-2100

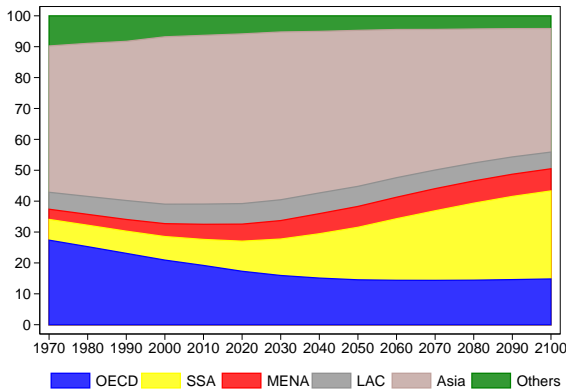
5.a. World population (billions)



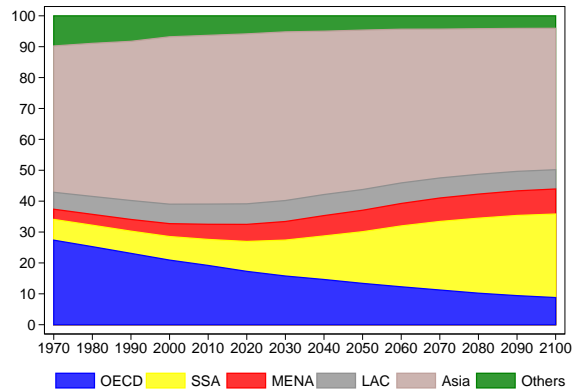
5.b. Share of college graduates (%)



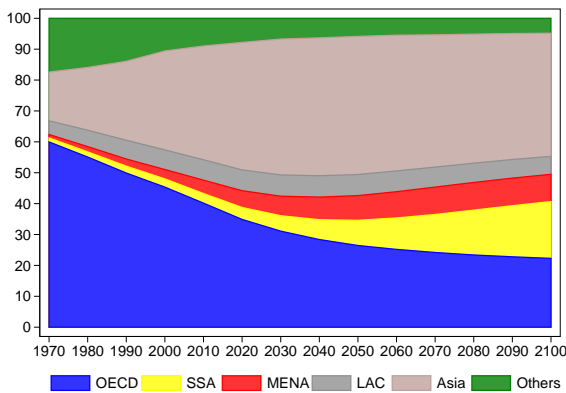
5.c. Population shares by region in SSP2



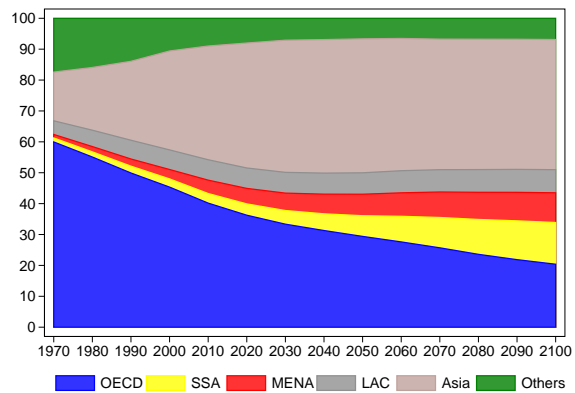
5.d. Population shares by region in SSP3



5.e. Shares of college graduates in SSP2



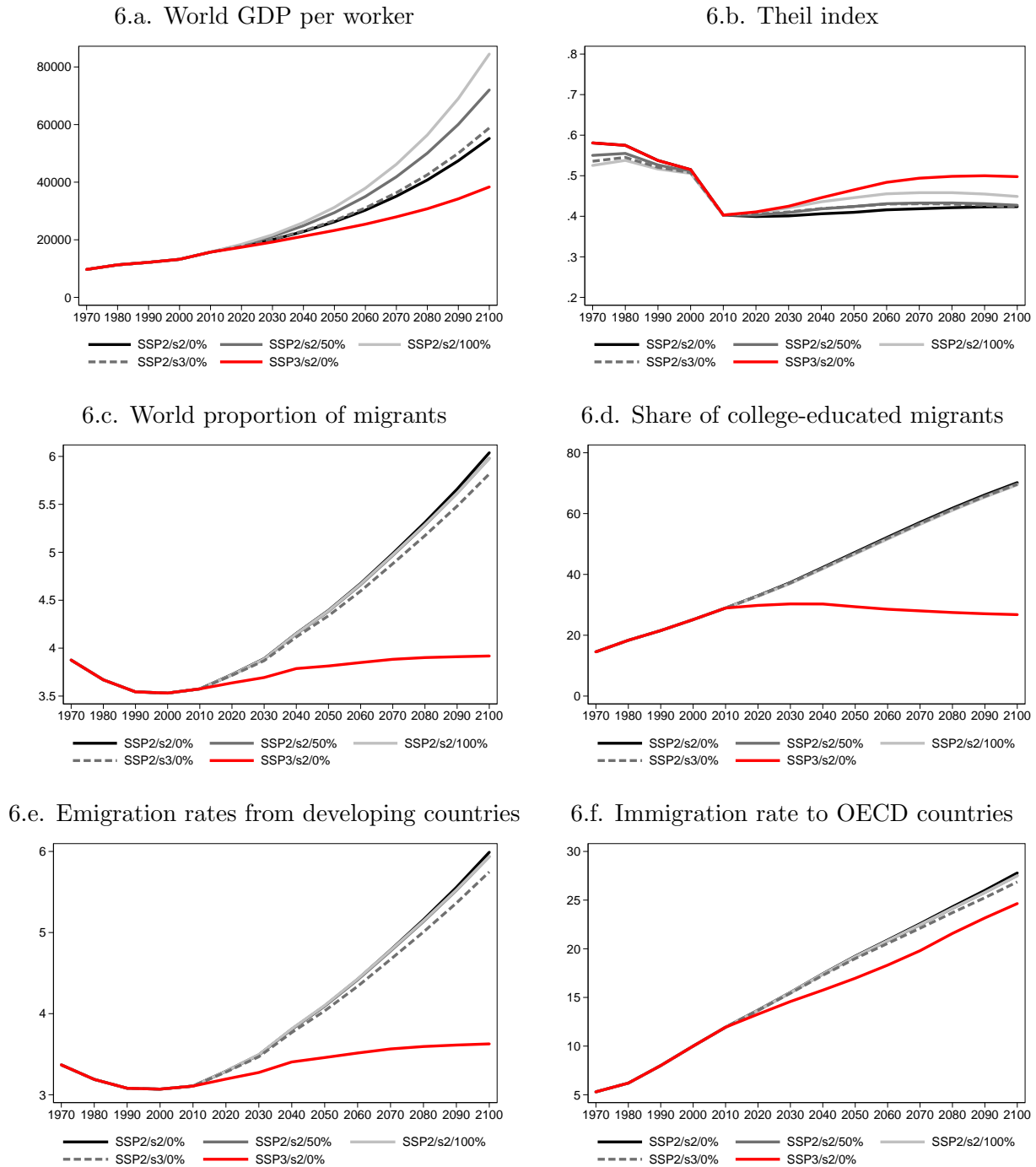
5.f. Shares of college graduates in SSP3



Global implications. – We turn now to the implications of our two socio-demographic scenarios for income growth, global inequality and migration pressures. It is important to acknowledge the reverse impacts of migration on population growth in sending countries. They are however not accounted for in this prospective paper, which takes socio-demographic scenarios as given in order to analyze their effects on income and migration. In addition to that, the longer the distance from 2010, the more uncertain are our projections. We can infer the predictability of our model from the reported coefficients of determination in Table

1 and Figure 3, which decrease with time departing from 2010 back to the past. Moreover, our forecasts do not account for future conflict, global warming, etc.. Compared to these factors that also affect migration, demography has higher level of predictability and can be seen as the driver of natural migration trend. Lastly, in all simulations we consider constant net migration costs $V_{ij,s,2010}$, which perform very well in backcasting past migration.

Figure 6. Global income and migration forecasts, 2010-2100



The global income and migration forecasts are depicted on Figure 6, which combines the data for the period 1970-2010, and the model forecasts for the subsequent years. We distinguish between five scenarios. In the first three ones, we consider that socio-demographic variables are governed by SSP2, and we combine it with the three technological variants defined in Columns (1), (2) and (3) of Table 2 (i.e., $\sigma = 2$ and technological externalities equal to 0, 50 or 100% of the correlation between productivity levels and the skill ratio). While keeping SSP2, the fourth scenario assumes $\sigma = 3$ and zero technological externalities (as in Column (4) of Table 2). Finally, the fifth scenario combines SSP3 with $\sigma = 2$ and full technological externalities (as in Column (6) of Table 2). In all scenarios with or without technological externalities, we assume an exogenous increase in TFP of 1.5% per year. It is worth noticing that under SSP3, worldwide changes in human capital are negligible; eliminating technological externalities hardly modifies the results.

Let us first focus on income projections. Figure 6.a shows the evolution of the worldwide level of GDP per worker. Under SSP3, the average GDP level in the year 2100 is 2.4 times greater than the level observed in 2010 (i.e., a growth rate of 1.0% per year). Under SSP2 and due to the rise in the level of schooling, the GDP level in 2100 is 3.5 times greater than the level observed in 2010 (i.e., a growth rate of 1.4% per year). Productivity growth is boosted when technological externalities are factored in. Assuming externalities are equal to 50 or 100% of the correlation, the annual growth rate reaches 1.7 and 1.9%, respectively. Finally, assuming a higher level for σ generates very similar income projections. Figure 6.b describes the evolution of the Theil index between 1970 and 2100. We combine our backcasts and forecasts, and account for between-country inequality and within-country inequality (between the college-educated and less educated representative workers, only). Globally, we show that the Theil index decreases from 1970 to 2010, a phenomenon that can be due to convergence in the productivity scale factors. Our projections do not account for convergence forces that are not driven by human capital. Under SSP2, the model predicts that the Theil index is constant over time, or is increasing slightly when externalities are included. Under SSP3, we predict a larger increase in the Theil index.

Figures 6.c and 6.d depict the evolution of the worldwide proportion of international migrants and of the skill structure of migration. Under SSP3, the proportion of migrants (ranging from 3.6 and 3.9%) and the share of college-educated (around 30%) are fairly stable. By contrast, under SSP2, progress in education makes people more mobile. Under constant migration policies, the proportion of migrants increases from 3.6% in 2010 to 4.5% in 2050 and to 6.0% in 2100, and the share of college graduates increases from 29% in 2010 to 34% in 2050 and to 70% in 2100. It is worth noticing that in Figure 6.c the important gap between the proportions of migrants in SSP2 and SSP3 does not result from a big difference in terms of migrant volume. In 2010, the working-age population is estimated at 3.28 billion, it will increase by 2100 to 4.29 billion according to SSP2, and more drastically to 6.26 billion following SSP3. While using SSP2 we predict a net increase in total migrants between 2010 and 2100 of about 111 million people, this number is a little bit smaller using SSP3 which is about 82 million. As regards the proportion of the high skill population, it should be recalled that our backcasts reveal that past changes in educational attainment were small in developing countries; they hardly affected the trajectory of global migration (see Figure 2.b). SSP2 predicts large educational changes in the coming decades, with strong implications for global migration. Another remarkable result is that the global trends in

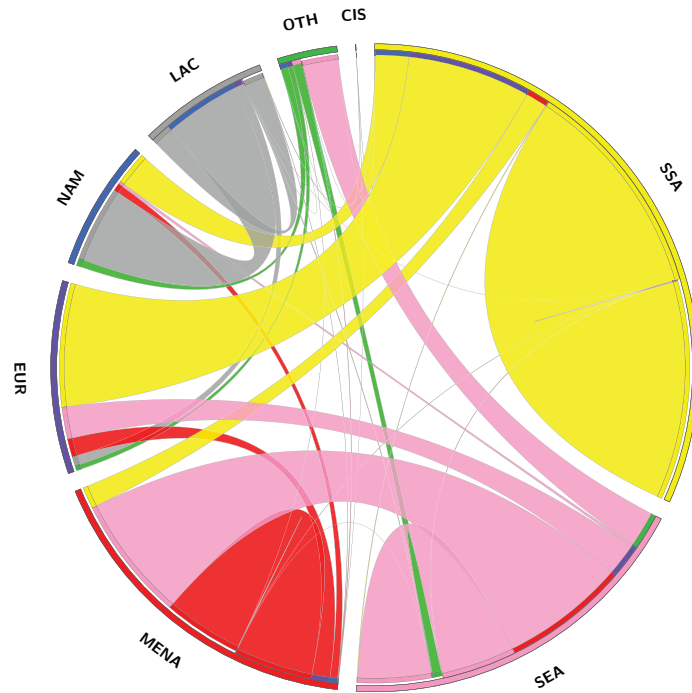
international migration are virtually unaffected by the technological environment; they are totally governed by socio-demographic changes.

We now focus on emigration and immigration rates, separately. Figure 6.e depicts the evolution of emigration rates, defined as the ratio of emigrants to natives originating from developing countries. The average emigration rate equals 3.1% in 2010. Under SSP2, it is predicted to reach 4.1% in 2050 and to be twice as large in the year 2100; under SSP3, it reaches 3.6% only by the end of the century. As explained above, the emigration rate is governed by the change in the average level of education in the developing world. Under SSP2 progress in education makes people more mobile (remember college graduates migrate more than the less educated). Under SSP3 emigration rates remain fairly stable over time given the slower progress in education. Similar patterns exhibit in both Figures 6c and 6e suggesting that the world proportion of migrants is shaped by emigration rates from developing countries. Finally, Figure 6.f depicts the evolution of the average immigration rate of OECD member states, defined as the proportion of foreign-born in the total population. This proportion equals 12% in the year 2010 and it is expected to increase drastically over the 21st century. Nevertheless, a remarkable result is that the magnitude of the change is highly insensitive to socio-demographic and technological scenarios. Under SSP3, emigration rates from developing countries vary little, but population growth is large. Under the SSP2 scenario, the rise in emigration rates is larger, but it is partly offset by the fall in the population growth rates of developing countries. By the year 2100, the share of immigrants reaches 27.8% under SSP2, and 24.6% under SSP3.

In Figure 7, we represent the net flows of low-skilled and high-skilled migrants over the 21st century. Origin and destination regions are represented by circular ideograms (Kzrywinski et al., 2009), and we use the same regions and colors as in Figure 4. Net flows are colored according to their origin, and their width is proportional to their size. The direction of the flow is captured by the colors of the outside (i.e., country of origin) and inside (i.e., country of destination) borders of the circle.

Figures 7.a and 7.b show the net flows of low-skilled migrants under the SSP2 and SPP3 socio-demographic scenario, respectively. Under SPP2, the total net flows amount to 32 million. The top-5 regional corridors are intra-African migration (24.3% of the total), migration from South and East Asia to the MENA (13.8%), migration from sub-Saharan Africa to Europe (13.7%), intra-MENA migration (8.7%), and migration from Latin America to Western offshoots (8.4%). Outflows from sub-Saharan Africa and South and East Asia to Europe are large. Under SPP3, the total net flows amount to 60 million and are greater for all regional corridors. Compared to Figure 7.a, Figure 7.b of scenario SSP3 with slower growth and greater fertility rates shows large outflows from Latin America to North America and within African regions. The top-5 regional corridors are Latin America to Western offshoots (16.4% of the total), intra-African migration (15.3%), intra-MENA migration (11%), migration from South and East Asia to Western offshoots (21.1%), and migration within South and East Asian countries (9.3%).

Figure 7. Global migration net flows, 2010-2100
(Technological variant with $\sigma = 2$ and with technological externalities)
 7.a. Less educated workers (SSP2)



7.b. Less educated workers (SSP3)

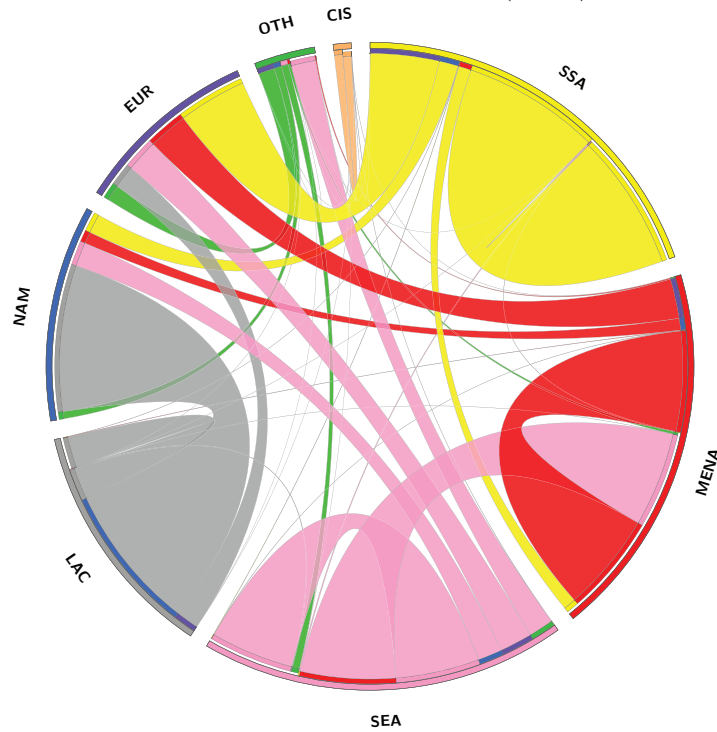
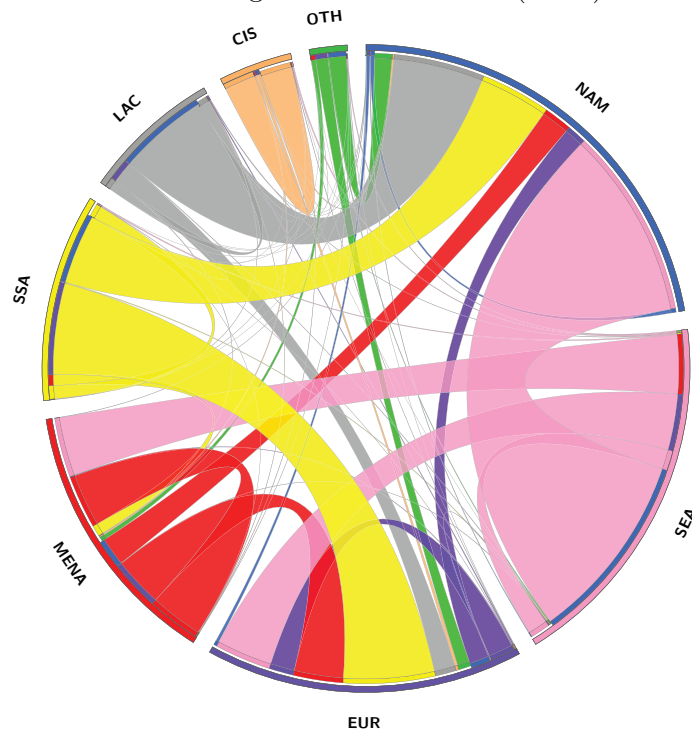
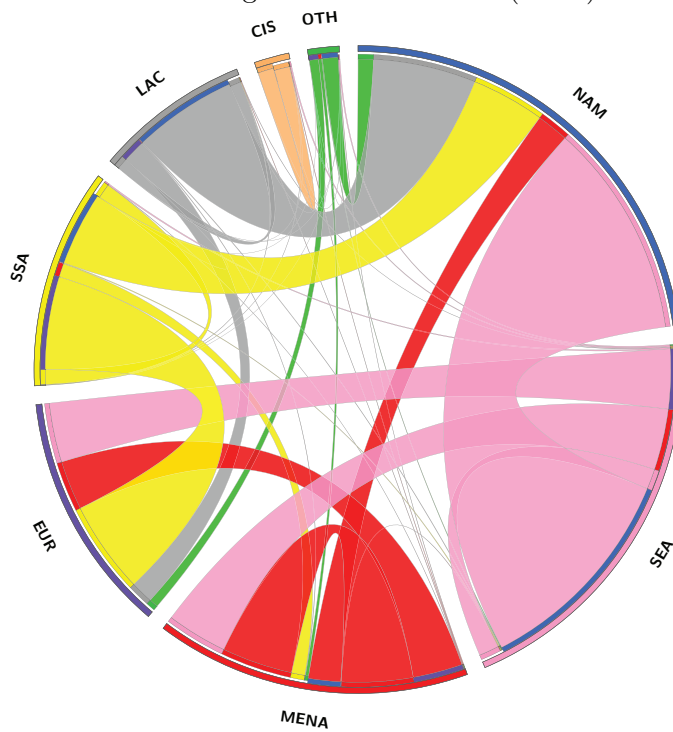


Figure 7. Global migration net flows, 2010-2100 (cont'd)
(Technological variant with $\sigma = 2$ and with technological externalities)
 7.c. College-educated workers (SSP2)



7.d. College-educated workers (SSP3)



Figures 7.c and 7.d show the net flows of college-educated migrants under the SSP2 and SPP3 socio-demographic scenario, respectively. Under SPP2, the total net flows amount to 79 million. The top-5 regional corridors are migration from South and East Asia to Western offshoots (21.1%), migration from sub-Saharan Africa to Europe (10.2%), migration from Latin America to Western offshoots (10.1%), migration from sub-Saharan Africa to Western offshoots (7.8%), and migration from South and East Asia to the MENA (6.6%). Inflows to Western offshoots and Europe are large. Under SPP3, the total net flow amounts to 22 million only, but the structure of worldwide migration is similar than under SSP2. The top-5 regional corridors are migration from South and East Asia to Western offshoots (24.2%), migration from Latin America to Western offshoots (11.5%), migration from sub-Saharan Africa to Europe (10.4%), migration from sub-Saharan Africa to Western offshoots (8.2%), and intra-MENA migration (8.0%).

Implications for HI countries. – Table 3 provides projections of immigration rates for the main high-income, destination countries and for constant immigration policies (remember this hypothesis performed well when producing backcasting results). Results obtained under the SSP2 socio-demographic scenario are presented in the top panel; results obtained under SSP3 are presented in the bottom panel. In both cases, we consider the variant with $\sigma = 2$ and full technological externalities, the scenario that is the most compatible with future educational changes.¹⁶ Under SSP2 and over the 21st century, the proportion of immigrants increases by 21.2% in the EU15 and by 14.3% in the United States. The greatest variations are obtained for the United Kingdom (+35.9%) and for Canada (+35.6%). Under SSP3, the average population growth rates are larger in developing countries, with the exception of Asia. The proportion of immigrants increases by 24.3% in the EU15 and by 22.4% in the United States. The greatest variations are obtained for Spain (+27%), the United Kingdom (+26.2%) and for Canada (+29.8%). Projections for the coming 50 years are rather insensitive to the socio-demographic scenario.

In line with Hanson and McIntosh (2016) or with Docquier and Machado (2007), future migration pressures mainly affect European countries, and are mostly due to rising migration flows from developing countries. To illustrate this, we use the same *Max-Sum Submatrix* algorithm as in the previous section, and apply it to the matrix of total migration net flows from developing countries to the 27 members of the European Union between 2010 and 2060; projections for subsequent years are more uncertain and scenario-sensitive. For each socio-demographic scenario, we identify the sub-matrix with a fixed dimension of 25×10 that maximizes the total migration net flows.

Under the SSP2 scenario, we obtain the following results (in alphabetical order):

- Main destination countries: *Belgium, France, Germany, Ireland, Italy, Netherlands, Portugal, Spain, Sweden, and the United Kingdom.*
- Main countries of origin: *Afghanistan, Algeria, Angola, Bangladesh, Cameroon, Dem. Rep. of Congo, Cote d'Ivoire, Ghana, India, Iran, Iraq, Kenya, Madagascar, Mali, Morocco, Mozambique, Nigeria, Pakistan, Philippines, Senegal, Somalia, Tanzania, Turkey, Uganda, and Zimbabwe.*

¹⁶Very similar results are obtained when technological externalities are zero, as shown in Table A1 in the Appendix.

Table 3. Proportion of working-age immigrants by main destination
(Scenario with $\sigma = 2$ and full technological externality)

	2010	2020	2030	2040	2050	2060	2070	2080	2090	2100	Δ
	SSP2, $\sigma = 2$, full technological externalities										
EU15	14.5	16.8	19.3	22.2	24.7	26.8	29.1	31.3	33.5	36.5	+21.2
France	14.7	18.0	21.0	24.0	26.2	28.2	30.3	32.4	34.4	36.5	+21.8
Germany	15.9	17.3	19.3	21.3	22.0	22.8	23.7	24.0	24.3	24.9	+9.0
Italy	10.5	11.8	13.1	14.8	15.9	16.3	16.9	17.6	18.1	18.7	+8.2
Spain	14.9	16.8	19.2	22.0	25.2	26.6	27.6	28.9	29.5	29.9	+15.0
United Kingdom	16.5	19.9	24.2	28.8	32.8	37.2	41.1	45.1	48.9	52.3	+35.9
Switzerland	31.4	33.2	35.7	38.8	40.7	42.9	45.0	46.9	48.9	51.0	+19.6
United States	17.7	20.4	23.3	25.2	26.7	28.0	29.1	30.1	30.9	31.9	+14.3
Canada	24.5	29.4	35.3	40.1	44.3	48.4	51.7	54.5	57.3	60.0	+35.6
Australia	28.7	31.2	33.8	36.3	38.4	40.7	42.5	44.3	46.3	48.2	+19.4
OECD	11.9	13.7	15.5	17.4	19.2	20.8	22.5	24.2	25.8	27.5	+15.6
	SSP3, $\sigma = 2$, full technological externalities										
EU15	14.5	16.4	18.4	20.7	22.8	25.3	28.2	31.9	35.4	38.9	+24.3
France	14.7	17.4	19.4	21.2	22.7	24.6	27.1	30.3	33.3	36.3	+22.2
Germany	15.9	17.3	19.3	21.5	23.2	25.6	28.9	32.3	36.0	40.0	+24.1
Italy	10.5	11.8	13.2	15.2	17.3	19.3	21.8	25.4	28.6	32.1	+21.6
Spain	14.9	16.6	18.7	21.4	25.2	28.1	31.0	35.4	38.8	41.9	+27.0
United Kingdom	16.5	18.6	21.3	23.4	25.5	28.6	31.7	35.8	39.8	43.6	+26.2
Switzerland	31.4	32.5	34.1	36.1	37.3	39.3	41.5	44.1	46.9	49.7	+18.4
United States	17.7	19.8	22.2	23.5	25.3	27.6	30.2	33.6	36.8	40.1	+22.4
Canada	24.5	27.4	31.2	33.5	35.7	39.1	42.3	46.3	50.3	54.2	+29.8
Australia	28.7	29.9	31.4	32.4	33.5	35.5	37.6	40.5	43.8	47.0	+18.2
OECD	11.9	13.3	14.6	15.7	16.9	18.3	19.8	21.6	23.2	24.6	+12.7

And under the SSP3 scenario, we have (by alphabetical order):

- Main destination countries: *Austria, Belgium, France, Germany, Italy, Netherlands, Portugal, Spain, Sweden, and the United Kingdom.*
- Main countries of origin: *Afghanistan, Algeria, Angola, Bangladesh, Bolivia, Colombia, Dem. Rep. of Congo, Cote d'Ivoire, Ecuador, Ghana, India, Iraq, Kazakhstan, Kenya, Madagascar, Mali, Morocco, Nigeria, Pakistan, Peru, Philippines, Senegal, Somalia, Turkey, and Uganda.*

Under SSP2, migration flows from sub-Saharan Africa and from the MENA play a key role, as well as the flows from a few Asian countries with large populations. As the majority of African migrants go to Europe, the EU15 experience greater migration pressures. Under SSP3, this change is mostly due to immigration from Africa, although the magnitude of this phenomenon is smaller than under SSP2. However, migration pressures from Asia, from

MENA, and from some Latin American countries are stronger. Clearly, there is a large intersection of 9 destination countries (see countries in italics above) that are all member states of the EU15, and for which future migration pressures are expected to be strong, whatever the socio-demographic scenario for the coming half century. And there is large intersection of 20 developing countries (in italics above) that are responsible for such migration pressures, including sub-Saharan African countries, the MENA countries, and a few Asian countries.

The case for Migration Compacts. – In line with the Sustainable Development Goals and the New York Declaration for Refugees and Migrants (United Nations, 2016), the European Commission has outlined a general line of action to cope with the global challenge of future migration (see the European Agenda on Migration and the new Partnership Framework on Migration). Migration Compacts have been designed for Jordan, Lebanon, Nigeria, Niger, Mali, Senegal, Morocco, Tunisia, Libya and Ethiopia as of 2017; they can also be implemented in other partner countries. They include a set of measures to be implemented in the home country, targeting the reinforcement of border controls, the readmission of migrants who have been denied entry, or a higher level of economic development. Readmission and border control strategies are difficult to implement in fragile states. Under the European Migration Compacts, an investment plan has also been proposed to stimulate employment opportunities and income in Africa, in the hope of reducing migration pressures. The effectiveness of these Migration Compacts depends on the resources allocated to their implementation (in comparison to the development targets to be reached), and on the effectiveness of the measures undertaken.

To illustrate the difficulty curbing future migration pressure, we consider the intersection of 20 developing countries emerging from our *Max-Sum Submatrix* problem (referred to as *Compact 1*),¹⁷ or the combined region of sub-Saharan African and the MENA countries (referred to as *Compact 2*). We consider these sets of countries as potential partners of a Migration Compact, and we quantify the homothetic change in TFP (above normal trend) and derive the consequent GDP annual growth rates required to keep their total emigration stocks to Europe at their levels of 2010. Our simulations account for all general equilibrium effects.

Table 4 provides the results of these policy experiments, taking the population size and structure as given. Our discussion mainly focuses on net migration flows in the next two decades, the period for which socio-demographic variations between SPP2 and SPP3 are smaller and less likely to be affected by the TFP changes. In other words, this consideration partially mitigates the issue that fertility and human capital are endogenously affected by income, which our model does not account for. Indeed, if TFP and GDP start increasing from 2010 onwards, population growth rates and the skill composition of the labor force will be gradually impacted. Results obtained for 2030 and after (essentially beyond one generation) are likely to overestimate the requested changes and should be treated with more caution.

Under the SSP2 socio-demographic scenario, keeping the stock of the 20 main origin countries (*Compact 1*) at its level of 2010 requires TFP to increase by 58% in 2020 and by 128% in 2030, compared to the baseline. Under the SSP3 scenario, the required TFP changes

¹⁷These include Afghanistan, Algeria, Angola, Bangladesh, Dem. Rep. of Congo, Cote d'Ivoire, Ghana, India, Iraq, Kenya, Madagascar, Mali, Morocco, Nigeria, Pakistan, Philippines, Senegal, Somalia, Turkey, and Uganda.

amount to 49% in 2020 and by 99% in 2030. Overall, this means multiplying GDP per capita by 2 above the normal trend over the next two decades. Equivalently, this requires a TFP growth rate of 5% per year under SPP2 (instead of 1.5% a year in the baseline), and a TFP growth rate of 4.2% a year under SPP3. In terms of GDP growth, the required levels are on average twice as high as the baseline levels; in all variants, the requested annual GDP growth rate is close to 10%. Implementing Migration Compacts with all sub-Saharan African and MENA countries (*Compact 2*) requires similar changes in TFP and gives rise to similar effects.¹⁸

Table 4. Development policies to limit migration pressures

	2010	2020	2030	2040	2050	2060	2100
I. Socio-demographic scenario: SSP2							
Baseline immigration rate to EU15	14.6	16.8	19.3	22.2	24.7	26.8	35.8
Compacts 1							
I.a. 20 main origin countries							
TFP change: $A_{j,t}/A_{j,t}^{Base}$	1.00	1.58	2.28	3.19	4.18	5.24	9.73
New immigration rate EU15	14.6	15.6	16.9	18.5	19.5	20.4	24.9
Mean annual GDP growth over decade (<i>Base</i>)		5.17	5.00	4.82	4.58	4.33	3.48
Mean annual GDP growth over decade		10.28	9.59	9.11	8.54	7.99	6.25
Compacts 2							
I.b. All sub-Saharan Africa and MENA							
TFP change: $A_{j,t}/A_{j,t}^{Base}$	1.00	1.58	2.28	3.24	4.30	5.51	11.81
New immigration rate EU15	14.6	15.6	16.9	18.3	19.3	20.0	22.6
Mean annual GDP growth over decade (<i>Base</i>)		5.06	4.85	4.67	4.42	4.16	3.34
Mean annual GDP growth over decade		10.22	9.47	9.05	8.48	7.95	6.37
II. Socio-demographic scenario: SSP3							
Baseline immigration rate to EU15	14.6	16.4	18.4	20.7	22.8	25.3	38.9
Compacts 1							
II.a. 20 main origin countries							
TFP change: $A_{j,t}/A_{j,t}^{Base}$	1.00	1.49	1.99	2.51	3.06	3.67	6.40
New immigration rate EU15	14.6	15.4	16.5	17.7	18.8	20.1	28.1
Mean annual GDP growth over decade (<i>Base</i>)		4.54	4.36	4.17	4.01	3.86	3.3
Mean annual GDP growth over decade		8.95	8.15	7.53	7.05	6.68	5.51
Compacts 2							
II.b. All sub-Saharan Africa and MENA							
TFP change: $A_{j,t}/A_{j,t}^{Base}$	1.00	1.49	1.97	2.48	2.99	3.54	5.89
New immigration rate EU15	14.6	15.4	16.5	17.7	18.8	20.2	28.8
Mean annual GDP growth over decade (<i>Base</i>)		4.51	4.25	4.05	3.85	3.67	3.1
Mean annual GDP growth over decade		8.95	8	7.38	6.84	6.42	5.22

Takeoffs of this nature have rarely been observed in the course of history.¹⁹ They basically

¹⁸We have also conducted another set of simulations (*Compact 3*) keeping constant the total emigration stocks of sub-Saharan African countries only. The resulting required TFP growth rates are much higher than the ones in *Compact 2* where growth is fostered in both the MENA and SSA regions. This shows the capacity of the MENA countries to absorb migrants from SSA. Thus smaller but simultaneous investment in both regions is recommended to keep immigration rates in Europe at constant levels.

¹⁹This was even the case during the Industrial Revolution. Between 1820 and 1900, GDP per capita rose 2.5 times in Western Europe, and 3.3 fold in the United States (Maddison, 2007). In other words, growth rates were 1.2 and 1.5% a year, respectively.

require all SSA and MENA countries to enter the "modern growth club" during the 21st century. Based on facts from the 19th and 20th centuries, Benetrix et al. (2015) estimate that joining the club requires an annual GDP growth rate above 5% over a period of ten years; Jones and Romer (2010) argue that higher threshold growth rates are needed in the current period. Still, "explosive-growth" episodes were indeed recently observed in emerging countries. Taiwan multiplied its income per capita by 5 between 1980 and 2000, and South Korea multiplied it by 7.5 over the same period; China has increased its income level tenfold since 1990 with an average GDP growth rate of 8% per year. Similar takeoffs have not been observed in sub-Saharan Africa. However, Rwanda, which is usually seen as one of the fastest growing economies in Africa, has increased its income per capita threefold since the genocide.

Sustaining TFP growth rates of 4 to 5% or real GDP growth rates of 8 to 10% per year on the spatial scale of a continent and over several decades is unprecedented. So far, development policies have not triggered such resounding and generalized economic booms. Hence, dramatic changes in the effectiveness of aid are needed if policymakers want to use development tools to reduce migration pressures (Berthelemy et al. 2009; Berthelemy and Maurel 2010; Gary and Maurel 2015). In addition, generating these booms in SSA and MENA would only attenuate migration pressures to Europe, but would not eliminate them since migration pressures from other countries and regions would still be observed. Table 4 shows that the EU15 immigration rate in 2060 would be around 20% in all scenarios, compared to 14.6% in 2010. Reinforcing immigration restrictions is another complementary policy avenue. However, it is a priori unclear whether changes in laws and policies can significantly affect the size of immigration flows. Past restrictions on migration have not prevented third-country nationals from moving in past decades (it may be recalled that our backcasts with constant $V_{ij,s,t}$ fit well past migration flows), and have caused displacements and increasing flows of irregular migrants. Over the 21st century, increasing migration seems to be an inevitable phenomenon, which raises important challenges in terms of policy coherence for most industrialized countries.

5 Conclusion

The number of asylum applications lodged in 2015 in EU Member States exceeded 1.3 million, putting migration policy in the forefront of the global policy debate. While the proximate cause of the current crisis is the conflict and political unrest in the Middle East and Africa, the recent trends and forecasts for the world economy strongly suggest that there may be further episodes of large-scale migration in the near future, in Europe and in other OECD countries. Specifically, the underlying root causes of increased migration (demographic imbalances, economic inequality, increased globalization, political instability, climatic changes) are all projected to exert a stronger influence in the coming decades.

Relying on socio-demographic and technological scenarios, this paper produces integrated backcasts and forecasts of income and bilateral migration stocks for all pairs of countries. Our model fits very well the trends in international migration of the last 40 years, and demonstrates that historical trends were mostly governed by demographic changes. Turning to the migration prospects for the 21st century, we also find that world migration prospects are mainly governed by socio-demographic changes; they are virtually insensitive to the

technological environment. We predict a highly robust increase in immigration pressures in general, and in European immigration in particular. These migration pressures are mostly explained by the demographic changes in sub-Saharan Africa and in the MENA countries. Curbing them with development policies requires triggering unprecedented economic booms in many developing countries. More than ever, improving the management of migration flows and the coherence between development and migration policies will represent major challenges for European countries in the 21st century.

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Table A1. Proportion of working-age immigrants by main destination
(Scenario with $\sigma = 2$ and no technological externality)

	2010	2020	2030	2040	2050	2060	2070	2080	2090	2100	Δ
	SSP2, $\sigma = 2$, no externality										
EU15	14.5	16.7	19.1	21.9	24.2	26.2	28.3	30.5	32.6	34.8	+20.2
France	14.7	17.8	20.6	23.2	25.2	27.0	28.9	30.9	32.8	34.8	+20.1
Germany	15.9	17.3	19.2	21.2	22.0	22.7	23.7	24.0	24.4	25.1	+9.2
Italy	10.5	11.7	12.9	14.6	15.6	16.0	16.5	17.1	17.6	18.2	+7.7
Spain	14.9	16.7	18.9	21.4	24.4	25.7	26.5	27.8	28.4	28.8	+13.9
United Kingdom	16.5	19.8	24.0	28.4	32.2	36.4	40.2	44.0	47.7	51.0	+34.6
Switzerland	31.4	33.3	35.7	38.8	40.8	43.0	45.0	46.9	48.8	50.9	+19.5
United States	17.7	20.6	23.6	25.6	27.4	28.8	30.1	31.3	32.3	33.5	+15.9
Canada	24.5	29.4	35.2	40.0	44.1	48.3	51.7	54.7	57.6	60.5	+36.0
Australia	28.7	31.1	33.7	36.1	38.2	40.4	42.3	44.1	46.0	47.9	+19.2
OECD	11.9	13.7	15.5	14.4	19.2	20.9	22.6	24.3	26.0	27.8	+15.8
	SSP3, $\sigma = 2$, no externality										
EU15	14.5	16.3	18.3	20.5	22.6	25.1	27.9	31.6	35.1	38.6	+24.0
France	14.7	17.4	19.4	21.2	22.7	24.6	27.1	30.3	33.3	36.3	+21.6
Germany	15.9	17.3	19.2	21.4	23.1	25.6	28.9	32.3	36.1	40.2	+24.3
Italy	10.5	11.8	13.2	15.3	17.3	19.3	21.9	25.4	28.7	32.1	+21.6
Spain	14.9	16.5	18.6	21.3	25.1	28.0	30.9	35.3	38.7	41.9	+27.0
United Kingdom	16.5	18.6	21.1	23.3	25.2	28.2	31.2	35.1	39.1	42.7	+26.2
Switzerland	31.4	32.6	34.2	36.2	37.4	39.4	41.6	44.1	46.8	49.6	+18.3
United States	17.7	20.0	22.4	23.7	25.5	27.9	30.4	33.9	37.1	40.4	+22.7
Canada	24.5	27.4	31.3	33.6	35.8	39.2	42.4	46.2	50.2	54.1	+29.7
Australia	28.7	29.9	31.4	32.4	33.4	35.4	37.5	40.3	43.5	46.6	+17.9
OECD	11.9	13.3	14.6	15.7	17.0	18.3	19.8	21.6	23.2	24.6	+12.7

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