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Technical Paper

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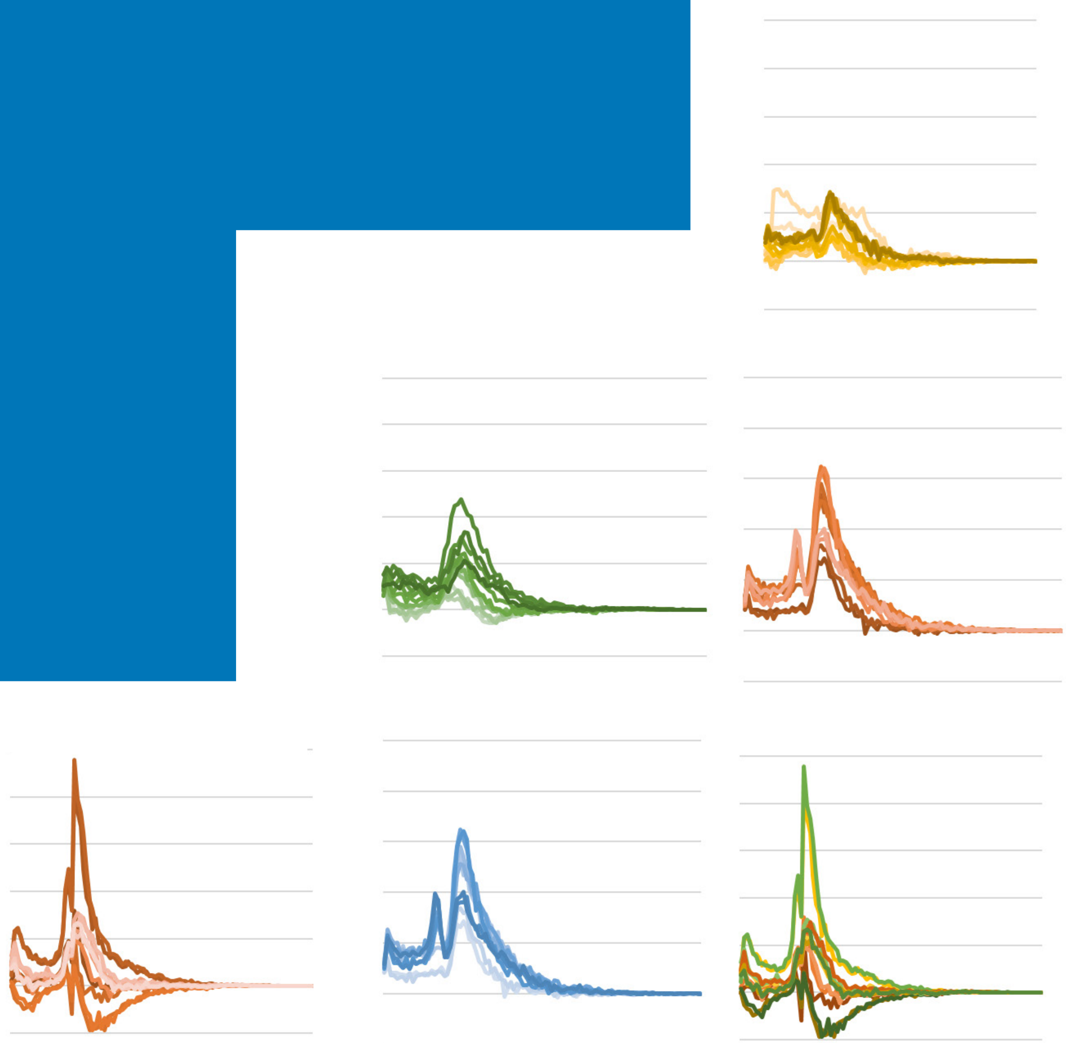

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Modelling the Age and Sex Profiles of Net International Migration*

James Raymer**, Qing Guan**, Tianyu Shen**, Sara Hertog***, and Patrick Gerland***

Abstract

This technical paper proposes a methodology for inferring the age and sex profiles of net migration. This approach enhances the capability of the Population Division of the United Nations Department of Economic and Social Affairs (United Nations Population Division) to estimate and project populations for the *World Population Prospects* (WPP). The age and sex profiles of net migration are crucial inputs to demographic accounting models for population estimation and projection. However, most countries in the world do not directly measure migration, and residual estimation methods for inferring patterns have proven inadequate owing to errors in population measures, births, and deaths.

Recognizing that net migration lacks consistent patterns across different ages and sexes, this study introduces a novel strategy: estimating immigration and emigration flows by age and sex—categories that demonstrate regular patterns–and using differences from these flows to estimate net international migration by age and sex. Empirical validations using data from Sweden and the Republic of Korea have yielded promising results, prompting the extension of the method to estimate age- and sex-specific net migration patterns for countries lacking migration data.

Keywords: Population projections, Population estimates, International migration, Age-sex composition, methods.

Sustainable Development Goals: 17

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EXPLANATORY NOTES

The following symbols have been used in the tables throughout this report:

A full stop (.) is used to indicate decimals.

References to countries, territories and areas:

The designations employed in this publication and the material presented in it do not imply the expression of any opinion whatsoever on the part of the Secretariat of the United Nations concerning the legal status of any country, territory, city or area or of its authorities, or concerning the delimitation of its frontiers or boundaries. The term "country" as used in this publication also refers, as appropriate, to territories or areas.

The following abbreviations have been used:

EU	European Union
GCC	Gulf Cooperation Council
IOM	International Organization for Migration
KOSIS	KOrean Statistical Information Service
OECD	Organisation for Economic Co-operation and Development
UN DESA	United Nations Department of Economic and Social Affairs
UNFPA	United Nations Population Fund
UNHCR	United Nations High Commissioner for Refugees
WPP	World Population Prospects
WS	Western Standard

I. Introduction

This study proposes a methodology to estimate the age and sex profiles of net international migration. These estimates are required by the Population Division of the United Nations Department of Economic and Social Affairs (UNDESA) to produce its biannual official population estimates and projections for all countries in the world. The Population Division's current methodology for estimating and projecting net international migration (United Nations, 2022a) is divided into two parts: (1) estimation of net migration totals and (2) distribution of net migration totals by age and sex.[1] The analyses and methodology presented in this paper focus on the second part—the distribution. The overall goal is to achieve improved standardization and transparency in the data and methods that underlie the World Population Prospects (WPP).[2] In relation to previous work, the key areas of interest are new approaches to better represent migration patterns in countries and time periods with (1) significant levels of both immigration and emigration in different age groups and (2) large flows of temporary labour migration.

The demographic impact of international migration is believed to be increasing with decreasing births, increasing longevity, and the demand for both low skilled and high skilled labour. Data on international migration, however, remain largely unknown because they are not collected or made accessible (Iredale and others, 2003; Hugo, 2005; Skeldon, 2006). The main weaknesses are thought to be in the "registration of foreign workers, estimates of unauthorized migration, measurement of return migration, estimating the number of nationals abroad, the public availability of migration statistics and institutional cooperation" (Huguet, 2008, p. 231). Moreover, migration policies and management differ across regions in the world. For example, Asia is characterized by "strict control of foreign workers, prohibition of settlement and family reunion, and denial of worker rights (especially for less-skilled personnel)" (Castles, 2009:451), whereas no restrictions are in place in the European Union for migrants who have citizenship from member countries.

Information on emigration and irregular migration is particularly problematic either because data have not been gathered when migrants left the country or because the nature of the movements has not been documented (Asis and Battistella, 2018). In other words, individuals rarely have incentives to report their departures in comparison to their arrivals, and those who migrate irregularly may have weak legal status and are thus less likely to engage with administrative authorities. Moreover, government authorities tend to focus on particular types of migration, for example, labour, education, family reunification, and they may not have the capacity, interest or official channels to communicate their data with other agencies to form a comprehensive picture of migration.

Previous approaches used by the Population Division to represent net international migration by sex and age in the WPP were reviewed and evaluated as part of this study, including estimates produced for the 2022 revision.[3] Subsequently, a novel method for modelling the age and sex profiles of international migrants is proposed, with applicability to both population estimation and projection. The model parameters of the new method are evaluated by assessing how closely the results replicate empirically observed patterns of net international migration by age and sex in Sweden and the Republic of Korea. To illustrate the method's applicability in data-scarce situations, the analysis is extended to scenarios without migration data, followed by a presentation of the generated outcomes. The paper concludes by summarizing the findings and offering recommendations for further research in this field.

[1] See https://population.un.org/wpp/Publications/Files/WPP2022_Methodology.pdf

[2] For further details on the most recent revision of the *World Population Prospects*, see https://population.un.org/wpp/.

[3] *World Population Prospects 2022*: www.un.org/development/desa/pd/content/World-Population-Prospects-2022.

II. BACKGROUND

The aim of this research is to improve the modelling of age and sex patterns of net international migration, where sex refers to males and females and age refers to single years of age groups. Ideally, net international migration totals are calculated by subtracting emigration from immigration that have occurred during a calendar year for a particular country. In situations where neither immigration nor emigration data are available, net international migration may be inferred by using the demographic accounting equation. That is, in simplified form, annual net migration $NM_i^{t-1,t}$ is equal to a population in country i at a particular time, P_i^t, less the population one year earlier P_i^{t-1} less births that occurred during the year, $B_i^{t-1,t}$, plus deaths that occurred during the year, $D_i^{t-1,t}$, that is,

$$NM_i^{(t-1,t)} = P_i^t - P_i^{(t-1)} - B_i^{(t-1,t)} + D_i^{(t-1,t)}. \quad (1)$$

The so-called residual method for estimating net international migration assumes that the available age and sex data on populations, births and deaths are accurate and complete. However, often the inferred net migration total includes measurement errors in the populations and vital events (Edmonston and Michalowski, 2004, p. 471). Small errors in the population counts may result in large errors in the estimation of net international migration. Moreover, population measurement errors can vary substantially in age, which can produce distorted age distributions using residual methods.

A. Age patterns of migration

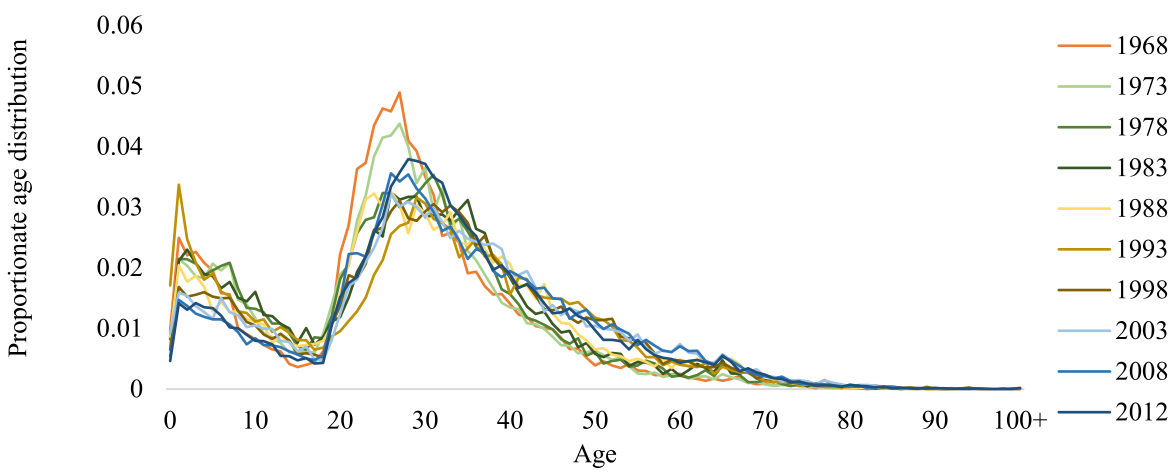
Similar to mortality, fertility, marriage, divorce and remarriage, age profiles of both internal and international migration exhibit remarkably persistent regularities when measured as directional movements (Rogers and Castro, 1981a, 1981b; Raymer and Rogers, 2008). The most prominent regularity in age-specific profiles of migration flows is the high concentration of migration among young adults. Levels of migration can also be high among children, starting with a peak during the first year of life and dropping to a low point around ages 12 to 16 years. Although relatively rare for international migration, some domestic (internal) migration flows exhibit humps at the onset of retirement and upward slopes at the oldest ages associated with migration to live closer to (adult) children or to seek care (Rogers, 1988).

Underlying regularities in the age patterns of migration include many underlying causes of migration that also have specific age patterns (Rogers and Castro, 1981b; Plane and Heins, 2003; Raymer and others, 2019). For example, migration for tertiary educational purposes is concentrated in the young adult age groups. Employment-related migration exhibits broader young adult age profiles that often include relatively high rates of young children migrating with their parents. The causes of different age profiles of migration may be interpreted from a life course perspective. The life course perspective explains how a series of individual life status transitions (for example from living with parents to living alone, unemployed to employed) or life events (for example completing education, marriage, having children) results in distinct forms of spatial movement (Elder, 1985; Kulu and Milewski, 2007). Moreover, migration is more than a collection of independent movements; it also includes those who are dependent on others, for example, children migrating with their parents, wives (husbands) with their husbands (wives), and elderly with their children.

Migration is also influenced by the compositional aspects of the population 'at risk' of migration. To understand these influences, Castro and Rogers (1983a, 1983b) illustrated a number of ways in which the age profile of migration is sensitive to relative changes in population age profile by disaggregating migrant populations according to age, sex, and whether the migrants were independent or dependent. Viewing the migration process within a framework of dependency allows one to predict the shape of the age profile. For example, if the migration process is largely comprised of individual movements, one might expect relatively few children and older migrants. On the other hand, if the migration process consists primarily of family migration, then the share of dependent children may become a very important component of the age pattern. In other words, population age compositions have the potential to be used to infer age profiles for migration (Little and Rogers, 2007).

To illustrate how migration varies by age, the patterns of emigration from Sweden for every five years from 1968 to 2012 are presented in figure 1. These data were obtained from a population register that maintains continuous and accurate accounting for population changes, including entries and exits. Only a handful of countries maintain such a system. In the figure, it is observed that the age profiles are dominated by young children and young adults. In addition, when expressed as proportions, the age patterns were remarkably similar for each year. The situation for immigration (not shown) is similar, except that the levels tended to be higher and somewhat less stable throughout the 44-year period. Also, males aged 15-16 years exhibited increasing immigration levels after 2000 that were linked to increases in unaccompanied minors seeking asylum (Çelikaksoy and Wadensjö, 2015).

Figure 1. Proportionate age distribution of male emigration from Sweden, 1968-2012

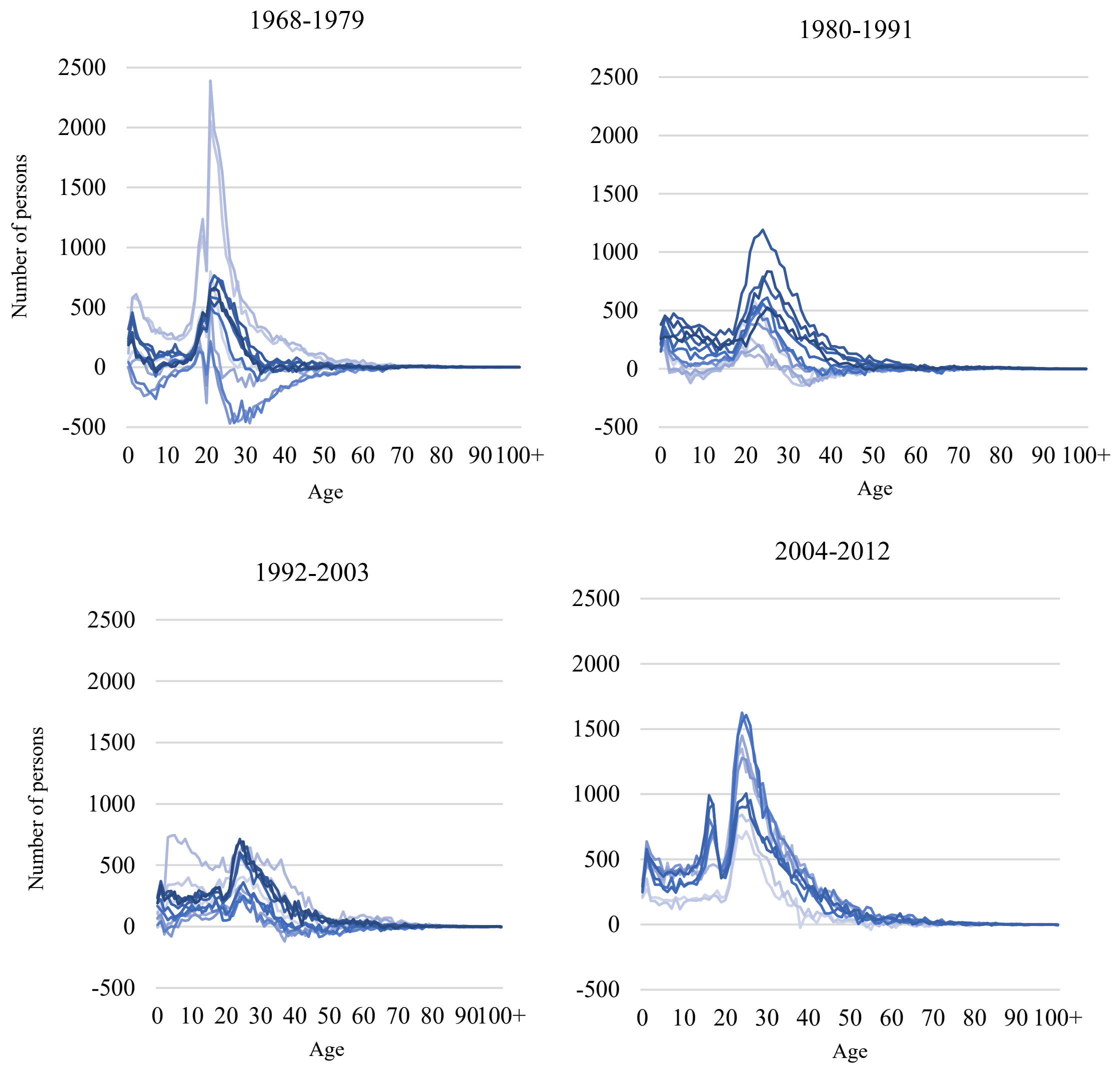


Source: Statistics Sweden Statistical Database (www.statistikdatabasen.scb.se/pxweb/en/ssd/).

In figure 2, the corresponding age patterns of net male migration separated into the following periods: 1968-1979, 1980-1992, 1993-2003, and 2004-2012 are presented. The late 1960s and 1970s were a relatively volatile period with considerable positive and negative values for young adults. The net male migration patterns for the 1980s to early 2000s appeared relatively stable. After 2004, net migration increased considerably across all ages due to the expansion of the European Union (EU).[4] In comparison to the emigration age profiles, the net age profiles of international migration were considerably less stable over time.

[4] Sweden joined the European Union on 1 January 1995 with Austria and Finland. In 2004, Cyprus, Chechia, Estonia, Hungary, Latvia, Lithuania, Malta, Poland, Slovakia, and Slovenia joined the EU. In 2007 Bulgaria and Romania joined the EU.

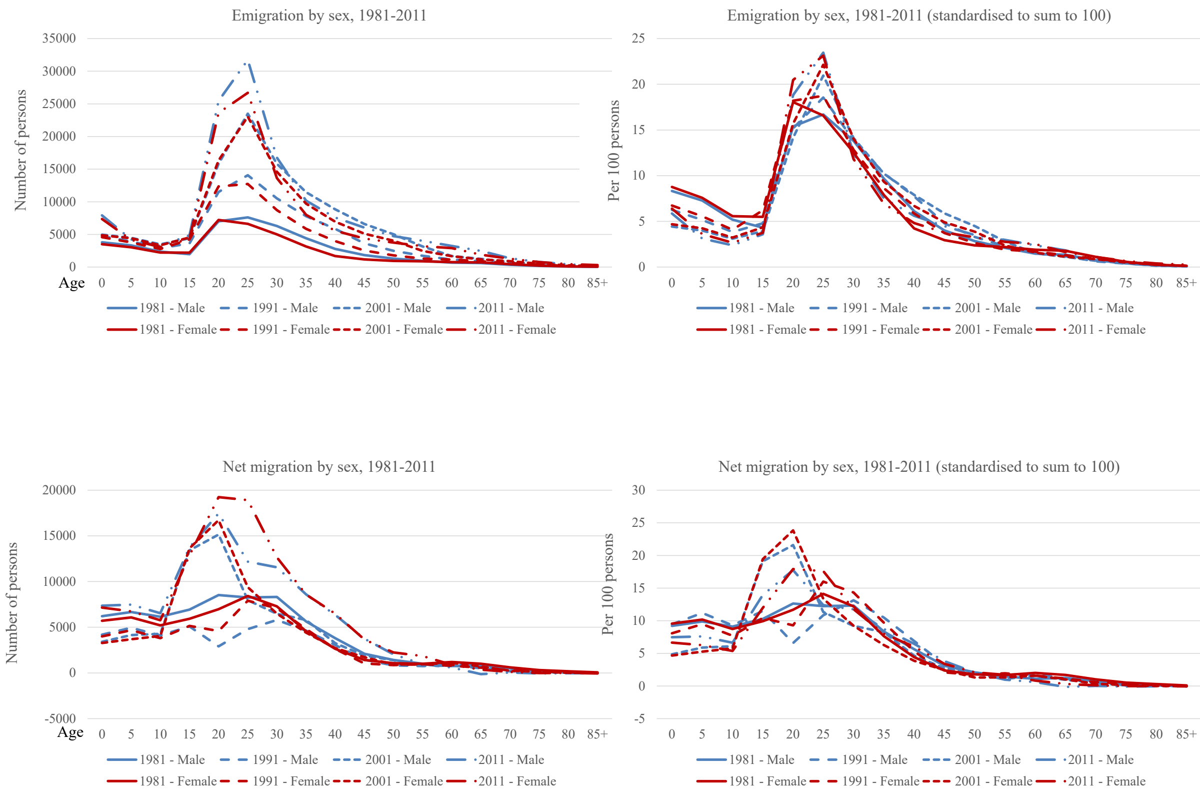
Figure 2. Male net international migration by age for Sweden, 1968-2012 (number of persons)



Source: Statistics Sweden Statistical Database (www.statistikdatabasen.scb.se/pxweb/en/ssd/).
Note: Lines are shaded by year with darker lines representing recent years.

Figure 3 illustrates the age profiles of emigration and net migration by sex for Australia during the years 1981, 1991, 2001 and 2011. These data come from an administrative register of travel documents that records the number of all overseas arrivals and departures. Being an island nation facilitates the maintenance of travel records, which tends to be more challenging in countries with land borders. In general, male and female migration patterns are similar over time with positive net migration across five-year age groups. While emigration levels increased greatly over the 30-year period (top-left chart), the standardised age patterns, in which the sex-specific levels of emigration by age are expressed as a proportion of the total emigration over all ages, remained remarkably similar (top-right chart). When the net migration age profiles were examined, increased levels over time (bottom-left chart) but more varied age patterns even when standardised (bottom-right chart) were also observed.

Figure 3. Annual emigration (number of persons) and net migration by age and sex (percentage) for Australia, 1981, 1991, 2001 and 2011



Source: Australian Bureau of Statistics

When expressed as proportions, the two illustrations of migration age patterns above show clearly that directional flows (that is, emigration) appear more stable and regular over time in comparison to the corresponding age patterns of net international migration. This makes sense as net migration is calculated as a difference in flows and changes over time may be due to increased (decreased) immigration or increased (decreased) emigration.

B. Sex patterns of migration[5]

Similar to age profiles of international migration, sex patterns of international migration are influenced by different types of migration (Schoorl, 2012). For example, in Western Europe between 1950 and 1970, low-skilled labour migration was dominated by young adult men who were recruited to work in construction, factories, harbours, mining, agriculture, and sanitation (De Haas and others, 2020, Chapter 6). In the 1970s and 1980s, family reunification became a major cause of migration which was comprised predominately of women and children. In 2019, males comprised 59 per cent of migrant workers globally and females 41 per cent, representing a slight shift towards more equal gender distribution than previously estimated (McAuliffe and Triandafyllidou, 2021, pp. 37-38). However, relatively equal shares of male to female migrant workers have been reported in Central and Western Asia, Europe, and Northern America.

[5] Adapted from Schoorl 2012.

Low skilled female migrants tend to work in the agricultural, manufacturing, textile, food processing, healthcare, restaurants, and hotels (UNDESA, 2006, pp. 30-32). Domestic service is also common occupation for migrant women. Demand is increasing for care services in less-skilled and under-valued jobs, such as domestic work and caring for children, elderly and disabled persons—these jobs are particularly targeted towards women. Skilled women, on the other hand, tend to seek employment in health and social fields, such as education, social work, and nursing (Jolly and Reeves, 2005; UN DESA, 2006).

Worldwide, refugees are comprised of 48 per cent women and 52 per cent men (UNHCR, 2021), although the gender composition of asylum seekers and refugees can vary. Some refugees arrive in a country of destination under formal resettlement schemes. They may be young people with high employment qualifications or families with single mothers. Of the asylum seekers who arrive in Europe, men are more numerous than women. Women account for about one third of the asylum applications in Europe. Part of this is due to the way data are collected: women are more likely to seek asylum as part of a family group or to be married (UNHCR, 2010; United Nations, 2011), and women are usually not primary applicants (UNFPA, 2006).

Finally, according to OECD data, female students accounted on average for 58 per cent of foreign tertiary education graduates in OECD countries in 2021 (OECD, 2023, table 5.2b). However, there can be differences depending on the degree to which male students typically have much higher proportions in the fields of information and communication technologies, engineering, manufacturing, and construction.

C. Family patterns of migration

Family-related migration can be categorised into three distinct types (Schoorl, 2012): (i) family reunification, whereby family members join someone, often a husband or father, who migrated earlier; (ii) marriage migration, where the bride or bridegroom migrates to the new spouse's country of residence; and (iii) joint family migration, when the members of a family migrate together at the same time. Family reunification refers to the process of bringing in immediate family members—usually a spouse and under-age dependent children, sometimes also parents and other dependent family members—by the primary migrant. Usually a waiting period applies, and the primary migrant has to satisfy a number of conditions including income and housing before dependents are admitted to the country. Joint family migration implies a sex-balanced composition of migration flows. This category is less common as many countries do not allow temporary permit holders to be accompanied by family members, except for highly skilled migrants. Some refugees, especially those entering on settlement schemes or quotas, are admitted jointly with their family (IOM, 2008).

There are several types of marriage migration. The first concerns second-generation descendants of migrants who bring in a spouse from their parents' country of birth. It tends to be gender-balanced, as both young men and young women may look for a bride or groom in their parents' country of origin. The second type of marriage migration involves native citizens who bring in a partner they have met while abroad for work, study or holiday. In this case, the marriage is a secondary effect of the reason for going abroad. The third type of marriage migration involves the recruitment of mostly women from other countries (Hwang and Parreñas, 2018). In exchange for marriage, the migrants may gain economic benefits or be able to send remittances back home. There is also the potential for exploitation or human trafficking with migrants not having equal rights to their spouses.

D. Return migration

Return migration occurs in almost all international migration situations. Return migrants are those who leave a country to reside in another, and then after a period of time, migrate back to the country of origin. The reasons for return migration are numerous, including, for example, completion of study or fixed-term position, loss of a job, to form a family, and a general desire to be closer to family or friends. With regard to age patterns of migration, migrants are obviously older when they return. For countries that experience more emigration than immigration, immigration is expected to have a slightly older age profile than emigration. The opposite is the case for countries that experience higher levels of immigration than emigration.

III. Methods for estimating patterns of migration

The estimation of migration provides a way to augment or overcome data limitations. To overcome the problems associated with inadequate and missing data, there are numerous examples of research on estimating both net international migration and international migration flows (see, for example, Poulain, 1993; Raymer, 2008; De Beer and others, 2010; Raymer and others, 2013; Wiśniowski and others, 2016; Abel, 2018; Fiorio and others, 2021). In situations where levels of temporary and undocumented migration are considered to be high compared to other world regions, estimates can assist in understanding the demand for basic human rights and protections (Asis, 2005). In the following subsections, methods for estimating net migration totals and age patterns of migration are reviewed.

A. Residual method for estimating net migration totals

The residual method for estimating net migration uses population totals, mortality and fertility to infer net migration and can be applied at any level of disaggregation, including across age cohorts. The method is relatively simple. The two most common residual methods used to estimate net migration are the vital statistics method and the survival ratio method (Bogue, 1969, 758-759). The vital statistics method for obtaining net migration relies on reported births and deaths between censuses and uses the demographic accounting equation (see equation 1). The basic assumptions of this method are that the population and natural increase amounts are exact (that is, without population undercounts or age misreporting).

The survival ratio method compares an estimated number of people at age x surviving and living in the same place from time t-1 to t with an observed population at time t. To estimate the number of survivors, this method uses a life table to apply age-specific mortality and assumes no migration occurred during the time interval. The difference between the observed number of persons at age x and time t and the corresponding estimated number of survivors (S) is attributed to net migration:

$$NM_i^{(t-1,t)}(x) = P_i^t(x) - S_i^t(x), \tag{2}$$

where: $NM_i^{(t-1,t)}(x)$ = net migration at age i between time t-1 and t,

$P_i^t(x)$ = number of persons at age i and time t,

$S_i^t(x)$ = number of survivors at age i and time t.

The basic assumptions in this model are that the population and mortality rates are exact.

The residual method does not provide information about the relative numbers of immigration and emigration or countries of origin or destination. Net migration estimates include both the difference between immigration and emigration and any error associated with the measurement of population stocks, births, and deaths, such as census undercounts or age misreporting. This second feature can be particularly problematic when examining historical data, or data in which the enumeration of the population does not closely resemble the true population. That said, indirectly estimated net migration numbers can be very useful, particularly in cases for which no migration flow data are available (Smith and Swanson, 1998). Net migration provides important information on how much the population grew or declined due to migration during a specified period of time. The figures are also easy to incorporate into cohort component projection models.

B. Model age schedules

Pittenger (1974, 1978) developed a typology of net internal migration age schedules for use in population projections based on place characteristics. The typology was based on directional flow patterns of internal migration in the United States and Canada, where areas were distinguished according to rural, exurban, central city, suburban and metropolitan characteristics. Each area was assumed to have low or high levels and early or late peaks in the young adult age groups with unattractive areas exhibiting early migration peaks. In the 1978 paper, Pittenger proposed a parameterised migration rate model for the age patterns of the directional flows, which could then be used to determine age patterns of net migration.

Also, Rogers and colleagues developed a model migration schedule for the flow data (Rogers and others, 1978; Rogers and Castro, 1981a). The fundamental problem with predicting net migration is that the measure represents a difference in flows, which makes it difficult to explain and results in biased predictions of population change (Rogers, 1990). Net migration may increase due to increased immigration, reduced emigration, or a combination of the two. For a given net migration total, there may be infinite combinations of numbers of immigrants and emigrants.

The model migration schedule is a parameter-based approach for smoothing and representing age patterns of migration based on combinations of exponential and double exponential curves. Rogers and Castro (1981) analysed 524 age profiles of migration and demonstrated that migration has strong regularities in age patterns much like fertility and mortality. A key component of the report was the specification of model migration families. In particular, four families of multiexponential model migration schedules were put forward: (1) a standard seven-parameter model, 2) a nine-parameter elderly post-retirement migration model, (3) an eleven-parameter elderly retirement peak model, and (4) a thirteen-parameter elderly retirement peak and post-retirement model. The standard migration schedule is the most commonly found in empirical data settings. Its basic form is specified as:

$$m_i = a_0 + a_1\, exp(\alpha_1 x) + a_2\, exp\{-\alpha_2(x - \mu_2) - exp[\lambda_2(x - \mu_2)]\}. \qquad (3)$$

where m_i is the predicted age profile of migration from origin i,

a_0 = a constant (that is, overall level),

$a_1\, exp(\alpha_1 x)$ = a negative exponential curve representing the pre-labour force ages,

$a_2\, exp\{-\alpha_2(x - \mu_2) - exp[\lambda_2(x - \mu_2)]\}$ = a double exponential (unimodal) curve representing the labour force ages.

This multiexponential model migration schedule is useful for describing or inferring age-specific migration patterns when data are incomplete or missing. It has been demonstrated to effectively capture most age profiles of migration with a high level of accuracy and has been used for a wide variety of situations.

The relatively stable shape of the age-specific migration curve provides analysts and researchers with the possibility of simplifying their underlying assumptions and estimation models. Indeed, many predictions of migration focus on indicator variables, such as net migration, total immigration, or total emigration, which are then distributed into assumed age-specific migration profiles for producing age-specific population projections (for example, Azose and others, 2016).

For the *World Population Prospects* (WPP), the sex and age patterns of net international migration defined by the Population Division vary according to country context and time period. Model migration schedules (Rogers and Castro, 1981a) were used to estimate the net international migration for many countries over time. Specifically, the `mig_un_fam()` function of the *DemoTools R* package (Riffe, 2022), include: a "family" model characterized by fairly even proportions of male and female migrants, a curve that concentrates migrants in the young adult age groups; a "male labour" model dominated by migration of males of working age; and a "female labour" model dominated by migration of females of working age. In some cases, a "population distribution" pattern was applied, in which the sex-age distribution of net migration is assumed identical to the sex-age distribution of the population.

In cases where countries had reliable census or population register data, residual methods were used to estimate both the total level of net international migration and the patterns by age and sex. First the censuses were evaluated and adjusted, as necessary, to address common issues including under- or over-enumeration, heaping of population counts on certain ages, such as those ending in zero or five, and the undercounts of very young children (Johnson and others, 2022). Then, those adjusted census population counts were interpolated to annual 1 January population counts over the intercensal period and the annual residual migration was computed between those interpolated populations using the population balancing equation, based on annual fertility and mortality rates estimated for the WPP.

For the subset of countries with highly accurate and regular population censuses or registers as well as complete registration of births and deaths by age and sex, probabilistic methods were used to infer the full time series of net international migration, including by age and sex (Wheldon and others, 2013).

C. Other methods

Multiplicative component models have been used to estimate origin–destination–age counts of internal and international migration (Willekens and Baydar, 1986; Raymer and others, 2006, 2017). These methods are most useful when some migration flow data are available. In the context of international migration, data are hardly available, especially for countries outside Europe.

Time series and probabilistic methods, including Bayesian, have been used to produce forecasts of net international migration (Bijak, 2011, 2012; Azose and Raftery, 2015). For these methods to work effectively, multiple observations on the migration indicators are needed.

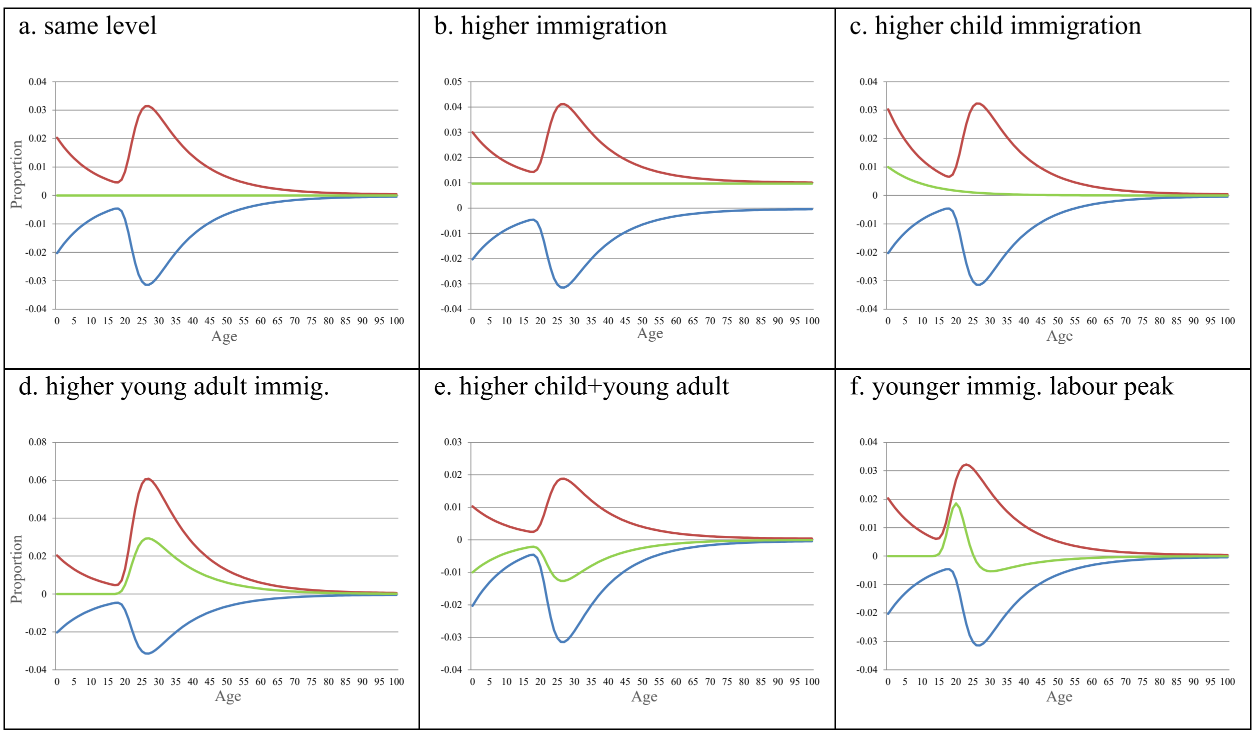
Hyndman and Booth (2008) forecasted age patterns of net migration using functional data analysis, a statistical approach for analysing data that are in the form of curves. Shang and others (2016) showed how functional data analysis may be used to forecast age patterns of mortality, fertility, immigration, and emigration using the same data as Wiśniowski and others (2015). Finally, Wiśniowski and others (2015) and Raymer Wiśniowski (2018) developed a Bayesian model to forecast age-specific immigration and emigration counts. This model represents an adaptation of the Lee–Carter model, originally designed for forecasting age patterns of mortality (Lee and Carter, 1992). This model essentially adjusts a standard age profile of migration with time-invariant parameters and produces forecasts by using time-series models.

IV. Methodology

In this section, a methodology to estimate net international migration by age and sex is presented. As there are no known systematic regularities of net migration across age and sex, the focus is first on estimating the age and sex patterns of immigration and emigration. Second, the difference of these estimated patterns is used to infer net international migration by age and sex.

Figure 4 illustrates the theoretical impact of age structure on net migration under varying levels of immigration and emigration. This is achieved by presenting hypothetical model migration schedules alongside their corresponding net migration schedules. The (positive) red line represents immigration, (negative) blue line representing emigration and the green line represents net migration. The first graph (figure 4a) shows how net migration is zero across all ages when both the levels and age compositions of migration the same. The second graph (figure 4b) shows how age-specific net migration increases when the overall level is increased. The remaining four illustrations (4c-4f) show how age-specific net migration changes when parameters associated child migration and young adult migration levels are changed, whilst holding the emigration level and age composition fixed.

Figure 4. Hypothetical age patterns of immigration, emigration and net migration



The procedure for estimating the distribution of net migration by age and sex is as follows. First, it is assumed that the annual net migration totals are both known and true. Second, the age and sex profiles of immigration and emigration flows were estimated. This involves obtaining (a) overall levels of immigration and emigration, and (b) age and sex profiles. Finally, the differences in these patterns were calculated to obtain estimates of net international migration by age and sex.

The overall model is specified as:

$$\hat{N}_{xy} = (\hat{I})(i_{x|y})(i_y) - (\hat{E})(e_{x|y})(e_y), \quad (4)$$

where $\hat{N}_{xy}$ denotes the estimated net international migration by age and sex; $\hat{I}$ and $\hat{E}$ are crude estimates of total immigration and emigration, $i_{x|y}$ and $e_{x|y}$ are the immigration and emigration age compositions (proportions) for males and females, respectively; and i_y and e_y are the proportions of immigration and emigration by sex. Further, let

$$\hat{I} = P * m + \frac{1}{2} N \quad (5)$$

and

$$\hat{E} = P * m + \frac{1}{2} N \quad (6)$$

where P is the mid-year population size of a country at time t and m is the corresponding average migration rate (0.003-0.015) used to approximate both immigration and emigration. The above specifications of immigration and emigration ensure that whatever average migration rate is used to estimate the flows, the result will match the specified net migration total. This is important because in the WPP procedures, net migration totals might first be estimated independent of age and sex patterns. It is assumed that immigration and emigration flows are highly correlated and proportional to the population of interest.

In summary, the decomposition of net migration into age and sex patterns requires six pieces of information: (a) the proportions of immigration and emigration by sex: i_y and e_y; and (b) age profiles of migration: male immigration by age, female immigration by age, male emigration by age, and female emigration by age: $i_{x|male}$, $i_{x|female}$, $e_{x|male}$, and $e_{x|female}$, respectively.

V. Tests with empirical data

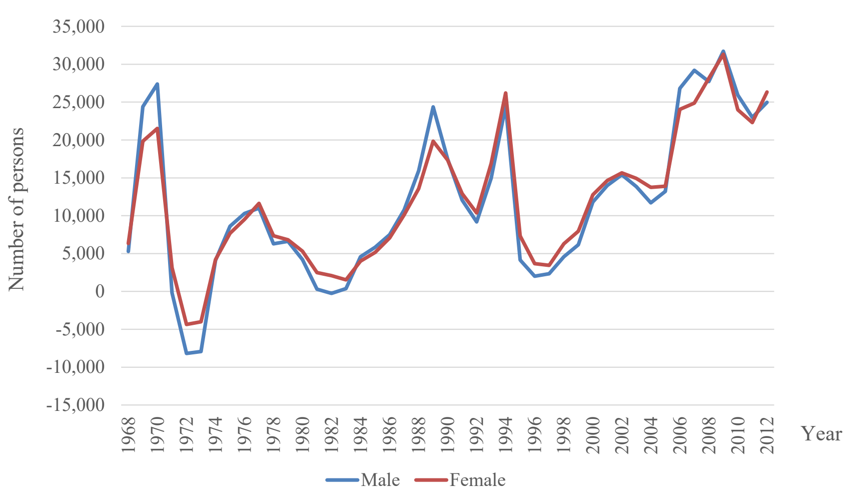
To test the method proposed in the previous section, it was applied to two countries known to have reliable single year age and sex data for both immigration and emigration over time. The first country is Sweden from 1968 to 2012. The second country is Republic of Korea for the years 2000 to 2021. In the tests, the parameter values represent averages of observed data over time.

A. Sweden 1968-2012

Annual immigration and emigration flow data by age and sex for Sweden were obtained from Statistics Sweden (www.scb.se) for a 44-year time period from 1968 to 2012. The flows are defined according to a twelve-month duration-of-stay criterion. The administrative data from population registers are considered to be of excellent quality and in line with the United Nations (1998) recommendations for measuring migration.

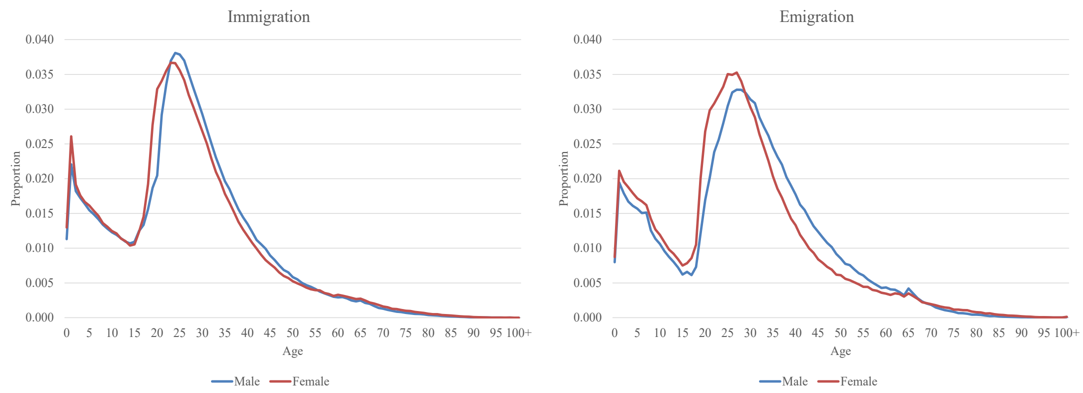
Figure 5 presents data on net international migration totals for Sweden, disaggregated by sex from 1968 to 2012. Analysis of this figure reveals significant temporal variations in the patterns, while highlighting a general parallelism between male and female trends. According to the Swedish Institute (https://sweden.se/migration/), migration was first characterized by those primarily seeking employment from countries such as Finland, Italy, Greece, the former Yugoslavia, Turkey, and other Balkan countries. In the 1970s, the Swedish government tightened its immigration policies, and flows subsequently decreased, alongside increased return migration of foreigners. Between 1980 and 1999, there was a rise in asylum seekers, particularly from Iran, Iraq, Lebanon, Syria, Turkey, Eritrea, and Somalia, as well as from some South American countries. Sweden joined the Schengen cooperation in 2001, which resulted in increased flows from European Union Member States.

Figure 5. Net migration totals by sex, Sweden 1968-2012



The time series of empirical data is shortened to 2003-2012 to reflect more current patterns. The age profiles of migration, averaged over the 2003-2012 period, are presented for immigration and emigration by sex in figure 6.

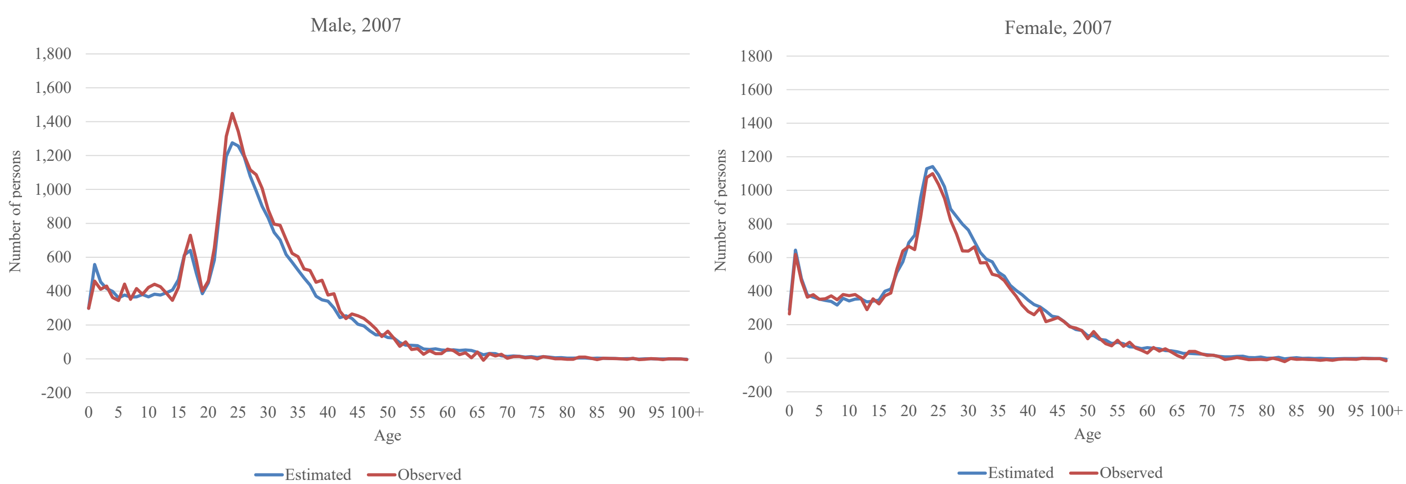
Figure 6. Average age profiles of immigration and emigration by sex, Sweden 2003-2012

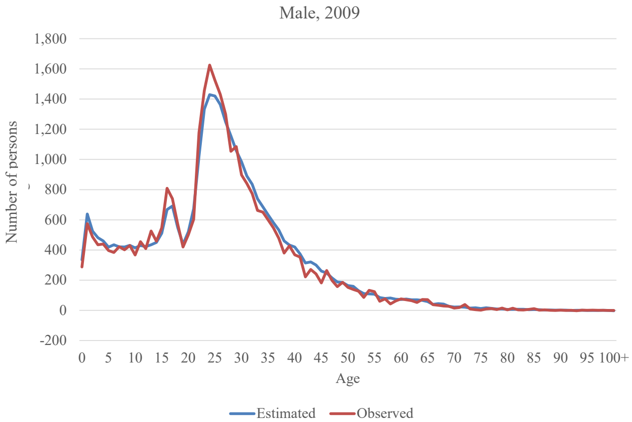


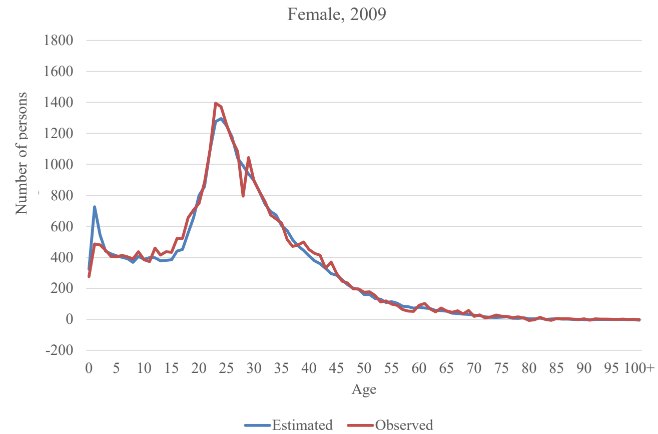
Annual levels of immigration and emigration are estimated by multiplying the population in each year by 0.007, which is close to the average observed proportion from 2003-2012. Note, the model using rates ranging from 0.003 to 0.015 was tested and it was discovered that the value used for *m* corresponding to equations 5 and 6 did not greatly influence the resulting age-sex patterns of net migration. Note, this assumes the constraining net migration total is smaller than the immigration and emigration flows.

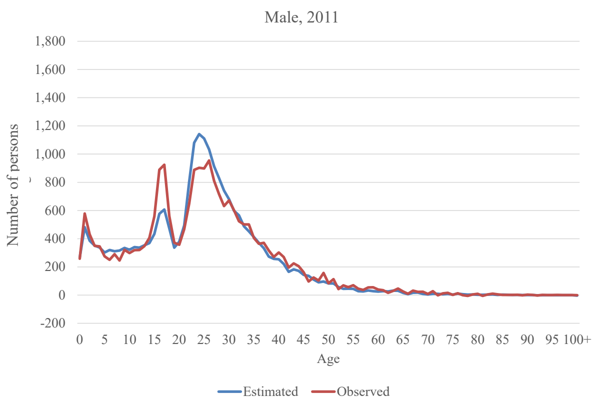
In this model, two sets of proportions are used. The first set of proportions capture the average proportions of total immigration and emigration by sex. For male immigration, it is 0.5210. For male emigration, it is 0.5373. The second set of proportions captures the average age proportions of male immigration and emigration, and female immigration and emigration (figure 6). As shown in figure 7, the model produced estimates very close to the observed values of net migration by age and sex in each year.

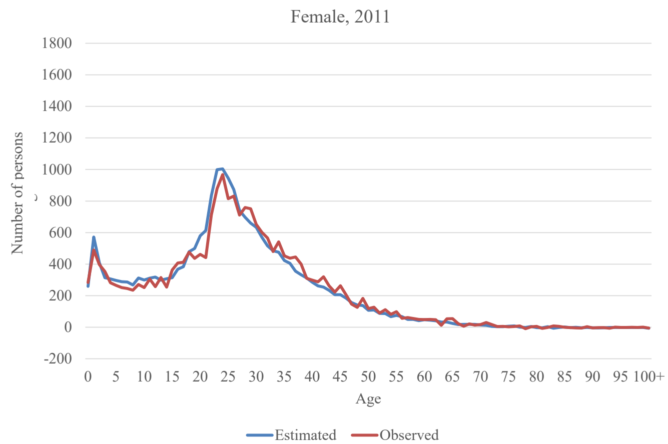
Figure 7. Comparison between observed and estimated net migration by age and sex for Sweden, 2007, 2009 and 2011











B. Republic of Korea

Migration data for Republic of Korea were obtained from the KOrean Statistical Information Service (KOSIS, http://kosis.kr/eng/). The data represent annual international migration arrivals and departures by age and sex from 2000 to 2021. These flows are measured using a twelve-month definition, that is, individuals must be in or out of the country for at least 12 months before qualifying as an international migrant.

Compared with Sweden, immigration to the Republic of Korea is relatively recent. Previously a net sender of migrants, the Republic of Korea has been a net receiver of migrants since the late 1980s (Oh and others, 2012). Today, immigrants consist largely of low-skilled temporary workers, foreign brides, and returning South Korean nationals. In 1990, there were 43,000 international migrants living in the Republic of Korea, increasing to 244,000 in 2000 and 1.1 million by 2015 (United Nations, 2017, table 1). According to Oh and others (2012), migration between 1990 and 2003 largely consisted of two groups: those involved in a technical training system and marriage immigrants from other Asian countries. From 2004 onwards, migration was regulated through a work permit system, and immigration both for marriage and for high-skilled work increased. Between 2000 and 2015, flows of immigration and emigration steadily increased from 371,000 (47 per cent foreign) and 363,000 (25 per cent foreign), respectively, to 684,000 (55 per cent foreign) and 622,000 (48 per cent foreign) (Statistics Korea, 2016).

Figure 8 presents the net international migration totals for the Republic of Korea by sex from 2000 to 2021. Here, it can be seen that the levels increased after 2005. While largely parallel, the male and female net migration totals deviated from each other in some years. For example, net migration was considerably higher for males in 2006 and 2014 and considerably higher for females in 2005, 2009 and 2020. The age profiles of migration, averaged over the 2000-2021 period, are presented for immigration and emigration by sex in figure 9.

Figure 8. Net migration totals by sex, Republic of Korea 2000-2021 (number of persons)

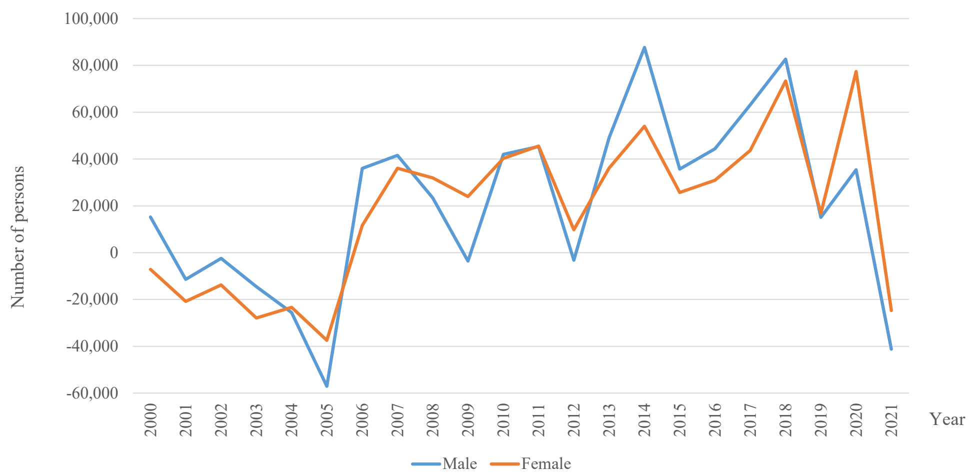
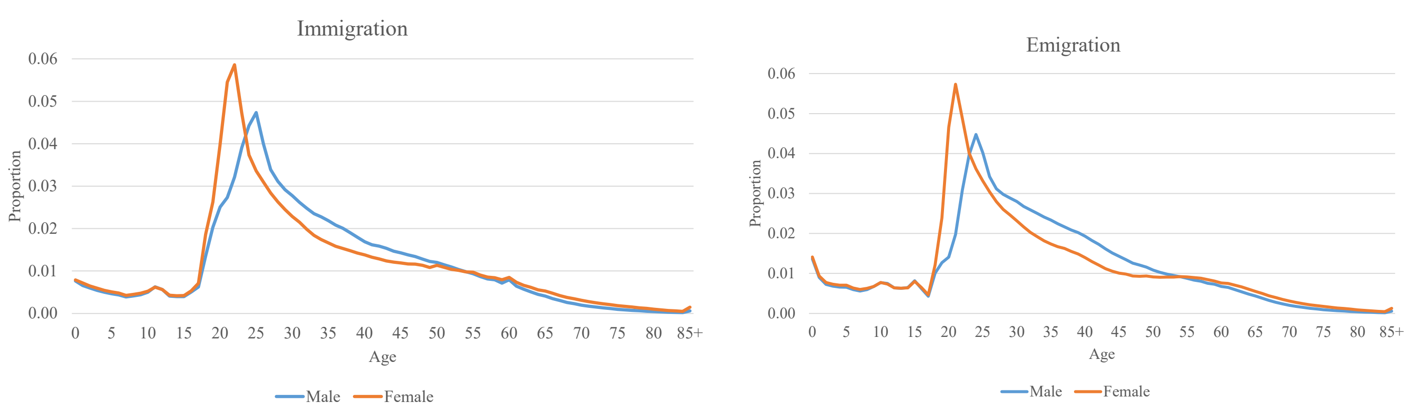
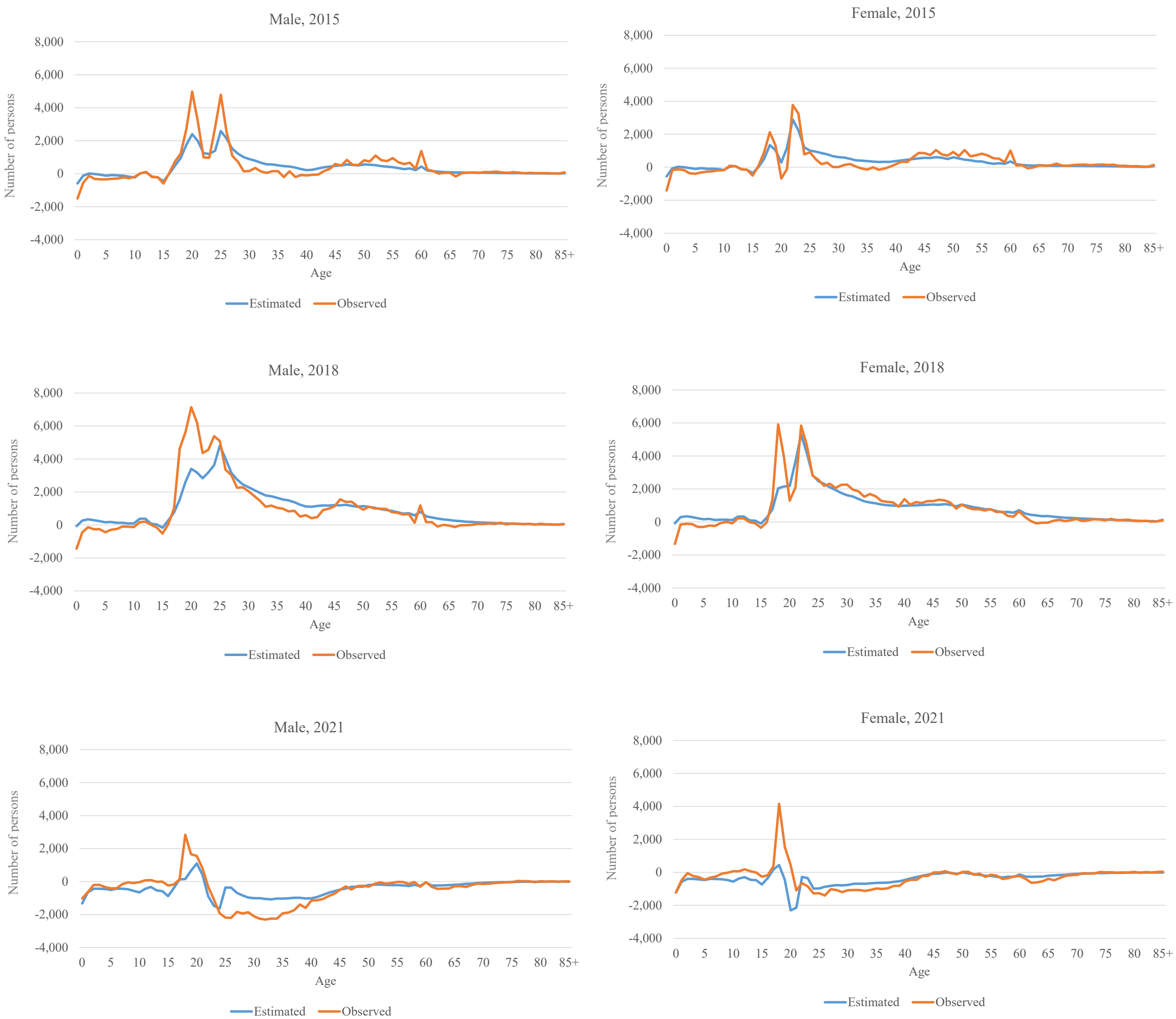


Figure 9. Average age profiles of immigration and emigration by sex for the Republic of Korea, 2000-2021



To estimate net migration by age and sex for the Republic of Korea, the annual levels of immigration and emigration were approximated by multiplying the population in each year by 0.012, which is close to the average proportion observed from 2000 to 2021. To distribute the estimated immigration and emigration levels by age and sex, two sets of proportions are used. The first set represents the average observed proportions for male and female immigration (0.5333 and 0.4667, respectively) and emigration (0.5321 and 0.4680, respectively). The second set represents the average age proportions of male and female immigration and emigration by age, as shown in figure 9. As with the data from Sweden, the model captured the observed estimates of age- and sex-specific net migration well. The results are shown in figure 10.

Figure 10. Comparison between observed and estimated net migration by age and sex for the Republic of Korea, 2015, 2018 and 2021



C. Summary

Based on empirical tests using data from Sweden and the Republic of Korea, the model appears to work well. Although not shown, the above procedure was also applied to estimate age and sex patterns of net migration for Australia, Canada and New Zealand, and obtained similar results.

For the application of the method to countries where migration data are not available, the following nine items need to be obtained or estimated in order to evaluate the age and sex patterns of net migration at the country level:

1. Annual mid-year population totals (estimates and projected values are available in WPP)
2. Annual net international migration totals (estimates and projected values are available in WPP)
3. Crude estimates of total immigration and emigration – can be obtained by multiplying mid-year populations by m = 0.003 to 0.011 with 0.005 recommended as the starting point. The resulting flow must be greater than the total net migration. For countries with very large annual labour flows, such as the Gulf Cooperation Council (GCC) countries, the proportions need to be considerably larger to achieve a plausible result. Results should be inspected for plausibility and internal consistency and the value of m adjusted, as necessary.
4. Proportion of immigration that are male (female)
5. Proportion of emigration that are male (female)
6. Age composition (proportion) of male immigration
7. Age composition (proportion) of female immigration
8. Age composition (proportion) of male emigration
9. Age composition (proportion) of female emigration

VI. Application to all countries

After testing the model on empirical data, the next step was to develop a framework and code in the R statistical package (R Core Team 2023) for application to any country situation without migration data. For estimating the total flows of immigration and emigration, the total population and net migration available in WPP data set from 1950 to 2022 were used (United Nations, 2022b). Rates of migration were initially set at 0.005 but in the R code, this parameter was made adjustable. With this information and the formulas set out in equations 1 and 2, crude levels of immigration and emigration were eventually estimated.

For distributing the crude levels of immigration and emigration by sex, the proportions from the sex-specific migration flow from stock estimates provided by Abel and Cohen (2022) were averaged and proportions that assumed equal shares of migration by sex. This had the effect of reducing sex-specific proportions that were considered extreme. The Abel and Cohen estimates include five-year migration transitions by origin, destination and sex from 1990-1995 to 2015-2020 based on six different methods. The pseudo-Bayesian estimates from the method that applied a closed demographic accounting system (Abel and Cohen, 2022; Azose and Raftery, 2019) were used as it showed the highest correlation with reported data.

To distribute the immigration and emigration totals by single-year age groups, a series of model migration schedules based on two age profiles: Western Standard and Low Dependency were created. Both schedules were adapted from a United Nations (1992) manual. The Western Standard schedule exhibited a broad labour force peak and had a downward sloping child migration curve. The Low Dependency schedule was dominated by a young adult peak. These schedules were adjusted depending on (1) direction of the flow and (2) sex. For direction of flow, it was assumed that receiving countries, that is, countries that exhibited positive net migration values, would receive younger immigrants than emigrants on average. The opposite was assumed for sending countries, that is, countries that exhibited negative net migration values. Similarly, adjustment was made to the model migration schedule parameters to estimate younger male patterns, younger female patterns or neutral (that is, same) patterns.

The parameters for the Western Standard and Low Dependency model migration schedules are presented in table 1 (see also equation 3). Here, the parameter values are the same between the two schedules except the Low Dependency schedule has a lower value for a_1 to represent a lower curve for child migration, higher value for a_2 to represent a higher labour migration peak, and a lower value for μ_2 to represent a younger labour force peak. Further the μ_2 parameter values were adjusted +/- 1 to produce slightly younger or older age profiles in each schedule. The resulting Western Standard and Low Dependency schedules are presented in figure 11 for the receiving countries. Figure 12 also presents the Western Standard schedule for different sex assumptions (that is, younger males, younger females, or neutral).

TABLE 1. MODEL MIGRATION SCHEDULE PARAMETERS FOR REPRESENTING AGE PATTERNS OF IMMIGRATION AND EMIGRATION

	Western Standard: Receiving		***Western Standard: Sending***		***Low dependency: Receiving***		***Low dependency: Sending***	
	Immig.	Emig.	Immig.	Emig.	Immig.	Emig.	Immig.	Emig.
a_1	0.0215	0.0215	0.0215	0.0215	0.0050	0.0050	0.0050	0.0050
α_1	0.1050	0.1050	0.1050	0.1050	0.1050	0.1050	0.1050	0.1050
a_2	0.0694	0.0694	0.0694	0.0694	0.0800	0.0800	0.0800	0.0800
α_2	0.1120	0.1120	0.1120	0.1120	0.1120	0.1120	0.1120	0.1120
μ_2	20.0400	**22.0400**	**22.0400**	20.0400	16.0900	**18.0900**	**18.0900**	16.0900
λ_2	0.3910	0.3910	0.3910	0.3910	0.3910	0.3910	0.3910	0.3910
a_0	0.0028	0.0028	0.0028	0.0028	0.0028	0.0028	0.0028	0.0028

Figure 11. Western Standard and Low Dependency model migration schedules for receiving countries

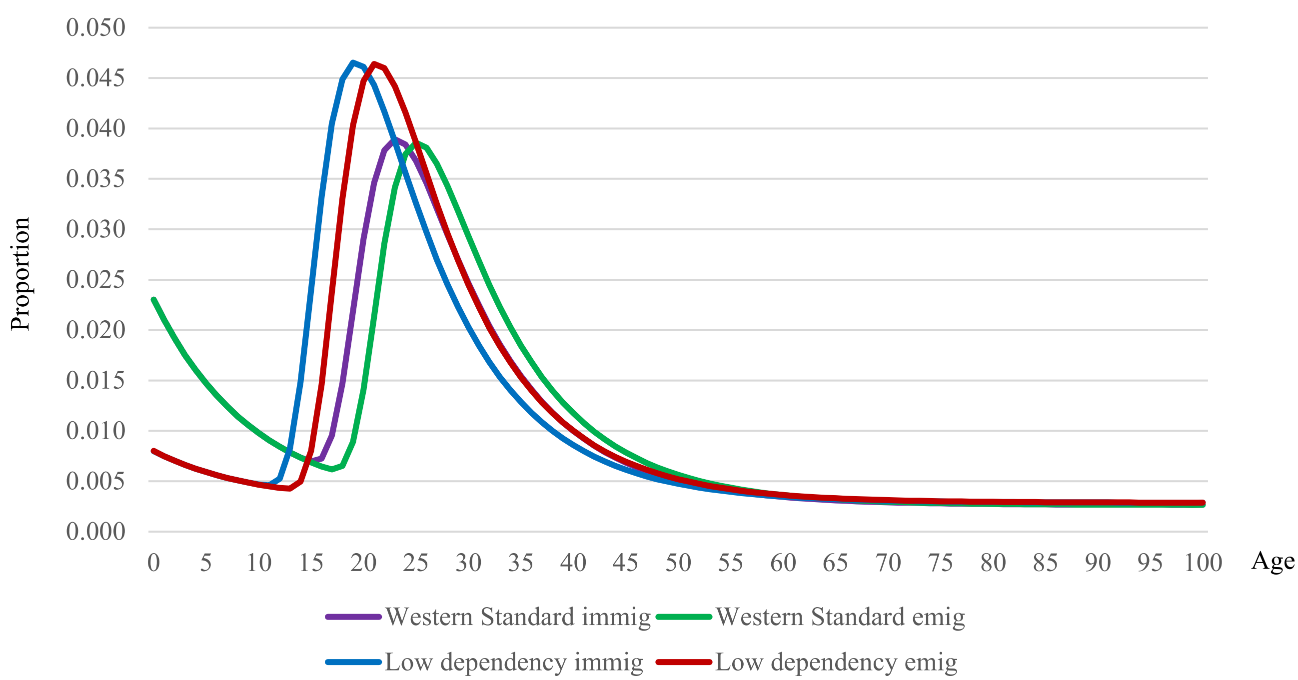
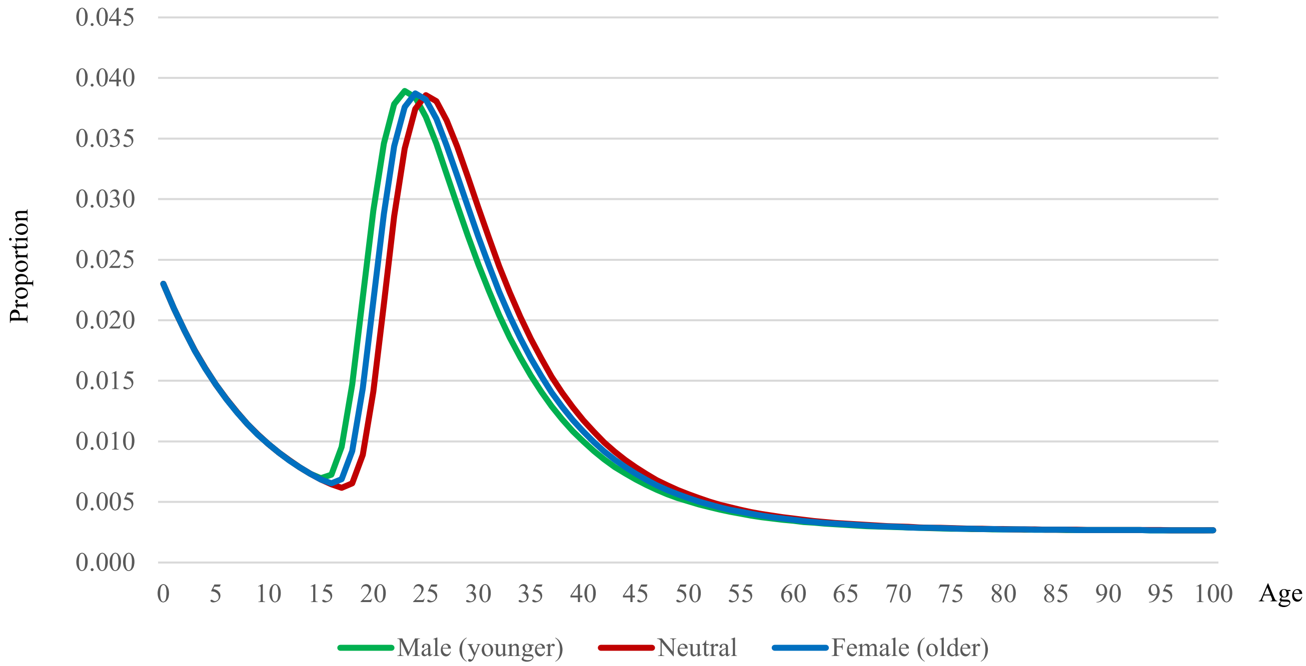


Figure 12. Western Standard model migration schedules for younger male, younger female and neutral assumptions



The final step involved combining the age assumptions for migration by direction and migration by sex. This was done to simplify the estimation of the four age profiles of migration. These two sets of age profiles can be averaged to provide reasonable estimates of the four age profiles. For example, the proportion in the first age group for male immigration would be equal to the proportion in the first age group of immigration plus the proportion in the first age group for males divided by two (that is, average). This makes the process simpler in the sense that one does not have to think about how, say, male emigration is different from female immigration. One just must think about how migration age patterns differ in terms of direction and how they differ by sex. For example, a receiving country with a Western Standard (WS) schedule and with assumed gender-neutral migration would have the following age-sex schedules of migration:

$i_{x|\text{male}}$ = [WS(immigration) + WS(neutral)]/2

$i_{x|\text{female}}$ = [WS(immigration) + WS(neutral)]/2

$e_{x|\text{male}}$ = [WS(emigration) + WS(neutral)]/2

$e_{x|\text{female}}$ = [WS(emigration) + WS(neutral)]/2

Also, in the R code, the following questions were set out to allow the analyst to make choices for each country of interest.

1. For country *i*, does the migration age profile follow the Western Standard (with family) or have low dependency?
2. Is country *i* a receiving or sending country?

3. Do you expect male migrants to be younger, female migrants to be younger, or the same for country *i*?

Figures 13 and 14 present two examples of modelled net migration by age and sex for China and the Philippines, respectively, for the years 2007 to 2022. Compared to the observed patterns presented for Sweden and the Republic of Korea, these estimates are smoother because they are based on model migration schedules. For China, large negative values for young adults followed by positive values representing return migrants were observed. Interestingly, the negative values are slightly higher for females, but the positive values are much larger for males, implying females are less likely to return. For the Philippines, it is the opposite – larger negative values for males and higher positive values for females. Also, there are no predicted positive values before 2015.

Figure 13. Estimated net international migration by age and sex for China, 2007-2022

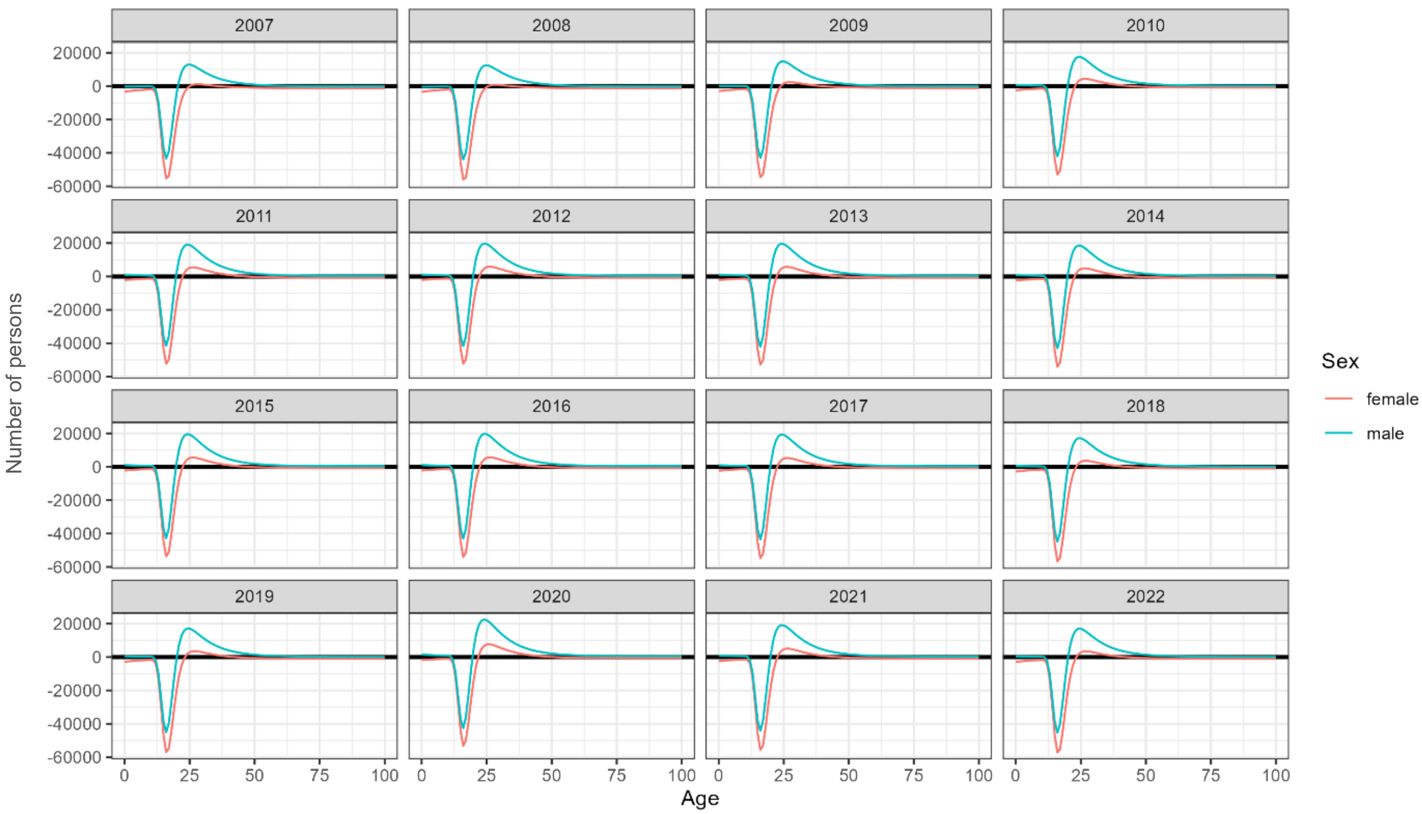
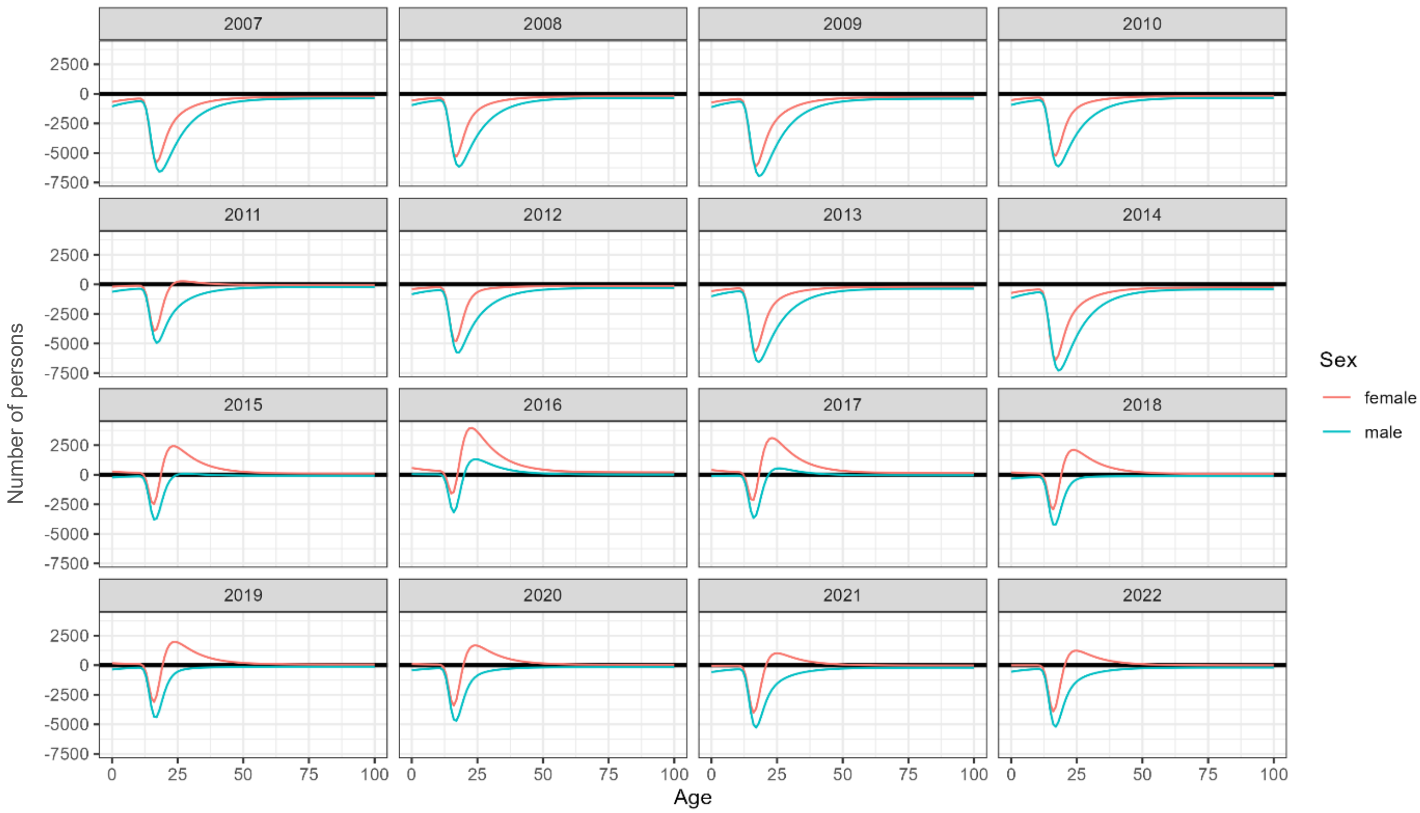


Figure 14. Estimated net international migration by age and sex for the Philippines, 2007-2022



The Western Standard and Low Dependency model migration schedules presented above should be considered a starting point. Further experimentation and testing are needed to determine the appropriateness of these schedules. During this process, a relational model approach could be developed whereby one starts with a general family schedule and then adjusts it depending on a set of covariate relationships. For example, one might expect that a more developed country with a large proportion of persons migrating would have an emigration profile with a wide labour force peak. The width of this peak might depend on how relatively old the population is in comparison to other aged populations. Similarly, the immigration level of child migrants could depend on whether the country has high levels of temporary migration, since temporary visa regimes are known to generally exclude the children of migrants.

VII. Conclusion

Developed here, is a relatively simple model for estimating the age and sex profiles of net international migration that can be applied to any country situation, with or without migration data. The model, coded in R, is flexible and can be modified to incorporate new data or assumptions. It can be applied to any country to estimate (or project) the age and sex patterns of net international migration.

This technical paper contributes to overcoming data limitations in the estimation and projection of populations and migration patterns. Continued analyses of model outputs and implications for population estimation and projection are needed. If required, the model framework may need further refinement and potential expansion of model migration age profiles. For example, small island countries or countries that have very high levels of temporary migrants (for example, GCC countries) may require specific models. It is believed that this work will greatly help to improve both understanding of migration processes as well as the estimation and projection of populations.

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