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Migration Projections: The Economic Case

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*Migration Projections: The Economic Case**

Thomas Buettner and Rainer Muenz†

Abstract

This paper adds an economic dimension to the projection of international migration flows. Using existing estimates of international migration flows and demographic projections from the United Nations, the paper analyzes the impact of economic development, expressed as gross domestic product (GDP) per capita, on international migration. The analysis was inspired by the migration transition hypothesis – also known as the “migration hump” theory – and confirmed ahypothesized nonlinear relationship between migration and GDP per capita. Despite the large variability of the data, nonparametric fits suggest that emigration rates are relatively low in low-income settings, rise with rising GDP per capita, and decline at high income levels. On the other hand, immigration rates seem to increase unabated with rising income levels. For the projection of international migration flows, the nonparametric curves were parametrized by logistic and bi-logistic functions. Migration projections for 183 countries with constant emigration rates and with migration rates augmented by (projected) GDP per capita were calculated and the results summarized. The results show that international migration flows might substantially increasing when countries pass from low- to high-income economies. The paper also considers possible interactions between labor force dynamics and international migration but finds insufficient evidence for the formal integration of employment dynamics into the formulation of assumptions of international migration. Labor force projections driven by demographic change and projections of labor force participation rates are calculated for 184 countries and summarized. This paper provides strong evidence that economic dynamics should be considered into the formulation of assumption for future trends of international migration.

Key words: International migration, Population projection, Migration transition hypothesis, Migration scenarios, Labor force, GDP

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1. INTRODUCTION

Demographic change is a powerful driver of international migration. At the same time, international migration shapes the demographic development of many countries. This was shown in Buettner and Muenz (2018a) with simple assumptions and for six regions of the world. By using current (2010–15) emigration and immigration rates, one can easily show that the still fast-growing population of Africa will generate a large volume of potential future migrants, but it is unclear how many of them will actually leave their countries and, ultimately, their continent. The population of Europe, on the other hand, is expected to change in the opposite direction, leading to demographic decline in the absence of significant immigration from other parts of the world. If Europe were to maintain its current rates of immigration over the next several decades, its population size would not change significantly. And even if all migrants arriving in Europe were to be of African origin, the migration potential of Africa could never be absorbed by Europe's potential need for additional migrants.

The paper on the demographic drivers of international migration quoted above (Buettner and Muenz 2018a) suggests a balancing solution to the apparent mismatch between projected or predicted emigration flows of sending countries vs. immigration flows of receiving countries that differential demographic trends would imply. However, most current global and national forecasts link either assumed net migration or both emigration and immigration to the dynamic of total population and age structure change. No systematic attempts have been made so far to link future migration forecasts to socioeconomic development and/or expected changes in the labor force.

In this paper, we approach the problem differently by focusing on the interaction between economic development, measured as a change in gross domestic product (GDP) per capita over time, and international migration (emigration and immigration). We are also looking at the possible interaction between labor force developments and international migration. This offers a more nuanced and direct way to address the possible means and motivations of leaving a country of origin (emigration) or to accept or even recruit migrants in a country of destination (immigration).

Calculations using an existing migration transition model (the so-called "migration hump" theory) and data on labor force participation rates from the International Labour Organization (ILO) were performed for all countries of the world. The results are summarized using the country groupings put forward by the World Bank Group and the United Nations.

2. DATA

2.1. Migration

The empirical data on international migration remain very limited. In countries with a developed statistical system, immigrants are usually much better documented and accounted for than emigrants. Yet for those countries, international comparison is made more difficult by the fact that they apply different concepts and practices in the process of registering migration flows.

Less developed countries often lack resources and stable institutions to account for international migration at all. Beyond the current migration statistics (measuring flows) produced by more developed countries, the only other data sources that allow the (indirect) estimation of migration flows are the migrant stock tabulations produced by decennial censuses. Based on these, international population projections normally use net migration, estimated as residual, as a proxy for the migration component.

In this context, Abel (2009, 2017) has pioneered the global estimation of migrant flows from migrant stock tables (using the stock-to-flow method). He has produced, in ever greater detail, migration flow estimates for the years 1960 to 2015 (Abel 2017). These data have been successfully used in global projection exercises (Buettner and Muenz 2018b; Lutz, Butz, and KC 2014a). But it also must be stressed that (indirect) estimates of international migration flows, while extremely useful, are also fraught with problems.

The most significant challenge is the very heterogeneous statistical bases—that is, census tabulations that are not using comparable concepts and definitions of who is "foreign born" (see Özden et al. 2011 for attempts to clean and verify the raw census data). Another challenge is the difficulty of defining a meaningful spatial structure in the estimation model (Abel 2013, 2017), whichuses geographic distance as a "deterrence function."

In aglobal projection exercise, Lutz, Butz, and KC (2014b) adjust the international migration flow estimates generated by a stock-to-flow methodology to match the net migration estimates published by the United Nations Population Division (UNPD) (United Nations 2015). Such an approach avoids confusion and relies on reputable UN estimates. Yet it cannot be ignored that net-migration estimates are essentially residuals from a demographic accounting exercise and contain, in addition to the real (but unknown) balance of in- and outflows of migrants, measurement deficits from censuses and estimation errors from vital statistics (e.g., births and deaths).

Preliminary analysis suggests that the stock-to-flow methodology tends to estimate lower net migration levels thandoes the UNPD, thus underestimating international migration. Sometimes the stock-to-flow methodology even yields estimates with a different sign (negative vs. positive net migration). A thorough investigation into the sources of these discrepancies is beyond the scope of this paper; but such an exercise could eventually help to improveglobal international migration estimates and solidify the basis for international migration projections.

In addition to model-based estimates of migration flows, this paper also analyzes the migrant stock data that form the bases for the flow estimates. We use the 2017 revision of the International Migrant Stock dataset (United Nations, 2017a). Based on the regularly updated dataset of the UNPD, the 2017 revision contains stock data on bilateral migrants for the years 1990, 1995, 2000, 2005, 2010, 2015, and 2017 for all countries. The estimates are based on official statistics on the foreign-born or the foreign population as reported in national censuses.

2.2.Gross domestic product

We use data from the ninth revision of the Penn World Tables[1] (Feenstra, Inklaar, and Timmer 2015), namely the indicator "Expenditure-based real GDP" [$RGDP^e$] (chained purchasing power parity in US$ 2011 million). The ninth revision of the Penn World Tables uses population data from the United Nation's 2015 Revision of World Population Prospects as the denominator (United Nations 2015).

For GDP projections, several sources are available. We chose to use the long-term projections of the Organisation for Economic Co-operation and Development (OECD) (Dellink et al. 2017), which are

[1] The data are available in electronic form, together with extensive documentation, on www.ggdc.net/pwt.

compatible with the "middle-of-the-road scenario" (scenario 2) of the Shared Socioeconomic Pathways (SSP2).[2]The projections are available from 2000 to 2100, expressed in billionsof (2005) U.S. dollars per year.

2.3. Employment

For our analysis of labor force participation, we employ ILO data (ILO, 2018) and the results of the 2017 Revision of the UNPD World Population Prospects (WPP 2017). We were aware of the rather wide definition of the labor force participation rate (LFPR)[3] and explored, as an alternative indicator, the employment-to-population ratio (EPR)[4]. Ultimately, we decided to use the EPR modelling the relationship between employment and GDP butproceed with LFPR for the projection exercise later in the paper because it is less volatile and because more data are available (including projections).

For greater flexibility in customizing aggregates, the ILO's LFPRestimates[5] were combined with the corresponding population data (for age groups 15–64) from the UNPD (United Nations 2017b).

2.4. Population

Data on population dynamics were obtained from the 2017 Revision of World Population Prospects, the latest revision at the time this paper was written (United Nations 2017b).

3. GLOBAL MIGRATION DYNAMICS

The flow of international migrants has increased over the past several decades. But did the volume of international migration grow because of pure demographic effects, namely population growth,or did it grow because the propensity/intensity of individuals'movement increased?

To answer these questions, we employ data on migration flows (Abel 2017). Figure **1** shows the trends in the total number of emigrants and immigrants from 1960–65 through 2010–15.[6] The absolute number of people on the move increased significantly, from less than 20 million in the five-year period of 1960–65 to about 45 million by 2010–15 and 36 million during the following five year period. The data, albeit aggregates from more than 200 sovereign countries and other territories, show some mild temporal

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[2]The International Institute for Applied Systems Analysis (IIASA) maintains a reference database for the Shared Socioeconomic Pathways (SSPs) that contains long-term GDP projections produced by OECD and IIASA. For the database, see: https://tntcat.iiasa.ac.at/SspDb/dsd?Action=htmlpage&page=about; https://data.oecd.org/gdp/gross-domestic-product-gdp.htm.

[3] The labor force participation rate: "… is a measure of the proportion of a country's working-age population that engages actively in the labour market, either by working or looking for work; it provides an indication of the size of the supply of labour available to engage in the production of goods and services, relative to the population at working age." See https://www.ilo.org/ilostat-files/Documents/description_LFPR_EN.pdf.

[4]The employment-to-population ratio is defined as the proportion of a country's working-age population that is employed.; see https://www.ilo.org/ilostat-files/Documents/description_EPR_EN.pdf.

[5] For a methodological note about the LFPR, see ILO (2017).

[6] The chart shows minor numerical discrepancies between total immigrants and total emigrants due to incomplete coverage (missing countries and territories). In reality (covered insufficiently by available data) the two figures should be the same, of course.

fluctuations that could be the result of better data estimation in years following a census.[7] But despite this, the fitted linear curve shows a clear upward trend.

Figure 1: Global Number of Migrants, by Five-Year Period, 1960–2015

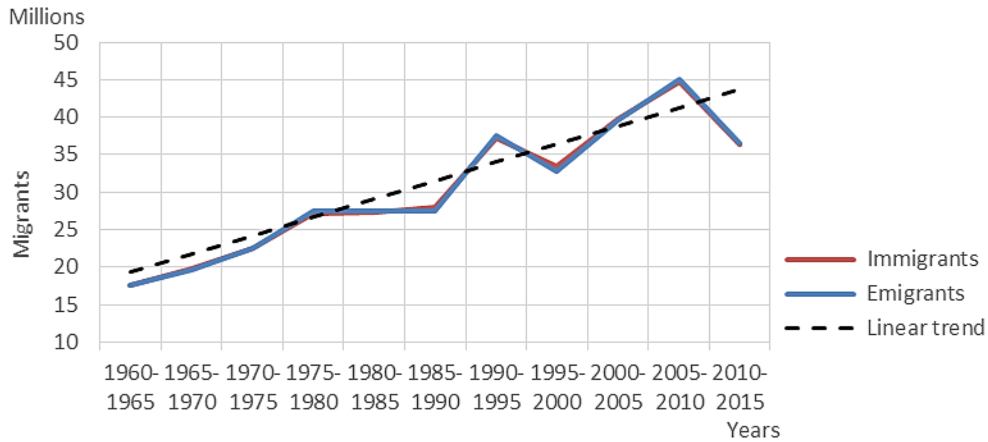
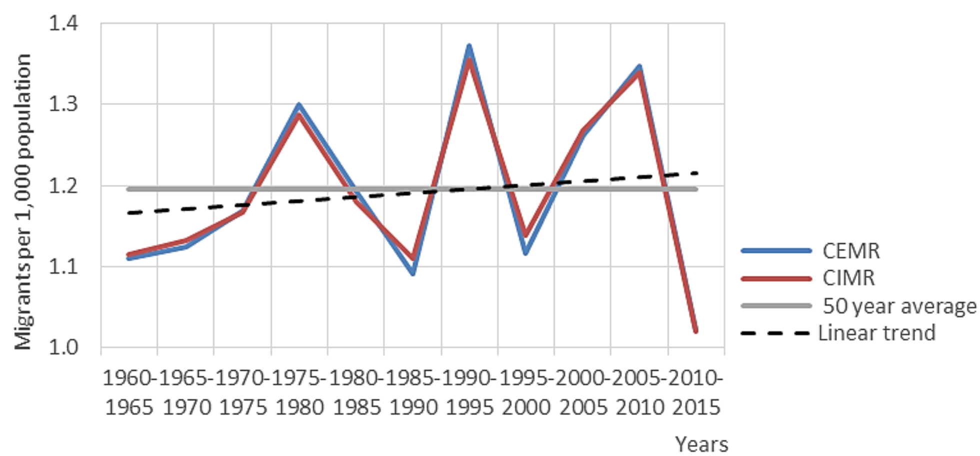


Figure 2: Global Migration Rates, by Five-Year Period, 1960–2015

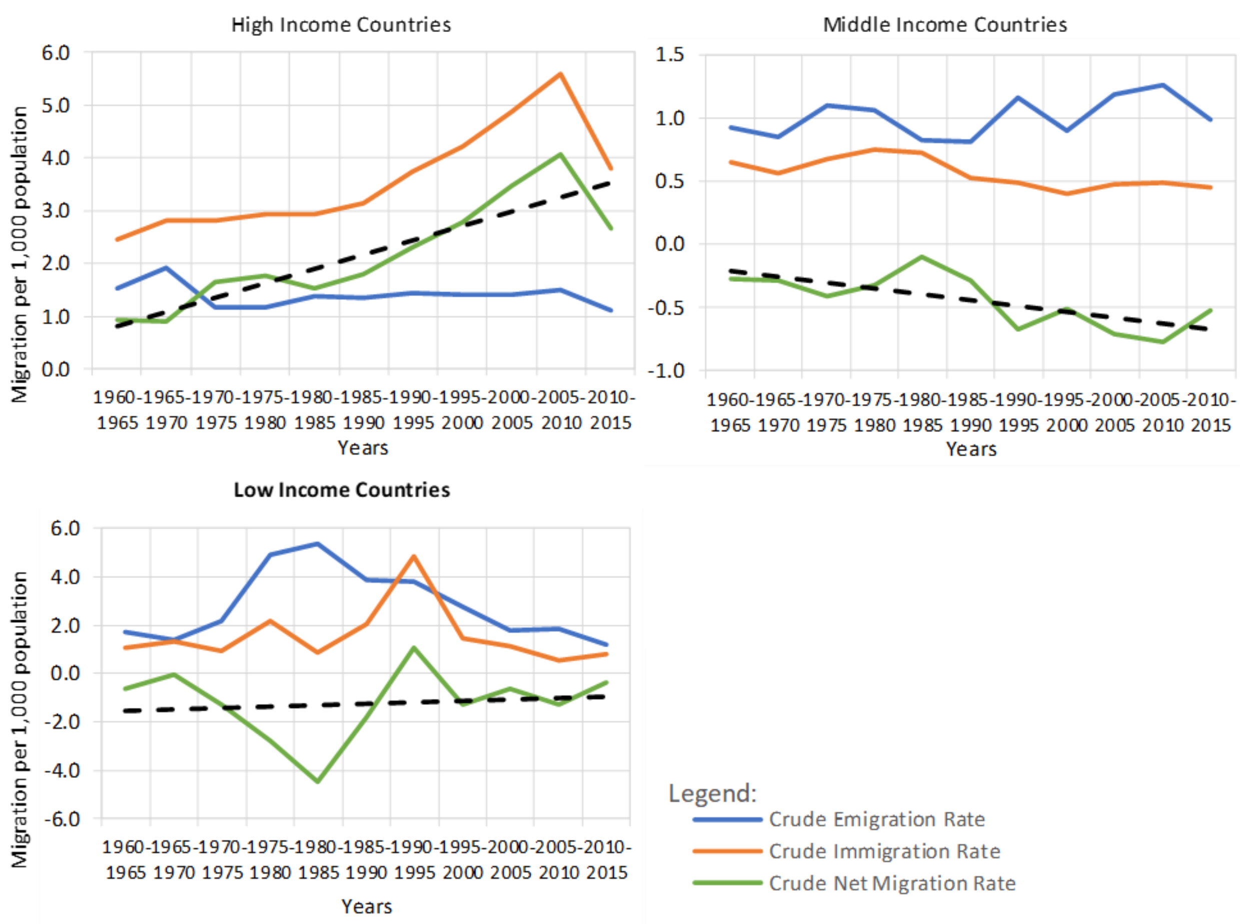


If we account for population growth, we still see a slight upward trend in the migration rates, but this is less pronounced than when looking at estimated absolute numbers (Figure 2). The overall development of the annual individual propensity to migrate (that is, the likelihood that a person will move), as represented by the linear trend line, is much less pronounced than the increase in the total flow of migrating persons (Figure 1). Between 1960–65 and 2010–15, the overall migration rate (emigration or immigration) fluctuated around the 50-year average of 1.2 migrants per 1,000 population. The drop in the migration rate for 2010–15 is possibly due to missing information, in the absence of a recent census, but it could also be the result of effects related to the global financial crisis.

[7] The migrant stock data are available for quinquennial periods (years ending in 0 and 5) but are based on decennial censuses. The estimates for years ending in 5 are therefore interpolations and possibly less reliable than for years ending in 0.

Migration flows – expressed as crude emigration rates (CEMR) and crude immigration rates (CIMR) – show several characteristic trends when analyzed separately by income group, a feature well in line with recent migration theory (de Haas 2010a). Later in this paper, we will translate the theory into a mathematical model suitable for projecting international migration.

Figure 3: Crude Migration Rates (per 1,000), by Country Income Group, 1960–2015



As Figure 3 shows, the average immigration rate in high-income countries showed a strong increase from the 1960s (with a clear drop, however, between 2005–10 and 2010–15), while the emigration rate remained largely unchanged and low. Therefore, the net migration rate also increased significantly over time. In contrast, middle-income countries showed a trend of increasingly negative net migration rates that reflect the consistently higher rates of emigration over immigration. The middle-income countries are prime sources of the immigration gains seen in high-income countries.

Low-income countries exhibit no clear trend, with large ups and downs. In 1990–95, low-income countries, as a group, even registered a positive net migration rate, mainly due to large immigration and return-migration spikes in Afghanistan, Ethiopia, and the Democratic Republic of the Congo. Overall, low-income countries had a negative net migration rate that declined slightly over time. Low-income countries appear to be a smaller player than middle-income countries in the global migration redistribution. In many places, people are just too poor and marginalized to migrate.

4. ECONOMIC DEVELOPMENT AS A DRIVER OF INTERNATIONAL MIGRATION

In this section, we analyze the link between migration flows and socioeconomic development, measured as a change in GDP per capita over time. We are inspired by the hypothesis of a "migration hump" or, better, a migration transition. The notion of a link between migration and development is now well established (see IOM 2018).De Haas (2009, 2010a) presents a justification from first principles. Skeldon (2012) discusses the continued relevance of the migration transition hypothesis. In de Haas et al. (2018), the authors emphasize that the migration transition is linked to phases of the demographic transition.[8]

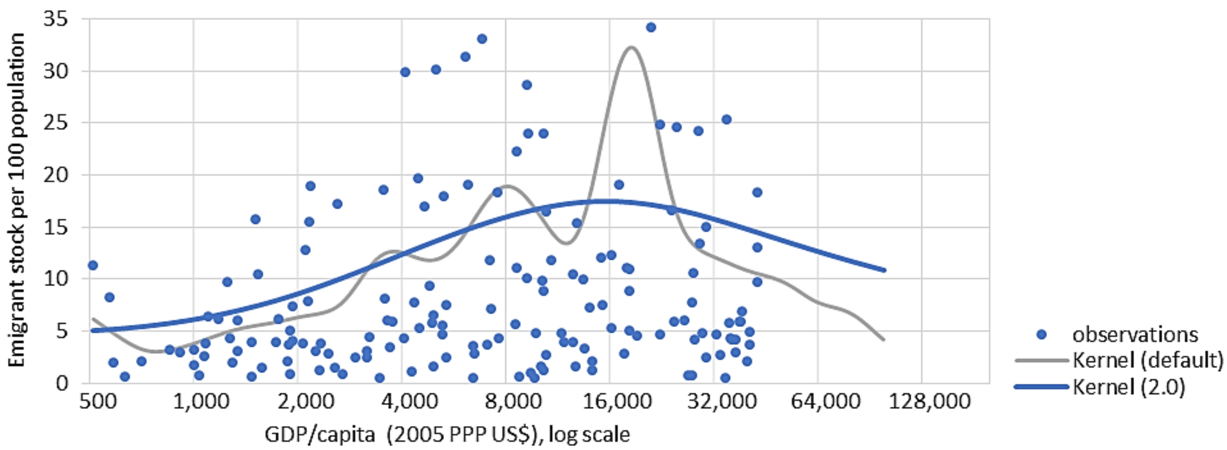
Clemens (2017) presents empirical evidence showing the inverted U-shape of the migration transition by combining the share of emigrants (defined as the fraction of people born in each country that live in all other countries) to the log of GDP per capita of the sending country. This proportion of migrant stock or diaspora by country of origin is a stock indicator and thus does not necessarily relate to recent migration flows. However, Clemens (2014) showed earlier that the relation between (decadal) emigration flows and GDP per capita also exhibits an inverted U-shape. In addition, an OECD study presented further empirical evidence of the migration transition and its typical inverted U-shape (OECD 2016). Another empirical analysis of the "migration hump" is presented by Natale, Migali, and Münz (2018).

[8] "…the migration transition hypothesis ... links phases of the demographic transition (from high to low fertility and mortality) and concomitant development processes to distinctive phases in a 'mobility transition,' in which development initially leads to more internal (rural-to-urban) and international emigration. Only when countries achieve higher income levels, emigration levels tend to decrease alongside increases in nonmigratory mobility – such as commuting – and immigration, which leads to their transformation from net emigration to net immigration countries" (de Haas et al. 2018).

4.1. GDP and migrant stocks

We reanalyzed the relation between migrant stock and national GDP per capita with updated migrant stock data (United Nations 2017a) and the most recent estimates of GDP per capita (Feenstra et al. 2015). Our analysis also found empirical evidence supporting the inverted U-shape of the migration transition (see Figure 4 for the year 2005).

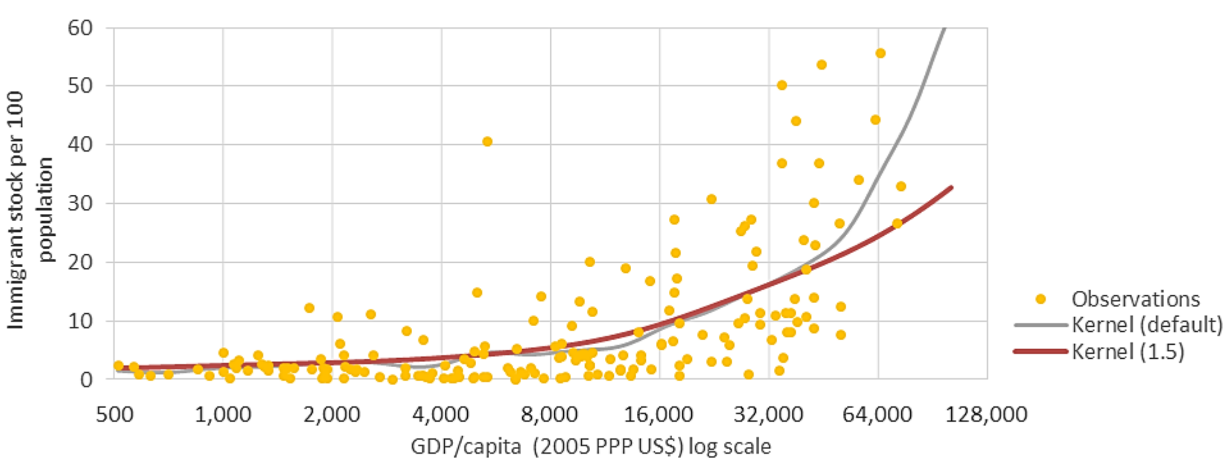
Figure 4: Migration Transition: Emigrant Stock (emigrants living abroad), 2005



Note: Function ksmooth, bandwidth = 2.0, n = 168.

So far, the authors addressing the migration transition phenomenon have concentrated on the relationship between emigration and GDP per capita, usually leaving immigration aside. This emigration bias (Buettner and Muenz 2018b) is quite common in demographic research but misses the fact that a large proportion of emigrants, at the end of their journey, turn into immigrants if they do not return within a foreseeable period of time to their country of origin. As a result, when applying the same approach as above to immigrant stocks, Figure 5 shows a completely different picture. The relationship between immigrant stock and GDP per capita does not exhibit a hump or any diverging trends (Figure 5). Clearly, increased wealth (GDP per capita) is associated with an increasing share of immigrants in the receiving countries.

Figure 5: Migration Transition: Immigrant Stock (share of foreign-born residents), 2005



Note: Function ksmooth, bandwidth = 2.0, n = 169.

Not surprisingly, the immigrant stock of receiving countries rises as GDP per capita increases. It must be remembered that these stock data show the accumulated results of migrants' moves over a longer period, but not necessarily the effects of recent flows and events causing migration.

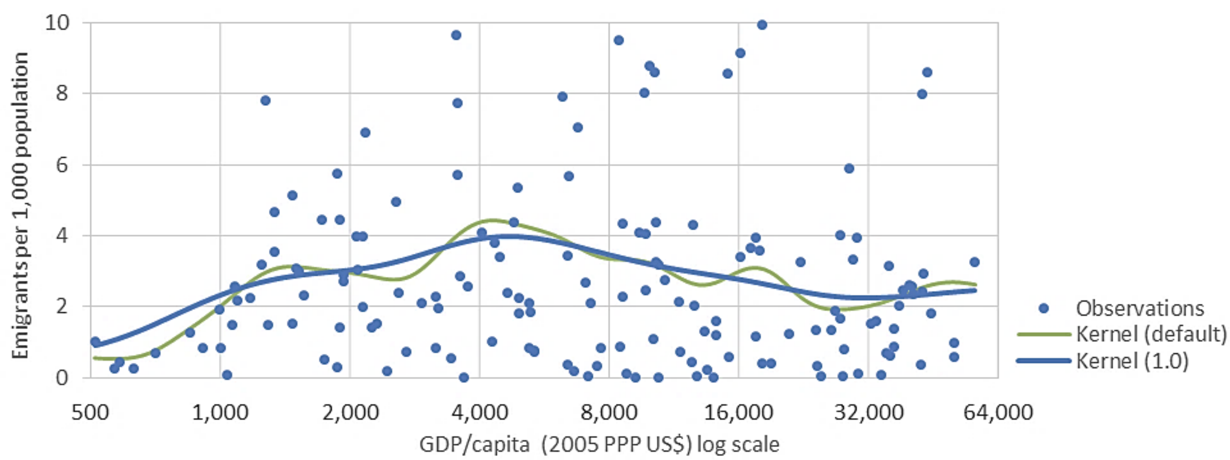
4.2. GDP and migrant flows

To analyze recent migration trends, we turn to migration flow estimates and their relationship to the level of economic output. This is for two reasons:

- We try to analyze recent migration flows that are not distorted by past events/mass flows related to violent conflicts and large-scale natural disasters/extreme weather conditions.
- We use the results of the analysis to propose a migration projection model better suited to making population projections than are most existing approaches. Population projections ideally require information or substantiated assumptions about total migration flows. If this is not possible, one must rely, at least, on net flows.

We apply the same methodology used to model the migration transition now to migration flows. Clemens shows that emigrant flows exhibit an inverted U-shape vis-à-vis GDP per capita (Clemens 2014). For updated data covering the period 2005–10, the estimated curve (Figure 6) unsurprisingly shows the inverted U-shape, too.

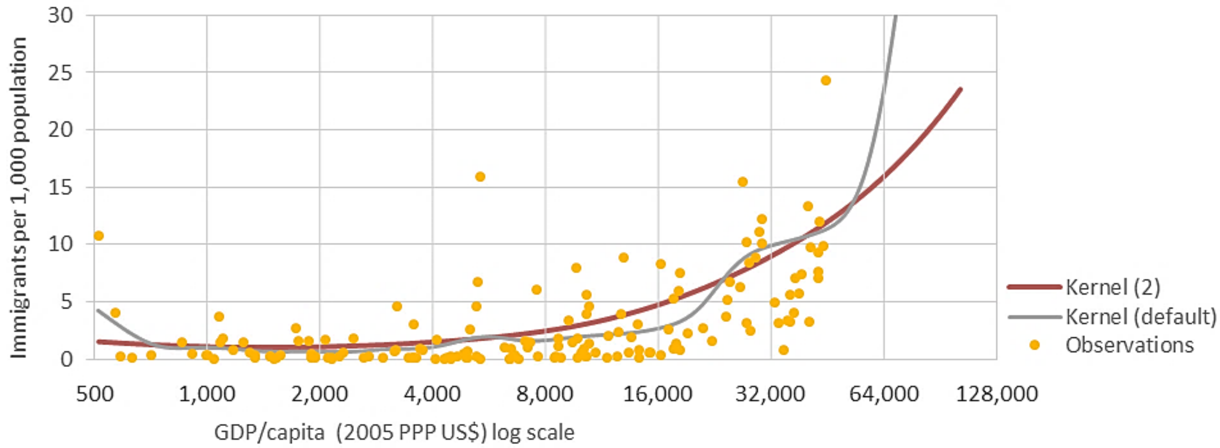
Figure 6: Migration Transition: Emigration Flows,2005–10



Note: Function ksmooth, bandwidth = 1.0, n = 160.

We are also interested in examining the opposite relationship: that is, between immigrant flows and GDP per capita. In that constellation, a country's actual admission of migrants is set in juxtaposition to the country's economic position at that particular point in time (Figure 7). Here, the relationship between migration and economic performance appears to be of a different shape. Even if one considers the large fluctuations, it is apparent that the greater a country's economic performance, the greater its draw for immigrants. This is not, of course, a completely new finding. In its functional form, though, it gives a handle on formulating projection assumptions (here for the immigration dynamics driven by GDP per capita).

Figure 7: Migration Transition: Immigration Flows, 2005–10



Note: Function ksmooth, bandwidth = 2.0, n = 156.

Although the original data (the dots in the figures) do not immediately reveal any clear pattern, the estimation method (kernel regression estimator) is able to summarize the empirical data into a smooth and coherent form. It must be noted, however, that the result is dependent on the choice of the bandwidth and thus is loaded with some discretionary elements. It is also important to note that the resulting curves are a "cleaned" average. As such, the curves are not immediately suitable for predicting migration flows for individual countries. Indeed, the curves obtained in this section need further adaptation to become a more suitable tool for modeling assumptions of future projections.

4.3. Migration models

In this section, we present parameterized models (orfunctions) representing the curves obtained through Kernel regressions.[9] We employ a re-parameterized logistic function introduced by Fisher and Pry (1971) and extensively used for modeling global change (Grübler 1998; Marchetti 1997; Marchetti, Meyer, and Ausubel 1996; Meyer, Yung, and Ausubel 1999; Riahi, Grübler,and Nakicenovic 2007). The Fisher/Pry functional form has parameters that are easier to interpret and fit to the empirical data as they have realistic meaning, such as the growth rate of the S-curve and the length of time the curve takes to reach the midpoint of the growth trajectory (AppendixC).

A logistic function exhibits an S-shape and describes a diffusion or growth process rising from an initial level to an upper or lower asymptote. However, most migration transition curves show a clear trend reversal. Such processes may be effectively modeled by a combination of two logistic functions whereby one diffusion process approaches an upper asymptote, and a second and delayed process approaches a lower asymptote. Combined, these two processes then represent trends with a reversal.

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[9] Nadaraya–Watson kernel regression estimates were calculated using the *ksmooth* function in the *stats* package available in the core implementation of the R language for statistical computing (R Core Team 2017). In addition, the package *npregfast* was used for validation (Sestelo et al. 2017).

Emigration model

We present first the results of fitting a bi-logistic model to the curve of the emigration-flow-based migration transition.

Figure 8: Migration Transition: Emigration Flow Model

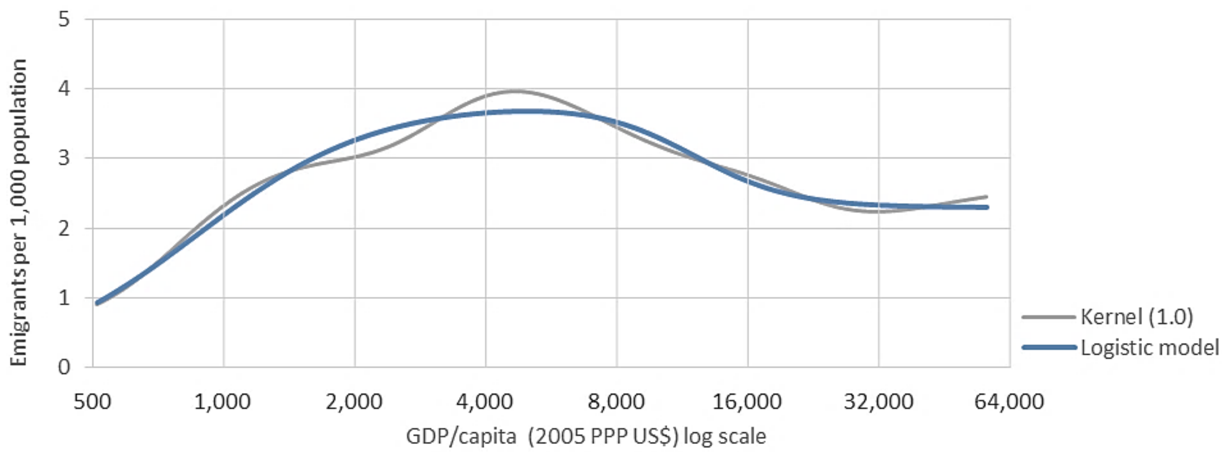


Figure 8 shows the estimated curve still exhibiting some (arbitrary) fluctuation, which the bi-logistic model (red curve) smoothed. We argue that such smoothing is advantageous for modeling and especially for forecasting, as it removes artefacts from becoming part of the input-affecting results.

The bi-logistic model depicted in Figure 8 is itself a combination of two logistic curves, one approaching an upper limit of 3.8 emigrants per 1,000 population (see Table 1). The second curve starts at midrange to counteract the process represented in the first curve. The combination of the two curves (or processes) results in the emigration flow model shown in Figure B.1 (AppendixB).

For modeling purposes, it may be easier to express the relationship between emigration flows and GDP per capita directly, without first transforming GDP per capita into log scale. The parameters of that model are also shown in the column “GDP” in Table 1.

Table 1: Parameters of the Bi-Logistic Emigration Model

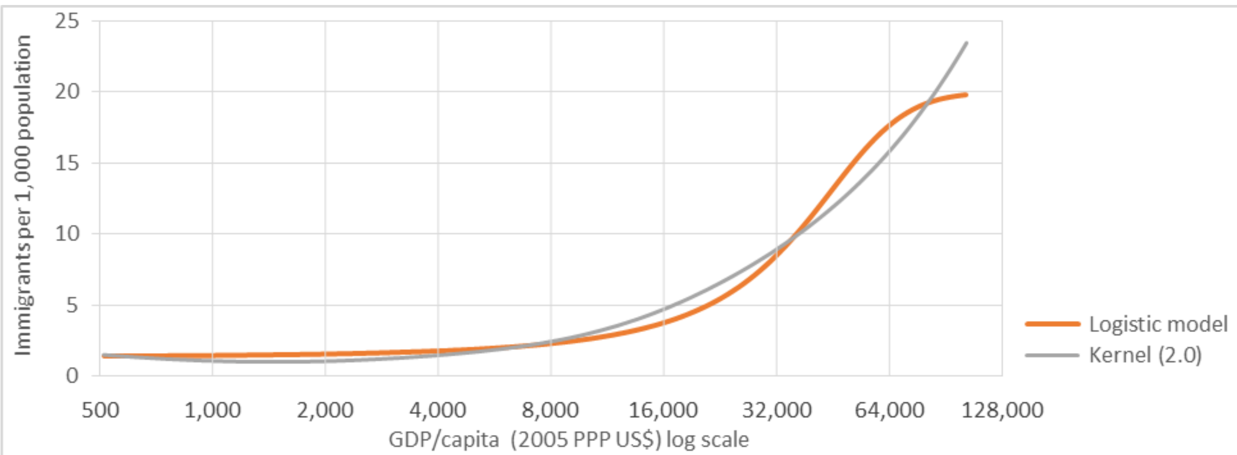
Parameters	Log (GDP)	GDP
k1	3.8	129.9
Delta_t1	2.1	4915.0
tm1	6.8	-3443.5
k2	-1.5	-127.6
Delta_t2	1.2	43873.1
tm2	9.4	-39004.3

Immigration model

Each emigration event turns, at its destination, into an immigration event. In other words, the countries of origin and the countries of destination interact, through migrants, with each other (for a discussion, see Buettner and Muenz 2018b, 2018a).

Analogous to the parametrized emigration flow models, we now present a logistic model for immigration flows, or admissions, into the destination country. A visual inspection of the smooth regression curve Figure 9) seems to suggest the use of a single logistic, as a clear trend of reversal seems to be absent.

Figure 9: Migration Transition: Immigration Flow Model



The virtual unchecked propensity of higher immigration rates as the GDP per capita rises may be caused, in part, by a few countries that have unusual immigration and economic histories, such as many countries in the Gulf and several Asian city-states. We therefore excluded these countries from the fit andfound a more plausible curve as a result. In addition, we implemented a ceiling value for the immigration (admission) rate into the model with GDP per capita at unit scale (Figure 9). Such a ceiling or upper limit introduces some degree of arbitrariness into the model. It is, however, preventing the model from producing unreasonable results. In any case, such ceilings should be verified by careful analysis. It may be useful to also allow for separate immigration models for certain groups of countries (not done here).

The logistic immigration model depicted in Figure 9 is represented by a single logistic function that appears sufficient to model the immigration flow depending on GDP per capita (see Table 2). The parameters of the logistic model are fitted to GDP per capita at unit scale but shown in log scale in Figure 9.

Table 2: Parameters of the Logistic Immigration Model

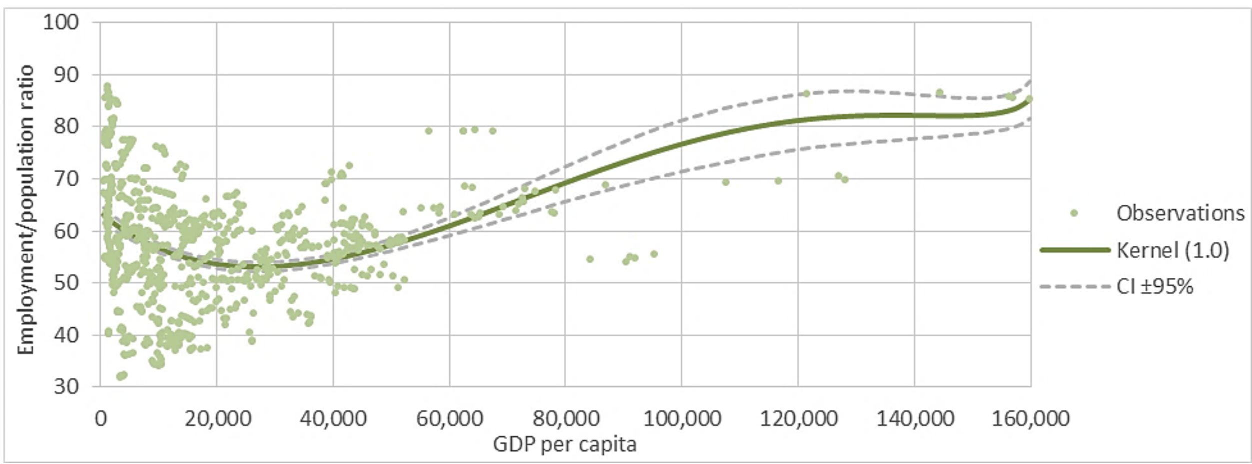
Parameters	Value
k1	20
Delta_t1	60,000
tm1	36,000

5. MIGRATION AND EMPLOYMENT

In Section 4 we showed that GDP per capita is associated with certain trends in corresponding migration flow rates. The labor market, as an integral part of the economy, should also exert an impact on migration, both emigration and immigration. In this section, we first discuss some trends in labor force participation vis-à-vis future demographic trends, and then hypothesize how these may inform the development of alternative migration scenarios.

A country's level of economic development is associated with the proportion of people engaged in work. This is obvious, though the relationship between the two factors is not clear-cut. Plotting employment - here expressed as the employment to (working age) population ratio - against GDP per capita (Figure 10) for 2010–14 (single years), we see that at lower levels of economic development, the proportion of people employed initially declines amid large variations in employment, but then rises to almost 80 percent at very high levels of GDP per capita. The latter may be an artefact, caused by relatively small countries/territories and city-states with a high proportion of foreign workers (Bahrain, Brunei Darussalam, Hong Kong, Luxembourg, Kuwait, Macao,Norway,Qatar, Singapore, Switzerland, and the United Arab Emirates).

Figure 10: Employment and GDP, 2010–14

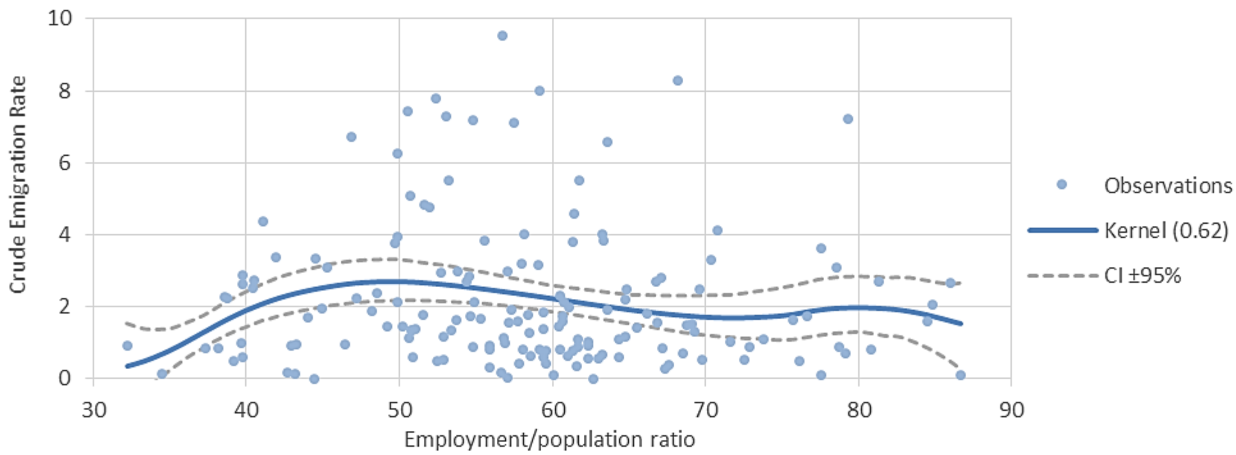


Note: Function npregfast, bandwidth = 1.0 (determined by cross validation), confidence interval 95%, n = 835.

Given the nonlinear relationship between employment and economic performance, is it possible to link employment to international migration directly? Is there an empirically verifiable association between employment and migration (emigration)? When plotting the share of employed persons against the crude emigration rate, no clear tendency appears (Figure 11). For almost the whole range of employment/population ratio, the fitted regression line is virtually a parallel to the *x*-axis, except for the tails with fewer observations.

This preliminary evidence suggests that the relationship of employment to international migration is complex and appears not to allow for an easy analytical expression needed for the formulation of migration projection scenarios. We will therefore concentrate the following discussion on a comparison between select labor market scenarios and our international migration projections developed in Section6. We still argue that the challenges of maintaining and expanding the number of jobs in fragile economies in the context of rapid population growth, especially in Sub-Saharan Africa, are significant. These challenges could largely determine future migratory movements.

Figure 11: Employment and Emigration, 2010–14



Note: Function npregfast, bandwidth = 0.62 (determined by cross validation), confidence interval 95%, n = 158.

This paper develops scenarios for the growth or decline ofthe absolute size of the economically active population and the corresponding labor force participation rates. The calculations are performed for all countries.[10] The results are then subsequently aggregated into common geographic or economic groupings (put forward by the World Bank and United Nations) for the reader's convenience. For this projection exercise, the ILO's projections of future Labour Force Participation Rates are employed.

Scenarios:

1. Labor force trends are estimated using ILO's projected country-specific LFPRsfor the years until 2030; for the remaining time until the end of the century the rates are held constant. The LFPRs are multiplied by the population aged 15–64 from the medium variant of the 2017 Revision of the UNDP's projections, both sexes combined, up to 2100. The assumed constant LFPRs after 2030 and the moderate changes modeled by ILO before 2030 give the underlying demographic dynamics priority.
2. Constant absolute labor force is then compared with the growth of that portion of the population that is at a productive age. Such a scenario assumes a constant economy vis-à-vis a changing population. This scenario is expressed using a fictive LFPR that would occur given the labor force of 2015 vis-à-vis demographic change through 2100.

Though the EPR used earlier in the modelling exercise issupposedly a more concrete expression of an economy's capacity to provide jobs, it was not available in ILO's projections. However, the differences between the usual LFPR and the EPR appear to be small (see Table A.7in AppendixBfor a comparison).

[10] Some smaller countries/territories are omitted, because they were not included in ILO's modeling.

5.1. Projected labor force

Under the assumption of ILO'sLFPR projected until 2030 and held constant thereafter,[11] combined with the demographic dynamics predicted by the United Nations, the geographic regions of the world exhibit strikingly different trends in terms of the implied size of their future labor force (Table 3).

Table 3:Projected Size of Labor Force, by World Bank Geographic Region, 2015–2100

Region	2015	2030	2050	2100
	Labor Force (15-64)			
East Asia & Pacific	1,186,922,785	1,154,498,499	1,047,916,294	805,820,018
Europe & Central Asia	425,654,091	410,967,093	382,974,704	337,360,724
Latin America & Caribbean	290,388,788	338,582,724	348,385,860	272,138,147
Middle East & North Africa	141,533,336	176,726,832	208,745,554	231,573,031
North America	170,554,489	174,902,295	189,514,725	201,206,219
South Asia	643,064,494	782,387,709	875,119,472	724,874,579
Sub-Saharan Africa	373,934,935	590,670,498	970,148,716	1,856,966,549

While some geographic regions exhibit a strong increase in their labor force (Sub-Saharan Africa), other show only little change (South Asia) or even a decrease over the period (Europe, East Asia and Pacific; Table 4, Table 5). The most dramatic increase in the labor force is expected to happen in Sub-Saharan Africa, where the size of the potentially economically active population would more than double by 2050, and even grow fivefold by the end of the 21st century. At the same time, Europe and Central Asia would see a significant decline.

Table 4:Absolute Change in the Labor Force, by World Bank Geographic Region, 2015–2100

Region	2015	2030	2050	2100
	Labor Force Change (absolute)			
East Asia & Pacific	0	-32,424,285	-139,006,491	-381,102,767
Europe & Central Asia	0	-14,686,998	-42,679,387	-88,293,368
Latin America & Caribbean	0	48,193,937	57,997,073	-18,250,641
Middle East & North Africa	0	35,193,496	67,212,218	90,039,695
North America	0	4,347,805	18,960,236	30,651,730
South Asia	0	139,323,215	232,054,978	81,810,085
Sub-Saharan Africa	0	216,735,563	596,213,781	1,483,031,614

Table 5: Relative Change in the Labor Force (%), by World Bank Geographic Region, 2015–2100

Region	2015	2030	2050	2100
	Employment Change (2015=100, %)			
East Asia & Pacific	100	97	88	68
Europe & Central Asia	100	97	90	80
Latin America & Caribbean	100	117	120	94
Middle East & North Africa	100	125	147	163
North America	100	103	111	118
South Asia	100	122	136	113
Sub-Saharan Africa	100	158	261	502

[11] Had we kept LFPRs (averaged over 2005–15) constant across the entire projection horizon, the global labor force would have been about 4 percent smaller when compared to our hybrid approach that included the ILO projection until 2030.

Thus, demographic changes are forecast to drive an unprecedented change in the geographic distribution of the global labor force (Table 6). Currently, the largest portion (38 percent) of the global labor force resides in the East Asia and Pacific region. By 2050, the share of the East Asia and Pacific region is projected to decline to 26 percent, almost on par with a rapidly increasing share in Sub-Saharan Africa (24 percent). By 2100, Sub-Saharan Africa would be home to 42 percent of the global labor force, an even larger proportion than the currently leading East Asia and Pacific region. Almost all other regions in this geographic classification would see a decline in their share of the global labor force, except for the Middle East and North Africa (MENA) region. While South Asia is projected to experience a growing labor force, its share would decrease by 2100.

Table 6:Labor Force Distribution, by World Bank Geographic Region, 2015–2100

Region	2015	2030	2050	2100
	Labor Force Share (15-64) (in %)			
East Asia & Pacific	36.7	31.8	26.0	18.2
Europe & Central Asia	13.2	11.3	9.5	7.6
Latin America & Caribbean	9.0	9.3	8.7	6.1
Middle East & North Africa	4.4	4.9	5.2	5.2
North America	5.3	4.8	4.7	4.5
South Asia	19.9	21.6	21.8	16.4
Sub-Saharan Africa	11.6	16.3	24.1	41.9
World	100	100	100	100

The consequences of such a dramatic reorganization of the global supply of labor are not easy to anticipate and build into a model. How will the global economy deal with such a dramatic change?

It may be comparatively easier to adjust to a shrinking volume and share of the labor force, as projected for East Asia and Pacific, Europe and Central Asia, and Latin America and the Caribbean. Technological progress could be the answer. Another option would be to fill any gaps that open with immigrants.

For Sub-Saharan Africa, the challenges seem rather formidable, even unsurmountable (see subsection5.2). It would require the region, possibly, to become the next “work bank for the world,” in combination with increased emigration into other regions of the world. It seems impossible to lessen the need for additional jobs by migration alone, however. It is hard to say how much of the pressure to employ ever-larger cohorts in the African labor force would result in increased emigration to other continents.

5.2.Constant labor force

Another way to illustrate the impact of demographic change on prospective labor markets is to assume a stagnant economy, here expressed as a constant volume of the labor force. Table 7 shows how the LFPR would evolve under such a scenario.

Table 7: Implied LFPR with Constant Labor Force (%), by World Bank Geographic Region,2015–2100

Region	2015	2030	2050	2100
	LFPR with Constant Labor Force (%)			
East Asia & Pacific	75	74	81	106
Europe & Central Asia	71	73	78	90
Latin America & Caribbean	69	60	59	75
Middle East & North Africa	51	40	34	31
North America	72	70	65	61
South Asia	57	47	42	50

Sub-Saharan Africa	69	44	27	14

The assumption of a constant labor force can lead to seemingly implausible results: In the case of East Asia and Pacific, the current size of the labor force is larger than the forecasted working-age population in 2100, resulting in LFPRs greater than 100 percent. Declining populations, such as in this region, could imply a need to actively seek immigration, to expand the participation of the native population, or to reduce the labor force.

The assumption of a constant labor force does, on the other hand, show how dramatic the impact of fast-growing populations can be. In Sub-Saharan Africa, the LFPR would fall from its current average of 69 percent to less than half in 2050 (27 percent) and even to 14 percent by the end of the century.

5.3. Does the labor market drive international migration?

We find insufficient evidence for the formal integration of employment dynamics into the formulation of assumptions of international migration. Clearly, more empirical and theoretical work is urgently needed. This is important precisely because the labor market plays such a dominant role in the past and current narratives of international migration.

We have shown that the demographic dynamics in certain world regions, combined with expected changes in levels of economic performance, may result in large quantitative increases in the number of migrants originating in, for example, Sub-Saharan Africa. The increase in the number of migrants originating in Sub-Saharan Africa might even be larger if the economies in that region fail to provide enough employment for the fast-growing working-age populations.

We have already shown that demographically driven changes in the absolute labor force in some regions may indicate a need to replenish the labor force by several means, immigration being one of them. We offer some preliminary thoughts on how to get a clearer picture of possible future emigration-immigration interactions in Section 6, below.

6. MIGRATION SCENARIOS

This section deals with the applicability of the migration transition models outlined in this paper. We address the challenge of transforming a model of a general tendency (e.g., the bi-logistic models) into a method suited to the diversity and variability of the global migration experience and propose a very simple method for adapting the model to individual cases (countries). We also discuss possible variations of that approach. We select the migration transition model for emigrant flows, expressed in terms of the crude emigration rate, and then transform this into projected total migrants using the latest UNDP population projections.

We choose to explore only the emigration model by combining economic (GDP) and demographic projections and projected crude emigration rates and total emigrants for all countries. This example of the migration transition theory is contrasted with a reference scenario of constant emigration rates.

The inclusion of the flip side of emigration movements – immigration – by using the model proposed in Section 4 is beyond the scope of this paper. A practical implementation would have to follow similar steps as outlined below for the emigration case. We suggest, however, that in a future exercise both emigration and immigration projections using the models presented in this paper should be simultaneously projected and then combined into consolidated projections of international migration flows. We have proposed, in a previous paper, a mechanism to implement a consolidation between emigration potential and immigration admission by means of suitable transfer functions (Buettner and Muenz 2018b, 2018a). As could be expected, we found, in Section 5, evidence of a (nonlinear) relationship between GDP and employment, but no or very little association between employment and emigration. Integrating the employment dimension into our migration projection model (as part of a demographic projection) seems to be a challenge. We take some assurance from our simple labor force projections (Section 5) that a combination with demographic projection is feasible (see subsection 6.2, below).

6.1. Toward alternative KNOMAD migration projections

The migration transition scenario

The migration transition hypothesis (the "migration hump") implies a nonlinear relationship between migration intensity (here, crude flow rates) and changes in the economic performance of countries. In our model, emigration flows are simultaneously affected by the underlying population dynamics and the level of economic performance. As will be shown, demographic and economic trends may reinforce one another, but also may act in opposite directions.

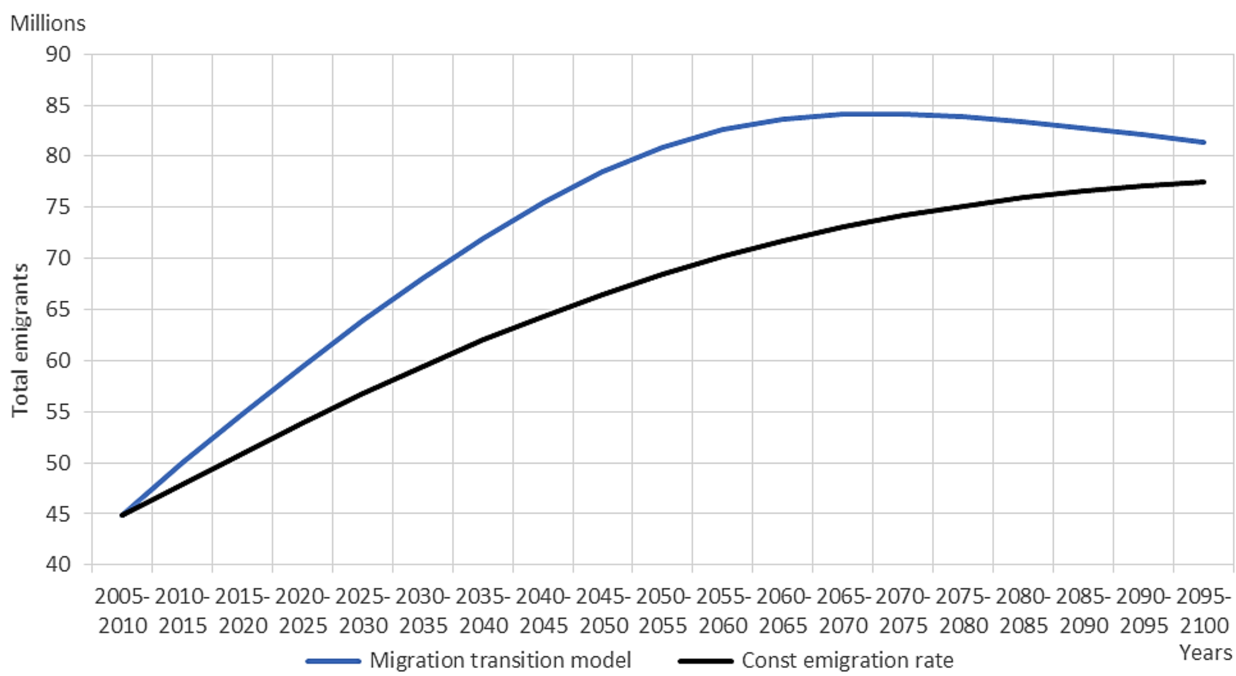
The projection of international migrants (emigrants) is organized in three distinct steps.

1. The future crude emigration rates (CEMR) for each quinquennial projection period are calculated by inserting the projected GDP per capita data (see subsection 2.2) into the bi-logistic model for the emigration transition model (see subsection 4.1). The results are CEMR for each country and period that express the average trend, or central tendency, of the emigration transition model relative to the country's GDP per capita. This initial CEMR estimate is not suitable for projecting total emigrants because it disregards the countries' actual base level of CEMR. Instead of using the initial CEMR directly, we use the force of change implied in the average migration transition model, implemented as a simple scaling factor (see below).

2. The CEMR obtained in step 1 is scaled upwards or downwards by using a scaling factor. This scaling factor – calculated by dividing the CEMR of the base period by the modeled CEMR – expresses the degree to which the model is adjusted (upward or downward). In a first scenario, the scaling factor is kept constant throughout the projection period. This procedure keeps the overall shape of the migration transition model but moves the curve parallel to the abscissa or *x*-axis.
3. In a next step, total emigrants for each projection period are calculated by multiplying the CEMR obtained in step 2 by the person-years for each projection period.

When setting the crude emigration rates for each country as constant, we see the full effect of demographic change in isolation. In the migration transition model, both forces act together. This is shown in Figure 12. Since at the global level emigration and immigration must be equal, the figure depicts the total amount of flows for each quinquennial projection period. Migration flows in both scenarios show a clear upward trend. Assuming constant migration rates, this trend is slowing somewhat at the end of this century (due to a slowing of population growth) and reaches 77 million migrants over the period 2095–2100, an increase of 171 percent (Table A.1, AppendixA). For a projection of future migration flows that combine population dynamics and economic change, the volume of migration flows is clearly larger than in the other case but is peaking at about 2070. This is attributable to the downward swing of the migration model once a certain level of economic performance is reached and passed.

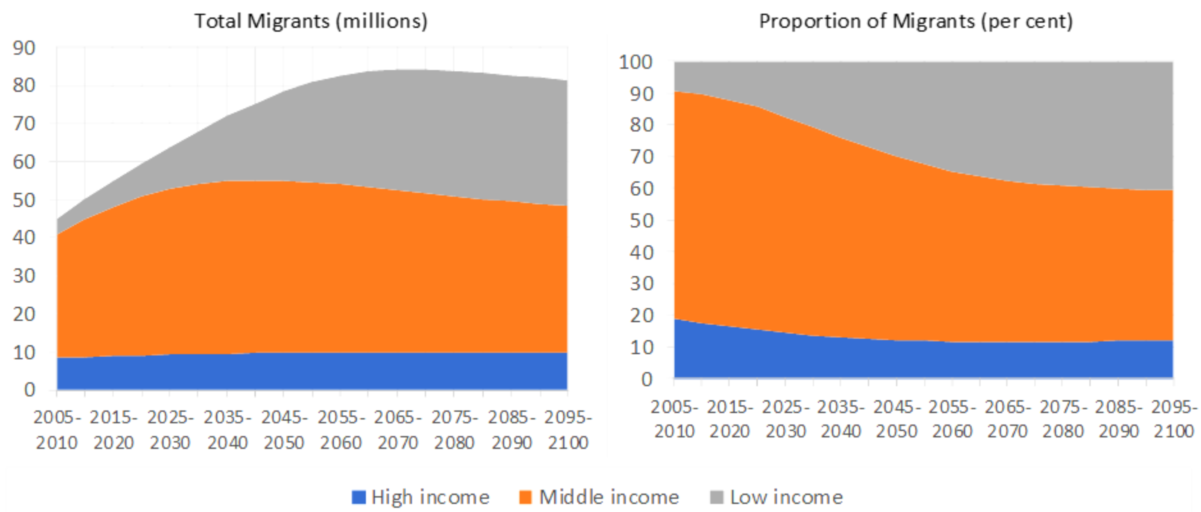
Figure 12: Total Global Migrants, by Scenario and by Five-Year Period, 2005–2100 (in millions)



In sum, the projections suggest that between 2015 and 2100, a total of 1.3 billion (in the transition model) or 1.1 billion (constant migration rate) moves could occur. This is not a small amount compared with the demographic components of births and deaths: the 2017 Revision UNPD projects a total accumulated sum of 11.3 billion births and 8 billion deaths for the period 2005–2100.

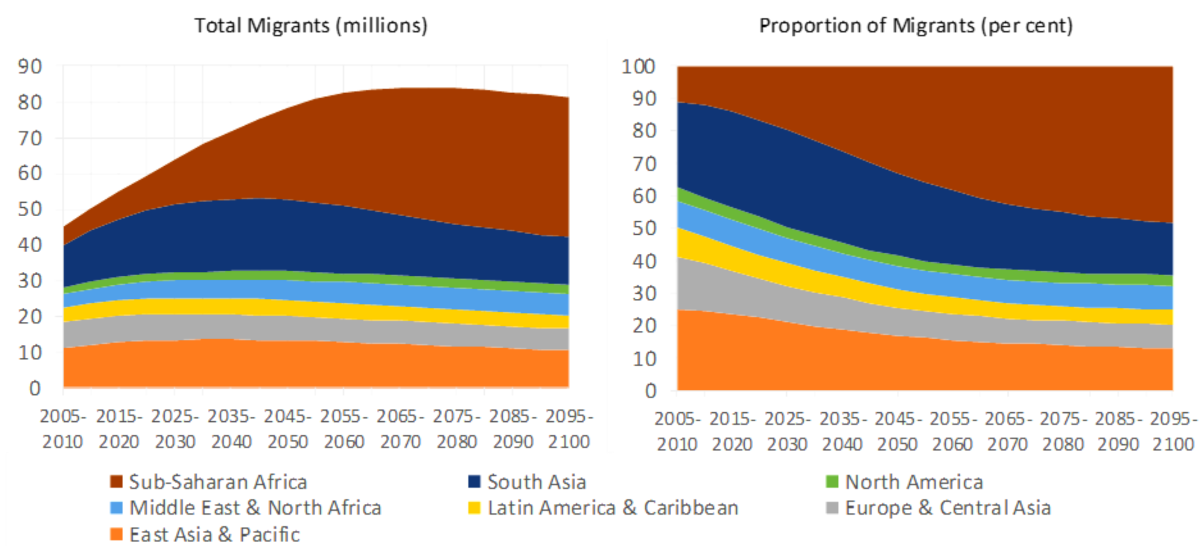
Among these total moves, a clear majority of migration is expected to originate in middle-income countries. Meanwhile, migrants originating in low-income countries are projected to increase significantly in size and share (Figure 13).

Figure 13:Absolute and Relative Size of Emigrants12, by World Bank Income Group, 2005–2100



The projection results also indicate significant changes in the geographic distribution of migrants. While the share of migrants originating in Sub-Saharan Africa is currently about 11 percent, it is projected to rise to 48 percent. All other regions will reduce their share of the total amount of migration during the projection period (see Table A.2 and Table A.3 in AppendixA).

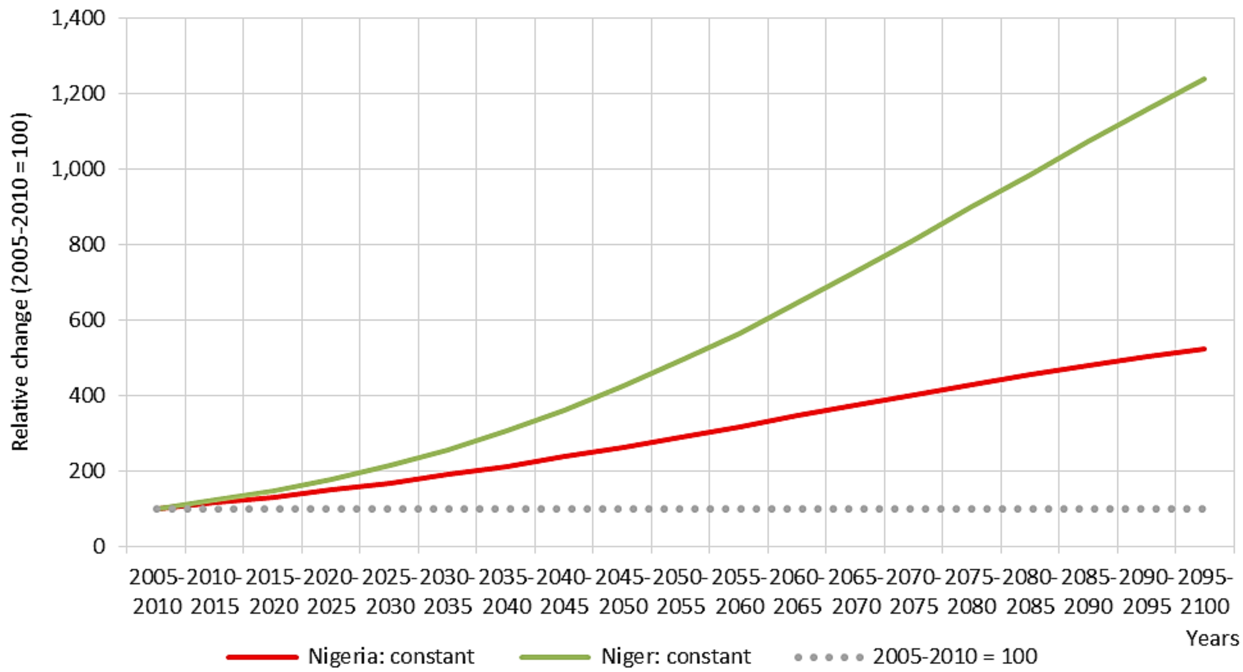
Figure 14:Absolute and Relative Size of Emigrants[13], by World Bank Geographic Region, 2005–2100



[12] By country of origin
[13] By country of origin

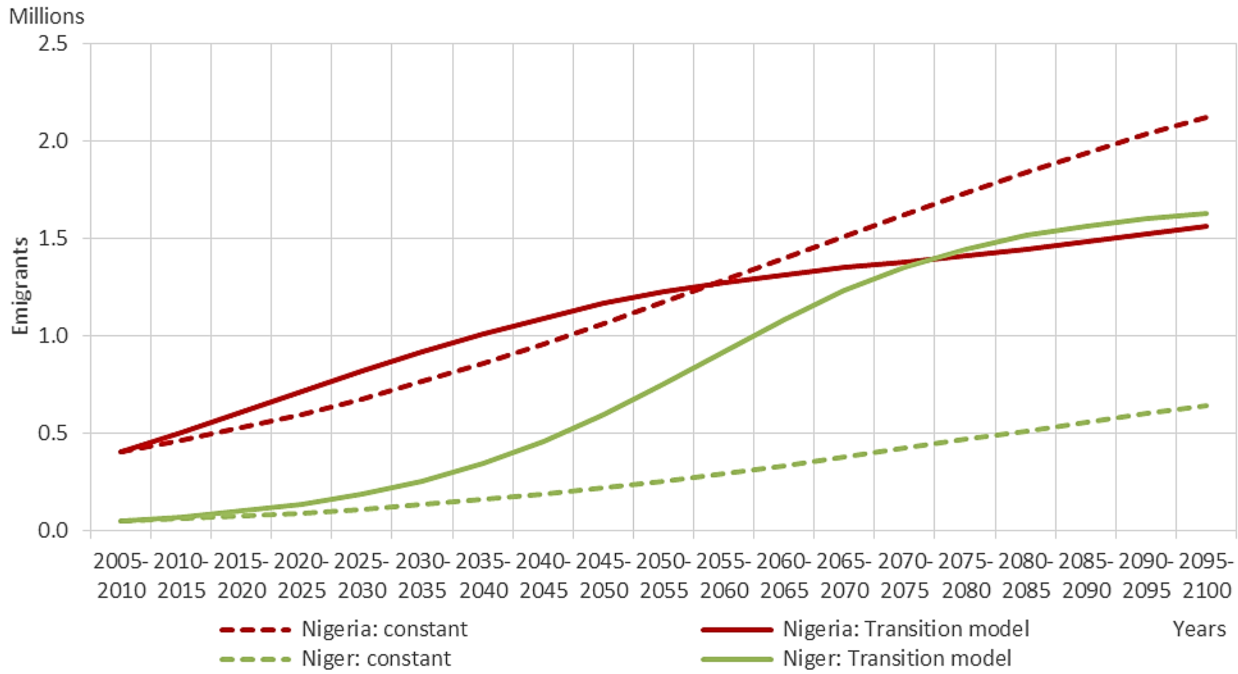
To illustrate the dynamics in Sub-Saharan Africa, we look at the migration projection for two fast-growing countries: Nigeria and Niger. Nigeria's total population is projected to grow from currently 181 million (2015) to a staggering 794 million by the end of the century, a more than fourfold increase. Niger, with about 20 million people in 2015, much smaller than Nigeria, is projected to reach 192 million in 2100, an almost tenfold increase. Our projection of migration originating in those two countries reflects the effect of demographic force in the constant rate projections (Figure 15).

Figure 15: Total Emigration from Nigeria and Niger, Constant Scenario (2005=100), 2005–2100



Combining the demographic change with economic growth from the GDP projections, a different perspective emerges. For Nigeria and Niger, the inclusion of economic growth has a different impact. Until the middle of the 21st century, the number of migrants originating from Nigeria is higher than in a constant (demographic growth only) scenario. After 2055, the increased GDP per capita is decelerating and thus the number of migrants from Nigeria is decreasing. At the end of the 21st century, there is a sizable gap – about 500,000 persons over a period of five years – between the potential number of Nigerian migrants according to the demographic model and the lower number according to the transition model.

Figure 16: Growth of Total Emigrants, Nigeria, and Niger, by Scenario, 2005–2100



The case for neighboring Niger is quite different. Here, both forces – demographic change and economic growth – push in the same direction. The transition model for Niger produces a total number of migrants that is about 2.5 times larger than the number projected in the demographic model, and even larger than those projected for Nigeria in the transition model.

Scenario with labor force extension

We suggest that it be possible to perform projections as outlined in the preceding subsection with an extension that includes the labor force. Our proposed extended projection model tries to avoid the challenges of extreme complexity by performing the demographic projections in two steps instead of fully integrating the labor force dimension into the state space of the multistate projection model.

We recall the demographic projection model used in a previous paper (Buettner and Muenz 2018b). It consisted of populations by country, age, and sex at the base year, plus age patterns of female fertility, age patterns of male and female mortality, and age patterns of male and female migration between countries of origin and destination for all projection periods. This model also included a transfer function used for consolidating emigration and immigration. This model could be amended to include additional nondemographic factors that act as relative weights of attraction and repulsion (Schoen 2006, p. 190).

It is theoretically possible to add more dimensions to this demographic projection model, such as employment, or even employment by educational level. Even if the LFPR were only considered as an additional dimension, it would be necessary to have fertility, mortality, and migration indicators by labor force status. This may be possible for a limited number of countries with strong statistical institutions, but doubtful for a global exercise.

We therefore suggest a hybrid or tandem approach that limits complexity by splitting the projection into two steps. In a first step, a demographic projection is performed that includes international migration as a true interaction, driven by demographic change and the level of economic performance (see Section 4). In a second step and using LFPR projections (see Section 5), the population by age and sex calculated in each projection step would be distributed into the labor force (by age and sex) and those outside the labor force (by age and sex). The result would be populations by age, sex, and labor force status.

The possibilities of specifying scenarios that address other dimensions of interest are not exhausted by our suggestions. It seems interesting, for example, to add migration status instead of employment status to the model. Such a model would project not only migration flows but also migrant stocks.

7. DISCUSSION

In this paper, we have approached the projection of international migration in a novel way. Inspired by recent theoretical and empirical advancements in the analysis and conceptualization of international migration (Clemens 2014, 2017; de Haas 2009; de Haas, Vargas-Silva, and Vezzoli 2010; IOM2018), we propose functional migration models driven by the level of economic performance of each country, in addition to their demographic trends. In line with the theoretical postulates of the migration transition (or "migration hump") hypothesis, our migration models result in a migration trend with two phases. In an initial phase, increasing GDP per capita adds, in de Haas's terms, migration capabilities to those with migration aspirations (de Haas 2010b). Once a certain level of economic development is reached, aspiration declines and capabilities to leave are offset by opportunities at home. Migration propensities become nonlinear, and the results become more realistic than in linear models.

We have implemented in this paper the emigration model alone and discussed results for the world's countries and selected country groupings up to the end of the 21st century. For the time being, in this model, the migratory moves are linked to the originating country and ignore changes in the potential destinations of these migratory movements.

We have also tried to explore possibilities of informing international migration models with data on labor market performance, expressed as the proportion and growth of the labor force. Here, although we did not find a clear empirical formulation for that link, we believe it is an important factor shaping migration flows. We did show the extremely varied trends of employment across countries and groups of countries that result from demographic change. We have identified Africa, and particularly the Sub-Saharan region, as the most challenging region of the world. Although a formal link to expected migratory moves remains elusive for now, the sheer amount of jobs that would be necessary in order to match rapidly growing populations and potential labor forces suggests a growing migration potential for that part of the world. One possibility to factor in labor market dynamics could be to relate the growth rates of the labor force in origin and destination countries (plus economic development). Demographically speaking, this would favor a flow from young populations (with a relatively large proportion of people in the labor force) to aging populations (with a declining proportion in the labor force). One way to formalize this would be to employ weighted harmonic averages for the consolidated emigration and admission(immigration) flows, affording higher weights to the countries with surplus labor, and less weight to countries in need of additional labor (i.e., countries with a stagnant or declining labor force).

This paper has opened new avenues for improving international migration projections. But additional options remain to be explored. The most important of these is to combine and reconcile the emigration model with an immigration model into a comprehensive population projections model (Buettner and

Muenz 2018b, 2018a). This would complete the implementation of the migration models presented in this paper with the immigration portion and establish the international migration system as a model of interactions between countries, their economies, and population dynamics.

Additional scenarios may also be explored in future work:

- Migration intensities could be assumed to converge to the average level embodied by the migration model by adjusting the scaling factors. Such a convergence option may be warranted for long-term projections, associated with growing uncertainties over time.
- The migration transition models have been determined based on empirical evidence for a certain period. Analysis of historical trends could reveal a drift in the relationship between migration intensity and economic performance. In the simplest implementation of such a scenario, the existing migration transition model would be shifted along the *x*-axis over time.
- A major challenge for contemporary migration projection models is the virtual constancy of the spatial dimension of migration flows, e.g. established sending-receiving country relations remain unchanged. By including the immigration transition model, it may be possible to find a way to change the global distribution of migrants in a transparent and data-driven way.[14] According to theoretical considerations and empirical findings, growing economic performance at first increases the share of population with means to emigrate, but in the second place also increases the potential of countries to absorb international migrants coming from other countries. As economic performance develops differently across countries, such differences could be used to explain changing migration distribution patterns.

We are aware that the proposed migration models, even with their extensions, can only contributefirst insights but not paint a full picture of the future. In this paper, and in the models, international migration is treated as experienced by homogenous groups of people. This is, of course, a stark simplification. The various types of international migrants would warrant more differentiated approaches to establish valid projection models. The more general approach in this paper is therefore acontribution to a more complex model, allowing for better forecasts of both migration patterns and changes in population size.

[14]Clemens discussed the need to foster new emigration destinations, as growing concentrations of international migrants may find traditional receiving countries insufficiently prepared to manage their rising numbers (Clemens 2017, p. 13).

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Appendix A. Tables

Table A.1: Total Migratory Movements, by Scenario and Five-Year Period, 2005–2100[15]

Period	Transition model	Const. migration rate
	Total migrant moves	
2005-2010	44,842,398	44,842,398
2010-2015	49,882,245	47,786,280
2015-2020	54,638,442	50,825,137
2020-2025	59,309,809	53,790,703
2025-2030	63,802,436	56,627,276
2030-2035	67,985,664	59,302,231
2035-2040	71,821,925	61,805,551
2040-2045	75,305,832	64,132,850
2045-2050	78,318,699	66,268,494
2050-2055	80,736,904	68,193,311
2055-2060	82,478,539	69,899,858
2060-2065	83,551,681	71,397,132
2065-2070	84,040,702	72,702,165
2070-2075	84,063,477	73,825,383
2075-2080	83,754,857	74,771,386
2080-2085	83,242,487	75,548,756
2085-2090	82,629,323	76,173,391
2090-2095	81,982,597	76,659,445
2095-2100	81,340,612	77,015,188

Table A.2: Total Emigrants, by World Bank Region, Selected Five-Year Period, 2005–2100

Region	2005-2010	2015-2020	2025-2030	2045-2050	2095-2100
			Total emigrants		
East Asia & Pacific	11,264,861	12,925,141	13,547,930	13,411,915	10,721,830
Europe & Central Asia	7,388,612	7,337,928	7,164,885	6,787,819	5,982,332
Latin America & Caribbean	3,959,734	4,229,163	4,433,539	4,448,130	3,530,104
Middle East & North Africa	3,684,794	4,451,575	4,927,928	5,552,890	6,030,314
North America	1,889,896	2,039,400	2,174,079	2,396,694	2,763,460
South Asia	11,763,552	16,049,753	19,067,467	19,966,623	13,106,738
Sub-Saharan Africa	4,890,949	7,605,481	12,486,607	25,754,629	39,205,835

Table A.3: Share of Migrants, by World Bank Region, Selected Five-Year Period, 2005–2100

Region	2005-2010	2015-2020	2025-2030	2045-2050	2095-2100
			Regional Distribution of Migrants (%)		
East Asia & Pacific	25	24	21	17	13
Europe & Central Asia	16	13	11	9	7
Latin America & Caribbean	9	8	7	6	4
Middle East & North Africa	8	8	8	7	7
North America	4	4	3	3	3
South Asia	26	29	30	25	16
Sub-Saharan Africa	11	14	20	33	48
World	**100**	**100**	**100**	**100**	**100**

[15] On the world level, emigrants must equal immigrants and thus are referred here to as migratory moves.

Table A.4: Total Emigrants, by World Bank Income Group, Selected Five-Year Period, 2005–2100

Group	2005-2010	2015-2020	2025-2030	2045-2050	2095-2100
	Total emigrants				
High income	8,205,217	8,714,824	9,011,285	9,390,160	9,650,626
Middle income	32,844,686	39,673,593	44,109,234	46,066,564	39,086,084
Low income	3,792,494	6,250,025	10,681,916	22,861,975	32,603,903

Table A.5: Total Emigrants, by UN Region, Selected Five-Year Period, 2005–2100

Region	2005-2010	2015-2020	2025-2030	2045-2050	2095-2100
	Total emigrants				
Africa	6,323,429	9,239,945	14,203,453	27,480,425	40,765,060
Asia	26,324,723	32,845,966	36,822,177	38,052,369	28,785,913
Europe	5,777,461	5,609,151	5,411,722	5,072,683	4,526,924
Latin America	3,959,734	4,229,163	4,433,539	4,448,130	3,530,104
Northern America	1,889,896	2,039,400	2,174,079	2,396,694	2,763,460
Oceania	567,154	674,817	757,465	868,399	969,153

Table A.6: Total Emigrants, by UN Development Group, Selected Five-Year Period, 2005–2100

Group	2005-2010	2015-2020	2025-2030	2045-2050	2095-2100
	Total emigrants				
Least developed countries	10,175,036	16,133,595	23,228,377	35,310,689	39,471,378
More developed regions	8,112,470	8,144,701	8,122,176	8,072,641	8,007,490
Other developed regions	26,554,892	30,360,146	32,451,883	34,935,368	33,861,744

Table A.7: Average Labor Force Participation Rate, by World Bank Region, 2005–15

Region	Labor force participation rates, 2005–15 (%)	
	Total labor force	Employment based
East Asia & Pacific	75	72
Europe & Central Asia	71	65
Latin America & Caribbean	69	64
Middle East & North Africa	51	46
North America	72	67
South Asia	57	55
Sub-Saharan Africa	69	64

AppendixB. Figures

Figure B.1: Components of the Bi-Logistic Emigration Flow Model

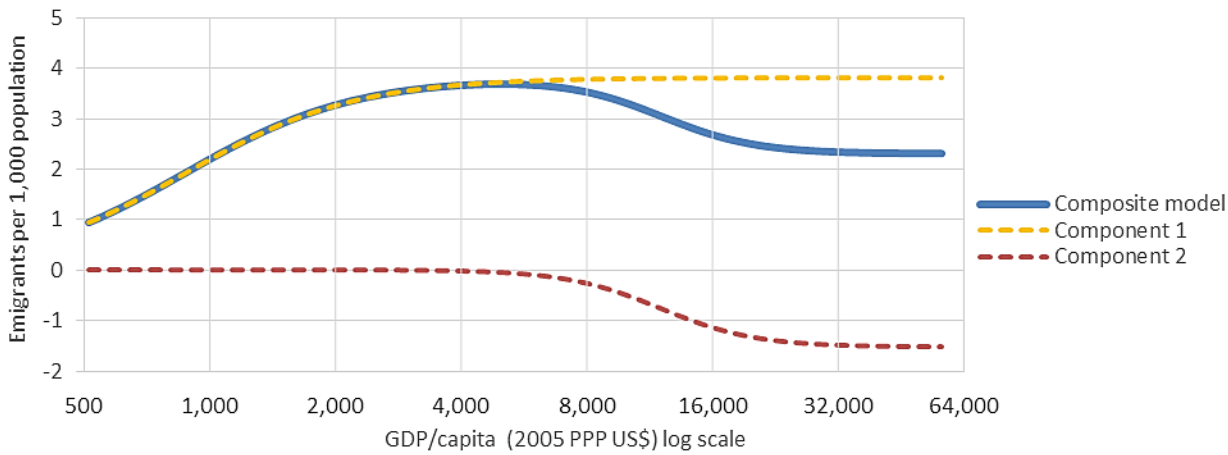
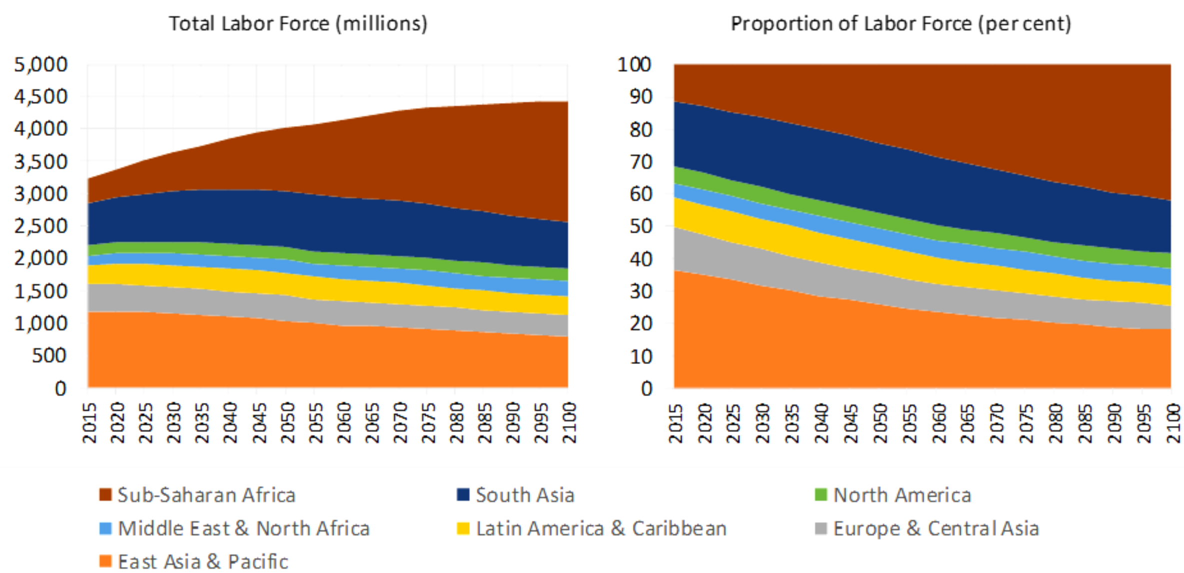


Figure B.2: Geographic Labour Force Distribution, Absolute and Relative, 2015–2100



Appendix C. Methodology

C.1 Bi-logistic migration model

For the parameterization of estimated migration transition curves, we employed the class of logistic functions as flexible and coherent mathematical models. The curves obtained from the kernel regression needed to be transformed into a parameterized form, for which logistic functions are well suited.

A logistic function exhibits an S-shape and describes a diffusion process growing from an initial level to an upper or lower asymptote. The general form of a logistic can be expressed as:

$$P(t) = \frac{k}{1 + \exp[-\alpha(t - \beta)]} \quad (1)$$

k Saturation level or asymptote of the diffusion process
α Growth rate of the *s*-curve
β Length of time the curve takes to reach the midpoint of the growth trajectory.

We use a re-parameterized logistic function introduced by Fisher and Pry (1971) and extensively used for global change modeling (Grübler 1998; Marchetti 1997; Marchetti et al. 1996; Meyer et al. 1999; Riahi et al. 2007). Th Fisher/Pry logistic function has parameters that are easier to interpret and are better suited to complex fitting exercises:[16]

$$P(t) = \frac{k}{1 + \exp[-\frac{Ln(81)}{\Delta t}(t - t_m)]} \quad (2)$$

t_m Midpoint of the growth/diffusion process
Δt Duration for the growth process to proceed from 10 percent to 90 percent of the asymptote (*k*).

However, most migration transition curves show trends with a clear trend reversal. Such processes may be effectively modeled by a combination of two logistic functions where one diffusion process approaches an upper asymptote, and a second and delayed process approaches a lower asymptote. Combined, these two processes represent trends with a reversal.

$$P(t) = \frac{k_1}{1 + \exp[-\frac{Ln(81)}{\Delta t_1}(t - t_{m1})]} + \frac{k_2}{1 + \exp[-\frac{Ln(81)}{\Delta t_2}(t - t_{m2})]} \quad (3)$$

The migration transition models are indexed by the level of GDP per capita, not time. Hence, the parameters t_m and Δt represent, in this setting, the midpoint of the GDP per capita growth/diffusion process, and the time that it takes for GDP per capita to grow from 10 percent to 90 percent of the asymptote (k), respectively. The time parameter t is replaced with GDP per capita (either in log-scale or unchanged).

[16]This function relates to the general form by substituting $\beta = t_m$; $\Delta t = \frac{\ln(81)}{\alpha}$.

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