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Modeling Alternative Projections of International Migration

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Modeling Alternative Projections of International Migration*

Thomas Buettner Rainer Muenz†

Abstract

This paper explores alternative approaches to the projection of international migration. Instead of relying on the residual concept of net migration or a migrant pool model of migration flows, an approach is suggested that uses estimates of international migration flows in an extended multiregional projection model. The contributions to the study of international migration are threefold. (1) The paper suggests that international migration must be modeled and projected as the interaction between sending and receiving entities (world regions), an aspect often present in subnational and internal migration studies, but virtually absent in the field of international migration projections. (2) The paper shows that the classic formulation of the demographic multiregional model is biased toward emigration, as it omits the other side of the migration process. Therefore, the multiregional model needs to be amended to include immigration (or admission) as well. Inspired by well-established approaches in nuptiality analysis that employ mating rules or marriage functions, the paper suggests using a migration transfer function that formally captures the interaction between sending and receiving entities, countries, or regions. Simple transfer functions are suggested. (3) The paper demonstrates the feasibility of an extended multiregional model with a range of migration scenarios (emigration- dominant scenario, immigration-dominant scenario, harmonic mean interaction scenario balances potential emigration and potential immigration/admission. A comparison suggests that the scenario that implements interaction is more realistic. An annex presents the mathematics of interacting migration flows and the reformulation of how to impose age structure on incomplete migration data.

See methodology brief here.

Key words: International migration, Population projection, Multiregional model, Migration scenarios, Regional interaction

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1. Introduction

The least reliable element of population projections is usually the modeling and forecasting of future migration. Data on past and recent flows and present stocks of migrants are normally incomplete. By using the concept of net migration gains or losses, projections do not take immigration and emigration into account separately. In addition, the most widely used global projections assume that in the medium and long terms the number of international migrants or the migration intensity will decrease.[1] We address these problems by looking at theories of international migration for guidance and inspiration.

Even after a long history of attempts, beginning with Ravenstein (1885), international migration has shown considerable resistance to the formulation of a comprehensive, verifiable, and quantifiable theory (or theories). About 25 years ago, Massey et al. (1993, 432) stated: "At present, there is no single, coherent theory of international migration, only a fragmented set of theories that have developed largely in isolation from one another, sometimes but not always segmented by disciplinary boundaries." More recently, Jennissen (2007, 411) finds no substantial progress, summarizing that "… research into international migration lacks a commonly accepted theoretical framework, which would facilitate the accumulation of knowledge." Bijak (2011, 50–51), after an extensive literature review, concurs and concludes that existing theories have very limited explanatory power and are difficult to operationalize.

What makes modeling and projecting international migration especially challenging (ignoring, for the movement, the dearth of sufficient, comparable, and consistent statistical data)? And what can be learned from the suggested theories?

Bijak (2011) suggests that migration across international boundaries differs substantially from internal migration in the underlying regime. International migrants usually face institutional barriers that are established by sovereign nation states with border control, admission, and immigration policies. Czaika and de Haas (2014) show that restrictive migration regimes have a significant impact on cross-border mobility, but other factors, such as language barriers, social norms, skills, and education, can also act as "borders" or resistance to potential immigrants.[2] Belot and Everdeen (2005, 2012) find strong empirical evidence of institutional and cultural barriers to international migration, even in the liberalized common labor market of the European Union. Czaika and de Haas (2014, 2015) argue that cultural distance (linguistic, legal, and phenotypical) has become more relevant for shaping international migration flows than the classic geographic distance. Although standard demographic models deal with (international) migration as an unconstrained process determined by the sending or receiving country alone (for example, the models are origin or emigration dominant), the notion of barriers or multidimensional or multifaceted distances points to the importance of the interplay between the sending and receiving countries (spatial interaction models).

Carling (2002) and Docquier et al. (2014) suggest a promising approach, which distinguishes between potential and actual migrants. According to their concept, people in an origin country become aspiring or potential migrants with a certain probability and depending on certain factors. In a second step, potential

[1] For an overview, see Buettner and Muenz (2016).

[2] Conversely, shared language, shared history, existing migrant networks, and comparable education systems may act as pull factors.

migrants become actual migrants, again with a certain probability depending on factors of the receiving or destination country.[3] The interactions between potential migrants and actual migration opportunities thus determine the flow of migrants.[4]

In sum, any modeling and projection of international migration should explicitly include the notion of interaction. As will be shown, this requires extending the standard multiregional model of demographic change to allow for interaction.

This paper is inspired—and encouraged—by two (demographic) requiems: our recent review of international migration in global population projections, and newly developed estimates of international migration flows.

1. *The Net Migration Requiem.* In 1990, Andrei Rogers wrote a requiem for "net migrants, a non-existing category of individuals" (1990, 283). However, tradition and a profound lack of data continued to force demographers to use the concept of "net migration"—that is, immigration minus emigration—when formulating assumptions for international population projections. Rogers' requiem, it seems, was performed for something holding quite successfully onto life.
2. *The Fixed Probability Requiem.* In 1993, David Plane published another requiem, burying the fixed-transition-probability migrant (1993). Here, the critique of conventional approaches to modeling migration is taken one step further. Plane argues that, although migration in multiregional models is formulated as flows (in a broad sense), the models assume constancy of emigration rates (or fixed transition probabilities) and thus neglect the interaction between sending and receiving countries or regions. However, most students of multiregional demography are still shown the beauty of stationary multiregional models with fixed transition probabilities. One reason for maintaining the constancy assumption is that it allows for concise mathematical analysis with attractive solutions. Like Rogers' "requiem," Plane's call for ending the unrealistic assumption of fixed transition rates has rarely been echoed in practice.
3. *Data problems.* Although international migration is a global phenomenon with wide-ranging implications and consequences, the scarcity and inconsistency of migration flow data have forced producers of international population projections to employ the concept of net migration or, in the case of Lutz, Butz, and KC (2014), to use a migrant pool model. In both cases, flows between countries are not explicitly covered and the underlying demographic dynamics are ignored (Buettner and Muenz 2016).
4. *New data sets.* For a long time, moving from "net migration" to measuring and analyzing migration flows seemed to have little chance, because of the dearth of data, especially for middle- and low-income countries: many of them lack administrative capacity and a tradition in migration data collection and aggregation. As a possible way out of this situation, estimating flows from migrant stocks was already suggested when the formalisms of multiregional demography were

[3] Carling calls this an aspiration/ability model. Rodrigue at al. (2013) also implicitly make this distinction by defining the term spatial interaction as: "A *realized movement* of people, freight or information between an origin and a destination." [emphasis added]

[4] For a more elaborate concept, Massey (2012) distinguishes six factors that are essential for models of international migration: (a) structural sources of immigrant supply, (b) structural sources of immigrant demand, (c) motivations for migration, (d) emergence of transnational structures, (e) behavior of states, and (f) efficacy of restriction.

put on a solid basis (Willekens 1977, 1979). In the meantime, the sustained data collection effort of the Global Migration Database, initiated by the United Nations Population Division (UNPD 2008), and maintained and extended through collaboration with the United Nations Statistics Division and the World Bank (Özden et al. 2011), provides sufficient empirical evidence for a practical attempt to estimate global migration flows. Abel (2009) responds to this emerging opportunity and reviews methods to estimate international migration flows from existing stock data. He developed a software package called "migest" (2014) that performs "stock-to-flow" transformations. A valuable outcome is comprehensive data sets with estimated flows for five-year periods[5] for 196 countries (Abel and Sander 2014a, 2014b).

We use this diagnosis as a starting point. The paper raises the following questions:

1. Which alternative approaches to modeling international migration could be applied in population forecasts?
2. How should we operationalize the new flow data sets to formulate projection assumptions?
3. How could we make better use of multiregional methods?
4. What would be the impact of a new model on calculated migration flows and total population size?

This paper is an extension and fuller application of the concepts and approaches developed by Rogers and Plane. It builds on the data generated by Abel and Sander (2014a, 2014b) and suggestions discussed in Buettner and Muenz (2016). The paper combines estimates of past international migration flows with a methodological reappraisal of modeling international migration, as suggested by the requiems. By adding interaction to the standard multiregional demographic model, the paper develops modeling techniques for projections of international migration on a global scale, aiming at a more realistic treatment of international/global migration.[6]

Such an approach opens a promising avenue for improved and more realistic projections of international migration. These avenues are a trade-off between the elegant and the practical. The elegant mathematical formulation of multiregional demographic models offers nice mathematical treatments with beautiful asymptotic solutions. However, treating migration adequately demands a trade-off between the beauty and the practical.[7]

The paper develops the approaches and shows how the suggested changes in methodology manifest in alternative projections for six major world regions: Africa, Asia, Europe, Latin America and the Caribbean, Northern America, and Oceania.[8]

[5] 1990–95, 1995–2000, 2000–05, and 2005–10.

[6] Some of the ideas and concepts in this paper are regular fare in regional science and demographic analysis of subnational regions within countries.

[7] Feeney (1973) states that including interactions in the standard formulation of the multiregional model would render it nonlinear.

[8] As defined by the United Nations Population Division (see table A.1 in annex A).

2. Data and Methods

The paper discusses ways to improve and enhance the treatment of international migration in population projections. It uses existing data for the projection exercises, and employs well established methods of mathematical demography, albeit with important enhancements. To address the need for treating international migration as flows of people between countries/regions, a multiregional model is used and amended for the analysis and projections. We decided to focus on six world regions to demonstrate the utility of the approach while keeping the amount of data at a reasonable limit. We also limited the model to a unisex approach (both sexes combined), a treatment that has previously been used in demography for the discussion of methodology. The gender dimension will have to be introduced with further refinement of the approach, as it has implications for fertility, mortality, and labor markets. Despite these restrictions, the software implementation for this exercise was designed to handle international projections on a global level with all countries covered.

Data from two sources are employed. We use the estimates and projections from the 2015 Revision of the United Nations World Population Prospects (UNPD 2015a, 2015c) as reference for the calculation of alternative migration projections. The migration flow data are based on data sets produced by Abel and Sander (2014a, 2014b),[9] using an estimation methodology developed by Abel (2009, 2013). The migration flow data set, which is the first of its kind, was used extensively in Lutz, Butz, and KC (2014).[10]

The migration flow data are available for four five-year periods (mid-year to mid-year): 1990–95, 1995–2000, 2000–05, and 2005–10, covering 196 countries. Abel and Sander (2014a, 2014b) adjust the original flow estimates to be consistent with corresponding net migration estimates from the 2010 Revision of UNPD's World Population Prospects. For this paper, we adjusted the migration flow data to be consistent with the net migration estimates from the 2015 Revision of UNPD's population projections. The transformation procedure used the migration efficiency indicator derived from the given flow estimates, to calculate from the United Nations net migration figures the corresponding gross flows and iterative proportional fitting to adjust the flow matrix to match the new marginal total.

The data are limited to the 196 countries covered in the data set used by Abel and Sander (the UNPD data set covers 233 countries and non-sovereign political entities). The difference in country coverage between the UNPD reference data and the migration data set concerns only small countries[11] (with fewer than 100,000 inhabitants) and has a negligible impact on the outcomes of the population projections, including international migration (table 1). Finally, for our projections, the UNPD reference data for the 196

[9] We use the S2 database, which is available as a supplement to Abel and Sander (2014b), http://science.sciencemag.org/content/343/6178/1520/suppl/DC1.

[10] In Lutz, Butz, and KC (2014), migration was not implemented as a full multiregional model, but in successive bi-regional increments.

[11] The only exception is Curaçao, which had a population of 129,398 in 2005. The island became a separate non-sovereign country after the dissolution of Netherlands Antilles in October 2010, and was therefore not included independently in earlier statistical publications by the United Nations. Therefore, it is not present in the estimated flow data.

countries were aggregated into the six world regions[12] used by UNPD in its standard tabulations: Africa, Asia, Europe, Latin America,[13] Northern America, and Oceania (table A.1 in annex A).

Table 1: Total Population in 2005 and Population Growth Rate and Net Migration in 2005–10

Region	Total population	Growth rate (%)	Population distribution (%)	Net migration	Total population	Net migration
	UNPD 2015 Revision: 233 countries				Study data set: 196 countries	
Africa	920,238,945	2.5	14.1	-1,813,334	920,145,924	-1,812,013
Asia	3,944,669,784	1.1	60.5	-11,368,746	3,944,669,784	-11,368,563
Europe	729,007,470	0.2	11.2	8,495,141	728,669,785	8,484,639
Latin America	563,825,875	1.2	8.6	-2,686,434	563,328,703	-2,715,104
Northern America	328,524,304	0.9	5.0	6,295,538	328,395,968	6,300,158
Oceania	33,369,472	1.7	0.5	1,077,834	33,025,339	1,110,883
World	6,519,635,850	1.2	100.0	0	6,518,235,503	-

Sources: UNPD 2015a; staff calculations.
Note: UNPD = United Nations Population Division.

The projections start at 2005 and extend to 2100. The base population in 2005 is taken from the UNPD data set. The projection variants vary only in the migration assumptions; the fertility and mortality assumptions are identical to UNPD's medium-projection variant.

The aggregation of global migration dynamics into six world regions "hides" a considerable amount of international migration that takes place within those world regions. This and the transformation of the migration flow data to be consistent with the latest United Nations estimates of net migration may be daring. However, the principal aim of this paper is to offer new methodological avenues. The data the paper employs and the projection results produced are illustrations with a strong affinity to real settings in the base period during 2005–10.

The analysis and projections were performed with a multiregional model based on the methodology developed by Rogers (1967, 1968, 1995). The computer model is coded in R language; the code is greatly inspired by the original Willekens and Rogers (1978) computer code,[14] enhanced with new functionality for modeling the interaction of migratory flows, plus additional data analysis features. The code developed for this projection exercise will be made available once the project is finished. For a concise treatment of the enhanced multiregional methodology see Buettner, Muenz (2017).

We discuss five scenarios (see table 2) and their projection outcomes. All five scenarios share the same fertility and mortality assumptions for the six world regions, and are identical to the corresponding aggregate settings of the 2015 Revision of World Population Prospects (UNPD 2015c). The focus is on alternative migration assumptions defined as follows:

- Base scenario 1 with constant crude emigration rates (**cemr**)
- Base scenario 2 with constant crude immigration rates (**cimr**)
- Main scenario treating migration as the result of interactions between sending and receiving countries, conceptualized as the harmonic mean adjustment (**hmean**)

[12] Major areas in UNPD terminology.
[13] Throughout, this refers to Latin America and the Caribbean.
[14] The original computer code was written in FORTRAN.

- Contrasting scenario 1 with constant emigration and immigration over the whole projection period (**cmig**)
- Contrasting scenario 2 with migration set to zero over the whole projection period (**mzero**).

Table 2: Migration Scenarios

Scenario	Symbol	Description
Constant emigration rates	**cemr**	*Base scenario 1* with constant emigration rates (**cemr**). Emigration rates are held constant at the 2005–10 level. Supply completely drives migration flows (emigration-dominant transfer function).
Constant immigration rates	**cimr**	*Base scenario 2* with constant immigration rates (**cimr**). Immigration rates are kept constant at the 2005–10 level. Demand completely drives migration flows (immigration-dominant transfer function).
Harmonic mean adjustment	**hmean**	*Main scenario* with harmonic mean adjusted rates (**hmean**). The interaction between sending and receiving countries is modeled by the harmonic mean of the emigration and immigration rates. Supply *and* demand determine migration flows (harmonic mean transfer function).
Constant total migration	**cmig**	*Contrasting scenario 1* with constant numbers of migrants (**cmig**). The absolute numbers of emigrants and immigrants are held constant at the 2005–10 level. This is equivalent to the assumption of constant net migration numbers.
Zero migration	**mzero**	*Contrasting scenario 2* with migration set to zero (**mzero**).

Of course, these scenarios are not evenly plausible. Base scenario 1, with constant emigration rates (**cemr**), represents the original formulation of the multiregional projection models, where the migration assumption must be made for emigration rates, albeit not necessarily constant ones. International migration is thus formulated as driven exclusively by the countries/regions of origin. In contrast, base scenario 2 reverses the perspective and assumes constant immigration rates (**cimr**), for example, international migration is driven by destination countries/regions.[15] In a stylized fashion, these two base scenarios represent the two sides of migration as an interaction, as formulated in the scenario with harmonic mean adjustment. We assume the scenario with harmonic mean adjustment to be the most plausible in this setting.

Contrasting scenario 1 represents the assumptions found in most international population projections, at least for a medium time horizon: a constant number of emigrants (and immigrants), resulting in constant net migration (**cmig**). As argued by Rogers (1990) and shown in Buettner and Muenz (2016), despite its ubiquitousness, such an assumption is more an expression of deficient data than a well-founded assumption about the dynamics of future migration trends.

[15] The practical implementation of this scenario is more demanding, as immigration rates first need to be transformed into corresponding emigration rates to comply with the emigration-dominant formulation of the multiregional models (see annex C.1).

In this paper, only the two base scenarios (**cemr** and **cimr**) and the main scenario (**hmean**) are discussed in some detail. The two contrasting scenarios (**cmig** and **mzero**) serve as references for comparisons, where needed.

3. Projecting Migration

This section develops a methodology for projecting (international) migration within the framework of multiregional demographic projection models. International population projections are often produced by developing the assumptions independently for each country. The international migration component must then be balanced on the aggregate/world level in a second step (see Buettner and Muenz 2016). Multiregional projection models, in contrast, project all the demographic forces of change (fertility, mortality, and migration) at each time step simultaneously. By definition, such a model is balanced within its system boundaries.

The base data for the projection scenarios are presented in two formats. One configuration includes intraregional migration, and thus allows for a better picture of the overall extent of mobility/migratory moves. The other format omits migration flows within regions, as is the case for the multiregional projection setting at the regional level.

In a second step, we introduce and discuss two projection configurations that are straightforward and common, yet do not adequately capture the nature of (international) migration as the movement of people between countries. In a third step, we propose a configuration that provides a better treatment of migration.

3.1. Database

According to the 2015 Revision of World Population Prospects (see table 1), the six world regions exhibit very different demographic characteristics. Asia, which is home to the two most populous countries in the world (China and India), houses the largest proportion of people: more than 60 percent of the global population lives there. At the other extreme, Oceania is home to 0.5 percent of the world's population. Africa, the second largest world region, grows the fastest, at 2.5 percent per year (implying a doubling of its population in less than 30 years). Europe (including the Russian Federation), which ranks third in population size, exhibits very small growth (0.2 percent per year), which is entirely due to a positive migration balance. Latin America, with about 564 million people, grows at 1.2 percent per year, which is comparable to Asia (1.1 percent per year), despite having a negative net migration balance. Northern America somewhat differs from the other world regions with advanced economies (Europe, East Asia, and Oceania), as it experiences fertility around replacement and net migration gains.

The estimated migration flows for the six world regions in 2005–10 are shown as flows from origin to destination in table 3, and as aggregates of total emigration and immigration plus corresponding net migration in table 4. Tables 3 and 4 contain intraregional migration, that is, migratory movements between the countries in each world region, as shown in the main diagonal of table 3.

Table 3: Intraregional and Transregional Migration within and between World Regions, 2005–10

Destination	Origin: Africa	Asia	Europe	Latin America	Northern America	Oceania	Total Immigration	Net migration
Africa	**2,137,220**	273,181	149,471	9,593	58,971	4,298	2,632,734	-1,812,013
Asia	496,900	**17,936,086**	247,866	88,152	313,592	36,474	19,119,070	-11,368,563
Europe	1,310,977	5,417,949	**2,965,269**	833,687	1,337,035	175,129	12,040,046	8,484,639
Latin America	6,152	58,334	12,697	**333,498**	231,863	1,448	643,992	-2,715,104
Northern America	408,192	5,694,015	74,908	2,079,202	**121,582**	33,253	8,411,152	6,300,158
Oceania	85,306	1,108,068	105,196	14,964	47,951	**169,342**	1,530,827	1,110,883
Total	4,444,747	30,487,633	3,555,407	3,359,097	2,110,994	419,944	44,377,822	0

Table 4: Migration Retention Ratios, by Origin and Destination, 2005–10

Region	Retention rate (%): By origin	By destination
Africa	48.1	81.2
Asia	58.8	93.8
Europe	83.4	24.6
Latin America	9.9	51.8
Northern America	5.8	1.4
Oceania	40.3	11.1
Total	53	53

The estimated total amount of emigration experienced by all countries in Africa was about 4.4 million people during 2005–10, of which an estimated 2.1 million people moved from one country to another in Africa. About 2.3 million people of the 4.4 million total emigrants originating in Africa headed to the other five world regions.

The estimates show that migration taking place within Africa is almost as large as the movements out of Africa, where Europe is the most important destination (with about 1.3 million migrants from Africa to Europe in 2005–10). The proportion of migration within Africa as region of origin to overall emigration, that is, the origin retention ratio, amounts to 48 percent (table 4).

A different picture emerges when looking at Africa as a destination for migrants. Obviously, the number of immigrants remaining within Africa is the same as the number of emigrants within Africa, 2.1 million. The overall number of immigrants coming to Africa from other regions is relatively small: an estimated 484,000 people during 2005–10. The difference between immigrants and emigrants—about -1.8 million people—turns Africa into a net sender of migrants. The two major world regions sending migrants to Africa during 2005–10 were Asia (with 273,000) and Europe (149,000). Africa's immigrant retention ratio—calculated by dividing the migration within Africa by the total amount of immigration—is a staggering 81 percent (resulting from very small numbers of migrants coming from other continents).

There are stark differences between world regions in migration that occurs within the region and migration flows related to other world regions. Migration between countries in Africa and Asia is larger than flows from and to other regions. For Europe (including Russia), Latin America, and Oceania, the largest migration flows are from or to other regions (table 3).

The retention measure for the whole system—the world—must be the same for origin and destination (box 1). At the level of the six world regions analyzed here, average overall retention is about 53 percent. In other words, for this geographic configuration, more than half of all movements occur within the six world regions, and thus outside the projection exercise. Any conclusion drawn from this example must therefore be mindful of the large amount of movement not directly visible in the analysis presented here.

Box 1: Measures of Retention

The migration retention ratio measures the extent of migration inside a region relative to the overall amount of migration of a region (UNPD 2014, p. 2). Therefore, the retention ratio provides information about the amount of movement within a region that is potentially hidden from analysis and is definitely absent in projections.

Emigration retention (retention by origin)	Immigration retention (retention by destination)
Proportion of people emigrating within a region to the overall number of emigrants of that region.	Proportion of people immigrating within a region to the overall number of immigrants into that region.
$R_i^O = \frac{E_{ii}}{\sum_j^n E_{ij}}$	$R_i^D = \frac{E_{ii}}{\sum_i^n E_{ij}}$

In the global migration system for 2005–10, there were three major areas with a negative net migration balance and three major areas with a positive net migration balance (see table 5): Africa, Asia, and Latin America lost people through migration, while Europe, Northern America, and Oceania gained population.

Table 5: Migrants, by World Region, Intraregional and Transregional Migration Combined, 2005–10

Region	Emigrants	Immigrants	Net migration
Africa	4,444,747	2,632,734	-1,812,013
Asia	30,487,633	19,119,070	-11,368,563
Europe	3,555,407	12,040,046	8,484,639
Latin America	3,359,097	643,992	-2,715,104
Northern America	2,110,994	8,411,152	6,300,158
Oceania	419,944	1,530,827	1,110,883
Total	44,377,822	44,377,822	0

In the multiregional projection model with the six world regions, intraregional mobility is necessarily excluded,[16] resulting in a matrix of migrant flows where the main diagonal is zero (table 6). The figures for total emigration and immigration change, but the amount of net migration remains the same (as shown in table 7).

[16] The demographic dynamics within the constituent regions are assumed to be homogeneous, just like the classical population projection for single countries omits the differential demography of its subregions.

Table 6: Transregional Flows of People between World Regions, 2005–10

Destination	Origin						Total immigration	Net migration
	Africa	Asia	Europe	Latin America	Northern America	Oceania		
Africa	0	273,181	149,471	9,593	58,971	4,298	495,514	-1,812,013
Asia	496,900	0	247,866	88,152	313,592	36,474	1,182,984	-11,368,563
Europe	1,310,977	5,417,949	0	833,687	1,337,035	175,129	9,074,777	8,484,639
Latin America	6,152	58,334	12,697	0	231,863	1,448	310,494	-2,715,104
Northern America	408,192	5,694,015	74,908	2,079,202	0	33,253	8,289,570	6,300,158
Oceania	85,306	1,108,068	105,196	14,964	47,951	0	1,361,485	1,110,883
Total	2,307,527	12,551,547	590,138	3,025,598	1,989,412	250,602	20,714,824	0

Table 7: Emigrants, Immigrants, and Net Migration, by World Region, 2005–10

Region	Emigrants	Immigrants	Net migration
Africa	2,307,527	495,514	-1,812,013
Asia	12,551,547	1,182,984	-11,368,563
Europe	590,138	9,074,777	8,484,639
Latin America	3,025,598	310,494	-2,715,104
Northern America	1,989,412	8,289,570	6,300,158
Oceania	250,602	1,361,485	1,110,883
Total	20,714,824	20,714,824	0

The regional (that is, spatial) structure of the migration system for 2005–10 is a defining element of the base period (table 3) that continues to play a role for the projection of international migration built into the assumptions. As a process between sending and receiving regions, the spatial distribution of migration can formally be described, in relative terms, as the spatial/regional distribution proportions of emigrants (table 8) and immigrants (table 9), respectively.

We start with the emigration distribution proportions, which are calculated by dividing the emigrants for a region of origin to each destination region by the sum of all transregional emigrants of that region (for example, operating along the columns in table 6).

Table 8: Emigration Distribution Proportions for World Regions, 2005–10 (%)

Destination	Origin					
	Africa	Asia	Europe	Latin America	Northern America	Oceania
Africa	0	2	25	0	3	2
Asia	21	0	42	3	16	15
Europe	57	43	0	28	67	70
Latin America	0	0	2	0	12	1
Northern America	18	45	13	68	0	13
Oceania	4	9	18	1	2	0
Total	100	100	100	100	100	100

The immigration distribution proportions are calculated in a similar fashion, by dividing the number of immigrants into one region of destination by the sum of all transregional immigrants into that region (operating along the rows of table 6).

Table 9: Immigration Distribution Proportions for World Regions, 2005–10 (%)

Destination	Origin						Total
	Africa	Asia	Europe	Latin America	Northern America	Oceania	
Africa	0	56	30	2	12	1	100
Asia	42	0	21	8	26	3	100
Europe	15	60	0	9	14	2	100
Latin America	2	20	4	0	74	0	100
Northern America	5	69	1	25	0	0	100
Oceania	6	81	8	1	3	0	100

Reviewing the transregional emigration and immigration distribution proportions of a given migration system reveals more clearly the relative importance of these migration flows in that system. Reading column-wise, table 8 shows that during 2005–10, transregional emigration from Africa was mostly directed toward Europe, while almost equal shares of people leaving Asia moved to Europe and Northern America. European transregional emigration was focused on Asia, and people leaving Latin America moved predominantly to Northern America. Two of every three of the few emigrants from Northern America and Oceania chose Europe as their destination.

Changing the perspective from emigration to immigration and from column-wise to row-wise scanning, table 9 shows that, during 2005–10, transregional immigrants into Africa mostly came from Asia, and most transregional immigrants into Asia came from Africa. More than half of Europe's transregional immigrants originated in Asia, followed by Africa and Northern America.

3.2. Multiregional Projections with Constant Migration Rates

This section discusses two versions of a constant rate model, to strengthen the argument in favor of a more realistic approach to migration in population projections. The two versions are simple and plausible, at least at first glance. Yet, comparing their results over time as well as judging the plausibility of their assumptions clearly reveals significant shortcomings.

The initial conceptualization of multiregional models requires age- and region-specific emigration rates, which implies limitations that may seriously limit the utility of the model for projections. Demographers have pointed to this problem as early as when the method was initially developed (Feeney 1973). Similar criticism was later repeated and further extended (Plane 1993; Courgeau 2006). However, suggested solutions have mostly been formal so far, not practical. In this paper, we suggest some simple, practical, and flexible options to measure and project the migration component in a multiregional model. At least two challenges need to be addressed:

1. *The emigration bias of multiregional models.* Although formulating the model's migration component exclusively as emigration allows for an elegant mathematical model, it excludes the interaction between sending and receiving regions. We address the emigration bias by explicitly considering emigration and immigration, and thereby including the interaction between sending and receiving countries.
2. *The mismatch between the model specification and operationalizing the migration assumptions.* Emigration is specified in the multiregional model in terms of age-specific emigration rates, an average person-type indicator (see box 2). We suggest that the migration assumptions should use population-

based indicators, which are a better communication device and a proper way to include immigration. We suggest simple ways to translate one type into the other.

The technical challenge is to run the core multiregional model with age- and region-specific migration rates, as required, while at the same time including the interaction and using population-based indicators for the migration assumptions. As will be shown, this is only possible with an iterative approach.

At first glance, what looks like an additional layer of complexity provides the versatility not only to employ easier to understand measures/metrics, but also to include immigration—which is the other side of the coin. This approach also brings the concept of the interaction—between sending and receiving countries/regions—into the model. Before introducing interaction formally and by example, we illustrate the implications of assuming constant crude emigration or constant crude immigration rates, by presenting the results of the multiregional projection scenarios for the six world regions for 2005–2100.

Box 2: Types of Demographic Indicators

It is useful to distinguish between two types of indicators used in demographic analysis:

- Population-based indicators
- Average person–based indicators.

The two types of indicators express two different aspects of demographic change that complement each other.

Population-based indicators	Person-based indicators
Population-based indicators measure the magnitude of demographic events or change relative to the whole population, and are usually expressed as events per 1,000 at-risk population.	Person-based indicators express the relative level of demographic events for the average person, thus abstracting from the peculiarities of the population composition by age (and maybe other characteristics).
Examples: • Crude birth rate (number of births per 1,000 at-risk population) • Crude death rate (number of deaths per 1,000 at-risk population) • Crude migration rate (number of emigrants/immigrants/net migrants per 1,000 at-risk population of the sending/receiving country/region).	Examples: • Total fertility rate (average number of children per woman) • Life expectancy at birth (average number of years a new-born is expected to live) • Gross migraproduction rate (average number of movements across borders a person will experience during his or her lifetime).

3.2.1. Base Scenario 1: Constant Emigration Rates

Base scenario 1 (**cemr**) with constant emigration rates[17] assumes that the number of emigrants from sending regions is determined only by the sending region's population size and the emigration rate. The scenario also keeps the geographic distribution of regions to which people emigrate constant over time. Under these assumptions, demographically growing regions would emit/generate growing numbers of emigrants, and regions with shrinking populations would emit/generate declining numbers of emigrants. In this scenario, immigration, which is the other side of emigration, is completely determined by the emigration dynamics. If a receiving region is the destination of a growing region, immigration would increase, and vice versa. Under the assumptions of this scenario, the dynamics of migration flows is thus completely linked to the demographic dynamics of sending countries by keeping emigration rates constant. In short, base scenario 1 (**cemr**) describes a world in which solely push factors operate.

Crude emigration rates in a multiregional setting are calculated for each region by dividing the number of emigrants from one region to all other regions by the population of the sending region. Crude emigration rates can also be calculated for each origin-destination pair (table 10). For a formal treatment, see annex C.1.

Table 10: Crude Emigration Rates, by Origin and Destination, 2005–10

Destination	Origin					
	Africa	Asia	Europe	Latin America	Northern America	Oceania
Africa	0	0.0135	0.0408	0.0033	0.0351	0.0249
Asia	0.1012	0	0.0677	0.0303	0.1865	0.2112
Europe	0.2669	0.2671	0	0.2868	0.7952	1.0140
Latin America	0.0013	0.0029	0.0035	0	0.1379	0.0084
Northern America	0.0831	0.2807	0.0205	0.7154	0	0.1925
Oceania	0.0174	0.0546	0.0287	0.0051	0.0285	0
Total	0.4698	0.6187	0.1612	1.0410	1.1832	1.4510

The results of a multiregional projection with constant emigration rates are presented in tables 11 and 12. With emigration rates held constant, the total number of people emigrating from Africa to other regions of the world would more than double, from 2.3 million during 2005–10 to 5.5 million during 2045–50. During 2095–2100, Africa would generate 9.2 million transregional emigrants, four times the figure in 2005–10.

These significant increases are caused not by a higher propensity to emigrate from Africa, but solely by the particularly high population growth projected for Africa (table 10); figure B.6 in annex B). Although Africa would quadruple its population and the number of transregional emigrants by 2100, the number of transregional immigrants into Africa would increase only marginally, from 496,000 (2005–10) to 622,000 (2095–2100). Again, this is the result of keeping emigration rates constant for all sending regions. The small increase in immigrants into Africa combined with the projected high population growth results in slightly declining crude immigration rates during the projection period (see figure B.7 in annex B).

[17] Unless explicitly mentioned otherwise, we use crude migration rates.

The migration trends projected for Europe under the constant emigration rates scenario seem to mirror the African trends, but with emigration and immigration interchanged. There would be little change in the emigration figures for Europe over the projection period, due to an almost stagnant population size.

The projected dynamic unfolds when looking at the corresponding immigration figures. Obviously, the large increase in emigration attributed to Africa should be reflected in increasing immigration into all the receiving regions. Incidentally, Europe is the region where, in recent times, most emigrants from Africa have moved (see table 11). Thus, the number of immigrants (from all other world regions) into Europe would increase, from about 9 million during 2005–10 to about 13 million during 2045–50 and more than 15 million during 2095–2100, an increase of 71 percent relative to the base period.

Table 11: Emigrants and Immigrants, Constant Emigration Rates (**cemr**)

Region	Emigrants			Immigrants		
	2005–10	2045–50	2095–2100	2005–10	2045–50	2095–2100
Africa	2,307,527	5,535,509	9,850,463	495,514	608,757	622,352
Asia	12,551,547	16,013,474	14,706,794	1,182,984	2,050,848	3,134,805
Europe	590,138	624,200	699,655	9,074,777	13,232,004	15,593,976
Latin America	3,025,598	3,969,808	3,545,326	310,494	413,593	501,577
Northern America	1,989,412	2,645,552	3,333,226	8,289,570	11,104,582	11,013,374
Oceania	250,602	433,526	614,035	1,361,485	1,812,284	1,883,415
World	20,714,824	29,222,069	32,749,498	20,714,824	29,222,069	32,749,498

Net migration (table 12) reveals the effective contribution of migration to each world region's population change. The constant emigration rate scenario produces results that allocate the largest impact to Africa. Net migration (in Africa's case, the excess of emigration over immigration) would increase from less than -2 million during 2005–10 to more than -9 million during the last projection interval, or five times the initial level. The second largest net migration change is allocated to Europe, increasing from +8.5 million during 2005–10 to +14.9 million during 2095–2100. The dynamics behind this are shown in table 11: immigration into Europe would grow significantly, caused by the stark increase in emigration from Africa, which for Europe means more immigration. At the same time, emigration from Europe would increase only marginally.

Table 12: Net Migration, Constant Emigration Scenario (**cemr**)

Region	2005–10	2045–50	2095–2100
Africa	-1,812,013	-4,926,752	-9,228,111
Asia	-11,368,563	-13,962,626	-11,571,989
Europe	8,484,639	12,607,804	14,894,321
Latin America	-2,715,104	-3,556,215	-3,043,749
Northern America	6,300,158	8,459,030	7,680,148
Oceania	1,110,883	1,378,758	1,269,380

Tables A.2 and A.3 (in annex A) are migration matrixes, which show flows between all regions for the projection periods 2045–50 and 2095–2100, respectively.

3.2.2. Base Scenario 2: Constant Immigration Rates

Base scenario 2 (**cimr**) with constant immigration rates takes the destination of migratory moves as the starting point, which is the opposite of base scenario 1. Base scenario 2 keeps the rate and geographic distribution of countries from which people immigrate constant over time; in other words, it assumes that the number of immigrants admitted by a receiving region is dependent on the population size of the receiving region. If a region were to grow in population size, it would admit and absorb growing numbers of immigrants while the immigration rate would stay constant. Regions experiencing population loss would attract declining numbers of transregional immigrants. Under the assumptions of this scenario, immigration completely determines the emigration dynamics. Base scenario 2 (**cimr**) describes circumstances in which only pull factors (demand for immigration) are relevant.

Crude immigration rates are calculated for each region by dividing the number of immigrants into a region by the population of that region. Total immigration rates as well immigration rates for the world region pairs are listed in table 13.

Table 13: Crude Immigration Rates, by Origin and Destination, 2005–10

Origin	Destination						Total
	Africa	Asia	Europe	Latin America	Northern America	Oceania	
Africa	0	0.0556	0.0304	0.0020	0.0120	0.0009	0.1009
Asia	0.0245	0	0.0122	0.0043	0.0155	0.0018	0.0583
Europe	0.3582	1.4804	0	0.2278	0.3653	0.0479	2.4795
Latin America	0.0021	0.0201	0.0044	0	0.0798	0.0005	0.1068
Northern America	0.2428	3.3864	0.0445	1.2366	0	0.0198	4.9300
Oceania	0.4939	6.4157	0.6091	0.0866	0.2776	0	7.8830

At a first glance, it seems that it is as easy to specify constant immigration rates (**cimr**) as it is to specify constant emigration rates (**cemr**). Like emigration rates, measures of immigration can be calculated by relating the events of people arriving in a country or region to the population of that country or region (at the risk of experiencing or witnessing the event). However, it is not possible directly to integrate constant immigration rates into the multiregional projection model. First, multiregional models are formulated with emigration rates (not immigration rates) as their input. For conceptual and practical reasons, in a multiregional model, immigration must therefore be operationalized as the other side of emigration. In other words, it seems that the most plausible way to introduce immigration is by identifying the corresponding emigration from elsewhere toward the respective country or region (see annex C.2).

The results for base scenario 2 with constant immigration rates (**cimr**) for the six world regions offer a stark contrast to the results for base scenario 1 (**cimr**), at least for some world regions. Not surprisingly, the total number of people from Africa admitted to the other world regions is significantly less than in the emigration-based scenario, as the other world regions are projected to exhibit much smaller population gains than Africa. In a migration setting completely determined by pull factors of the receiving regions (that is, constant admission rates at the levels estimated for 2005–10), the total emigration from Africa into all other world regions would only grow at a very small scale: from 2.3 million in 2005–10 to 2.7 million in 2045–50 and 2.9 million at the end of the projection period, an increase of only 27 percent over the whole projection period (see table 14).

Table 14: Emigrants and Immigrants, Constant Immigration Rates (**cimr**)

Region	Emigrants			Immigrants		
	2005–10	2045–50	2095–2100	2005–10	2045–50	2095–2100
Africa	2,307,527	2,693,435	2,935,236	495,514	1,205,173	2,194,309
Asia	12,551,547	15,887,129	20,377,557	1,182,984	1,511,256	1,374,094
Europe	590,138	987,799	1,439,674	9,074,777	9,324,007	9,376,850
Latin America	3,025,598	3,773,200	4,656,967	310,494	408,865	362,443
Northern America	1,989,412	2,310,275	2,437,700	8,289,570	10,988,384	14,411,978
Oceania	250,602	283,287	302,124	1,361,485	2,497,441	4,429,584
World	20,714,824	25,935,126	32,149,258	20,714,824	25,935,126	32,149,258

The comparatively low emigration originating in Africa in base scenario 2 is caused by "weak demand" in the major receiving world region, Europe. The total immigration into Europe would not change significantly, which is the result of an almost stagnant population size. Under the constant immigration scenario, the major migration flows are not from Africa to Europe, but from Asia to Northern America. Northern America, with its small but robust population growth, would attract increasing numbers of immigrants, rising from about 8.3 million during 2005–10 to 11 million during 2045–50 and 14.4 million during 2095–2100.

Table 15: Net Migration, Constant Immigration Rates (**cimr**)

Region	2005–10	2045–50	2095–2100
Africa	-1,812,013	-1,488,263	-740,927
Asia	-11,368,563	-14,375,873	-19,003,463
Europe	8,484,639	8,336,208	7,937,176
Latin America	-2,715,104	-3,364,335	-4,294,524
Northern America	6,300,158	8,678,108	11,974,278
Oceania	1,110,883	2,214,154	4,127,460

Table 15 shows the overall impact of migration for each world region under the constant immigration rate scenario. Several observations are noteworthy. Projected net emigration from Africa declines, caused mainly by a growing African population leading to higher numbers of immigrants, and eventually declining populations in Asia and stagnant population size in Europe do not increase African emigration. Asia's projected net emigration increases strongly, mainly attracted by Northern America's growing population. The case of growing immigration into Northern America demonstrates a peculiar implication of assuming fixed rates (here, fixed immigration rates). If the dynamics of migration is determined by the size of the population in the receiving region, and if that population is growing not least because of immigration, the growing immigration leads to a positive feedback loop attracting even more immigrants.

3.3. Multiregional Projection with Origin-Destination Interaction

3.3.1. Overview

The projections presented thus far with constant emigration and immigration rates produce very different migration outcomes. This may be somewhat puzzling, as the system of six regions is in perfect balance in the base period: we obtain identical migration results for 2005–10 if constant emigration or immigration rates are applied. This equivalency does not hold for future periods, even when migration rates are kept constant.

This problem could be blamed on the multiregional model specification. Indeed, migration must be specified as emigration in multiregional models. Consequently, emigration drives immigration. This feature of multiregional models could be called an emigration bias or fallacy. However, it is possible to deal with this problem by introducing appropriate enhancement to the model.

Apart from a methodological limitation, we are confronted with a conceptual problem. International migrants need to cross borders when leaving their country of origin and entering a country of destination. Any model that does not take this into account would imply that receiving countries have no control over how many migrants they admit: every potential emigrant would eventually move.

How can the discrepancy between emigration and admission be solved? Both perspectives—the emigration- or supply-based system and the admission- or demand-based system—are internally consistent, as the flows of migrants are balanced at the world level. Both perspectives are also plausible, as they are based on assumptions that have been empirically observed, here for the period 2005–10. The reason for the discrepancies is the differential in the future demographic dynamics of the world regions. As the regions grow, stagnate, or decline differently, their population sizes change in different directions, and thus their potential to send or receive migrants. Two contrafactual outcomes of the model are noteworthy. (a) Only in the case in which regions exhibit identical population growth rates would supply and demand remain in balance, and there would be no discrepancy between the two perspectives. (b) With identical demographic growth for all regions involved, the migration volume would grow at the same rate as the population, but without discrepancies between supply and demand. Such a setting will not materialize, because regions or countries evolve differently over time, and thus their emissions and admissions of migrants will differ. What is needed is a mechanism to resolve these discrepancies: a mechanism that avoids the extremes of a purely emigration/supply-based solution or a purely immigration/admission-based solution.

This is not a new finding. Demographers have been aware of the shortcoming of the classical multiregional model in its handling of the migration component. Since the 1970s, several demographers have observed that modeling migration in multiregional models by fixed emigration rates is not a realistic approach (Feeney 1973; Plane 1993; Courgeau 2006; Dion 2013). Such an approach assumes that migration depends exclusively on the country from which the migrants originate. In a subnational context, with relative freedom of movement, this may be a reasonable simplification. But in an international context, where migrants crossing borders are subject to certain legal requirements and limitations, this view of migration as a purely supply-side phenomenon is inadequate.[18] The projections with constant emigration and immigration rates lead to different outcomes depending on the perspective chosen to illustrate the shortcomings of these assumptions.

Modeling migration flows as results of interaction means that migration events are no longer independent from (or uncorrelated to) the population dynamics of which they are a part. This also means that the population model is no longer linear, departing from (relatively) simple solutions.

This paper argues that interregional demographic models need to include both sides of migration—emigration and immigration. At the model level, a solution should let regions or countries interact in determining the amount of movements between them. The literature suggests several approaches that

[18] See Jandl (1994) for a discussion of the demand and supply sides of international migration from an economist's point of view.

are based on weighing the two (or more) interacting entities. For population projections, it seems appropriate as well as practical to use the results of the projection exercise to bring the flows of people into balance. Such an approach is not dependent on assumptions or forecasts of possible covariates, thus keeping the exercise comparatively simple and robust.

In demographic analysis, there is a straightforward analogy that resembles the problem at hand: marriage markets. One solution to consolidate “market imbalances” is to use the device of the harmonic mean (Keyfitz 1972; Keilman 1985a; Schoen 1988). For a situation with two actors (in this case, sending and receiving regions/countries), this simple formula consolidates ("harmonizes") the two potential flows.[19]

Other options for modeling the flows of migrants as interacting have been suggested for formulating appropriate and practical migration transfer functions (see annex C.3). Feeney (1973) suggests an updating schema like the harmonic mean; Schoen (1988) suggests a method he calls the *Relative State Attraction method*[20]; Courgeau (2006) proposes an *index of migration intensity* (operating at the cohort level); and Dion (2013) presents a *Net Migration Rates Preservation Model.* Another conceptualization of migration as an interregional interaction is put forward by Liaw and Rogers (1999) and Rogers et al. (2002). They compare observed or estimated interregional migration flow matrixes with a corresponding theoretically neutral migration flow matrix that allows for determining the “emissiveness” of sending regions (origins) and “attractiveness” of receiving regions (destinations) within that setting.[21] The migration transfer functions have been suggested explicitly or implicitly for internal migration. They merit further conceptual work and testing to assess their usefulness for international migration.

3.3.2. Main Scenario: Migration Projections Based on Harmonic Mean Adjustment

The interaction between sending and receiving regions may be modeled in a variety of ways. An interesting approach is to calculate the harmonic mean for the emigration and immigration rates for each pair of interacting regions. Although other, more complex approaches are possible, we want to demonstrate the principle by providing a solution that is simple and plausible. More ambitious and complex approaches would require additional information than is likely to be available for projections of international migration in a global context.

Further, the base assumption of constant emigration or immigration rates is only one among various possible and plausible assumptions. For rapidly growing populations, for instance, increasing emigration rates could be assumed. For the classic immigration countries, such as the United States, it seems plausible that eventually immigration rates may decline. Or an opposite scenario may happen, where existing diasporas in a country reinforce pull factors that result in an increasing immigration rate, triggered by an ever-growing population with migrant background.

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[19] For a discussion of consistency requirements, see Keilman (1985b), who notes that the harmonic mean solution satisfies, inter alia, the availability, monotonicity, homogeneity, and competition requirements.

[20] Schoen (2006, 190) explains the concept behind his *relative state attraction* method: "A simple behavioral notion is that some demographic states "attract" people while others "repel" them. If region R is experiencing economic prosperity, that region is apt to attract more immigrants and experience less out migration. While it clearly oversimplifies reality, the attraction/repulsion notion offers a plausible, behaviorally based criterion for adjusting demographic rates."

[21] We will not use that interesting concept in this paper, but may consider it at a later stage of modeling.

Given these considerations, we propose as our main scenario a projection based on harmonic mean adjustment (**hmean**). When analyzing the results of the migration projections generated under a harmonic mean adjustment, it is important to remember that the base assumptions—here, constant rates of emigration and immigration—describe the potential forces of emigration or immigration. Only after the adjustments through the harmonic mean have been carried out has the actual movement materialized.

The results of the multiregional projection with harmonic mean adjustment are shown in tables 16 and 17. As expected, this approach produces results that are between the two scenarios with constant immigration/emigration rates. In our opinion, the most important result is the greater plausibility of the results because of considering the interplay/interaction between the affected entities (here, world regions).

The results of the main scenario (**hmean**) confirm a global tendency of increasing migration flows. In our view, this makes the main scenario more plausible than other global scenarios.[22] The total amount of transregional migratory movements (emigration or immigration) could increase from about 20.7 million during 2005–10 to 28.5 million during 2095–2100.

Table 16: Emigrants and Immigrants, Harmonic Mean Adjustment (**hmean**)

Region	Emigrants			Immigrants		
	2005–10	2045–50	2095–2100	2005–10	2045–50	2095–2100
Africa	2,307,527	3,605,295	4,481,777	495,514	783,551	922,956
Asia	12,551,547	15,679,141	16,227,053	1,182,984	1,663,677	1,765,324
Europe	590,138	720,745	798,488	9,074,777	10,791,590	11,309,620
Latin America	3,025,598	3,837,352	3,923,497	310,494	402,398	410,746
Northern America	1,989,412	2,374,532	2,704,502	8,289,570	10,880,840	11,780,634
Oceania	250,602	334,222	406,677	1,361,485	2,029,231	2,352,712
World	20,714,824	26,551,287	28,541,993	20,714,824	26,551,287	28,541,993

In this main scenario (**hmean**), Asia is the world region with the largest number of transregional emigrants: between 2.5 million (2005–10) and 3.2 million people (projected for 2095–2100) leave Asia annually. Latin America is the world region with the second largest number of transregional emigrants during 2005–10 (0.6 million annually), but may rank third during 2095–2100 (0.8 million), as the number of emigrants from Africa is projected to increase from 0.5 million (2005–10) to almost 0.9 million on average every year by 2095–2100.

In the main scenario (**hmean**), immigration into Europe and Northern America increases over time. In Europe, the increase is from 1.8 million transregional immigrants annually during 2005–10 to a projected 2.3 million during 2095–2100; in Northern America, it is from 1.7 million to 2.4 million annually during the same period. More than 80 percent of all transregional immigrants are destined to these two world regions. In this scenario, Africa and Latin America attract only small numbers of immigrants during the whole projection period.

[22] For further details, see Buettner and Muenz (2016).

Table 17: Net Migration, Harmonic Mean Adjustment (**hmean**)

Region	2005–10	2045–50	2095–2100
Africa	-1,812,013	-2,821,744	-3,558,821
Asia	-11,368,563	-14,015,464	-14,461,728
Europe	8,484,639	10,070,845	10,511,133
Latin America	-2,715,104	-3,434,954	-3,512,751
Northern America	6,300,158	8,506,308	9,076,132
Oceania	1,110,883	1,695,009	1,946,035

3.4. Discussion

The migration scenarios calculated for this paper employ simple and straightforward assumptions. They only vary migration levels, and are all based on the same underlying fertility and mortality assumptions.

Keeping the number of emigrants per 1,000 population (**cemr**) or the number of immigrants per 1,000 population (**cimr**) or their absolute number (**cmig**) constant employs a transparent and plausible assumption. However, assuming constant migration rates might be plausible in the absence of an underlying socioeconomic scenario, but not necessarily realistic. For instance, Africa might experience higher emigration rates in the future, higher than those estimated for 2005–10. At the same time, increasing immigration rates in the United States, Canada, or Western Europe could be fueled by growing diasporas that enact strong pull effects, or explained by the growing attractiveness of countries based on additional demand for labor and skills. Similarly, declining immigration rates may be the result of restrictive government policies or a prolonged period of economic stagnation.

Thus, the assumption of constant rates was chosen to illustrate and justify the suggested inclusion of an interaction device in multiregional models. This novel methodological approach, which is exemplified in the main scenario, can cope with increasing and declining immigration, as well as fluctuating rates, which may be the result of restrictive policies. The harmonic mean adjustment approach is flexible enough to incorporate a wide range of plausible narratives about future migration trends. The trends do not need to be set in a mechanistic way. In our view, this “compromise” between the sending and receiving perspectives (the harmonic mean) is fully transparent.

Under the settings of the scenarios, the only factors driving the level and age composition of future migration are the projected population dynamics between 2015 and 2100. Fertility and mortality are not directly affected.[23] Yet, the migration trajectories calculated with these scenarios are identical. Comparing the aggregated effect of the three main scenarios on net migration (table 18; figures B.4 and B.5 in annex B), Africa would see a significant decline in net emigration and Europe a comparable decline in net immigration, should pull factors prevail (constant immigration rates) or the harmonic mean adjustment come to bear. In the case of Oceania, these pull factors (**cimr**) would lead to significantly greater immigration. The three other world regions would experience net migration levels roughly like the ones estimated for 2005–10.

[23] The latter should be considered in future migration projection modeling, as migrants might have fertility and mortality patterns that differ from those of the sending and receiving societies. Ongoing research by KNOMAD’s Thematic Working Group "Data on Migration and Demographic Changes" aims at identifying such differences. See: https://www.knomad.org/thematic-working-group-single/1.

Table 18: Net Migration, by Projection Scenario, 2045–50

Region	Scenario		
	Constant emigration rate (**cemr**)	Constant immigration rate (**cimr**)	Harmonic mean (**hmean**)
Africa	-4,926,752	-1,488,263	-2,821,744
Asia	-13,962,626	-14,375,873	-14,015,464
Europe	12,607,804	8,336,208	10,070,845
Latin America	-3,556,215	-3,364,335	-3,434,954
Northern America	8,459,030	8,678,108	8,506,308
Oceania	1,378,758	2,214,154	1,695,009
Total emigration	0	0	0

The projected trajectories produced by the scenarios analyzed in this paper have different impacts on future population size and dynamics. For world regions that are net receivers of migrants and at the same time have low fertility (Europe, Northern America, and Oceania), migration shapes future population trends markedly. Without migration, Europe would experience a significant population decline, between 225 million and 340 million fewer inhabitants in 2100 (compared with the 2005–10 zero migration scenario). The continued net immigration implied in the scenarios for Europe would help maintain current population size (**cimr**) or produce a moderate increase, to about 875 million people (plus 20 percent, **cemr**; see figure B.1 in annex B).

Northern America and Oceania would keep their current population even in the absence of any migration (**mzero**), as fertility in both world regions is not below replacement level. In addition, both regions would continue to grow, due to the projected migration gains under all the non-zero scenarios. The other three world regions show much less impact from migration.

For the world, all the migration scenarios have only a very small impact on future population size. This is plausible because the different migration streams between the six world regions must balance at the world level. The small difference in population size is attributable to mortality and fertility differences between the regions from which migrants emerge and regions that admit migrants.

Projecting migration in gross flows allows calculating the indicator of gross migration or migration volume. Gross migration or migration volume is defined as the sum of emigration and immigration, counting the totality of migratory moves irrespective of the direction of migration. The migration volume for the world is composed of equal numbers of emigrants and immigrants; that is, global gross migration is twice the number of those moving across international boundaries. For individual regions or countries, emigration and immigration are not necessarily balanced.

The gross migration figure for the spatial configuration presented here is about 41.4 million transregional migratory moves crossing the boundaries of the six world regions for the base period of 2005–10. Driven by the implied demographic dynamics of the medium-projection variant of the United Nations, gross migration volume increases to about 64 million by 2095–2100 for constant emigration rates or constant immigration rates, and to 57 million transregional migratory moves during 2095–2100 for the interaction scenario calculated with the harmonic mean adjustment. This calculation is for the aggregate six world areas, which cover 196 countries; the calculation excludes migratory movements between countries within these six world regions.[24]

Although the number of migratory moves (for example, gross migration or migration volume) between the six world regions is similar for the **cemr** and **cimr** scenarios, the two scenarios differ markedly in the spatial allocation of migration flows. The **cemr** scenario is calculated with a constant spatial allocation of emigrants (constant emigration ratios; table 8); the **cimr** scenario is calculated with a constant spatial allocation of immigrants (immigration rates; table 9).

Put differently, the supply-side **cemr** scenario will generate migrants according to the (measured or estimated) emigration rates of 2005–10 kept constant and the changing demographic dynamics of the sending regions. This will result in changing numbers of immigrants in the receiving regions *and* a changing spatial distribution of those immigration flows. In the demand-side **cimr** scenario, the reverse happens: the number of immigrants is driven by the demographic dynamics of the six-region system with the (measured or estimated) immigration rates of 2005–10 kept constant. Under these assumptions, emigration changes according the immigration “demands" and not the changing demographic settings (total population size) of the sending regions.

In the scenario with constant emigration rates (**cemr**), the composition of immigrants for the three net receiving world regions of migrants—Europe, Northern America, and Oceania—will change significantly (tables 9 and 19). The share of immigrants received in Europe will shift more to African origins, which would more than double its share between 2005–10 and 2095–2100, from 15 to 36 percent. A similar trend emerges for Northern America, which would experience a tripling of the share of African immigrants, from 5 to 16 percent. Oceania would also see a significant change in the share of immigrants from Africa, from 6 to 19 percent. As the proportion of African immigrants increases, the percentage of immigrants into the three world regions from Asia declines, but remains at a high level.

Table 19: Immigration Ratios for Six World Regions, Constant Emigration Rates (**cemr**), 2095–2100

Destination	Origin						Total
	Africa	Asia	Europe	Latin America	Northern America	Oceania	
Africa	0	52	29	2	16	2	100
Asia	68	0	9	3	17	3	100
Europe	36	41	0	6	14	3	100
Latin America	5	14	3	0	77	1	100
Northern America	16	61	1	22	0	1	100
Oceania	19	69	7	1	4	0	100

The scenario with constant immigration rates (**cimr**) implies that the rate of immigration and the corresponding spatial allocation of immigrants are kept at the levels of 2005–10. Consequently, the spatial allocation of emigrants will change (tables 8 and 20).

Taking Europe, with its declining native population, as an example, the projections show a decline in the share of people migrating to Europe from the five other world regions. The proportions of people

[24] The total number of migratory moves between all 196 countries would be much larger. For the base period of 2005–10, the gross migration figure for the 196 countries is about 89 million. This amounts to a volume of about 17.8 million migratory moves per year during 2005–10.

emigrating from Africa, Asia, and Latin America (all net sending regions) to Europe all decline between 2005–10 and 2095–2100, from 57 to 46 percent for Africa, from 43 to 27 percent for Asia, and from 28 to 18 percent for Latin America.

Table 20: Emigration Ratios for Six World Regions, Constant Immigration Rates (**cimr**), 2095–2100

	Origin					
Destination	Africa	Asia	Europe	Latin America	Northern America	Oceania
Africa	0	6	46	1	11	6
Asia	20	0	20	2	15	14
Europe	46	27	0	18	57	60
Latin America	0	0	1	0	11	1
Northern America	24	49	9	77	0	19
Oceania	9	18	24	1	6	0
Total	100	100	100	100	100	100

The projections also show the aging of migrants, which is driven completely by the aging of populations, taking place even with constant model age patterns of migrants. Figure B.8 in annex B depicts the trends in the median age of migrants for each world region, for emigrants and immigrants. There is a clear trend for most world regions in the aging of migrants. Only emigrants from Europe and Northern America and immigrants into Latin America maintain their age composition over the projection period. Depending on each region's current and future population age composition, emigrants and immigrants differ in their age composition, but tend to converge eventually. Emigrants from Africa, for instance, are significantly younger than the immigrants the region receives. The situation is somewhat reversed in Europe, which receives immigrants who are younger than the emigrants leaving the region. These differences are attributable to the age composition of the regions' populations.

4. Outlook and Suggestions

This paper explores simple, yet novel approaches and techniques for modeling international migration in population projections, including sending and receiving regions, in a multiregional projection framework that is demonstrated for a system of six world regions. The approach lays the groundwork for a next step: preparing projections for other aggregates and finally extending coverage to all relevant countries. In addition, several extensions and variations may be discussed.

The direction of our practical proposals is clear: we would like to see population projections based not only on better empirical data, but also on more realistic assumptions for future migration.

- *Differentiate between different types of migration.* Distinguishing different types of migration flows, such as permanent migration, circular labor migration, refugee movements, and so forth, would increase the analytical power of the migration projections. Each migration type may be modeled with its own age and temporal characteristics, with refugee movements being the most difficult to anticipate.
- *Investigate the evolution of spatial patterns of migration and reduce complexity.* Empirical analysis has shown that migration systems are relatively stable in the dominant corridors along which migrants move. It would be useful to investigate more fully the spatial structure of migration and identify stable patterns. This information could be used to reduce the complexity of the multiregional model, by

shrinking the state space to the most important actors. Reducing complexity will also help to communicate better the main trends for the future.

- *Implement specific population segments as factors determining international migration.* We suggest linking the supply and demand of migration not just to the total population, but to segments of the population, such as the number or proportion of working-age people. Calculation of labor force replacement migration scenarios is also a promising option.
- *Link migration flows to existing migrant stocks.* The migration flow estimates utilized in this paper were derived from large collections of migrant stock data. It may be interesting to turn the migration projections into a tool that also projects migrant stocks into the future.[25]
- *Introduce covariates.* It should be possible to include covariates to make the migration component of the multiregional model more powerful.[26] Such an avenue would require projecting into the future the covariates that were selected, to determine the amount or distribution of future migration flows. The close relationship between migration gains or losses and the level of gross national product or gross national income (GNI) per capita suggests that scenario-based assumptions for future economic growth should be incorporated into the model. Countries with low levels of GNI per capita are predominantly sending countries with a negative migration balance; most high-income countries are on the receiving end. The migration projections could then be used to investigate the following question: how could the international migration matrix be affected by changes in the level and distribution of GNI per capita?
- *Consider uncertainty.* The credibility and utility of global migration projections might benefit from opening the model to temporary fluctuations created by external or internal shocks. Broadly, such "shocks" could be making significant changes in migration quota policies, opening alternative, or closing traditional migration routes, declining economic opportunities related to the exhaustion of natural resources, rapid climate change, dramatic political changes, and similar shifts.[27]

[25] For an attempt, see Bohk (2012) and ongoing work in KNOMADs Thematic Working Group "Data on Migration and Demographic Changes."
[26] See Willekens (2008).
[27] For discussion, see Walmsley, Winters, and Ahmed (2007), Chang Seng and Birkman (2011), Foresight (2011), and Bijak (2011, 137–52).

Annex A. Tables

Table A. 1: Economies and World Regions

ISO	Economy or area	ISO	Economy or area	ISO	Economy or area
	Africa				
12	Algeria	266	Gabon	566	Nigeria
24	Angola	270	Gambia, The	638	Réunion
204	Benin	288	Ghana	646	Rwanda
72	Botswana	324	Guinea	678	São Tomé and Príncipe
854	Burkina Faso	624	Guinea-Bissau	686	Senegal
108	Burundi	404	Kenya	694	Sierra Leone
120	Cameroon	426	Lesotho	706	Somalia
132	Cabo Verde	430	Liberia	710	South Africa
140	Central African Republic	434	Libya	728	South Sudan
148	Chad	450	Madagascar	729	Sudan
174	Comoros	454	Malawi	748	Swaziland
178	Congo, Rep.	466	Mali	768	Togo
384	Côte d'Ivoire	478	Mauritania	788	Tunisia
180	Congo, Dem. Rep.	480	Mauritius	800	Uganda
262	Djibouti	175	Mayotte (Fr)	834	Tanzania
818	Egypt, Arab Rep.	504	Morocco	732	Western Sahara
226	Equatorial Guinea	508	Mozambique	894	Zambia
232	Eritrea	516	Namibia	716	Zimbabwe
231	Ethiopia	562	Niger		
Asia					
4	Afghanistan	364	Iran, Islamic Rep.	608	Philippines
51	Armenia	368	Iraq	634	Qatar
31	Azerbaijan	376	Israel	410	Korea, Rep.
48	Bahrain	392	Japan	682	Saudi Arabia
50	Bangladesh	400	Jordan	702	Singapore
64	Bhutan	398	Kazakhstan	144	Sri Lanka
96	Brunei Darussalam	414	Kuwait	275	West Bank and Gaza
116	Cambodia	417	Kyrgyzstan	760	Syrian Arab Republic
156	China	418	Lao PDR	762	Tajikistan
344	Hong Kong SAR, China	422	Lebanon	764	Thailand
446	Macao SAR, China	458	Malaysia	626	Timor-Leste
158	Taiwan, China	462	Maldives	792	Turkey
196	Cyprus	496	Mongolia	795	Turkmenistan
408	Korea, Dem. People's Rep.	104	Myanmar	784	United Arab Emirates
268	Georgia	524	Nepal	860	Uzbekistan
356	India	512	Oman	704	Vietnam
360	Indonesia	586	Pakistan	887	Yemen, Rep.
Europe					
8	Albania	300	Greece	498	Moldova
40	Austria	348	Hungary	642	Romania
112	Belarus	352	Iceland	643	Russian Federation
56	Belgium	372	Ireland	688	Serbia
70	Bosnia and Herzegovina	380	Italy	703	Slovak Republic
100	Bulgaria	428	Latvia	705	Slovenia
830	Channel Islands	440	Lithuania	724	Spain
191	Croatia	442	Luxembourg	752	Sweden
203	Czech Republic	470	Malta	756	Switzerland
208	Denmark	499	Montenegro	807	Macedonia, FYR
233	Estonia	528	Netherlands	804	Ukraine
246	Finland	578	Norway	826	United Kingdom
250	France	616	Poland		
276	Germany	620	Portugal		

Table A.1 *(continued)*

ISO	Economy or area	ISO	Economy or area	ISO	Economy or area
	Latin America and the Caribbean				
32	Argentina	218	Ecuador	558	Nicaragua
533	Aruba	222	El Salvador	591	Panama
44	Bahamas	254	French Guiana	600	Paraguay
52	Barbados	308	Grenada	604	Peru
84	Belize	312	Guadeloupe	630	Puerto Rico
68	Bolivia	320	Guatemala	662	Saint Lucia
76	Brazil	328	Guyana	670	Saint Vincent and the Grenadines
152	Chile	332	Haiti	740	Suriname
170	Colombia	340	Honduras	780	Trinidad and Tobago
188	Costa Rica	388	Jamaica	850	Virgin Islands (U.S.)
192	Cuba	474	Martinique	858	Uruguay
214	Dominican Republic	484	Mexico	862	Venezuela, RB
	Northern America				
124	Canada	840	United States		
	Oceania				
36	Australia	583	Micronesia, Fed. Sets.	882	Samoa
242	Fiji	540	New Caledonia	90	Solomon Islands
258	French Polynesia	554	New Zealand	776	Tonga
316	Guam	598	Papua New Guinea	548	Vanuatu

Table A. 2: Flows of People between World Regions, Constant Emigration Rates (**cemr**), 2045–50

Destination	Origin						Total Immigration	Net migration
	Africa	Asia	Europe	Latin America	Northern America	Oceania		
Africa	0	350,790	158,870	12,676	78,927	7,495	608,757	-4,926,752
Asia	1,193,427	0	261,778	115,690	416,843	63,110	2,050,848	-13,962,626
Europe	3,144,272	6,912,909	0	1,094,122	1,777,760	302,942	13,232,004	12,607,804
Latin America	14,814	74,533	13,421	0	308,317	2,508	413,593	-3,556,215
Northern America	978,387	7,261,940	79,109	2,727,676	0	57,471	11,104,582	8,459,030
Oceania	204,609	1,413,303	111,022	19,644	63,705	0	1,812,284	1,378,758
Total	5,535,509	16,013,474	624,200	3,969,808	2,645,552	433,526	29,222,069	0

Table A. 3: Flows of People between World Regions, Constant Emigration Rates (**cemr**), 2095–2100

Destination	Origin						Total Immigration	Net migration
	Africa	Asia	Europe	Latin America	Northern America	Oceania		
Africa	0	322,362	178,443	11,311	99,611	10,625	622,352	-9,228,111
Asia	2,123,600	0	293,372	103,278	525,183	89,372	3,134,805	-11,571,989
Europe	5,595,587	6,351,537	0	977,655	2,240,066	429,131	15,593,976	14,894,321
Latin America	26,362	68,465	15,027	0	388,172	3,551	501,577	-3,043,749
Northern America	1,740,897	6,666,996	88,580	2,435,545	0	81,356	11,013,374	7,680,148
Oceania	364,017	1,297,433	124,233	17,537	80,195	0	1,883,415	1,269,380
Total	9,850,463	14,706,794	699,655	3,545,326	3,333,226	614,035	32,749,498	0

Table A. 4: Flows of People between World Regions, Constant Immigration Rates (**cimr**), 2045–50

Destination	Origin: Africa	Asia	Europe	Latin America	Northern America	Oceania	Total Immigration	Net migration
Africa	0	664,548	363,200	23,397	143,537	10,492	1,205,173	-1,488,263
Asia	636,244	0	315,893	112,449	400,059	46,611	1,511,256	-14,375,873
Europe	1,349,674	5,564,723	0	855,703	1,373,767	180,140	9,324,007	8,336,208
Latin America	8,162	77,144	16,694	0	304,955	1,910	408,865	-3,364,335
Northern America	542,406	7,548,378	99,282	2,754,183	0	44,134	10,988,384	8,678,108
Oceania	156,949	2,032,336	192,729	27,469	87,958	0	2,497,441	2,214,154
Total	2,693,435	15,887,129	987,799	3,773,200	2,310,275	283,287	25,935,126	0

Table A. 5: Flows of People between World Regions, Constant Immigration Rates (**cimr**), 2095–2100

Destination	Origin: Africa	Asia	Europe	Latin America	Northern America	Oceania	Total Immigration	Net migration
Africa	0	1,207,388	663,561	42,347	261,927	19,085	2,194,309	-740,927
Asia	578,086	0	287,805	101,754	364,139	42,311	1,374,094	-19,003,463
Europe	1,358,244	5,594,319	0	858,346	1,384,827	181,114	9,376,850	7,937,176
Latin America	7,231	68,259	14,817	0	270,447	1,690	362,443	-4,294,524
Northern America	712,943	9,904,441	130,739	3,605,932	0	57,923	14,411,978	11,974,278
Oceania	278,733	3,603,150	342,752	48,588	156,361	0	4,429,584	4,127,460
Total	2,935,236	20,377,557	1,439,674	4,656,967	2,437,700	302,124	32,149,258	0

Table A. 6: Flows of People between World Regions, Harmonic Mean Adjustment (**hmean**), 2045 –50

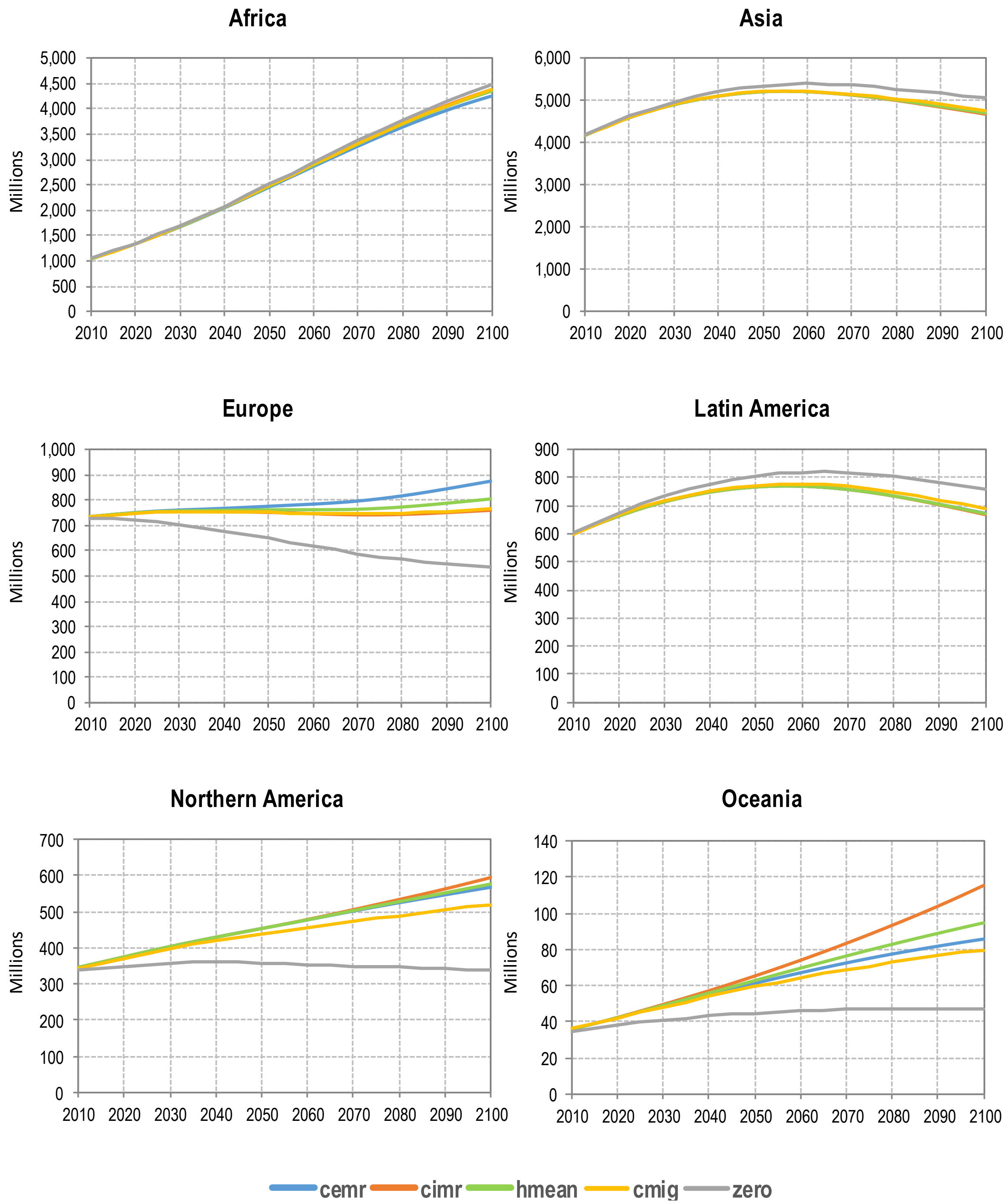
Destination	Origin: Africa	Asia	Europe	Latin America	Northern America	Oceania	Total Immigration	Net migration
Africa	0	451,110	209,844	16,726	97,386	8,486	783,551	-2,821,744
Asia	824,809	0	276,480	114,939	395,138	52,311	1,663,677	-14,015,464
Europe	1,901,192	6,185,908	0	967,124	1,514,901	222,463	10,791,590	10,070,845
Latin America	10,822	78,688	14,406	0	296,343	2,138	402,398	-3,434,954
Northern America	695,052	7,335,622	85,601	2,715,742	0	48,824	10,880,840	8,506,308
Oceania	173,419	1,627,813	134,414	22,821	70,764	0	2,029,231	1,695,009
Total	3,605,295	15,679,141	720,745	3,837,352	2,374,532	334,222	26,551,287	0

Table A. 7: Flows of People between World Regions, Harmonic Mean Adjustment (**hmean**), 2095–00

Destination	Origin: Africa	Asia	Europe	Latin America	Northern America	Oceania	Total Immigration	Net migration
Africa	0	497,606	253,653	18,122	139,657	13,917	922,956	-3,558,821
Asia	909,721	0	273,013	103,284	421,580	57,726	1,765,324	-14,461,728
Europe	2,286,134	6,085,751	0	938,426	1,733,924	265,384	11,309,620	10,511,133
Latin America	11,773	70,817	14,044	0	311,787	2,325	410,746	-3,512,751
Northern America	991,016	7,785,495	97,788	2,839,011	0	67,324	11,780,634	9,076,132
Oceania	283,132	1,787,383	159,989	24,654	97,554	0	2,352,712	1,946,035
Total	4,481,777	16,227,053	798,488	3,923,497	2,704,502	406,677	28,541,993	0

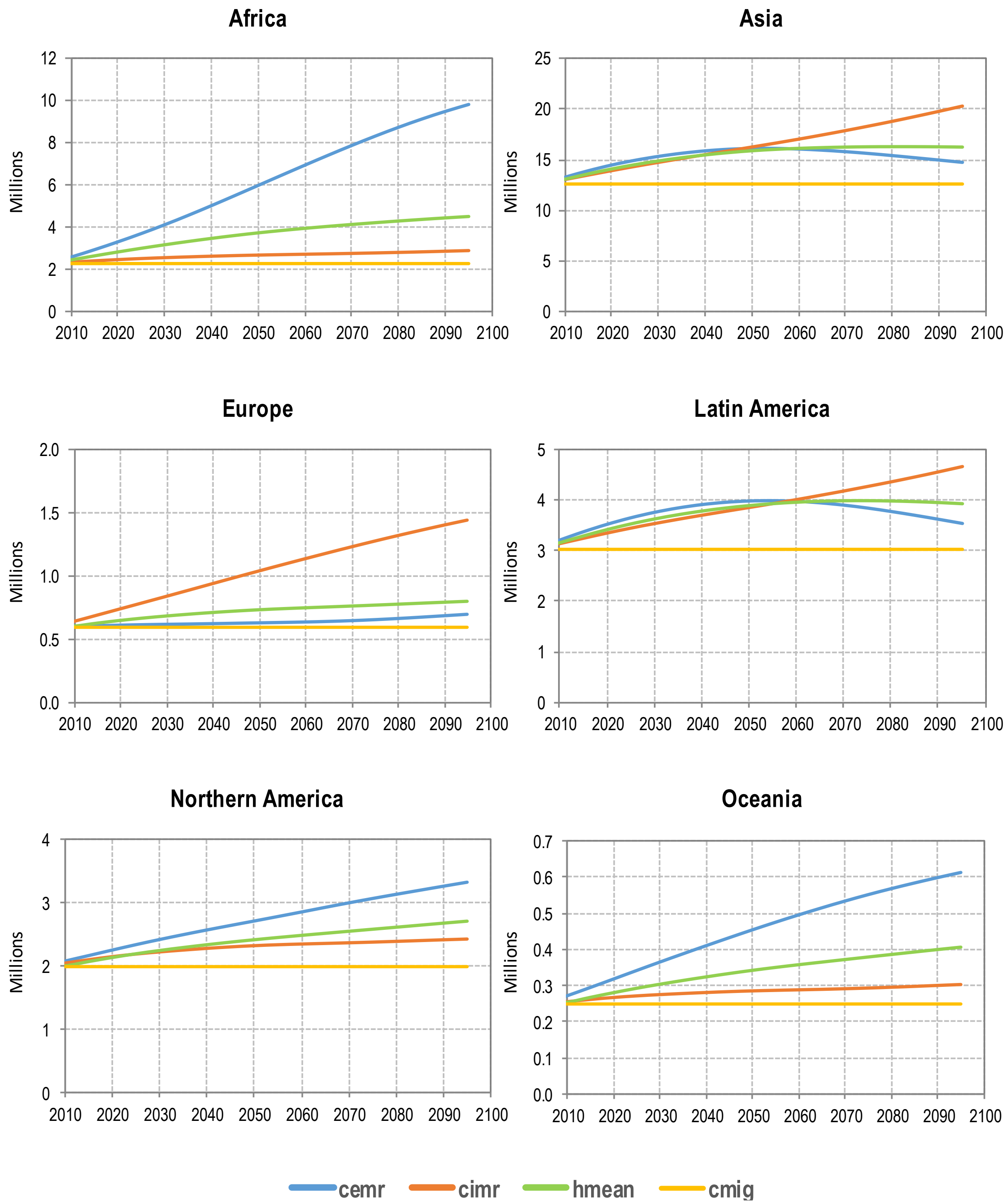
Annex B. Figures

Figure B.1: Total Population, by Migration Scenario and World Region, 2005–2100



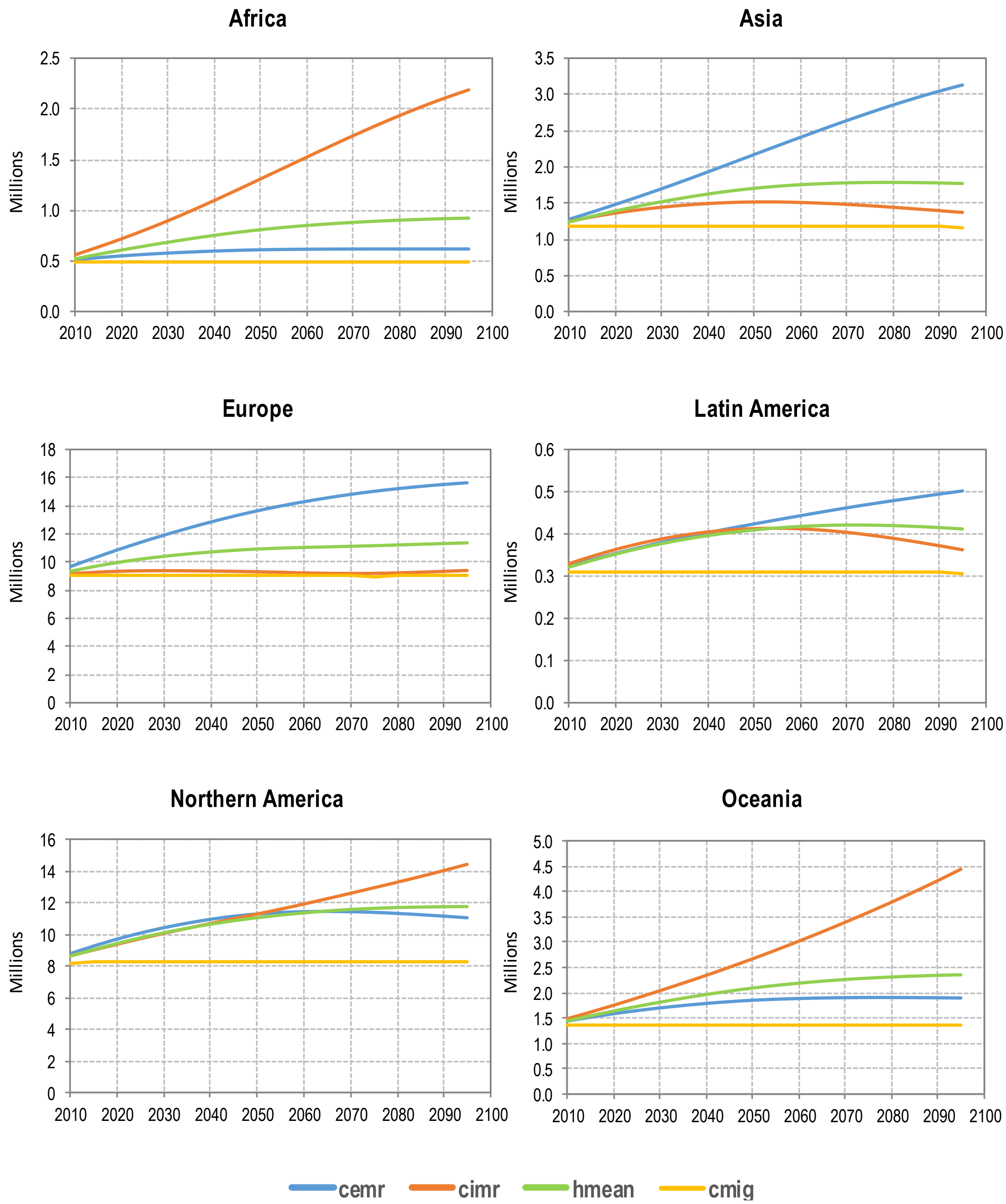
Note: **cemr** = constant emigration rates; **cimr** = constant immigration rates; **cmig** = constant total migration; **hmean** = harmonic mean adjustment; **zero** = zero migration.

Figure B.2: Total Emigrants, by Migration Scenario and World Region, 2005–2100



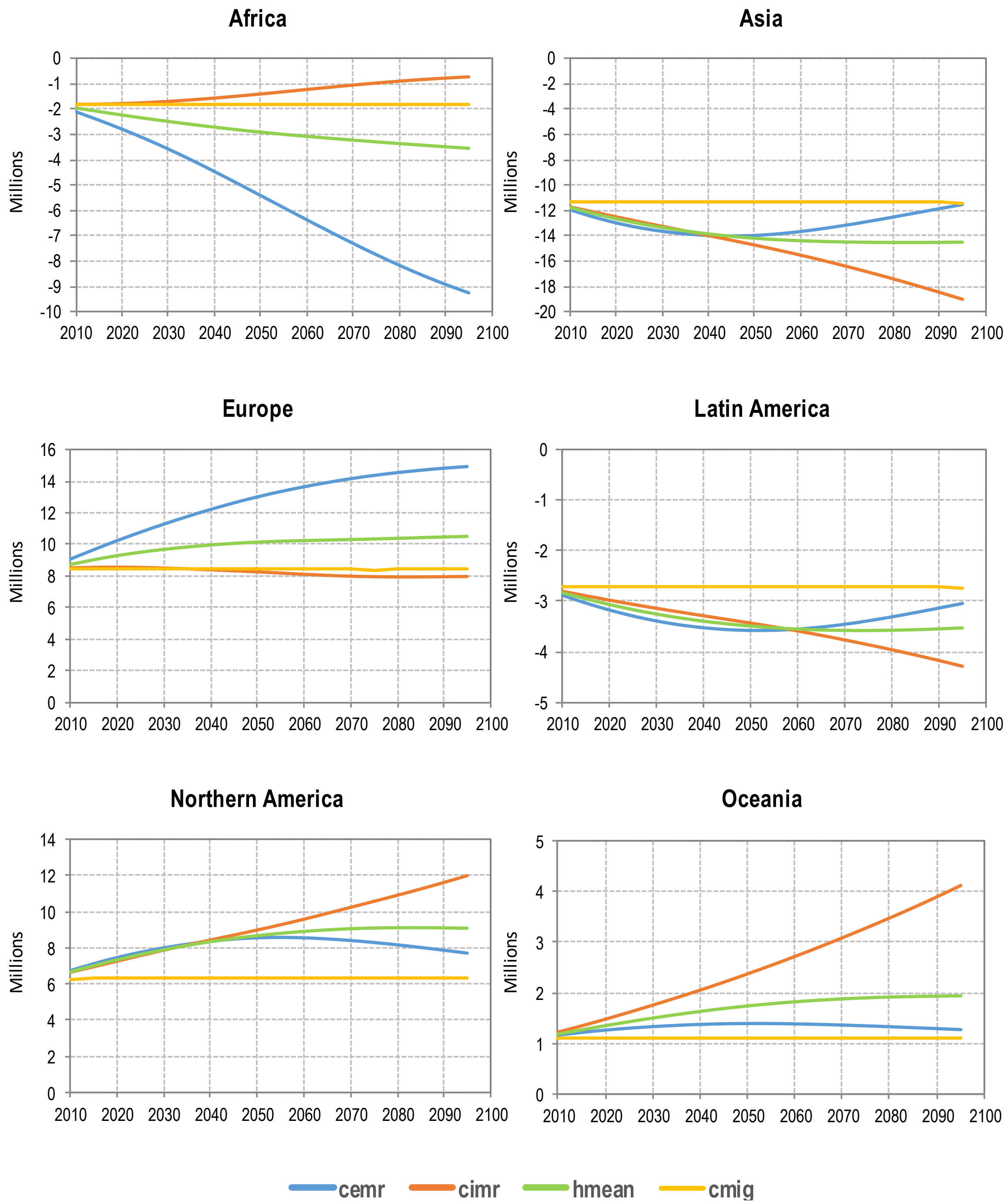
Note: **cemr** = constant emigration rates; **cimr** = constant immigration rates; **cmig** = constant total migration; **hmean** = harmonic mean adjustment.

Figure B.3: Total Immigrants, by Migration Scenario and World Region, 2005–2100



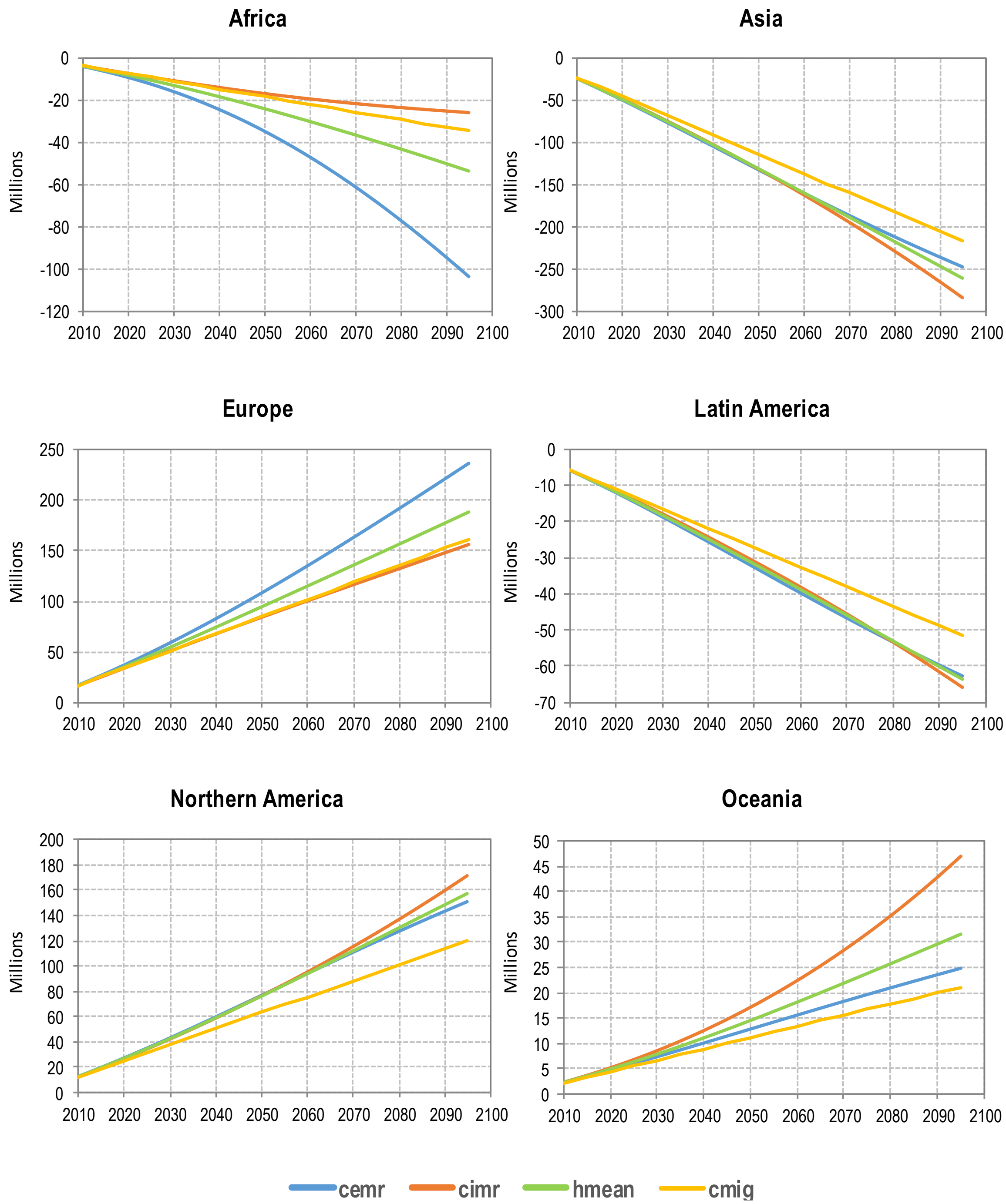
Note: **cemr** = constant emigration rates; **cimr** = constant immigration rates; **cmig** = constant total migration; **hmean** = harmonic mean adjustment.

Figure B.4: Net Migration, by Migration Scenario and World Region, 2005–2100



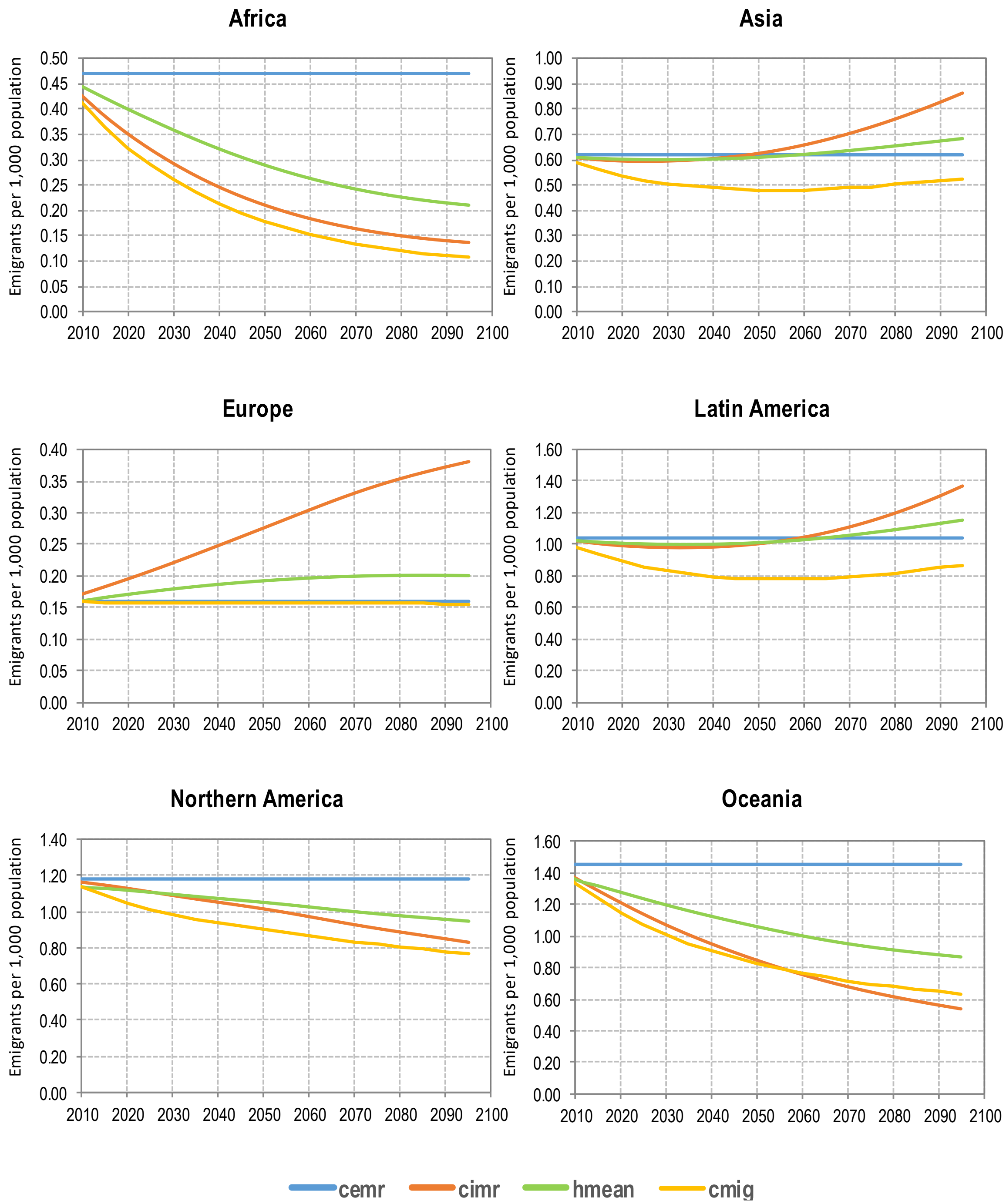
Note: **cemr** = constant emigration rates; **cimr** = constant immigration rates; **cmig** = constant total migration; **hmean** = harmonic mean adjustment.

Figure B.5: Cumulated Net Migration, by Migration Scenario and World Region, 2005–2100



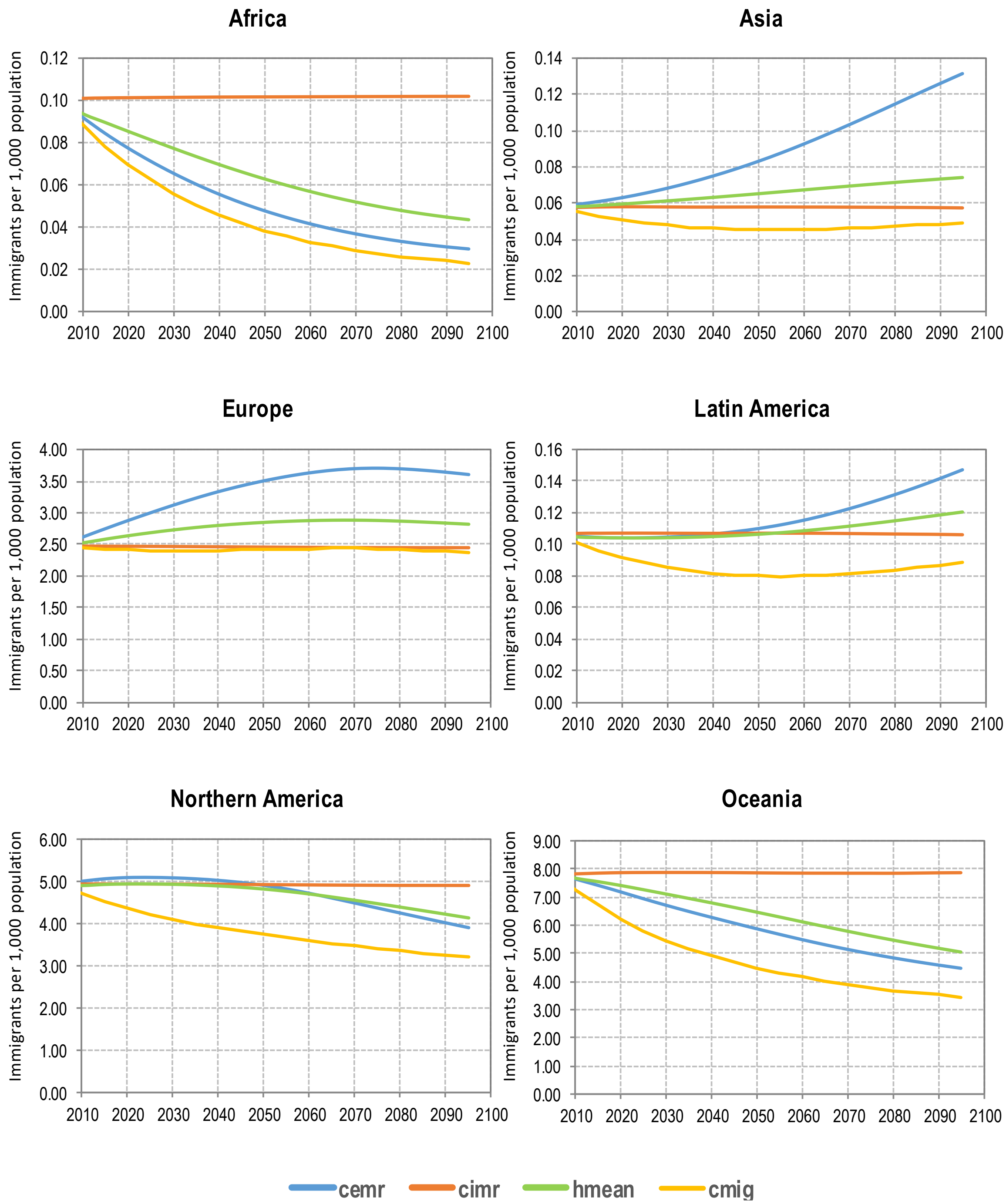
Note: **cemr** = constant emigration rates; **cimr** = constant immigration rates; **cmig** = constant total migration; **hmean** = harmonic mean adjustment.

Figure B.6: Crude Emigration Rate, by Migration Scenario and World Region, 2005–2100



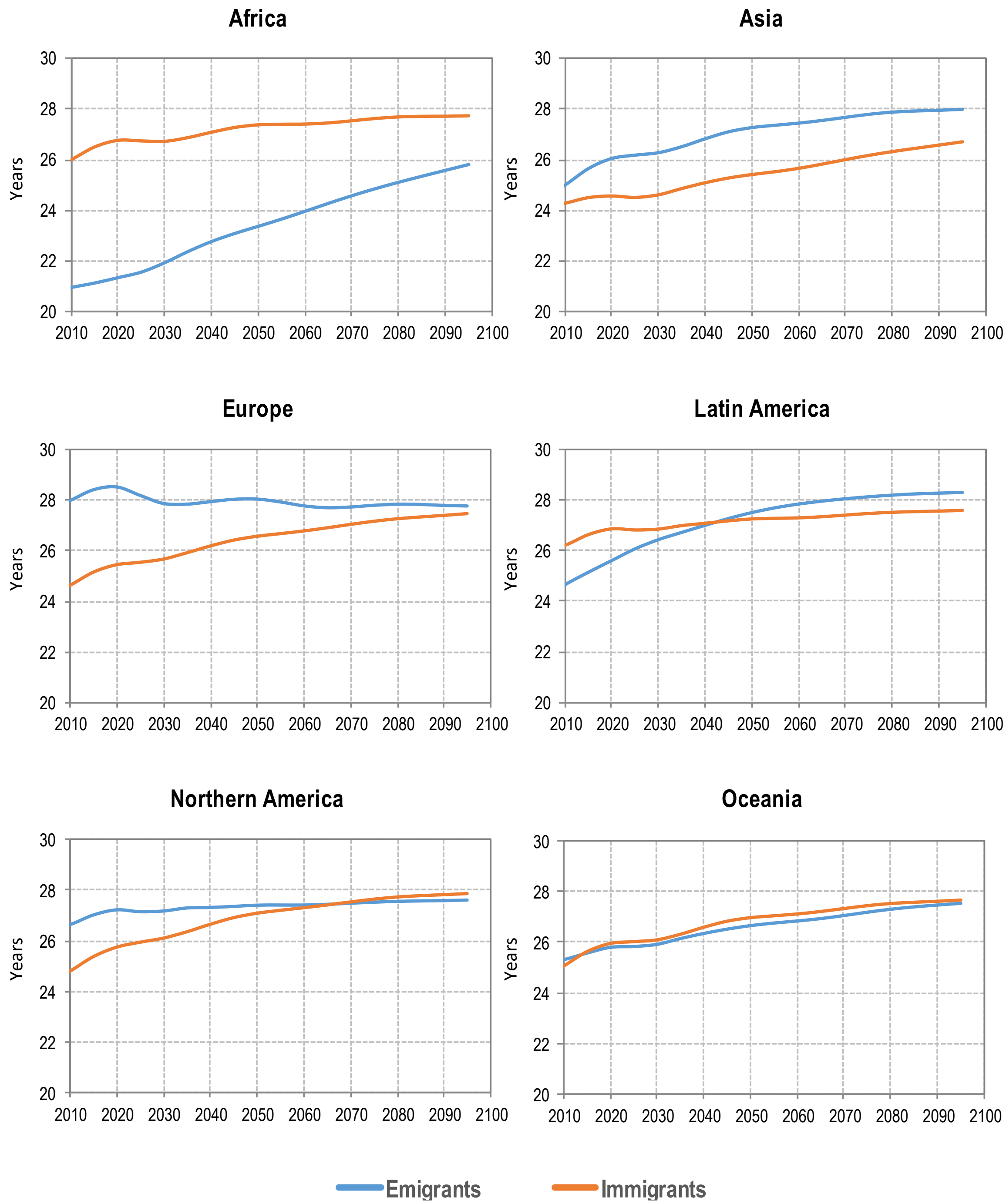
Note: **cemr** = constant emigration rates; **cimr** = constant immigration rates; **cmig** = constant total migration; **hmean** = harmonic mean adjustment.

Figure B.7: Crude Immigration Rate, by Migration Scenario and World Region, 2005–2100



Note: **cemr** = constant emigration rates; **cimr** = constant immigration rates; **cmig** = constant total migration; **hmean** = harmonic mean adjustment.

Figure B.8: Median Age of Emigrants and Immigrants, by World Region, 2005–2100



Note: Median age trends are taken from the harmonic mean (**hmean**) scenario. All other scenarios produced similar figures and therefore are not shown.

Annex C. Mathematics of Multiregional Migration Modeling

C.1 Operationalizing Multiregional Migration Assumptions

The multiregional demographic model (Rogers 1967, 1968, 1995, 2008; Willekens and Rogers 1978; Rogers and Willekens 1986; Schoen 1988, 2006) extends the classical approach of analyzing and projecting population beyond single, independent populations.[28] Rogers (2008, 279) notes that the multiregional approach not only considers population as an interacting system of populations, but also it "... employs rates of flow that refer to the appropriate at-risk populations..." This paper extends the notion of interacting populations by a reformulation of what the population at risk is in the case of migration.

We first introduce the classical formulation of migration flow rates as occurrence/exposure rates. It is important that migration in multiregional models is implemented exclusively as emigration. This allows the combination of all moves out of a region/state into one survivor proportion that moves the population forward. In a multiregional model, these moves are deaths (leaving the system to an absorbing state) and emigration (for example, moving out of a region and entering another one). In this model, immigration, such as moves into a region, is implicit.

Age-Specific Migration Rates

The multiregional demographic model requires all components of change to be specified as age-specific occurrence/exposure rates. Age-specific emigration rates from region i (i = 1…m) are denoted by the symbol $e_i(x)$ and calculated by dividing emigrants from region i at age x by the at-risk population[29] in region i at age x:

$$e_i(x) = \frac{E_i(x)}{K_i(x)} \qquad \text{(C.1)}$$

The $e_i(x)$ is then the total exit rate by migration from region i at age x. This definition of the age-specific emigration rate does not consider the destination of the moves out of region i. A more comprehensive treatment that includes origin and destination is introduced separately.

The definition of the age-specific emigration rate resembles the definition of the age-specific fertility rate (*tfr*) for region i, with births to mothers at age x replaced by emigration events at age x. This analogy and that migration, as fertility, is a repeatable event yield an easy way to summarize the level of mobility in a summary indicator called the gross migraproduction rate.

Gross Migraproduction Rate

The gross migraproduction rate (*gmr*) is the area under the curve of age-specific migration rates, which is approximated by summing the age-specific emigration rates for a region (Rogers 1995, 193). Like the *tfr*, it measures how many events may occur over a lifetime, here, outmigration per person. The

[28] The multiregional model has been generalized to a multistate model, with the concept of movements between different geographical locations extended to include states such as marital status, health status, and so forth.
[29] For the sake of simplicity and readability, we denote the population at risk of emitting or admitting migrants by the symbol K and omit reference to the reference period. The at-risk population is captured as person-years lived during the period under study.

migraproduction rate for all outmigration events from region i is calculated by summing all the age-specific emigration rates, multiplied by the scaling factor n, the width of the age groups.[30]

$$gmr_i = n \sum_x e_i(x) \tag{C.2}$$

Proportionate Age-Specific Emigration Pattern

By dividing the age-specific emigration rates by the level of emigration (*gmr*), we obtain a level-independent proportionate age schedule of emigration,[31] ($ms_i(x)$). As the proportionate age-specific emigration rates are level independent, they sum to unity.

$$ms_i(x) = \frac{e_i(x)}{n \sum_x e_i(x)} = \frac{e_i(x)}{gmr_i}$$
$$\sum_x ms_i(x) = 1.0 \tag{C.3}$$

Finally, the age-specific migration rate from region i may be expressed as the product of the gross migraproduction rate of region i and the corresponding proportionate age pattern in region i:

$$e_i(x) = gmr_i \cdot ms_i(x) \tag{C.4}$$

The model migration schedules—mathematical formulations of representative age profiles of migration—are formulated as proportionate age-specific migration rates (Rogers and Castro 1981, 1986). For a reformulated calculation scheme of such model schedules, see annex C.4.

Spatial Structure of Emigration

Thus far, we have distinguished total emigration from a region to all other destination regions. We now add the spatial structure of a fully specified migration system, by referring explicitly to the destination regions, denoted by the subscript *j* (j = 1…m).

$$e_{ij}(x) = \frac{E_{ij}(x)}{K_i(x)} \tag{C.5}$$

All emigration events from region *i* to regions *j* share the same population at risk of region i. As suggested by Rogers, Willekens, and Raymer (2001), Rogers, Raymer, and Willekens (2002), Rogers et al. (2002), and Willekens (2005a, 2005b, 2008), this allows us to separate the level of migration from its spatial distribution, a step that will be important for the modeling approach. We first calculate the proportions of emigrants from region i moving to region *j* by dividing migrants from region i to *j* by the total number of emigrants from region i:

$$d_{ij}(x) = \frac{E_{ij}(x)}{E_i(x)} \tag{C.6}$$

[30] The scaling factor is omitted in some of the later formulas.
[31] For scaling the migration age patterns to unity, the factor n is omitted.

The spatial distribution proportions sum to unity for each region i.

$$\sum_j d_{ij}(x) = 1.0$$

A simple rearrangement expresses the emigrants from i to j as the product of the total emigrants from region i and the spatial distribution proportions:

$$E_{ij}(x) = d_{ij}(x) * E_i(x) \quad \text{(C.7)}$$

Inserting equation C.7 into equation C.5 yields a corresponding expression for crude emigration rates.

$$e_{ij}(x) = \frac{d_{ij} \cdot E_i(x)}{K_i(x)}; i \neq j \quad \text{(C.8)}$$

Age-Specific Emigration Rates Reformulated

We can now express the age-specific rate of emigration from region i to region j $e_{ij}(x)$, as the combination of the generating component $e_i(x)$ and the distributing component $d_{ij}(x)$:

$$e_{ij}(x) = d_{ij}(x) \cdot e_i(x) \quad \text{(C.9)}$$

Recalling the definition of the age-specific emigration rate as the product of the gross migraproduction rate and the proportionate age schedules of migration, we arrive at a composite formula for the age-specific emigration rate as composed of a distributional term $d_{ij}(x)$, a level term gmr_i and an age pattern term $ms_i(x)$:

$$e_{ij}(x) = d_{ij} \cdot gmr_i \cdot ms_i(x) \quad \text{(C.10)}$$

Formulating the migration component of the multiregional model as the product of a level term, an age-schedule term,[32] and a spatial distribution term bears promising potential for developing better migration assumptions for future migration projections by also modeling the spatial allocation of migrants.

We proceed to formulate a simplified projection model that employs the level component of the migration rates as the dynamic part, while keeping constant the age patterns (*ms*) and spatial distribution (*d*). In the component formula for the age-specific emigration rates, the reference period is denoted by a star symbol and the index T is assigned to denote a (future) period. The age-specific emigration rate for a period in the future is then

$$e_{ij}^T(x) = d_{ij}^* \cdot gmr_i^T \cdot ms_i^*(x) \quad \text{(C.11)}$$

The age-specific emigration rates $e_{ij}^T(x)$ for period T are the required input for the multiregional projection model, depending only on the level component gmr_i. It is entirely possible to let the spatial distribution or age schedule vary between regions and across time. However, considering the very limited empirical evidence on the time series of migration flows and their age patterns, limiting our presentation

[32] The level and age-schedule terms are also called the generating term.

to a selected number of variables is reasonable and appropriate for showing the outlines of our modeling approach.

Migration Intensities versus Crude Rates

To formulate the migration assumptions, this paper suggests the use of crude rates or total migration figures. However, using crude rates or even total migration figures as a communication device must not compromise the formulation of the underlying projection model. The formulation of the multiregional model employs age-specific emigration intensities as driving forces. When one concept is used at the implementation level and another for formulating the projection assumptions, one needs to be translated into the other. This section develops the mathematics. For the sake of consistency and simplicity, we continue to assume that the spatial distribution and age patterns of emigrants are constant over time.

We observe that the crude emigration rate e_i of region i is proportional to the gross migraproduction rate gmr_i of that region:

$$gmr_i^T \approx e_i^T \tag{C.12}$$

We want to find an updating scheme that helps to update the reference gross migraproduction rate such that it produces the target crude emigration rate at the future period T:

$gmr_i^T = gmr_i^* \cdot f_i^T$, that is the (known) gmr_i^* of the base period multiplied with an update factor f_i^T. Rearranging, we find an expression for the update factor:

$$f_i^T = \frac{gmr_i^T}{gmr_i^*} \tag{C.13}$$

Because of the proportionality between e_i and gmr_i, we define a related updating factor $\tilde{f}_i^T$, which is the ratio between the target crude emigration rate e_i^T and the crude emigration rate in the base period e_i^*:

$$\tilde{f}_i^T = \frac{e_i^T}{e_i^*},\ \tilde{f}_i^T \approx f_i^T \tag{C.14}$$

As the updating factor for the crude emigration rate is proportional to the update factor for the gross migraproduction rate, we use the former in place of the latter. The projection for period T, from t to $t+n$, is repeated with updated values of *gmr* until the target and reference values of the crude emigration rates at period T have converged to the reference values, except for a very small number ε:

$$\left|e_i^T - e_i^*\right| < \varepsilon$$

There is another, strong reason for using iteration to arrive at the desired crude emigration rate: the calculations of the crude emigration rates and age-specific emigration rates have as their denominator the population at risk. However, the at-risk population, for example, the person-years lived during period T, is dependent on the migration component. As both elements are not known in advance, an iterative approach, which repeats projections and updates migration at any period T, allows the population at risk and selected migration indicator to converge to the desired values.

C.2 Modeling Origin-Destination Interaction

In a multiregional model, migration flows link regions of origin and destination. Each movement/flow out of one region must enter one or more destination regions. In classic migration analysis, a movement out of a region (origin) is called emigration, and a move into a region (destination) is called immigration. For clarity, we suggest keeping the term emigration for outmigration, but use admission instead of immigration in the following exposition. We posit that this change in terminology expresses more clearly the active role of the receiving region/country. In this way, we follow other authors who make similar proposals (Rees and Wilson 1977, 190; Rees, Lomax, and Boden 2015).

Rates of Emigration and Admission

To capture the interaction between place of origin (emigration) and place of destination (immigration or admission), we calculate corresponding rates of emigration and admission, respectively. The modeling of migration flows is based on the concept of total events or crude rates. We argue that communicating past developments and future trends of migration flows is easier in terms of population-based indicators, while person-based migration indicators, and especially the gross migraproduction rate, are relatively little known. Further, expressing the process of admission in person-based indicators seems to pose even more challenges.[33]

The emigration rate from region i to region j is defined by dividing the emigration from region i to region j by the population in region i:

$$e_{ij} = \frac{E_{ij}}{K_i} \tag{C.15}$$

Equivalently, the admission rate of people moving from region i to j is calculated by dividing the emigrants from i to j by the population of the receiving/admitting region j:

$$a_{ij} = \frac{E_{ij}}{K_j} \tag{C.16}$$

The two rates have the same numerator, but different denominators, which is a setting that will help in transforming one rate into the other.

Transforming Emigration Rates into Corresponding Admission Rates and Vice Versa

A person moving from one region to another is called an emigrant. The same person is called an immigrant in the region of destination. When dealing with the event, we speak of emigration and admission,

[33] The challenge lies in the plausibility of such an approach. Calculating age-specific rates of immigration, relating immigrants to the at-risk population of the destination region, is formally possible. But it would literally mean that each population age group of the destination region would somehow decide how many immigrants of the same age group it accepts or attracts. In other words, policy makers would consider separately matches between each age group of the resident population and the immigrants. We argue that, while formally correct, this is neither plausible nor practical.

respectively. It will be useful to switch the perspective from sending to receiving country and vice versa, because this allows addressing the two sides of the same event or flow. This is important for another reason: although the interaction between origin and destination is critically important for modeling the dynamics of (international) migration, it is still the origin that shapes the demographic characteristics of the people who are moving. In other words, when focusing on admission, the age and sex patterns of the people admitted are determined by the populations of the sending countries. Here, the transformation from admission to emigration enables treating admissions by the corresponding emigrations.

Fortunately, transforming the rates from one type to the other is straightforward. The two formulas for emigration and admission rates are only different in the denominator, so transforming them is achieved by multiplying the rates by the ratio of the population of the sending country to the population of the destination country and by the ratio of the population of the destination country to the sending country, respectively.

Translating admission rate into emigration rate	Translating emigration rate into admission rate
$a_{ij} = e_{ij} \cdot \frac{K_i}{K_j}$ (C.17)	$e_{ij} = a_{ij} \cdot \frac{K_j}{K_i}$ (C.18)

The transformation of emigration rates into admission rates and vice versa can be used to implement certain migration assumptions for population projections. One case, explored in this paper, is to formulate a migration trajectory that maintains constant admission rates for all future projection intervals. We still want to drive the migration by its corresponding emigration rates, thus relating the events (emigration turned into immigration) to the underlying population at risk. We add a reference to the period to the formulas, denoting the reference period with superscript *ref* and the target period with superscript T.

Assuming the constant admission rates of the reference period, the corresponding emigration rates at the target period T are obtained by multiplying the reference admission rate by the ratio of destination to origin population at period t (equation C.20).

Projecting admission rates based on constant emigration rate as of the reference period	Projecting emigration rates based on constant admission rate as of the reference period
$a_{ij}^{T} = e_{ij}^{ref} \cdot \frac{K_i^T}{K_j^T}$ (C.19)	$e_{ij}^{T} = a_{ij}^{ref} \cdot \frac{K_j^T}{K_i^T}$ (C.20)

This approach assumes the same spatial structure of emigration/immigration as in the reference period.

Harmonic Mean Adjustment

We develop the harmonic mean adjustment for a combined scenario of constant emigration and immigration rates. We begin by developing a harmonic mean adjustment of the total emigration and admission figures, followed by a corresponding formula for the migration/admission rates.

With constant emigration rates/admission rates and populations at risk in the target period T, the number of emigrants/admissions in period T can be calculated as follows:

Total number of admissions in target period T with constant admission rates of the reference period	Total number of emigrants in target period T with constant emigration rates of the reference period
$A_{ij}^{T} = a_{ij}^{ref} \cdot K_{j}^{T}$ (C.21)	$E_{ij}^{T} = e_{ij}^{ref} \cdot K_{i}^{T}$ (C.22)

Keeping emigration rates and admission rates constant and relating them to the projected populations at a future date, the identity between emigration and immigration (emigration and admission) no longer holds (except for the unlikely case in which all populations grow at the same rate): $A_{ij}^{T} \neq E_{ij}^{T}$. Instead, driven by the different demographic dynamics of the populations under study, increasingly different migration flows are produced by holding emigration rates or admission rates constant.

Bringing emigration and admission into balance, the harmonic mean[34] of each emigration-admission pair is calculated as follows:

$$H_{ij}^{T} = \frac{2 \cdot E_{ij}^{T} \cdot A_{ij}^{T}}{E_{ij}^{T} + A_{ij}^{T}} \qquad \text{(C.23)}$$

For a balanced interaction between immigration and emigration, equation C.23 may be further simplified to obtain a simple updating mechanism. We begin by expanding the expressions for total emigration and admissions in period T.

$$\begin{aligned} E_{ij}^{T} &= e_{ij}^{ref} \cdot K_{i}^{T} = \frac{E_{ij}^{ref}}{K_{i}^{ref}} \cdot K_{i}^{T} \\ &= E_{ij}^{ref} \cdot \frac{K_{i}^{T}}{K_{i}^{ref}} \end{aligned} \qquad \text{(C.24)}$$

The number of emigrants from region i to region j can thus be obtained by updating/multiplying the original migrants by the ratio of populations at i from the current period and the reference/base period.

For the total admission from i into j:

$$\begin{aligned} A_{ij}^{T} &= a_{ij}^{ref} \cdot K_{j}^{T} = \frac{E_{ij}^{ref}}{k_{j}^{ref}} \cdot K_{j}^{T} \\ &= E_{ij}^{ref} \cdot \frac{K_{j}^{T}}{K_{j}^{ref}} \end{aligned} \qquad \text{(C.25)}$$

Before we further simplify the consolidation formula, we define a new variable, the ratio between base and current population in region i:

$$r_{i}^{T} = \frac{K_{i}^{T}}{K_{i}^{ref}} \qquad \text{(C.26)}$$

[34] We calculate the harmonic mean for two elements, which is numerically simple. For a more thorough discussion, see https://en.wikipedia.org/wiki/Harmonic_mean.

Inserting this ratio, we obtain formulas for the number of emigrants/immigrants at period T that are associated with the reference crude emigration/immigration rate:

$$E_{ij}^{T} = E_{ij}^{ref} \cdot r_{i}^{T}$$
$$A_{ij}^{T} = E_{ij}^{ref} \cdot r_{j}^{T} \tag{C.27}$$

Substituting the variables E_{ij}^{T}, A_{ij}^{T} with the expressions just obtained yields

$$H_{ij}^{T} = \frac{2 \cdot E_{ij}^{ref} \cdot r_{i}^{T} \cdot A_{ij}^{ref} \cdot r_{j}^{T}}{E_{ij}^{ref} \cdot r_{i}^{T} + A_{ij}^{ref} \cdot r_{j}^{T}} \tag{C.28}$$

Observing that, in the base/initial year, the system is balanced, we substitute the total admissions for that year by the corresponding emigration figures:

$$E_{ij}^{ref} = A_{ij}^{ref} \tag{C.29}$$

Rewriting formula C.28 using equation C.29, we obtain

$$H_{ij}^{T} = \frac{2 \cdot E_{ij}^{ref} \cdot r_{i}^{T} \cdot E_{ij}^{ref} \cdot r_{j}^{T}}{E_{ij}^{ref} \cdot r_{i}^{T} + E_{ij}^{ref} \cdot r_{j}^{T}} \tag{C.30}$$

Further simplification yields

$$H_{ij}^{T} = E_{ij}^{ref} \cdot \frac{2 \cdot r_{i}^{T} \cdot r_{j}^{T}}{\left(r_{i}^{T} + r_{j}^{T}\right)} \tag{C.31}$$

We see that the updating function contains the harmonic means of the proportions of the populations in regions i and j between the current year and the reference year. As the population in each country or region changes mostly independently, the harmonic mean needs to be recalculated at each projection step.

For ease of notation, we summarize the factor for updating the harmonic mean into a variable f_{ij}^{T} :

$$f_{ij}^{T} = \frac{2 \cdot r_{i}^{T} \cdot r_{j}^{T}}{\left(r_{i}^{T} + r_{j}^{T}\right)} \tag{C.32}$$

It follows directly that

$$H_{ij}^{T} = E_{ij}^{ref} \cdot f_{ij}^{t} \tag{C.33}$$

For convenience, we derive an update formula for the consolidated migration rates h_{ij}^{T} instead of the total emigration and admission events.

Expressing the total number of emigrants in the reference period as the product of the at-risk population in region i and the emigration rate from i to j:

$$E_{ij}^{ref} = e_{ij}^{ref} \cdot K_{i}^{ref} \tag{C34}$$

Substituting equation C.34 into the formula for calculating H_{ij}^{T} (equation C.33), we get

$$H_{ij}^{T} = e_{ij}^{ref} \cdot K_{i}^{ref} \cdot f_{ij}^{T} \tag{C.35}$$

Dividing both sides of equation C.32 by the at-risk population in region i at period T yields an expression for the harmonic mean consolidated emigration rate h_{ij}^{T} :

$$\frac{H_{ij}^{T}}{K_{i}^{T}} = \frac{e_{ij}^{ref} \cdot K_{i}^{ref} \cdot f_{ij}^{T}}{K_{i}^{T}} = h_{ij}^{T} \tag{C.36}$$

Rewriting equation C.36, we obtain a formula that updates crude migration rates by means of the harmonic mean:

$$h_{ij}^{T} = e_{ij}^{ref} \cdot f_{ij}^{T} \cdot \frac{K_{i}^{ref}}{K_{i}^{T}} \tag{C.37}$$

With the definition for r_{i}^{T} (equation C.26), in formula C.37, the inverse of r_{i}^{t} is included.

$$h_{ij}^{T} = e_{ij}^{ref} \cdot f_{ij}^{T} \cdot \frac{1}{r_{i}^{T}} \tag{C.38}$$

Expanding f_{ij}^{T} and simplifying, we arrive at:

$$h_{ij}^{T} = e_{ij}^{ref} \frac{2 \cdot r_{j}^{T}}{\left(r_{i}^{T} + r_{j}^{T}\right)} \tag{C.39}$$

As for the case of the harmonic mean adjustment for total migration events, we summarize the factor for harmonic mean updating into a variable g_{ij}^{T} :

$$g_{ij}^{T} = \frac{2 \cdot r_{j}^{t}}{\left(r_{i}^{t} + r_{j}^{t}\right)} \tag{C.40}$$

which results in a compact expression for updating migration rates to their harmonic mean:

$$h_{ij}^{T} = e_{ij}^{ref} \cdot g_{ij}^{T} \tag{C.41}$$

So far, we have developed a procedure that transforms and adjusts the total emigration and admission events or the corresponding crude rates, that is, events of emigration and admission per 1,000 population. However, the multiregional projection models require age-specific rates of movement as input. A flexible and consistent approach for transforming absolute migration figures into age-specific migration is implemented in the projection software prepared for this paper (documentation forthcoming).

C.3 Migration Transfer Functions

This paper employs a concept of interaction between sending and receiving entities that determines the amount of migratory flows between them. There is a large body of literature on a similar topic, namely, what demographers call the two-sex problem, as it relates to union formation and reproduction (Keilman

1985a; Keyfitz 1972; McFarland 1972; Pollard 1997), which may be adapted for use in migration modeling. As in union formation, potential emigrants must find a match, in this case, a country admitting them. Conversely, potential (desired) immigration needs to be matched against available/potential emigrants.

The term $T_{ij}(E, A)$ denotes a migration transfer function that reconciles the potential emigration (*E*) from i to *j* and the potential admission of immigrants (*A*) from i into *j*. For the time being, we explicitly exclude the age dimension. Although marriage/union formation shows strong and characteristic age preferences, we find it difficult to consider the same for the case of international migration, especially for the case of admissions.[35] However, the approach suggested in this paper is not void of the age dimension of international migration. It is included through suitable implementation of migration schedules, which imprints the changing age composition of the sending country's population on the age patterns of migrants. For the age dimension, the model is therefore origin dominant.

Table C.1 shows a selected number of possible migration transfer functions, formulated for the absolute number of (potential) emigrants and immigrants/admissions). In this paper, migration scenarios were formulated in terms of crude emigration and immigration/admission rates, which are directly related to the functions in table C.1.

Table C.1: Migration Transfer Functions

Transfer function	Description	No.
$T_{ij}(E,A) = k_i E_{ij}$	Sending country (emigration) dominant	(C.42)
$T_{ij}(E,A) = k_j A_{ij}$	Admitting country (immigration) dominant	(C.43)
$T_{ij}(E,A) = k_{ij} \min(E_{ij}, A_{ij})$	Minimum transfer: the number of migrants equals the minimum number of potential emigrants and the potential number of immigrants	(C.44)
$T_{ij}(E,A) = k_{ij} \dfrac{2E_{ij}A_{ij}}{\left(E_{ij} + A_{ij}\right)}$	Harmonic mean adjustment	(C.45)
$T_{ij}(E,A) = k_{ij} \dfrac{2E_{ij}A_{ij}}{\left(u_{ij}E_{ij} + w_{ij}A_{ij}\right)}$	Weighted harmonic mean: the weights *u* and *w* reflect the relative attractiveness and emissiveness of countries i and j, respectively	(C.46)
$T_{ij}(E,A) = E_{ij}^{ref}\left(\dfrac{k_j}{k_i}\right)$	Relative State Attraction method (Schoen 2006, 190)	(C.47)

In each case, k is a suitable constant (which was omitted in the model projections for reasons of simplicity). Transfer functions 42, 43, and 45 are used in this paper as constant emigration rate (**cemr**), constant admission rate (**cimr**), and harmonic mean adjustment (**hmean**) scenario).

The harmonic mean is used in nuptiality models to capture the interaction between the sexes in forming marriages/unions. As migration bears a semblance to marriage markets, as the number of emigrants of one country is (among other things) also dependent on the admissions of these emigrants (now

[35] Of course, there are exceptions. Some countries pursue active labor recruitment programs that directly or indirectly implement age preferences for admitting immigrants. However, this is a policy outcome, not an individual preference of people in the receiving countries.

immigrants) in the receiving or destination country, the harmonic mean is proposed to be employed as a migration transfer function. Unlike the arithmetic average, the harmonic mean has a few attractive properties for capturing the flow of migrants between countries/regions:

- *Availability.* The number of emigrants from country/region i to country/region j cannot exceed the number of immigrants admitted into j from i. Particularly, if the number of immigrants admitted into country/region j from country/region i is zero, there will be no emigrants from i to j. Similarly, if there is no emigration from i to j, no admissions can be made in j from i. The first two transfer functions in table C.1 (emigration- and immigration-dominant migration) lack this useful property.
- *Monotonicity.* An increase in the number of (potential) emigrants from i to j can only result in an increase of the number of admissions in j, or increased availability should not decrease admission.
- *Symmetry.* The number of emigrants should equal the number of immigrants for any pair of countries and for all periods. This trivial property is initially often violated when multicounty projections are formulated with the net migration assumption, requiring an additional step for numerical reconciliation.

C.4 Imposing Age Structure on Incomplete Migration Data

Model migration schedules, developed by Castro and Rogers (1979) and Rogers and Castro (1981, 1986) and described more recently by Raymer and Rogers (2008), reflect observed empirical regularities and types of typical age patterns of migration. As mathematical functions, they have become a very valuable tool for demographers to incorporate the age dimension in multiregional models, even in the virtual absence of such information. Model migration schedules have been derived from a host of empirical data, mostly from internal migration streams. Castro and Rogers (1983) also developed patterns of family migration, and Castro introduced model schedules for international net migration (see UNPD 1989). In this paper, we employ the simplified basic (Rogers-Castro) standard migration schedule with seven parameters (Rogers and Castro 1986, 188) (figure C.1).[36]

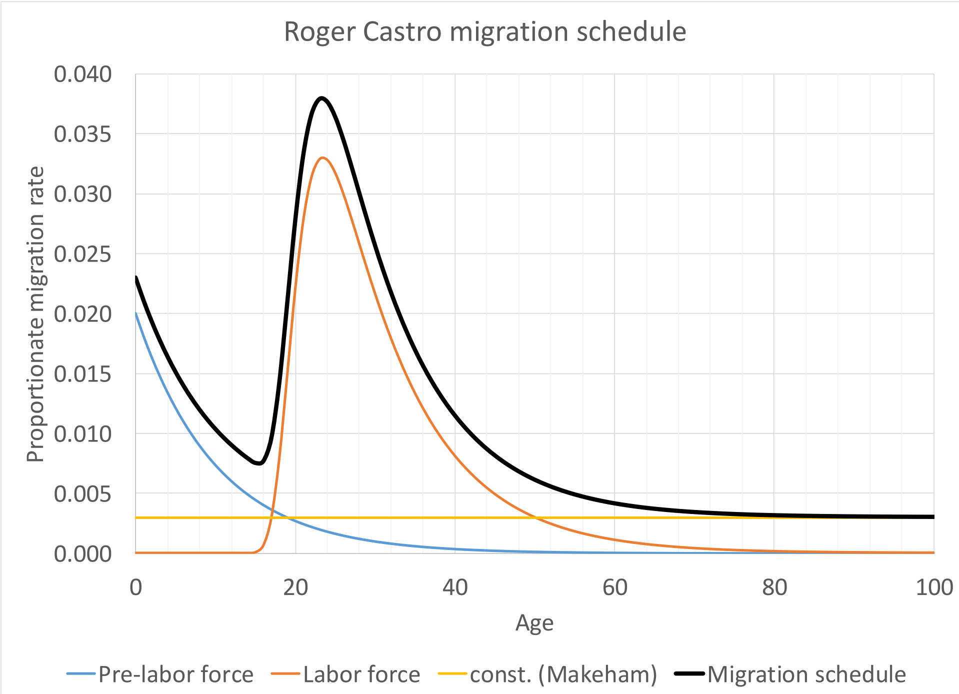
$$\begin{aligned} ms(x) = {} & a_1 \times \exp(-\alpha_1 x) \\ & + a_2 \times \exp\left(-\alpha_2 (x - \mu_2) - \exp\left(-\lambda_2 (x - \mu_2)\right)\right) \\ & + c \end{aligned} \qquad \text{(C.48)}$$

$$\sum_x ms(x) = 1.0$$

Model migration schedules are formulated as proportionate age-specific migration rates that sum to unity. This makes them very flexible, as they are level independent.

[36] A discussion of the parameters of the schedule and its interpretation is beyond the scope of this paper. Rogers and Castro (1986) provide a detailed discussion.

Figure C.1: Castro-Rogers Simplified (Seven-Parameter) Model Migration Schedule



A common approach for imposing age structure on migration data with deficient or missing such information is to use the model migration schedule directly in lieu of the age composition of migrants. For example, total population figures are split proportionally by the model migration schedule; see, for example, Raymer and Rogers (2006, 20), UNPD (1989), and Lutz, Butz, and KC (2014, 356). Although it is a useful shortcut, this approach ignores the age composition of the population at risk, and therefore yields biased results. We develop an alternative approach that avoids this problem.

As a starting point, we have the total number of migrants, E ; the population at risk by age, $K(x)$; and the age-specific model migration schedule, $ms(x)$. We wish to calculate the migrants by age, $E(x)$, and the age-specific migration rates, $e(x)$.

The number of migrants by age is calculated by multiplying the age-specific migration rate at age x by the population at age x (only the population at risk is known at this point):

$$E(x) = e(x) * K(x) \tag{C.49}$$

The age-specific migration rate, *e(x)*, can be written as the product of the gross migraproduction rate and a level-independent age pattern, here, the model migration schedule (see formula C.4 in annex C.1).

$$e(x) = gmr * ms(x) \tag{C.50}$$

Substitution yields the formula for the number of migrants at age x, where *K(x)* and *ms(x)* are known:

$$E(x) = gmr * ms(x) * K(x) \tag{C.51}$$

Summing the migrants by age results in an expression in which the only unknown quantity is the gross migraproduction rate *gmr*:

$$
\begin{aligned}
E &= \sum gmr * ms(x) * K(x) \\
&= gmr \sum ms(x) * K(x)
\end{aligned}
\qquad \text{(C.52)}
$$

Finally, the last unknown quantity, *gmr*, is easily calculated:

$$
gmr = \frac{E}{\sum ms(x) * K(x)} \qquad \text{(C.53)}
$$

Next, we calculate the number of migrants by age, inserting *gmr* into formula C.51:

$$
\begin{aligned}
E(x) &= gmr * ms(x) * K(x) \\
&= \frac{E * ms(x) * K(x)}{\sum ms(x) * K(x)} \\
&= E * \frac{ms(x) * K(x)}{\sum ms(x) * K(x)}
\end{aligned}
\qquad \text{(C.54)}
$$

After some rearrangements, we obtain a formula for the number of migrants at age x that is the product of the total number of migrants, E, and a factor that we call the population-weighted proportionate model migration schedule, or $pms(x)$:

$$
pms(x) = \frac{ms(x) * K(x)}{\sum ms(x) * K(x)}; \sum pms(x) = 1.0 \qquad \text{(C.55)}
$$

Having obtained the number of migrants by age, it is straightforward to calculate the related age-specific migration rates, e(x):

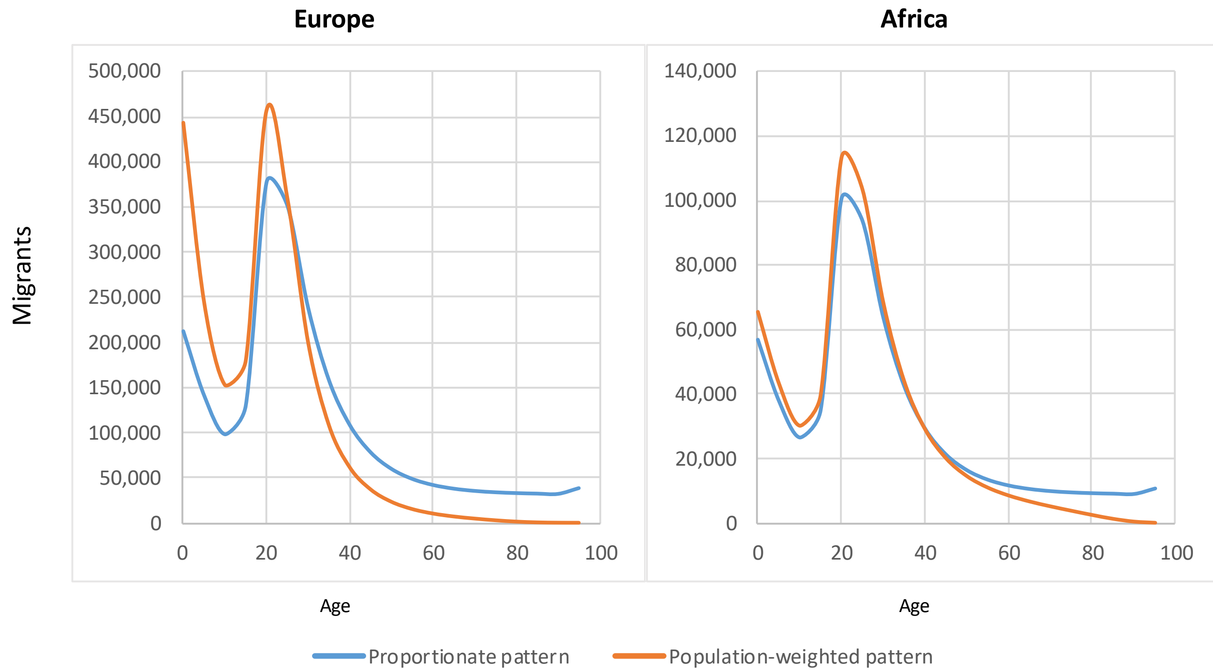
$$
e(x) = \frac{E(x)}{K(x)} = \frac{E}{K(x)} * pms(x) \qquad \text{(C.56)}
$$

It is important that with this approach the resulting number of migrants by age will age or rejuvenate as the underlying population ages or rejuvenates, even as the underlying model migration schedule remains unchanged.

Most demographers use above shortcut, which implicitly assumes that the underlying population's age structure has no impact on the final age composition of migrants; for example, the population age distribution is ignored. Figure C.2 compares the two procedures for emigration estimates for Africa and Europe,[37] and table C.2 lists the median ages of the two approaches. Table C.3 provides a side-by-side comparison of the two approaches.

Figure C.2: Comparison Model Migration Age Patterns, Africa and Europe, 2005–10

[37] Data are from the projection exercise presented in this paper, **hmean** scenario.



The differences between the two approaches are especially striking for Africa, where the median age of migrants in 2005 is significantly lower (21.5 years) than in the proportionate migration model (27.7), due to the very young population of Africa. The population aging of Africa in the future is also reflected in the aging of the migrants, reaching 25.6 years by 2095. Europe, by contrast, with its already very old population composition, is associated with older age patterns of migrants that do not change significantly during the projection horizon.

Table C.2: Median Age of Migrants, Europe and Africa, 2005–10 and 2095–2100 (years)

Method	Europe		Africa	
	2005–10	2095–2100	2005–10	2095–2100
Proportionate	27.70	27.70	27.70	27.70
Population weighted	27.35	27.54	21.46	25.62

Table C.3: Comparison of Formulas for Applying Model Migration Schedules

Migration indicator	Calculation method	
	Population weighted	Proportionate
Migrants by age	$E(x) = E * \frac{ms(x)}{\sum ms(x) * K(x)}$	$E(x) = E * ms(x)$
Age-specific migration rate	$e(x) = \frac{E}{K(x)} * \frac{ms(x) * K(x)}{\sum ms(x) * K(x)}$	$e(x) = \frac{E}{K(x)} * ms(x)$

C.5 Notation and Indicators

In this paper, uppercase letters denote absolute numbers of events or stocks. Lowercase letters refer to relative measures, such as the various rates or probabilities used in the demographic analysis. Matrixes are denoted with bold letters. As this paper deals with regional/spatial analysis, right subscripts represent the spatial dimension(s). References to time (points in time or periods) are placed in the right superscript; the duration of events or length of age groups is placed in the left subscript; and sex is indicated in the left superscript (figure C.3). The reference to age, if appropriate, is added in parentheses to an indicator symbol. Crude rates, that is, events per 1,000 population at risk, are denoted in lowercase letters, but without a reference to age. Table C.4 provides a list and description of the symbols used in the analysis.

Since this paper is predominantly concerned with migration flows, a distinction is made throughout between emigration and immigration. The latter is also called admission, to reflect the link between sending and receiving countries.

Figure C.3: Indicator Notation

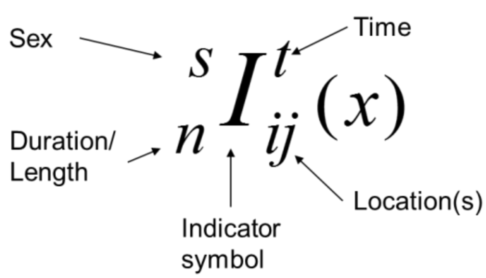


Table C.4: List of Symbols

Symbol	Description
K_i	Total population in region i
$K_i(x)$	Population in region i in age group x
E_i	Total emigrants moving from region i
E_{ij}	Emigrants moving from region i to region j
$E_{ij}(x)$	Emigrants moving from region i to region j in age group x
e_i	Total crude emigration rate of migrants from region i
e_{ij}	Crude emigration rate of migrants from region i to region j
$e_{ij}(x)$	Age-specific emigration rate from region i to region j
A_j	Total admitted migrants into region j (immigrants into j)
A_{ij}	Total admitted migrants from region i into region j (immigrants from i to j)
$A_{ij}(x)$	Admissions of migrants from region i into region j in age group x (immigrants in age group x from i to j)
a_j	Total crude admission rate from region i to region j (immigration rate from i to j)
a_{ij}	Crude migrant admission rate from region i to region j (immigration rate from i to j)
$a_{ij}(x)$	Age-specific admission rate of migrants from region i to region j (immigration rate)
NM	Total net migration
nm_i	Crude net migration rate of region i
gmr_i	Gross migraproduction rate for region i
$pms_i(x)$	Population-weighted migration model schedule at age x, region i
$d_{ij}(x)$	Spatial distribution proportions
$ms_i(x)$	Proportionate age-specific migration rate for region i (model migration schedule)
R_i^O	Retention ratio by origin for region i
R_j^D	Retention ratio by destination for region j
H_{ij}	Harmonic mean adjusted migrants from region i to region j
h_{ij}	Harmonic mean adjusted crude migration rate from region i to region j
r_i	Ratio between base and current population in region i
f_{ij}	Harmonic mean update factor for total migrants
g_{ij}	Harmonic mean update factor for crude migration rates
tfr	Total fertility rate

Symbol	Description
i	Index of region of origin; i= 1, 2…, m
j	Index of region of destination; j=1, 2, …, m
m	Number of regions
n	Width of age group, length of period (years)
x	Exact age, age group (x, $x+n$) (years)
z	Last age group
t	Time (point in time, date)
T	Time period [t, $t+n$]

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