Modelling the Age and Sex Profiles of Net International Migration

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14 August 2024

ABSTRACT

In this study, we test and apply a methodology to infer the age and sex profiles of net migration. Age and sex profiles of net migration are required as inputs into demographic accounting models for population estimation and projection. However, most countries in the world do not directly measure migration and residual methods for inferring age and sex patterns have proven inadequate, due to errors in the measures of populations, births and deaths. Since net migration rarely exhibits regularities across age and sex, we develop a strategy to first estimate flows of immigration and emigration by age and sex. Differences from these flow estimates represent our estimates of net international migration by age and sex. Based on promising results from empirical tests that used data from Sweden and the Republic of Korea, the methodology is extended to estimate age-sex patterns of net international migration for countries lacking migration data.

ACKNOWLEDGEMENTS

This research supports the United Nations Population Division's estimation and population projection procedures for producing the World Population Prospects (WPP).[3]

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[3] The views expressed in this paper are those of the authors, and do not necessarily reflect the views of the United Nations.

1. INTRODUCTION

International migration is an increasingly important driver of population change in many countries. Particularly for those in the advanced stages of the demographic transition with low fertility and mortality rates, the future levels of net international migration will determine whether the population grows or declines during the coming decades (United Nations, 2024). Unfortunately, empirical data on international migration, remain sparse, because they are either not collected or not accessible to users (Iredale et al. 2003; Hugo 2005; Skeldon 2006). In particular, 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) are especially weak. Moreover, the stark differences in migration policies and management across regions in the world further complicate the measurement of international migration. Parts of Asia, for example, are 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). By contrast, no restrictions are in place in the European Union for migrants who have citizenship from member countries.

The majority of countries in the world do not publish or otherwise share data on international migration flows (Raymer et al. 2019, 2022). Countries that report flows of immigration and emigration are located mostly in Europe, North America and Oceania. 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, e.g., 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.

Because of the absence of migration flow data, assessments of international migration for most countries rely on indirect estimation methods that infer the total levels of net migration and patterns by sex and age based on information about changes in overall population size and age structure over time. To produce its estimates of net international migration for all countries in the world, the United Nations (2022a) uses a combination of residual methods, which compare populations enumerated in successive censuses, and model migration age schedules, which apply an assumed age distribution based on flows observed in a small number of countries with available data. These approaches have limitations, however. Residual methods are hampered by errors in the measurement of populations and vital rates. Model schedules are intended to describe flows and are not well-suited to represent net migration patterns, which are characterized by substantial levels of both immigration and emigration in some countries (Rogers 1990). In light of these challenges, further efforts are needed to improve the estimation of net migration profiles by age and sex.

In this paper, we propose a model framework to estimate the age and sex profiles of net international migration by dividing the net into the parts represented by (1) immigration by age and sex; and (2) emigration by age and sex. The differences between these two flows then yields the estimates of net international migration by age and sex. The method was developed to support the Population Division of the United Nations Department of Economic and Social Affairs (UNDESA) efforts to produce its biannual official population estimates and projections for all countries in the world in the World Population Prospects (WPP). The Population Division's current methodology for estimating and projecting net international migration is divided into two parts: (1) estimation of net migration totals and (2) distribution of net migration totals by age and sex. The analyses and methodology presented in this paper focus on the second part --- the distribution.

Next, we identify key age, sex and compositional regularities of international migration that are fundamental to our model design, followed by a review and evaluation of previous approaches used to estimate net international migration by sex and age. We then propose a new method to model the age and sex profiles of international migrants that can be used for 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. Finally, we apply the methodology to situations in which there are no migration data. The paper ends with a conclusion and recommendations for future research in this area.

2. 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 to single-year 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 or the survival ratio method (see Section 3.1).

These so-called residual methods for estimating net international migration assume 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). Moreover, small errors in the population counts may result in large errors in the estimation of net international migration. Also, population measurement errors can vary substantially by age, which can produce distorted age distributions via residual methods.

2.1 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).

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 et al. 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 (e.g., from living with parents to living alone) or life events (e.g., completing education) result 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, spouses with their partners, 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 for use in inferring age profiles of migration (Little and Rogers 2007).

To illustrate how migration varies by age and sex, we present in Figure 1 the patterns of emigration from Sweden every five years from 1968 to 2012. These data were obtained from a population register that maintains a continuous and accurate accounting of population change, including entries and exits. In the figure, we see that the age profiles are dominated by young children and young adults. Also, when expressed as proportions, the age patterns are remarkably similar 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).

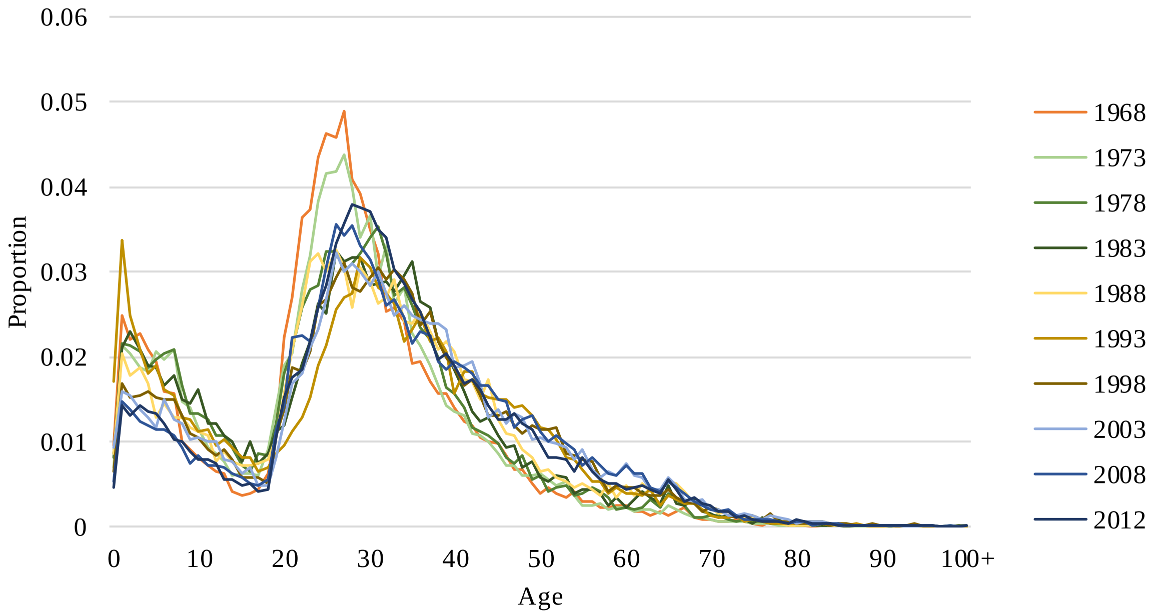


Figure 1. Proportionate age distribution of male emigration from Sweden, 1968-2012
Source: Statistics Sweden Statistical Database (https://www.statistikdatabasen.scb.se/pxweb/en/ssd/)

In Figure 2, we present the age patterns of net migration for males in Sweden, separated into the following four periods: 1968-1979, 1980-1992, 1993-2003, and 2004-2012. The late 1960s and 1970s were a relatively volatile period with considerable positive and negative values for young adults. The net migration patterns for the 1980s to early 2000s appeared relatively stable[4]. After 2004, net migration increased considerably across all ages due to the expansion of the European Union (EU)[5]. In comparison to the emigration age profiles, the net age profiles of international migration were less stable over time.

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

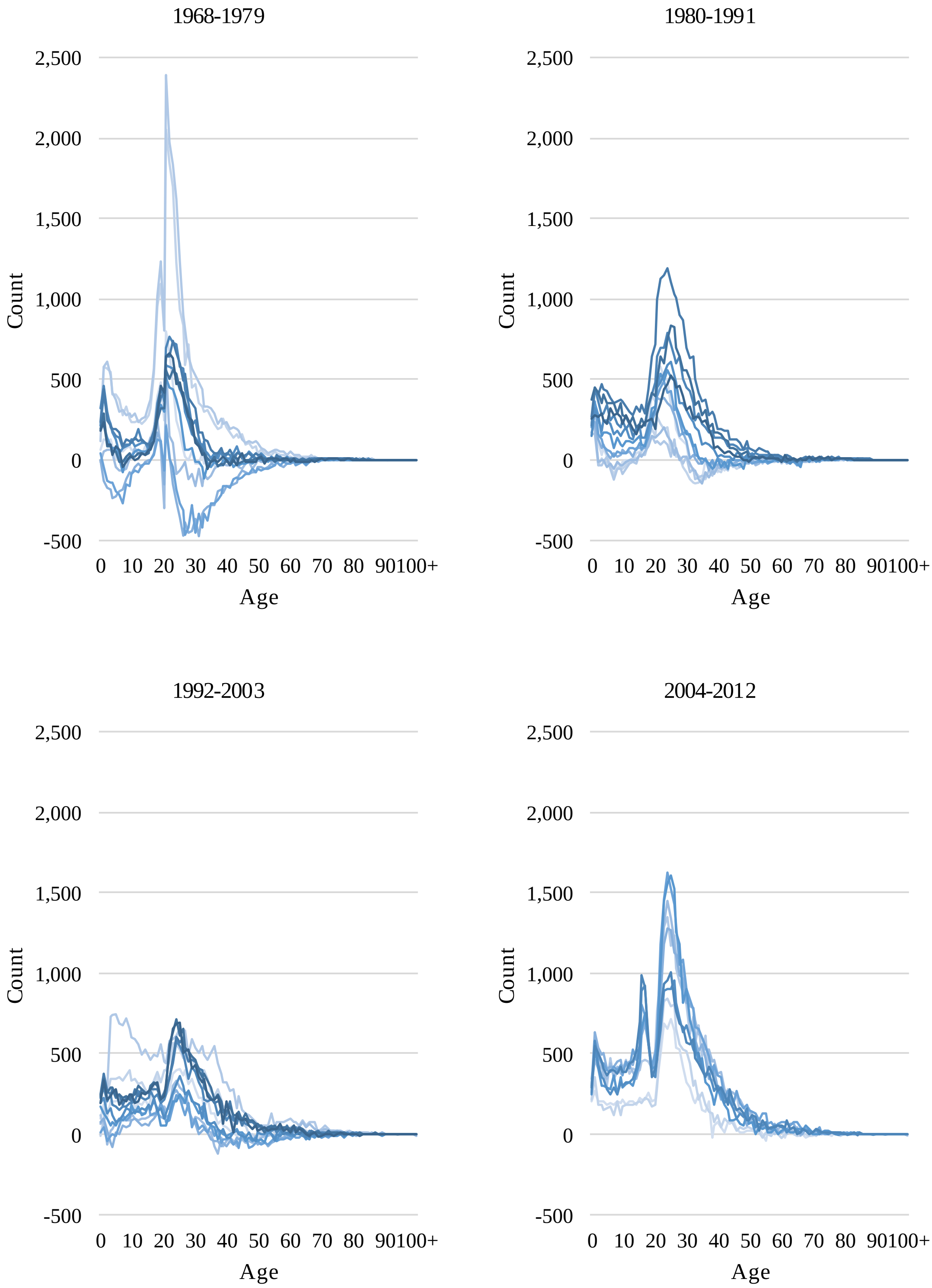


Figure 2. Male net international migration by age for Sweden, 1968-2012 (persons)
Source: Statistics Sweden Statistical Database (https://www.statistikdatabasen.scb.se/pxweb/en/ssd/). Note, lines are shaded by year with darker lines representing recent years.

We illustrate in Figure 3 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 record numbers of all overseas arrivals and departures. Being an island nation facilitates maintenance of travel records that 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 we examine the net migration age profiles, we also see increased levels over time (bottom-left chart) but more varied age patterns even when standardised (bottom-right chart).

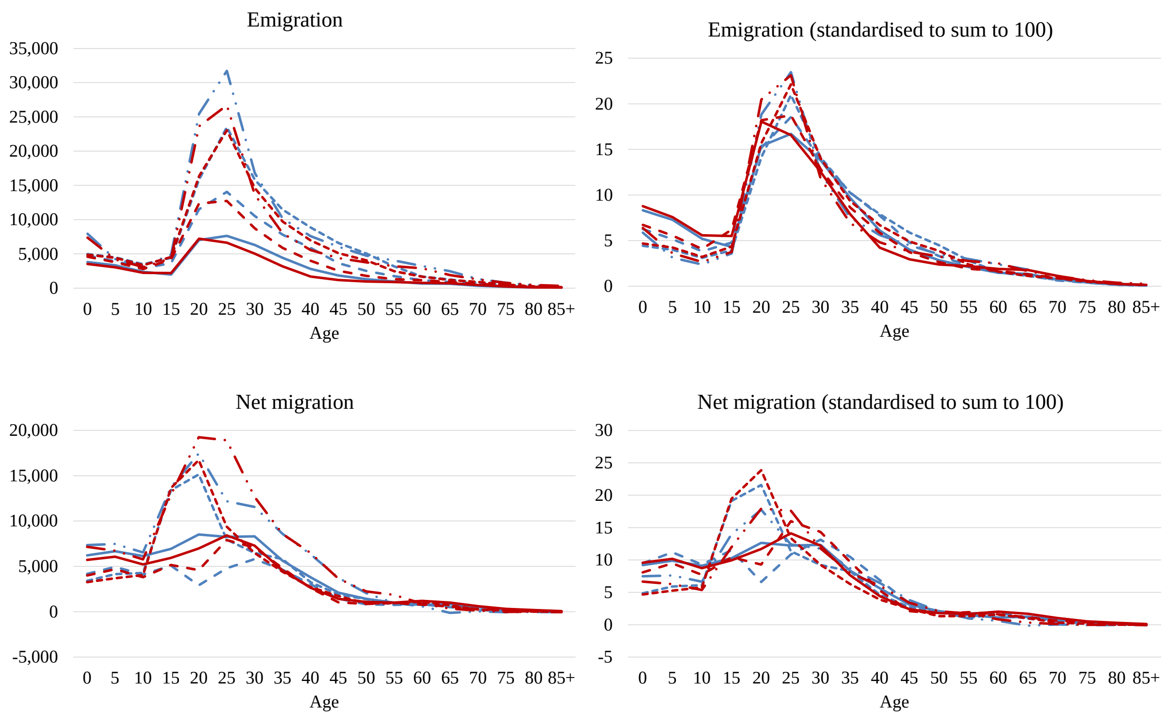


Figure 3. Annual emigration (in persons) and net migration by age and sex (in per cent) for Australia, 1981, 1991, 2001 and 2011
Source: Australian Bureau of Statistics

When expressed as proportions, the three illustrations of migration age patterns above show clearly that directional flows (i.e., 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.

2.2 Sex patterns of migration

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 et al. 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, migrant worker populations were comprised of 59% males and 41% females, representing a slight shift towards more equal gender distribution than previously estimated (McAuliffe and Triandafyllidou 2021, pp. 37-38).

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 and caring for children, elderly and disabled persons are also common occupations for low-skilled migrant 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; UNDESA 2006).

Worldwide, refugees are comprised of 48% women and 52% men (UNHCR 2021). 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 be seeking asylum as part of a family group or to be married (UNHCR 2010; UNPD 2011; IOM 2022), and women are usually not the primary applicants (UNFPA 2006).

Females represented 58 per cent of foreign tertiary education graduates in OECD countries in 2021 (OECD 2023, Table B5.2). However, there can be differences depending on the degrees being sought with male students typically having much higher proportions in the information and communication technologies and engineering, manufacturing and construction fields of study.

2.3 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 regarding income and housing before dependents are admitted to the country. Women form a clear majority of those admitted for family reunification (EMN 2008). 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 migrants who bring in a spouse from their parents' country of birth. 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.

2.4 Return migration

Return migration occurs in nearly all situations of international migration. 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, we would expect immigration to have a slightly older age profile than emigration. The opposite is the case for countries that experience higher levels of immigration than emigration.

3. METHODS FOR ESTIMATING PATTERNS OF MIGRATION

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, e.g., Poulain 1993; Raymer 2008; De Beer et al. 2010; Raymer et al. 2013; Wiśniowski et al. 2016; Abel 2018; Fiorio et al. 2021). The estimation of migration provides a way to overcome data limitations. 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). Below, we review a number of methods that have been used to estimate the patterns of migration, including the approach used by the United Nations.

3.1 Residual methods for estimating net migration totals

The residual methods for estimating net migration use 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. That is, in simplified form, annual net migration $NM_i^{t-1,t}$ is equal to a population in a 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, $D_i^{t-1,t}$, i.e.,

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

The basic assumptions of this method are that the population and natural increase amounts are exact (i.e., 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:

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

where: $NM_i^{t-1,t}(x)$ denotes net migration for country *i* at age *x* between time *t*-1 and *t*, and $P_i^t(x)$ and $S_i^t(x)$ denote the corresponding number of persons and survivors, respectively. The basic assumptions in this model are that the population and mortality rates are exact.

Both residual methods described above do not provide information about the relative numbers of immigration and emigration or countries of origin or destination. For a given net migration total, there may be infinite combinations of immigrants and emigrants. This makes net migration difficult to explain and may result in biased predictions of population change (Rogers 1990). Further, residual estimates of net migration 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.

3.2 Model age schedules

In the 1970s, 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 / high levels and early / 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.

Around the same time that Pittenger was developing a typology of net internal migration age schedules, Rogers and colleagues developed a model schedule for migration flow data (Rogers et al. 1978; Rogers and Castro 1981a). 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 (i.e., overall level), $a_1 \exp(\alpha_1 x)$ is a negative exponential curve representing the pre-labour force ages, and $a_2 \exp\{-\alpha_2(x-\mu_2) - \exp[\lambda_2(x-\mu_2)]\}$ is 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 that require age patterns of migration.

As argued by Rogers and Castro (1981), 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 (e.g., Azose et al. 2016).

3.3 Other methods

There are other methods that have been used to infer age and sex patterns of migration. For these methods to work effectively, multiple observations on the migration indicators are needed.

Multiplicative component models have been used to estimate origin–destination–age counts of internal and international migration (Willekens and Baydar 1986; Raymer et al. 2006; Raymer et al. 2017; Shen et al. 2024), from which net migration can be derived. These methods are particularly useful when some of the information on migration flows are available, such as total immigration or total emigration. 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).

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 et al. (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 et al. (2015). Finally, Wiśniowski et al. (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.

3.3 The United Nations' approach

In the United Nations' World Population Prospects, the estimated sex and age patterns of net international migration vary according to the country's context and time period. Model migration schedules are used to estimate net international migration for many countries over time. Specifically, the `mig_un_fam()` function of the *DemoTools R* package (Riffe et al. 2019), includes: 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 age-sex distribution of net migration is assumed identical to the age-sex distribution of the population. In cases where countries had reliable census or population register data or other high-quality population estimates, residual methods were used to estimate both the total level of net international migration and the patterns by age and sex.

4. METHODOLOGY

In this section, a new 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 differences in these estimated patterns are used to infer net international migration by age and sex.

To illustrate the age pattern effects on net migration by different levels of immigration and emigration, we present some hypothetical model migration schedules and the corresponding net migration schedules in Figure 4. The positive red line represents immigration, the negative blue line represents 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 immigration and emigration are the same. The second graph (Figure 4b) shows how age-specific net migration increases when the overall level is increased consistently across all ages. 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.

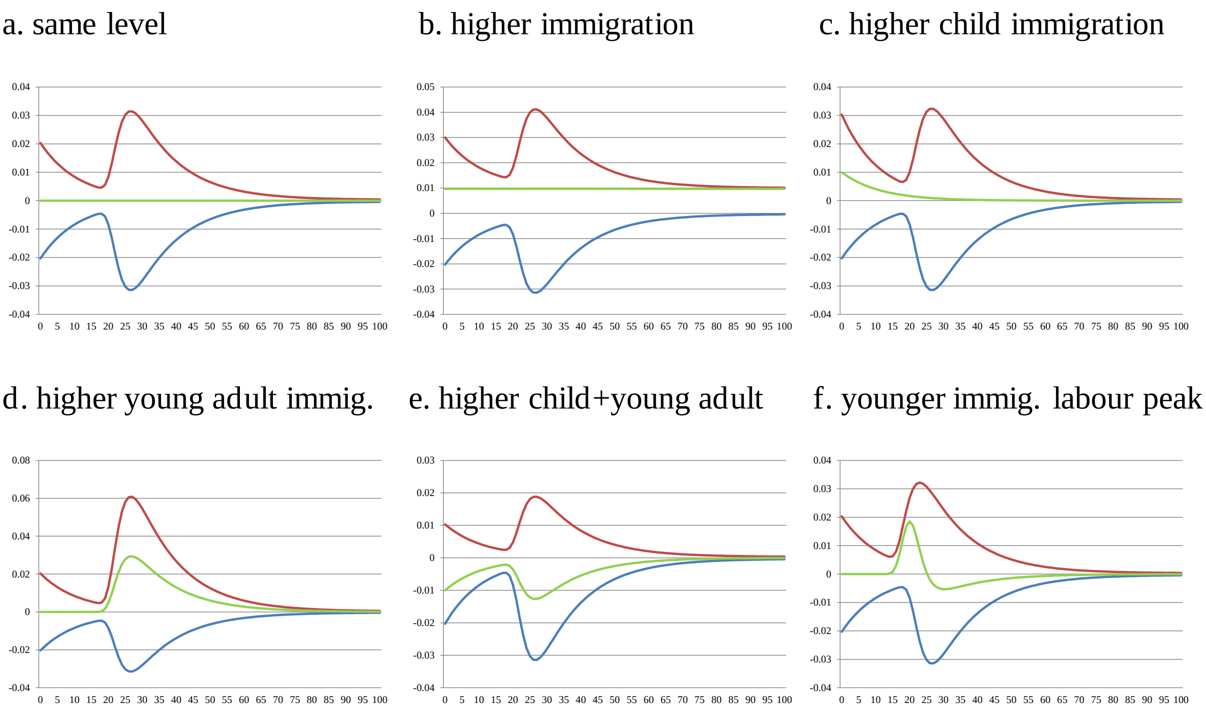


Figure 4. Hypothetical age patterns of immigration (red lines), emigration (blue lines) and net migration (green lines)

The procedure for estimating how net migration should be distributed by age and sex is presented below. First, we assume annual net migration totals are known and true. Second, we estimate age and sex profiles of immigration and emigration flows. This involves (a) crudely estimating the overall levels of immigration and emigration and then (b) disaggregating by age and sex. Finally, we calculate the difference of these patterns to obtain estimates of net international migration by age and sex.

The overall model is specified as

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

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

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

and

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

where P is the mid-year population size of a country at time t, and m is an average migration rate specified to be somewhere between 0.003 and 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 are first estimated independently of the age and sex patterns. We also assume that immigration and emigration flows are highly correlated and proportional to the population of interest --- the procedure also ensures both of these conditions are met.

Once crude estimates of immigration and emigration levels are approximated, the next step is to decompose them by age and sex. This requires estimating the proportions of immigration and emigration by sex, i_y and e_y, and age profiles for male immigration, female immigration, male emigration, and female emigration, denoted by $i_{x|male}$, $i_{x|female}$, $e_{x|male}$, and $e_{x|female}$, respectively.

5. TESTS WITH EMPIRICAL DATA

To test the method proposed in the previous section, we apply it to two countries known to have reliable single year age and sex data for both immigration and emigration. The countries are Sweden and the Republic of Korea. In the tests, the parameter values represent averages of observed data over time.

5.1 Sweden 1968-2012

Annual immigration and emigration flow data by age and sex for Sweden were obtained from Statistics Sweden (http://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 United Nations (1998) recommendations for measuring migration.

In Figure 5, the net international migration totals for Sweden are presented by sex from 1968 to 2012. Here we see that the patterns vary greatly over time but that male and female patterns are largely parallel. According to the Swedish Institute,[6] 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.

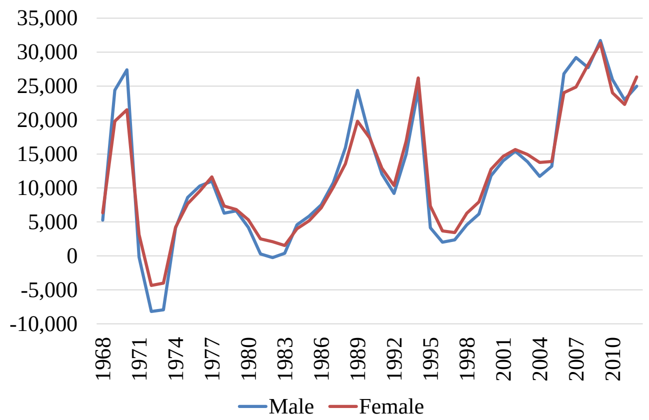


Figure 5. Net migration totals by sex, Sweden 1968-2012

For the empirical data tests, the time series is shortened to 2003-2012 to reflect more current patterns. The age profiles of migration, averaged over the 2003-2012 period, are

6 https://sweden.se/culture/history/sweden-and-migration

presented for immigration and emigration by sex in Figure 6. Here we see that the age profiles of immigration are similar but females exhibit slightly younger age patterns in the young adult years. For the corresponding emigration patterns, females have higher rates before 30 years, whereas males exhibit higher rates in ages between 30 and 60 years.

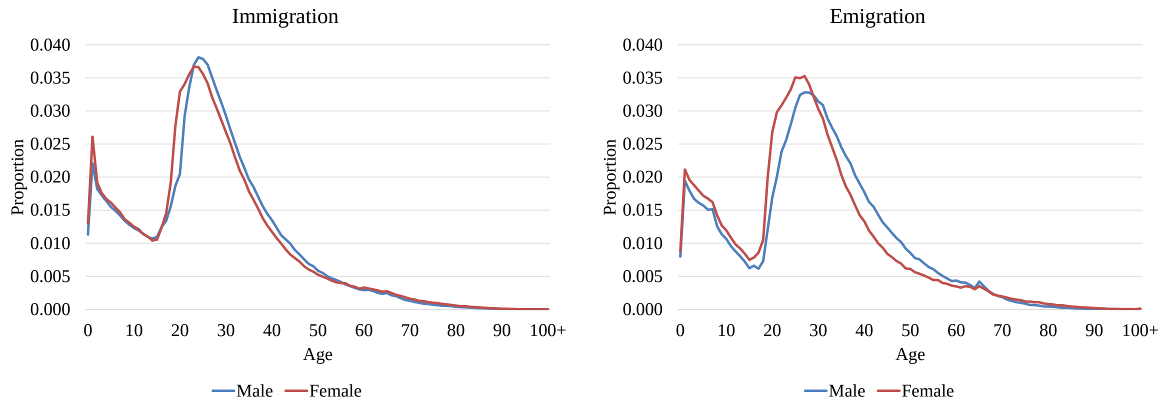


Figure 6. Average age profiles of immigration and emigration by sex, Sweden 2003-2012

Annual levels of immigration and emigration, m, are estimated by multiplying the population in each year by 0.007, which is the observed average rate from 2003-2012. Note, we tested the model using rates ranging from 0.003 to 0.015 and found the value of m did not greatly influence the resulting age-sex patterns of net migration. Note, this assumes the constraining net migration total, N, is smaller than the immigration and emigration flows.

For distributing $\hat{I}$ and $\hat{E}$ by age and sex, two sets of proportions are used. The first captures the proportion of total immigration and emigration by sex, i.e., i_y and e_y, respectively. For male immigration, we used the observed average proportion of 0.5210. For male emigration, we used 0.5373. The second set of proportions captures the average age proportions of immigration and emigration by sex, i.e., $i_{x|y}$ and $e_{x|y}$, respectively. We used the proportions presented in Figure 6.

Using Equation 4 and the parameter inputs described above, we estimated the net migration totals by age and sex for Sweden from 2003 to 2012. A selection of the results for males and females are presented in Figure 7 for the years 2007, 2009 and 2011. As can be seen, the model produced estimates that were very close to the observed values in each year.

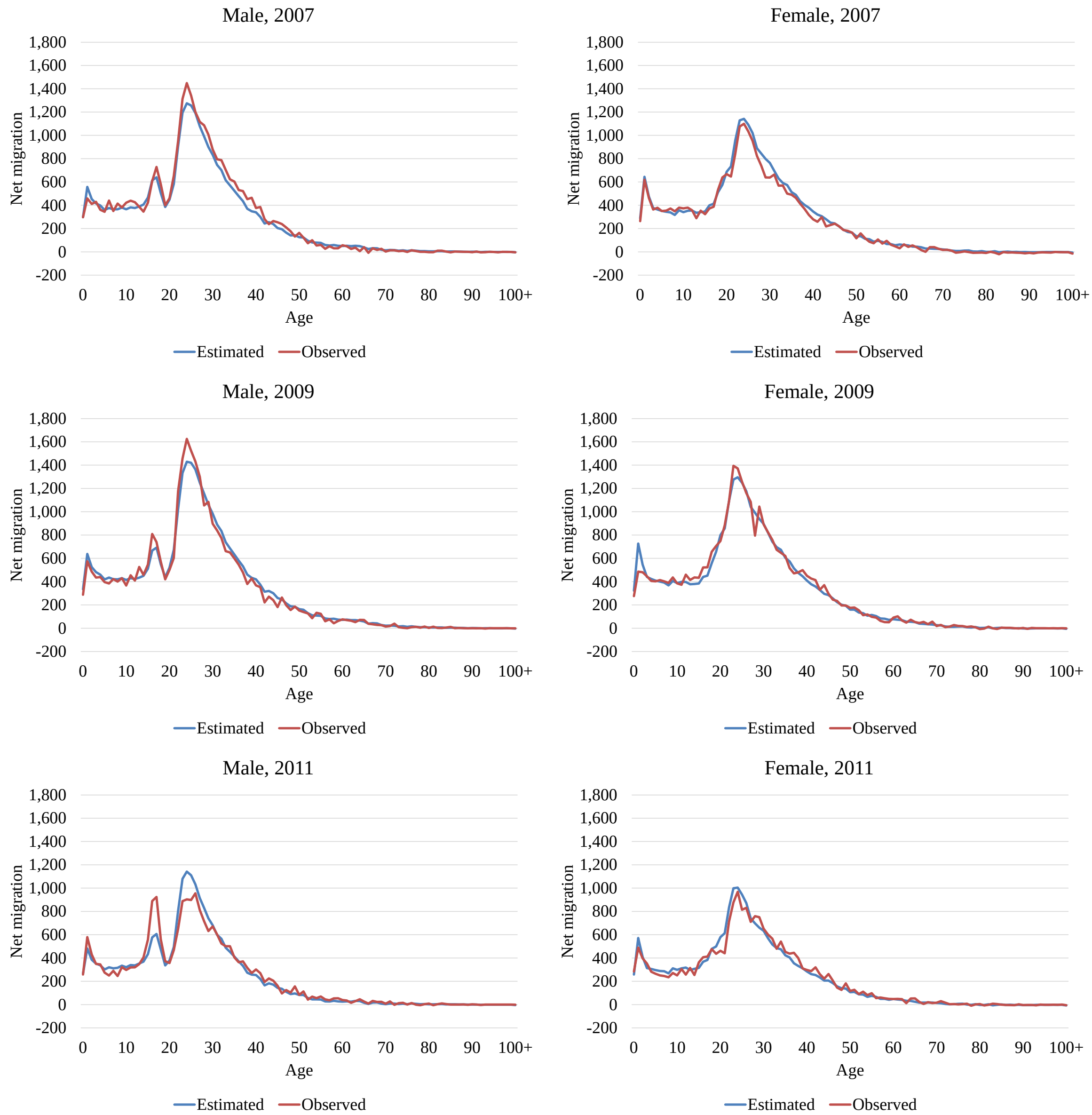


Figure 7. Comparison between observed and estimated net migration by age and sex for Sweden, 2007, 2009 and 2011

5.2 Republic of Korea 2000-2021

Migration data for the Republic of Korea were obtained from the KOrean Statistical Information Service (KOSIS)[7] operated by Statistics Korea. 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 et al. 2012). Today, immigrants consist largely of low-skilled temporary workers, foreign brides, and returning South Korean nationals. In 1990, there were 43 thousand international migrants living in the Republic of Korea, increasing to 244 thousand in 2000 and 1.1 million by 2015 (UNPD 2017, Table 1). According to Oh et al. (2012), migration between 1990 and 2003 largely consisted of two groups: those involved in the technical training system and marriage migrants 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 thousand (47 per cent foreign) and 363 thousand (25 per cent foreign), respectively, to 684 thousand (55 per cent foreign) and 622 thousand (48 per cent foreign) (Statistics Korea 2016).

In Figure 8, the net international migration totals for the Republic of Korea are presented by sex from 2000 to 2021. Here we see 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.

[7] http://kosis.kr/eng/

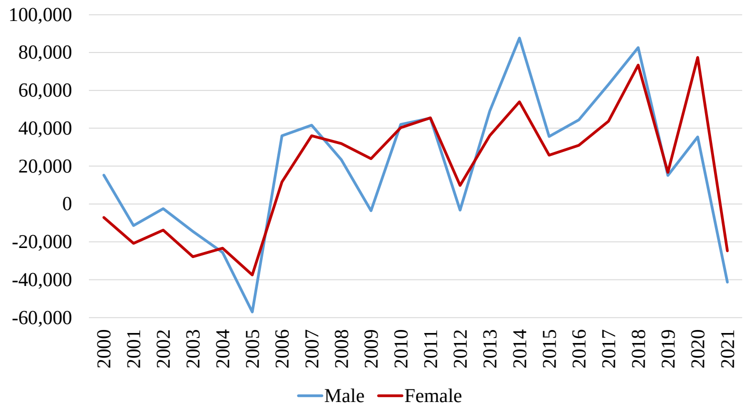


Figure 8. Net migration totals by sex, Republic of Korea 2000-2021 (persons)

The age profiles of immigration and emigration, averaged over the 2000-2021 period, are presented for by sex in Figure 9. In both cases, female proportions are higher between ages 19 years and 22/23 years and male proportions are higher between ages 22/23 years and 49/51 years. In comparison to Sweden, the age patterns for the Republic of Korea are more focused in the young adult years and do not contain many child migrants.

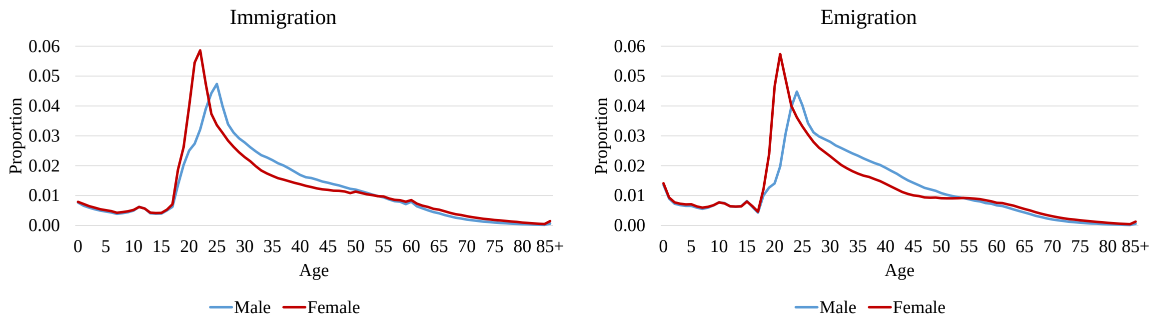


Figure 9. Average age profiles of immigration and emigration by sex for Republic of Korea, 2000-2021

For the empirical test of the age-sex distribution model for the Republic of Korea, annual levels of immigration and emigration were approximated by multiplying the population in each year by 0.012, which is the average proportion observed from 2000 to

2021. The average observed proportions of immigration and emigration for males were 0.5333 and 0.5321, respectively. We used the average age proportions of immigration and emigration by sex presented in Figure 9. As with Sweden, the model reproduced the patterns of observed age- and sex-specific net migration, albeit with some differences in the young adult years. In Figure 10, we present a selection of results by sex for the years 2015, 2018, and 2021. Here, we see that the observed and estimated net age profiles exhibited two positive labour force peaks in 2015 and 2018 while in 2021 the patterns changed to a positive and then negative peak.

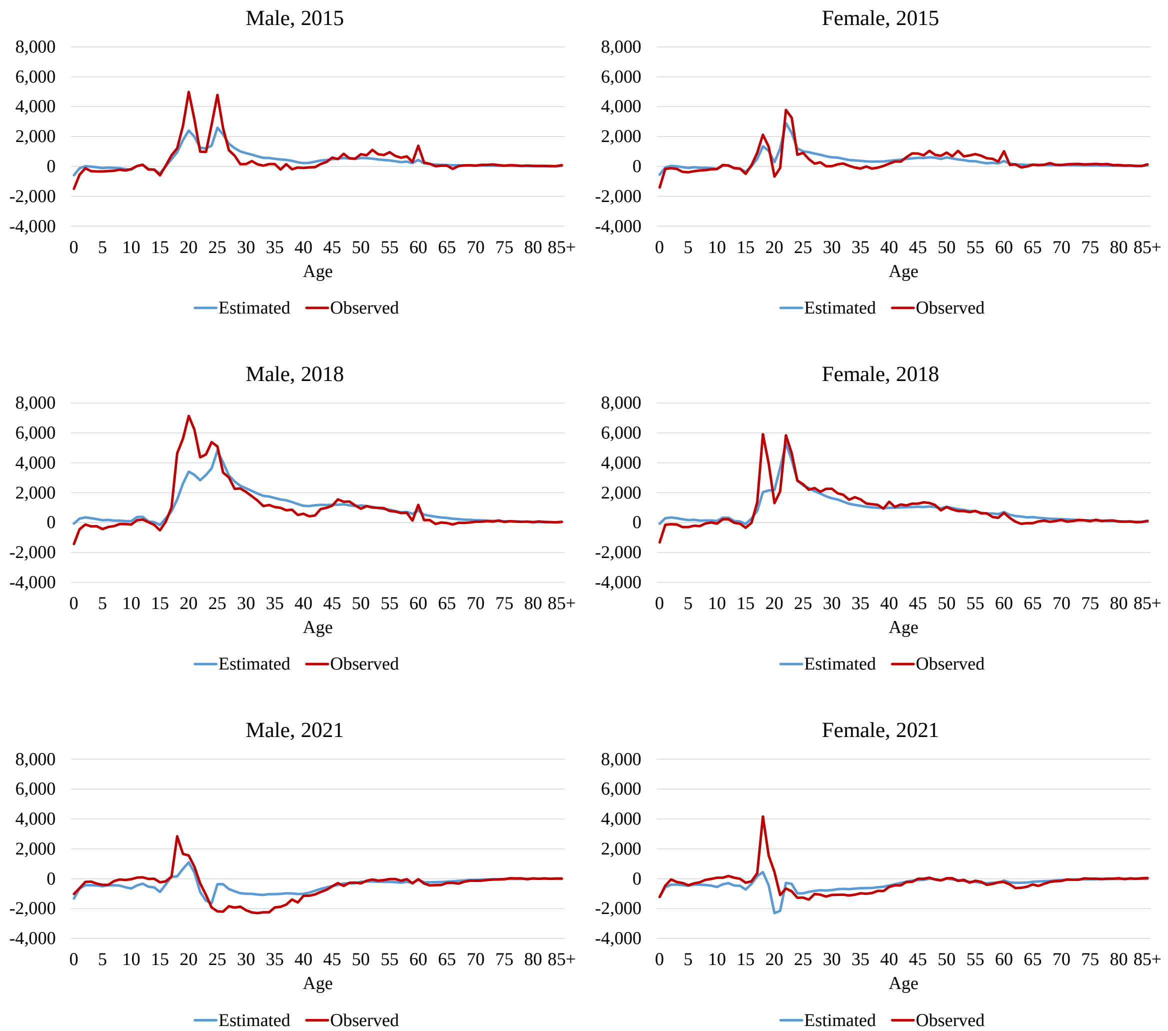


Figure 10. Comparison between observed and estimated net migration by age and sex for the Republic of Korea, 2015, 2018 and 2021

5.3 Summary

Based on empirical tests using data from Sweden and the Republic of Korea, the model expressed in Equation 4 appears to work well. Although not shown, we also applied the above procedure 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 flow data are not available, we need to obtain or estimate the nine items in Equations 4-6. The first is the annual mid-year population totals, P; estimated and projected values are available in WPP. The second is annual net international migration totals, N; estimates and projected values are available in WPP. The third is an average crude estimate of total immigration and emigration; this value has to be estimated by multiplying mid-year populations by a set value of m = 0.003 to 0.011 with 0.005 recommended as the starting point.[8] Furthermore, the works (Abel 2018; Azose and Raftery 2019; Raymer et al. 2022) estimating international flow could provide information for a reasonable m value of each country. The fourth and fifth are the proportions of immigration (i_y) and emigration (e_y) by sex, respectively; these values have to be estimated. The sixth, seventh, eighth and ninth are the age compositions of male immigration ($i_{x\backslash male}$), female immigration ($i_{x\backslash female}$), male emigration ($e_{x\backslash male}$), and female emigration ($e_{x\backslash female}$), respectively. In the application section below, we describe our procedure for estimating the fourth through ninth parameters in the context of any empirical data.

6. APPLICATION TO ALL COUNTRIES

[8] Note, the resulting flow must be larger than the net migration total. For countries with very large annual labour flows, e.g., GCC countries, the proportions will need to be considerably larger to achieve a plausible result.

After testing the model on empirical data, we develop a framework and code in the R statistical package for application to any country situation without data.[9] For estimating the total flows of immigration and emigration, the total population and net migration available in the WPP data set from 1950 to 2022 were used. Rates of migration were initially set at 0.005 but in the R code, and we made this parameter adjustable. With this information and the formulas set out in Equations 5 and 6, we were able to estimate crude levels of immigration and emigration ($\hat{I}$ and $\hat{E}$).

For distributing the crude levels of immigration and emigration by sex, we averaged the proportions from the sex-specific migration flow-from-stock estimates provided by Abel and Cohen (2022) 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. We used the pseudo-Bayesian estimates from the method that applied a closed demographic accounting system (Abel and Cohen 2022; Azose and Raftery 2019) as it showed the highest correlation with reported data.

For distributing the immigration and emigration totals by single year age groups, we created a series of model migration schedules based on two age profiles: Western Standard and Low Dependency. Both schedules were adapted from a United Nations (1992) manual for internal migration. 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. We adjusted these schedules depending on (i) direction of the flow and (ii) sex. For direction of flow, we assumed receiving countries, i.e., countries that exhibited positive net migration values, would receive younger immigrants than emigrants on average. The opposite was assumed for sending countries, i.e., countries that

[9] The R code can be found at https://osf.io/5wvmc/?view_only=c885d295e0194aa183452db769285c91.

exhibited negative net migration values. Similarly, we adjusted the model migration schedule parameters to estimate younger male patterns, younger female patterns or neutral patterns (i.e., same age profiles by sex).

The parameters for the Western Standard and Low Dependency model migration schedules are presented in Table 1 (see also Equation 3). Here we see 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, a 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 receiving countries.

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

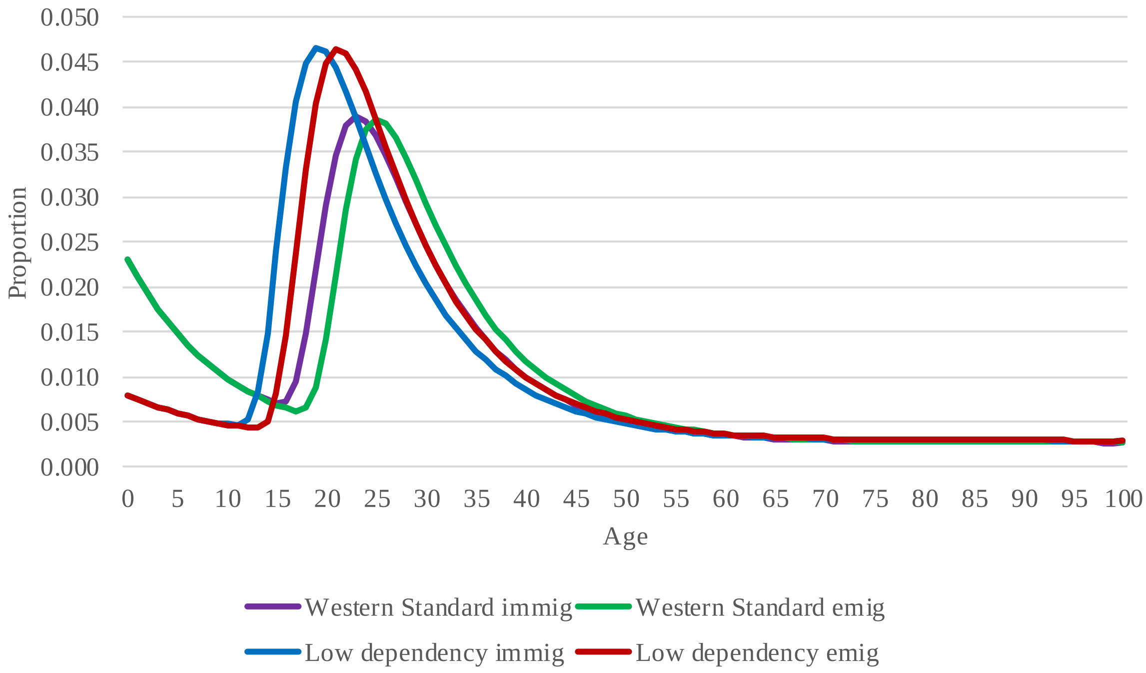


Figure 11. Western Standard and Low Dependency model migration schedules for receiving countries

The final step involved combining the age assumptions for migration by direction and migration by sex. We did this 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 (i.e., 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 has to 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

The model design is flexible to incorporate different sets of assumptions for the age schedule. For each country, three questions are used to add assumptions to the age schedules for migration by direction and sex:

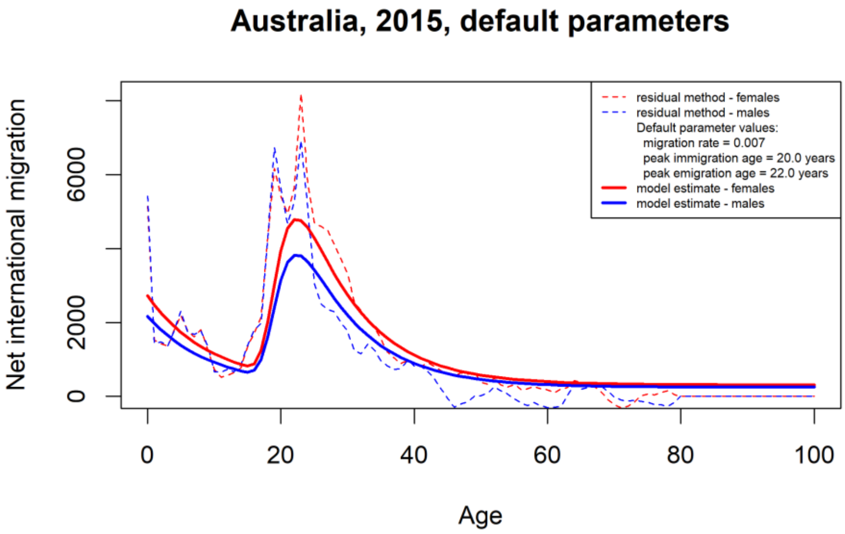
I. Does the country's migration age profile follow the Western Standard (with family) or have low dependency?

II. Is the country a receiving or sending country?

III. Comparing the sex composition of migrants for the country, are male migrants younger, female migrants younger, or about the same?

For the 2024 revision of the World Population Prospects, the new method was applied to estimate the net migration sex-age profiles for all countries over the projection horizon 2024-2100. During the course of this work, some adjustments were made to the default parameters in order to more closely represent the age patterns inferred by residual methods. Specifically, for all country-years with high-quality residual estimates of sex- and age-specific net international migration, we sought to identify the parameter values that would minimize the difference between the modelled and residual patterns. We used the optim() function of the stats package for R to optimize the values of the migration rate *m* and the peak ages of immigration and emigration μ_2, while maintaining the default values of the other parameters described in Table1. Two sets of optimized parameters were identified for each country-year: one for the Western Standard profile and the other for the Low Dependency profile.

Figure 12 plots the residual estimates of net migration by sex and age against the model estimates with the default parameter values on the top and against the model estimates with the optimized migration rate and peak ages on the bottom. This example is for Australia in 2015 with the Western Standard age profile. The optimized value of the migration rate, at 0.008, is very similar to the default rate of 0.007. But the optimized values of the peak ages of immigration and emigration differ substantially for the defaults. Australia is a receiving country, with immigrants younger than emigrants. The optimized peak age of immigration is 18.4 years, which is slightly younger than the default value of 20.04 years, while the optimized peak age of emigration is 28.9 years, which is nearly seven years older than the default value of 22.04. The results indicate that while the default parameter values produce a reasonable approximation of the net international migration profile estimated via residual methods, the optimized parameter values yield a closer representation.



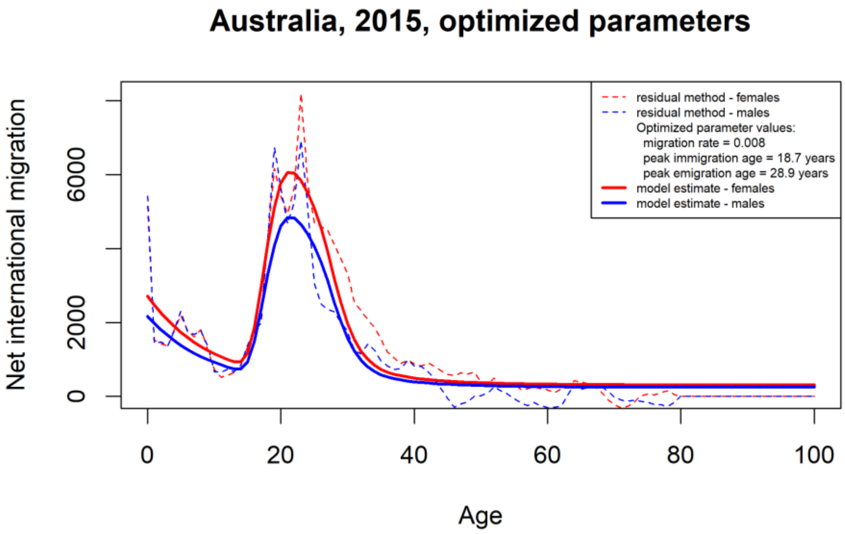


Figure 12. Model and residual estimates of net international migration by age and sex for Australia, 2015

Figure 13 gives another example, this time for Oman (Low Dependency), a country that hosts large flows of temporary labour migration that can change in magnitude and direction from one year to the next. In 2017, residual estimation based on population register for the WPP indicates that immigration to Oman exceeded emigration by around 12,000. In 2018, residual estimates indicate that the level of net international migration for Oman turned negative, amounting to around -52,000. The optimized peak age parameter values for 2018 are essentially the same as for 2017, but the optimized migration rate for 2018 is 0.214, compared to 0.340 for 2017.

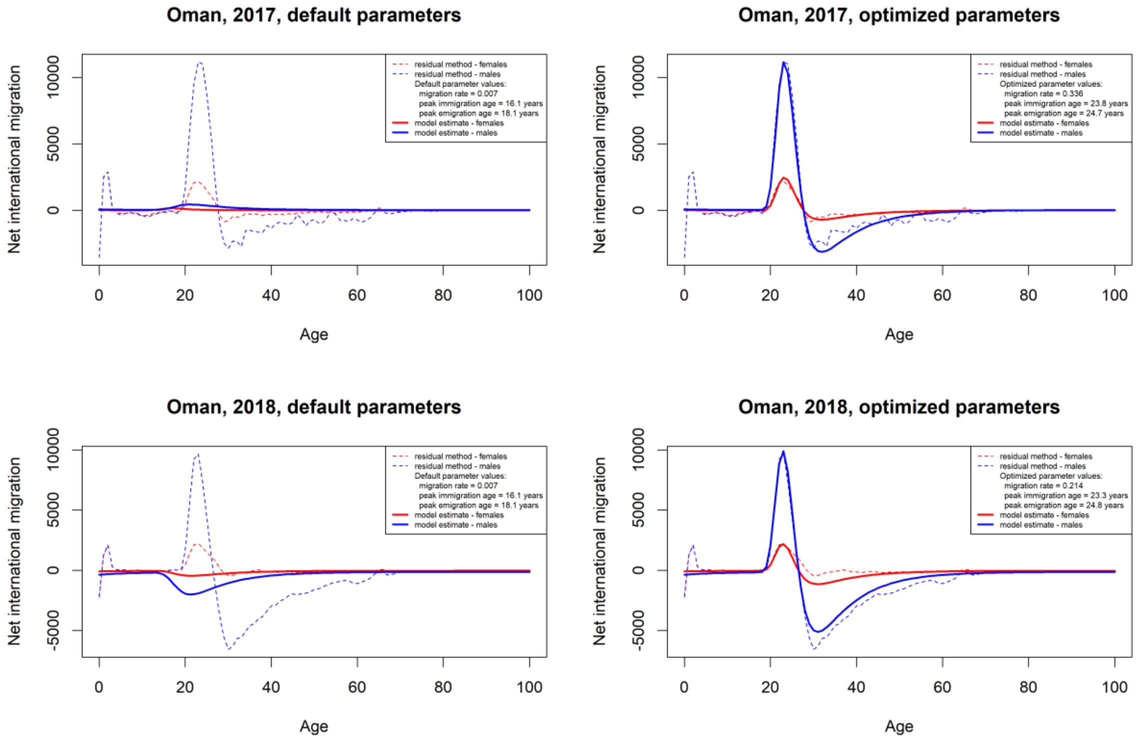


Figure 13. Model and residual estimates of net international migration by age and sex for Oman, 2017 and 2018

For countries with high-quality estimates of population and vital rates, the optimized parameter values over the most recent 15 years of the estimation period were used to define the migration age-sex profiles over the projection period. For countries that lack sufficient data to produce reliable estimates of net international migration by age and sex using residual methods, the average values computed across countries with high-quality data were used to inform the parameters applied in the projection period. Figure 14 shows the resulting sex-age profile of net international migration projected for India in 2030 (solid lines), compared to the profile implied by the residual migration pattern estimated on the basis of the 2001 and 2011 population censuses (dashed lines). Both series presented in the figure correspond to a total level of net international migration of approximately -388,000. Applying the inter-censal residual pattern to that total yields an age profile with multiple pronounced peaks and valleys, which likely reflect inconsistencies in the age distributions of the populations enumerated in the two censuses and not the true patterns of net international migration to and from India. Using model profiles corresponding the average parameter values across countries with good data, however, yields a much more plausible age pattern, with the largest net outflows occurring among young adults and some net return migration reflected in positive net values at older adult ages.

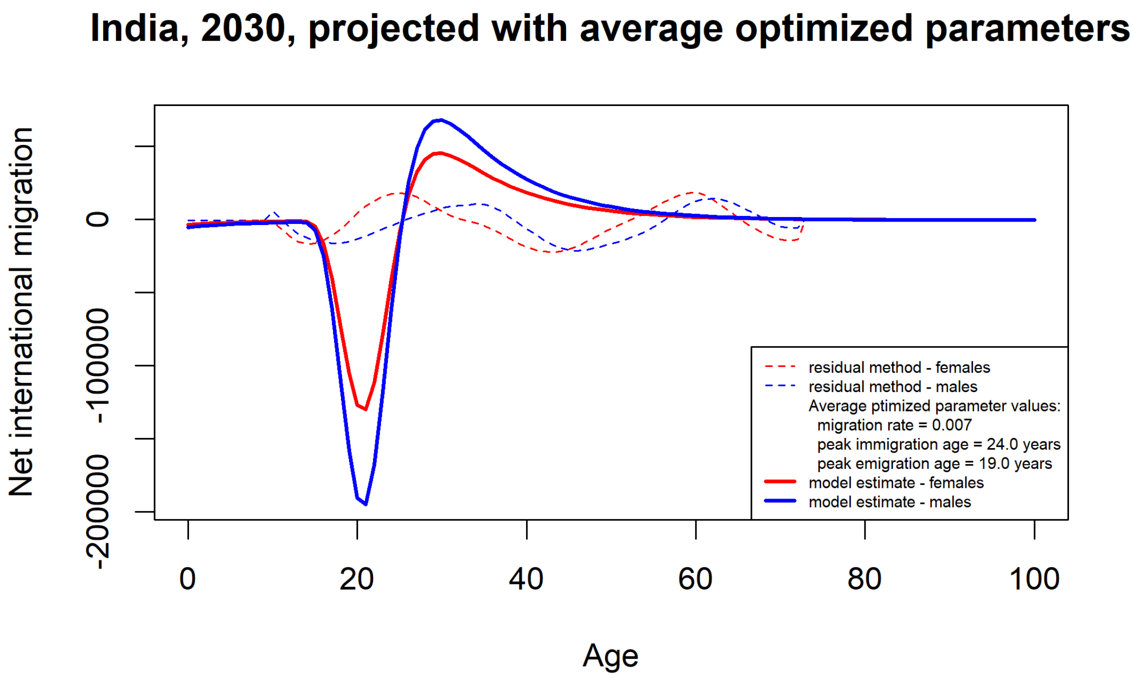


Figure 14. Model and residual estimates of net international migration by age and sex for Oman, 2017 and 2018

In Figures 15 and 16, we present two examples of the modelled net migration by age and sex for China and the Philippines, respectively, for the years 2007 to 2022. They were both assumed to have low dependency, be sending countries, and the same age patterns by sex. Compared to the observed patterns presented for Sweden and the Republic of Korea, the net migration estimates for China and the Philippines are smoother because they are based on model migration schedules. For China, we see large negative values for young adults followed by positive values representing return migrants. 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 hardly any predicted positive values before 2015 due to significantly large negative net migration values in WPP (i.e the *N* component in Equation 5 and 6): *N* ranged between -238,000 to -104,000 between 2007 and 2015.

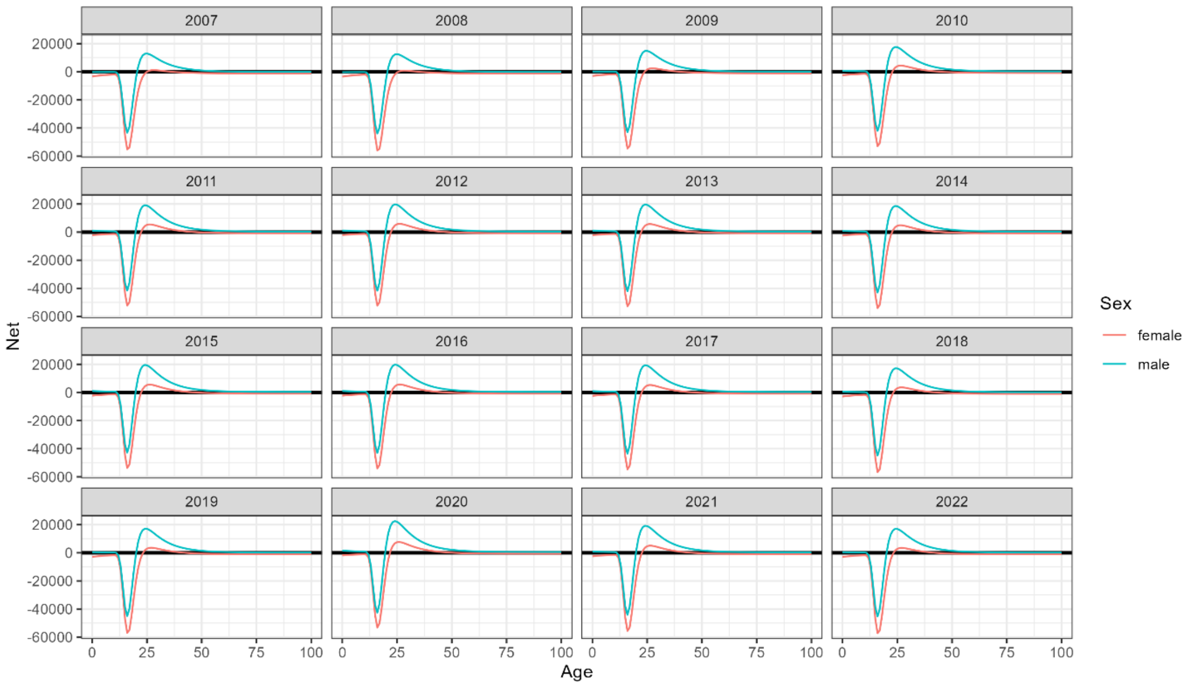


Figure 15. Estimated net international migration by age and sex for China, 2007-2022

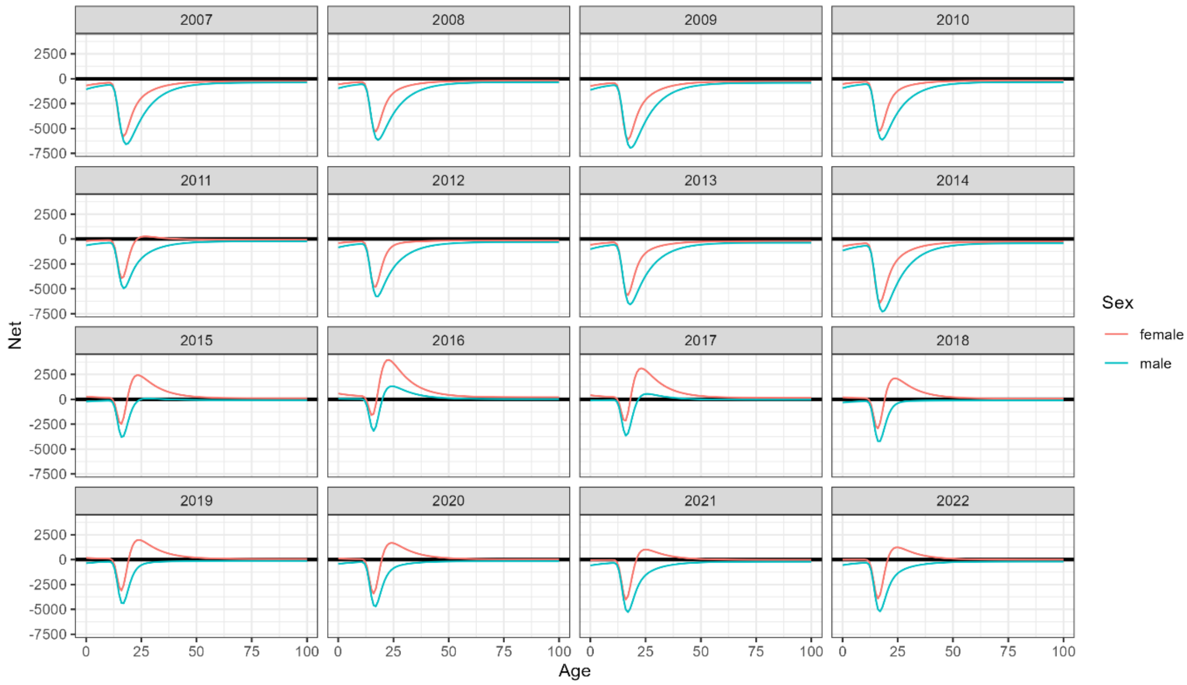


Figure 16. Estimated net international migration by age and sex for the Philippines, 2007-2022

Finally, when implementing the model for the WPP, we found that the estimated net migration at older ages was too high. See the figure above for Australia, for example. To deal with this, we set net migration above age 75 to zero and redistributed those counts proportionally below age 75 years.

7. CONCLUSION

Age and sex profiles of net international migration are required in population estimation and projection, yet the direct measures are often absent from reported migration data. Instead, population scientists and policymakers rely largely on model-based estimates that are derived from residual methods as inputs into demographic accounting models and use them to understand population changes. Given the known irregularities in net migration age schedule and errors in population and vital statistics measures, in this paper we have developed a relatively simple yet powerful model for estimating the age and sex profiles of net international migration from estimated immigration and emigration age-sex profiles. The model is flexible such that it can be applied to any country situation, with or without data, and can be modified to incorporate new data or assumptions. The model has been coded in R, which makes it possible to estimate (or project) the age and sex patterns of net international migration for any country in the United Nations' World Population Prospects dataset.

The work presented in this paper should be considered a starting point to estimate net migration age and sex 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 (e.g., Gulf Cooperation Council countries) may require specific models. Also, the Western Standard and Low Dependency model migration schedules could be further tested to determine the appropriateness of these schedules. A relational model approach could be developed whereby one starts with a general model migration schedule and then adjusts it depending on a set of covariate relationships. One might expect a highly developed population with a large proportion of migrants to have emigration flows with a wide labour force peak. The width of this peak could depend on how relatively old the population is in comparison to other migrant populations. Similarly, the immigration level of child migrants could depend on whether the country has high levels of temporary migration or not, where temporary visa regimes are generally assumed to exclude children of migrants.

Albeit the future efforts on refining the model, we believe we have made an important contribution to overcoming data limitations and this work will greatly help improve both understanding of migration processes as well as the estimation and projection of populations. Further, while the method was designed with net international migration in mind, the procedure is general enough to be applied towards any geographic classification where migration data are missing, including local or regional areas, and those involving domestic movements.

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