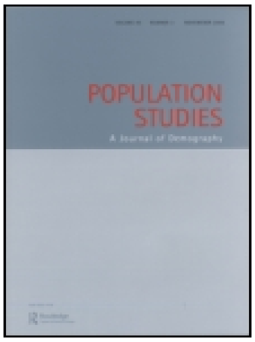

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Improved measures for the cross-national comparison of age profiles of internal migration

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We develop and demonstrate the application of a concise set of measures intended to encapsulate key features of the age profile of internal migration and highlight the significant differences that exist between nations in these profiles. Model schedules have been the most common method of comparing internal migration patterns but issues related to the estimation and interpretation of their parameters hinder their use for cross-national comparison. We demonstrate that the interpretation of exponential coefficients as rates of ascent and descent does not best reflect the slopes of migration age profiles, and we propose more consistent measures based on the rate of change in migration intensity. We demonstrate, through correlation and factor analysis, that most of the inter-country variance in migration age profiles is captured by the age at and intensity of peak migration. The application of these two indicators to 25 countries reveals significant differences between regions.

Keywords: internal migration; age patterns; model migration schedule; comparative measures; cross-national comparison

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1. Introduction

Migration within a country is an age-selective process, with young adults being the most mobile group (Rogers and Castro 1981). The migration intensity—which denotes the proportion of people who moved—typically peaks at young adult ages, then steadily declines with increasing age, sometimes rising again around the age of retirement. A peak is also often seen among young children. Rogers and Castro (1981) have demonstrated that, in broad terms, this profile is replicated across a variety of countries and at various spatial scales, although there is evidence of significant differences between nations in the ages at which migration occurs, particularly with reference to the peak at which working-age people move. For example, Bell and Muhidin (2009) demonstrated that migration within Asian countries is highly concentrated amongst people in their early 20s, whereas in Latin America migration peaks in the late 20s and is more widely dispersed across the age spectrum. In a similar manner, Ishikawa (2001) has shown that migration is more concentrated amongst young adults in Sweden than in Canada or Japan.

Comparative studies can provide valuable insights into the dynamics of internal migration. They also aid the construction of theories and can contribute to the formulation of policy (Bell et al. 2002). However, if rigorous comparisons are to be made, a concise set of measures is needed in order to capture and compare the key features of migration age profiles. This paper presents the results of a project intended to establish the optimum combination of measures required to allow the robust representation of age profiles of migration in a form which facilitates comparison between countries and underscores the differences observed. The work forms part of the IMAGE project (Internal Migration Around the GlobE, http://www.gpem.uq.edu.au/image), an international programme of collaborative research. Its aim is to develop and implement a set of rigorous statistical indicators to measure several dimensions of internal migration, including age, which may be used to make comparisons between countries.

Model migration schedules have become the pre-eminent method used to compare age profiles of migration since they were first introduced by Rogers et al. (1978). The parameters of these model schedules provide summary measures of how migration varies with age, and these have subsequently been used to compare age patterns of migration across a number of countries (Kawabe 1990; Ishikawa 2001; Rogers et al. 2007). Although this work has contributed valuable insights into cross-national differences in migration, its utility has been diminished by issues related to the estimation and interpretation of the parameters of the model schedules.

The estimation of the parameters for model migration schedules, a composite exponential function, presents a three-way challenge. First, there are the difficulties of selecting an optimal set of component curves with which to depict national migration age profiles as accurately as possible (Rees et al. 2000). Second, the parameter estimates can be unstable (Congdon 1993) and third, the estimates can be sensitive to the initial parameter values chosen (Rogers et al. 2005). If a large number of parameters, many of them with limited substantive meaning, are used to model age schedules of migration, this can hinder the interpretation and analysis of the models, inhibiting their use as a basis for international comparison (Rees et al. 2000; Bell et al. 2002). The most effective models are parsimonious, relying on the smallest number of parameters required to provide an accurate approximation of the structural information present in the data (Burnham and Anderson 2002).

To establish a concise set of measures that capture the key features of age profiles of migration, we first revisit the model schedule parameters, and show that their use of exponential coefficients to represent the rates of descent and ascent of the slopes of the component curves of the age profile of migration is not the best way of capturing the slopes of these curves and can result in misleading comparisons. We propose new measures based on the maximum rate of change of the component curves, and demonstrate that these constitute more consistent and robust indicators of the slopes being described than those provided by the exponential coefficients. We pool these new measures with a number of other summary indicators, all of which have been employed by previous researchers to capture the age profile of migration, explore their relative strengths and limitations, and show the associations between them. We then apply selected measures to identify the extent of global variation in age profiles of migration.

The paper is organized as follows. After discussing model migration schedules in Section 2, we review issues associated with their use in cross-national comparisons in Section 3. In Section 4 the new measures we are proposing, based on the rate of change of component curves, are outlined and then validated. In Section 5 we set out our new measures alongside a suite of alternatives, assess their comparative strengths and limitations, and demonstrate that migration age profiles can be adequately summarized by age and intensity at peak migration. In Section 6 these two new summary measures are used to compare the age profiles of internal migration within 25 countries. The paper concludes with recommendations for the comparison of migration age profiles between countries and suggests directions for future work.

2. Model migration schedules

Rogers et al. (1978) were the first to establish a mathematical model which could summarize and codify the regularities observed within the consistent shape of migration age profiles. The model migration schedule is a composite exponential function, comprising a childhood curve, m_1, a labour force curve, m_2, and a constant, c. In reduced form, as represented in Figure 1, the model schedule is the sum of the three component functions and comprises seven parameters:

a_1 = the height of the childhood curve
α_1 = the rate of descent of the childhood curve
a_2 = the height of the labour force curve
λ_2 = the rate of ascent of the labour force curve
α_2 = the rate of descent of the labour force curve
μ_2 = the age at peak of the labour force curve
c = a constant.

Algebraically the schedule can be expressed as

$$m(x) = \underbrace{a_1 \exp(-\alpha_1 x)}_{m_1(x)} + \underbrace{a_2 \exp\{-\alpha_2(x-\mu_2) - \exp[-\lambda_2(x-\mu_2)]\}}_{m_2(x)} + c. \quad (1)$$

The first term of the model schedule, m_1, is associated with migration amongst children and teenagers. It is a negative exponential function which starts from an initial maximum value of a_1, declining at a rate of α_1 thereafter, as depicted in Figure 1. The second term, m_2, is a double exponential function describing the age profile of migration of working-age people; four parameters are required to describe the level, position, and shape of the curve. Within this age span the curve may peak early or late, as indicated by the value of μ_2. The peak, its height defined by a_2, can be sharp or gentle; the rates of ascent and descent are

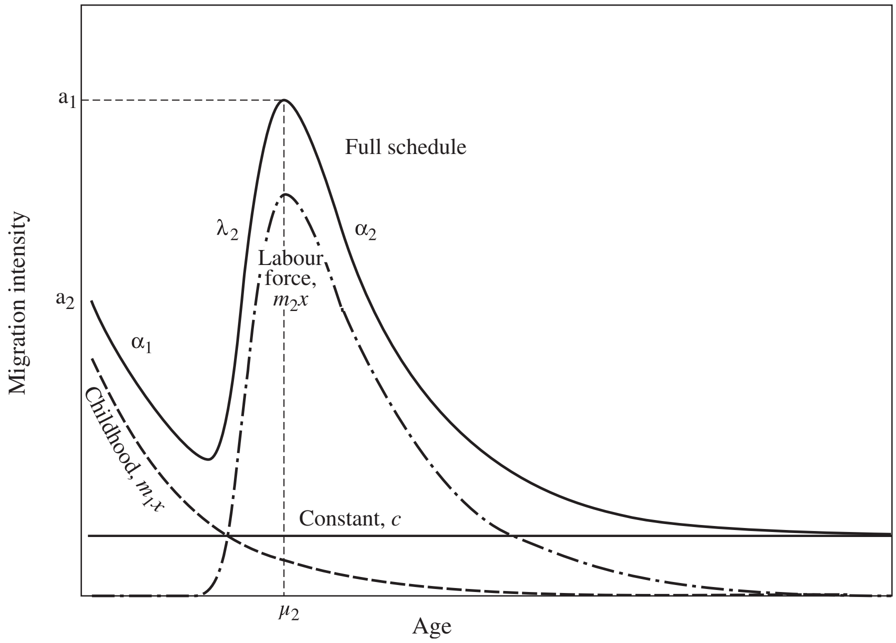

Figure 1 The reduced form and component curves of the model age schedule of migration
Source: Based on Rogers and Castro 1981.

represented by λ_2 and α_2, respectively. The curve can be decomposed into a double exponential upward slope and a single exponential downward slope. The double exponential function constrains the upward slope to grow at a significantly faster rate than the downward slope. Finally, the model schedule includes a constant c that defines a base level of migration across all ages. In some instances, the model also includes a retirement curve to capture moves out of metropolitan areas to warm coastal areas and areas with high levels of amenities (Rogers 1988).

This standard model was later extended with the addition of an upward slope for the elderly (Rogers and Watkins 1987) and a curve representing student migration to centres of education (Wilson 2010). Increasing migration intensities at very old ages tend to be over short distances while student peaks are prominent in migration flows to metropolitan centres.

Depending on how a model schedule is to be specified, it can consist of three, four, five, or six component curves, and can therefore involve from 7 to 17 descriptive parameters. The retirement curve, the upward slope for the elderly, and the student curve can each be added independently to the reduced form of the model schedule, making possible a total of eight different combinations of the component curves. Rogers and Castro (1981) showed, by comparing 500 age profiles of migration drawn from 139 regions of 17 different countries, that seven-parameter model schedules were most commonly needed to depict them.

Since model migration schedules were first introduced over 30 years ago, they have been widely used to compare migration age patterns between countries. The first and most extensive comparison was undertaken by Rogers and Castro (1981), who used model schedules to compare the age profiles of migration in Japan, the USA, the USSR, and 14 countries in Western and Eastern Europe. Subsequent studies have been restricted to smaller numbers of countries, comparing, for example, Japan, Korea, and Thailand (Kawabe 1990) or Japan, Sweden, and Canada (Ishikawa 2001). While such studies have contributed valuable insights into cross-national differences in the age patterns of migration, there are a number of issues related to the estimation and interpretation of the parameters contributing to the model schedules that diminish the utility of the schedules when they are used to conduct such comparisons between nations.

3. Limitations of model schedule parameters

We can identify five limitations on the utility of the model schedule parameters when used for intercountry comparisons. Three of these bear upon the variability, sensitivity, and instability of the parameters being estimated, while two concern the comparability and interpretability of the parameters once they have been estimated.

3.1. Variability in the number and value of parameter estimates

The number of component curves into which an age profile of migration can be decomposed depends on the overall shape and complexity of the profile; usually, 7, 11, or 13 parameters are used. The fact that different numbers of parameters may be used when constructing model schedules is an obvious potential impediment to comparisons between countries. This problem is exacerbated by the fact that the choice of which component curves to include in the model, and hence the number of parameters needed to describe the full model, affects the value of the parameters estimated (Congdon 1993). For instance, using in-migration flows to Brisbane, Australia, Wilson (2010) showed that the inclusion of a student curve in his model schedule modified the value of the parameters describing the labour force and retirement curves. By incorporating additional component curves, researchers improve the fit of their models to the observed data, but at the expense of overall statistical stability (Congdon 1993). Evidently, a balance needs to be struck between obtaining the best possible fit and using the minimum number of parameters possible (Burnham and Anderson 2002).

3.2. Sensitivity of parameter estimates to the initial value selection

Another limitation on the use of model schedule parameters for comparison between countries arises from the sensitivity of parameter estimates to the initial selection of parameters. To see how well model schedules fit observed migration rates requires non-linear curve-fitting programs. Various software packages have been used to identify the parameters of model schedules, including FORTAN (Rogers and Little 1994), TableCurve 2D (Rogers and Raymer 1999), MATLAB (Rogers et al. 2010), and Excel (Wilson 2010). All non-linear estimation procedures suffer from the problem of constrained optimization. Initially, the chosen algorithm is set to run, or seeded, with a set of user-specified parameters and it then produces a revised set of optimum parameter estimates by iteratively substituting alternative values until a set of pre-determined convergence criteria are met. Because any change to the initial parameter set can result in widely varying parameter estimates, and because of the high level of correlation among the parameters within a model (Rogers et al. 2005), issues of sensitivity arise. Limited guidelines exist on how to choose a good set of initial parameters. 'Fitting th[e] function [model schedule] to empirical data requires non-linear regression methods and often some experimentation with alternative initial parameters' (Rogers et al. 2005, p. 17). Researchers have usually drawn the initial values for their models from previous studies (Congdon 2008). However, typical parameter values are available for only a handful of countries—primarily the USA and the UK—and no guidelines exist on how best to select the initial values when constructing a model. Researchers have had to make informed decisions, employing trial-and-error approaches to decide which initial values of the parameters in their particular models will yield the best goodness of fit.

3.3. Instability of parameter estimates

Parameters can be set to different values yet deliver similar degrees of goodness of fit. This is a problem, known as over-parameterization. It can occur in three situations: when iterative, non-linear fitting routines fail to converge; when standard errors are too large, rendering the parameter statistically insignificant; or when the parameters used within a model are highly correlated (Congdon 1993). One consequence of over-parameterization is that parameter estimates fluctuate erratically over time and space. Congdon (1993) found sharp fluctuations in his parameter estimates from one year to the next when considering migration flows out of London between 1975 and 1989. This was particularly acute for the parameters depicting the childhood and retirement curves, and Congdon concluded that parameters used in model schedules could not be used reliably to set migration assumptions for forecasting purposes. In a similar way, when comparing model schedules of age-specific migration between countries, the instability of parameter estimates can prejudice the comparison by causing observed differences in the parameters between countries to be driven by measurement errors rather than by genuine variation in the underlying migration processes.

Like the labour force curve, the retirement curve is a double exponential function and Congdon (1993) has suggested replacing this with a function similar to that proposed by Peristera and Kostaki (2007) in order to improve the stability of the parameters describing it (see also Wilson 2010). The Peristera–Kostaki function can be expressed as

$$m_3(x) = a_3 \exp\left[-\left(\frac{x-\mu_3}{\sigma_3}\right)^2\right] \tag{2}$$

where a_3 is the height of the retirement curve, μ_3 is the position of the retirement curve on the age axis, and σ_3 is the rate of ascent and descent of the retirement curve. If this is done the result is a symmetrical function; the rates of ascent and descent in the retirement migration peak are taken to be equal. While the goodness of fit of Peristera–Kostaki functions has been thoroughly tested in fertility studies, this has not been done in the study of migration, for which their use has been restricted to the consideration of retirement-related moves. Despite their apparent potential, Peristera–Kostaki functions are still based on non-linear regression and do not mitigate the risk of convergence failure when using iterative, non-linear fitting routines.

In order to address the problem of parameter instability, Rogers et al. (2005) proposed replacing conventional, non-linear, curve-fitting procedures with three alternative linear estimation methods, which would not require an iterative algorithm. While this may yield more stable parameter estimates, these still have to satisfy established constraints, such as the sum of component weights being unity.

3.4. Comparability of the parameter estimates

In addition to the problems related to the estimation of parameters, those using such schedules have to contend with issues associated with the interpretation of the parameters defining each schedule. If a large set of parameters is used this can present a difficult analytical challenge, particularly when comparing age schedules of migration between countries. For instance, Ishikawa (2001) used model schedules to compare the age patterns of interregional migration within Canada, Japan, and Sweden for three time periods. Since the result was a 7 × 57 table, extending this approach to a larger sample of countries would be a major analytical undertaking. In an attempt to contain the task within manageable limits, Rogers and Castro (1981) identified four key indicators to differentiate between the 500 regional age profiles they drew from 17 different countries: Peaking, denoted by μ_2, Dominance, a_1/a_2, Asymmetry, λ_2/α_2, and Regularity, α_1/α_2. Peaking differentiated those age-specific schedules where the labour force curve peaked at a relatively late age from those where it peaked at a relatively young age. Dominance captured the height of the childhood curve relative to that of the labour force curve and differentiated between child-dependent and labour-dominant age profiles. Asymmetry indicated whether the labour force curve was symmetrical or skewed asymmetrically around its peak value. Regularity represented the degree to which the migration rates of children mirrored those of people of working age.

By using this classification and introducing a high and low value for each indicator, Rogers and Castro reduced their analysis to four binary variables, rather than a minimum of seven parameters, but 16 different variable combinations remain possible, and it is clear from the literature that their classification has not been widely adopted. Recent comparative studies have, however, continued to highlight the need for a concise set of summary measures to replace the large number of model schedule parameters (Rees et al. 2000; Bell et al. 2002). As stressed by Box and Jenkins (1970, p. 17), the principle of parsimony should lead researchers to specify models with ‘the smallest possible number of parameters for adequate representation of the data’.

3.5. Interpretability of the parameter estimates

Interpreting the meaning and implications of parameter estimates calculated for different countries is another challenge for researchers. The parameters a_1, a_2, and μ_2 effectively measure the relationship between age and migration by reference to two key elements: the heights of the childhood and labour force curves and the age at which the labour force curve peaks. The value of a_1, a_2, and μ_2 can be read directly from the age profile curve being studied. For instance, higher values of μ_2 indicate that migration peaks at older ages. The parameters α_1, α_2, and λ_2, on the other hand, are exponential coefficients, and their interpretation is even more challenging. While Rogers and Castro acknowledged that exponential coefficients are not true rates of ascent and descent, and that ‘the actual rates of ascent are very different from the λ_2 value, except for ages close to $x = \mu_2$’ (1981, p. 31), they proceeded to use α_1, α_2, and λ_2 to compare the slopes of component curves.

Intuitively, exponential coefficients can be related to the rate of change within a curve. We argue, however, that they do not best capture the slope of component curves and that the first derivative, which gauges the rate of change, provides a more accurate and consistent measure of the slope. The first derivative generally changes for every x value, except for linear functions, and while the exponential coefficient and the first derivative are related, they are not equivalent measures of the slope. Equation (3) describes a simple exponential function with an exponential coefficient a. Equation (4) gives the first derivative of this exponential function, and shows that it is a function of the exponential coefficient a but is not equal to it:

$$f(x) = \exp(ax) \tag{3}$$

$$f'(x) = a\exp(ax). \tag{4}$$

This brief review has identified a number of issues related to the estimation and interpretation of model schedule parameters which prejudice their utility, reliability, and suitability for the comparison of age patterns of migration between different countries. Model migration schedules remain a highly effective tool with which to explore regularities within such age profiles, particularly with regard to the shape of the labour force migration curve. However, if comparisons of age-specific migration profiles are to be made between countries using model parameters, it is imperative that their deficiencies, outlined above, are addressed first. To that end, the next section proposes a new measure of slope, based on the rate of change, to be used in such comparisons and demonstrates that it provides a more consistent indicator of the slope. By way of illustration, we apply the proposed measure to the upward slope of the labour force curve of 25 countries.

4. Towards a consistent set of age profile indicators

The rate of change of any mathematical function is measured by its first derivative at a given point. Because model migration schedules are non-linear functions, the rate of change is different at each age. For comparison purposes, however, we need to capture the rate of change with a single summary measure. As a summary measure of an upward slope of the labour force curve we selected the maximum rate of change on that slope, denoting it the maximum upward rate of change, or MURC. To compute this measure without using model migration schedules we took a series of observed migration age profiles and smoothed them using kernel regression for each profile. This smoothing technique has been shown to capture the underlying age structure of migration more effectively than model migration schedules (Bernard and Bell 2012). Because kernel regressions are non-parametric, they do not provide a function that can be differentiated analytically, so we calculated the rate of change by taking the difference in migration intensity between two consecutive ages, repeating this sequentially across the upward slope of the labour force curve, to find its maximum. The result was equivalent to taking the first derivative of the continuous function, which is the model migration schedule, while avoiding the issues of variability, sensitivity, and instability identified in Section 3. We found the maximum downward rate of change, or MDRC, in the same way. Appendix A provides worked examples, showing how to compute the MURC and MDRC for Brazil in 2000 and France in 2006.

In order to evaluate how the MURC performs as a measure of the slope, we compared it to the exponential coefficient, λ_2. We constructed age profiles from census data drawn primarily from the Integrated Public Use Microdata Series (IPUMS) database maintained by the Minnesota Population Center (2011). The sample included migration data from 25 countries encompassing all major world regions: Ghana, Senegal, and South Africa were chosen to represent Africa; China, Indonesia, Malaysia, Nepal, the Philippines, and Vietnam represented Asia; Argentina, Bolivia, Brazil, Chile, Colombia, Costa Rica, Ecuador, and Peru represented Latin America; Canada, Mexico, and the USA represented North America; France, Greece, Portugal, and Spain represented Europe; and Australia was the sole representative of Oceania. Migration age profiles were computed using 5-year interval data disaggregated by single-year age groups. We used migration recorded between minor administrative units of each country, in selected years, as specified in Appendix B. For each country the migration intensities were normalized to sum to unity across all ages so that the comparison of age profiles of migration would be independent of variations in overall migration intensities between the countries.

To obtain model schedule parameters against which to compare our proposed measures for each of the 25 countries, seven-parameter model schedules for each country were estimated using the MATLAB program for fitting non-linear functions written by Rogers et al. (2010). Since we wished to focus on the labour force curve by way of illustration, we restricted analysis to the 5–65 age range in order to minimize the problem of parameter instability discussed above (Congdon 1993). Had we included migrants of retirement age, 11- and 13-parameter model schedules would have had to be fitted to the data drawn from countries with a retirement curve and a post-retirement slope. As indicated earlier, this would have affected the parameters of the labour force curve, which would in turn have biased any comparison with age profiles fitted to seven-parameter schedules.

The Pearson correlation coefficient between MURC and the exponential coefficient, λ_2, reveals a moderate level of association: $r = 0.67$. When the two measures are plotted against each other, as in Figure 2, some anomalies become apparent in countries such as Brazil, China, Colombia, Indonesia, Senegal, and South Africa. For these countries, MURC and λ_2 are significantly different, confirming that the two measures are related but not equivalent. Comparisons of selected pairs of countries (shown in Figure 3) illustrate how the exponential coefficient, λ_2, provides an inconsistent and misleading picture of the differences between countries in the shape of the upward slope of the labour force curve of their migration age profiles. The first pair, China and Colombia, both have high values of λ_2, the second pair, Indonesia and Senegal, have mid-values and the third pair, South Africa and Brazil, have low values. While China and Colombia both have a λ_2 value of 0.4, the two countries exhibit significantly different age profiles of migration; the upward labour force slope for China being much steeper than that for Colombia. In the same way, Indonesia and Senegal are characterized by exponential coefficients with similar values, despite clearly different labour force profiles. The discrepancy between the profiles of South Africa and Brazil is smaller, but λ_2 for Brazil is higher than that for South Africa, despite Brazil exhibiting a flatter peak.

Table 1 demonstrates that MURC, the new measure proposed in this paper, overcomes this inaccuracy problem when considering the three pairs of outlier countries. The MURC for China, at 0.006, was higher than Colombia's MURC of 0.002, whereas, as we have seen, λ_2 for both countries was the same. Similarly, MURC was higher for Indonesia than for Senegal, which is consistent with the graphical evidence. When considering South Africa and Brazil, MURC was also a better match for the graphical representation of the age profiles than the two exponential coefficients. For each pair of countries, MURC offered a measure of the upward slope of the labour force curve which was more closely aligned to the graphical representations of age profiles than λ_2.

We expected the improvement in accuracy brought by the maximum rate of change to hold for other components of the age profile curve. Examining the downward slope of the labour force

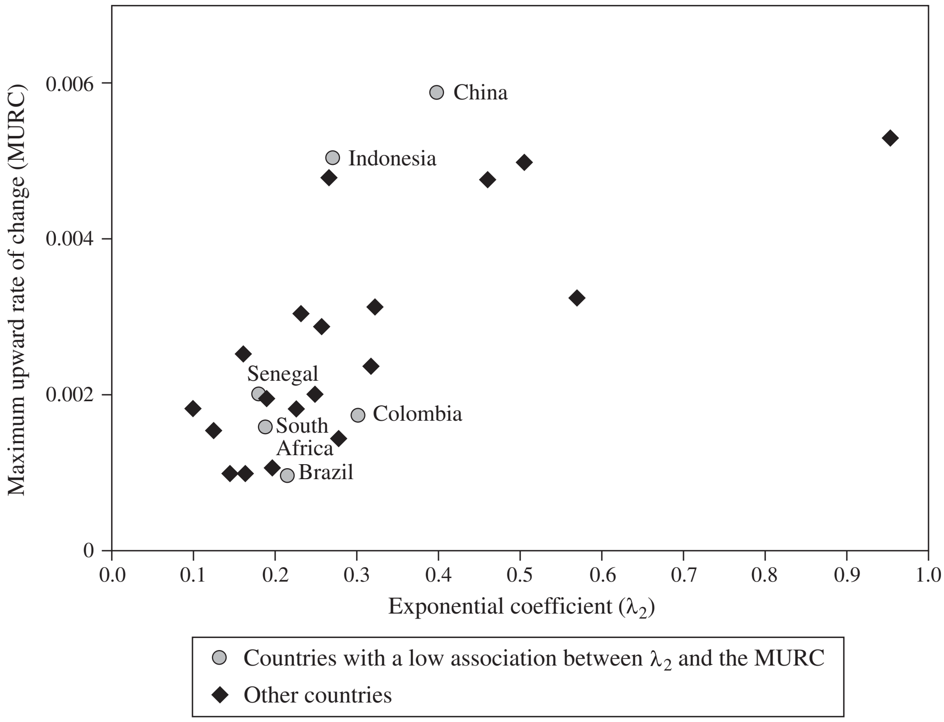

Figure 2 The maximum upward rate of change, MURC, in internal migration plotted against the exponential coefficient, λ_2 ($r = 0.67$), 25 selected countries
Source: IPUMS database.

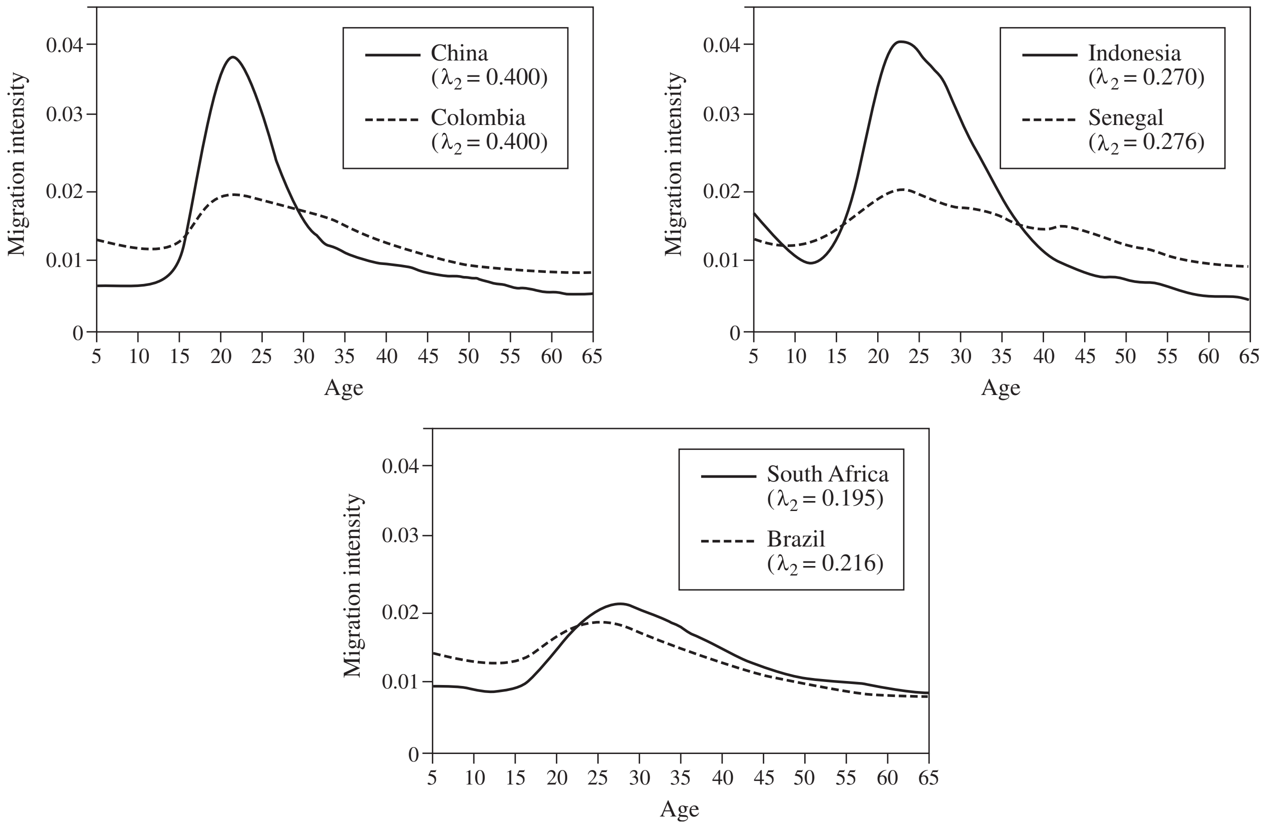

Figure 3 Migration age profiles, selected countries
Note: Kernel-based smoothing, λ_2 is the exponential coefficient of the upward slope of the labour force curve.
Source: IPUMS database: China (1985–90), Colombia (2000–05), Indonesia (1995–2000), Senegal (1997–2002), South Africa (1996–2001), and Brazil (1995–2000).

curve across our sample of 25 countries confirmed that the correlation coefficient between MDRC and the exponential coefficient (α_2) was relatively low at r = 0.66, again indicating that the two measures are not equivalent. Because the other component curves of the model schedules—the childhood, student, retirement, and elderly curves—can also be expressed as exponential functions and have the same mathematical properties as the labour force curve, the use of the maximum rate of change as a measure of the slope could be extended to these curves for comparative purposes if required.

5. Towards a concise set of indicators for migration age profiles

While model schedules have gained widespread acceptance in migration research, a number of other measures have also been employed to compare age profiles of migration within and between countries. In one early example, Bracken and Bates (1983) based a classification of the migration profiles of 116 local authorities in England and Wales on model schedule parameters and age-specific migration rates. The authors concluded that twelve age profile

Table 1 A comparison of the maximum upward rate of change, MURC, in internal migration and the exponential coefficient, λ_2, as measures of the upward slope of the labour force curve, selected countries

	High value λ_2		Mid-value λ_2		Low value λ_2	
	China	Colombia	Indonesia	Senegal	Brazil	South Africa
	(1990)	(2005)	(2000)	(2002)	(2000)	(2001)
λ_2	0.400	0.400	0.270	0.276	0.216	0.195
MURC	0.006	0.002	0.005	0.001	0.001	0.002

Source: IPUMS database.

clusters could be distinguished on the basis of three key criteria: the age of peak migration, the extent to which migration activity was concentrated in the ages around the peak, and the presence or absence of a retirement curve. More recently, Rees et al. (2000) and Bell et al. (2002) proposed a more general battery of measures for use when comparing migration profiles between nations. They concluded that age profiles of migration might best be compared using just two measures: the peak migration intensity, or intensity at peak and the age at which that peak intensity occurs, denoting this as age at peak. They argued that these are more easily computed and interpreted than model schedule parameters. Rees et al. (2000) complemented these two indicators with a general measure of the level of migration, the gross migraproduction rate, which is the area under the migration age profile curve, but this measure does not indicate how migration intensity varies with age. Building on these proposals, Bell and Muhidin (2009) explored differentials in mobility across 19 countries, and noted that the concentration of migration activity around the age of peak migration varied sharply from one country to another. To capture this, they suggested complementing age at peak and intensity at peak with a measure to identify the breadth of the migration peak, which they defined as the sum of migration intensities within each of the five years of age before and after the age of peak migration intensity. They then classified the observed breadths as narrow (>30 per cent), moderate (25–30 per cent), or broad (<25 per cent).

Which of the various measures described above best captures the key features of age profiles of migration, and provides the most effective discriminant between the profiles from different countries? Following the principle of parsimony we had to identify the smallest number of measures that would allow robust comparisons between countries. To establish this analytically we explored the relationships between the measures identified above, having calculated them using the data from our sample of 25 countries. We continued to confine our focus to the labour force curve for four reasons. First, the majority of moves occur when people are in the early years of their working life. For instance, over 70 per cent of rural migrants in China are between 15 and 35 years of age (Wu and Zhou 1996). Second, there is substantial evidence that the differences between countries' migration age patterns are mainly centred on the labour force curve (Bell and Muhidin 2009). Third, because child and teenage mobility tends to mirror that of their parents (Rogers and Castro 1981), the childhood parameters are to some extent already captured by the parameters of the labour force curve. Finally, we wished to consider a baseline scenario, with no retirement-related migration, because this has been demonstrated to be the most common type of age profile (Rogers and Castro 1981). We identified six principal measures that have been used to characterize the labour force curve in the previous studies cited above: the age at peak, the intensity at peak, the rate of ascent, the rate of descent, the degree of asymmetry between the rate of ascent and descent, and the breadth of the peak. Table 2 lists the six summary measures along with their notational terms and definitions.

We used Pearson correlation coefficients to analyse the relationships between the six summary measures in the data from the 25 case-study countries, and investigated which of the measures best characterized age profiles of migration. The matrix showing the correlations (Table 3) reveals a strong association between intensity at peak, MURC, MDRC, and breadth of peak; the coefficients are all greater than 0.8. This result indicates that these four measures all gauge the same underlying characteristic of age-related migration. We also observe a negative relation between age at peak and asymmetry: $r = -0.45$. The later the age at which migration peaks, the more symmetrical is the curve. This can be readily explained by the fact that because the labour force

Table 2 Summary measures of age profiles of migration

Name of measure	Definition
Intensity at peak	The peak value of migration intensity.
Age at peak	The age at which migration intensity peaks.
Breadth of peak	The sum of the migration intensities for each of the five years of age before and after the age at peak and for the age at which migration peaks.
MURC	The maximum rate of change in the upward slope of the labour force curve.
MDRC	The maximum rate of change in the downward slope of the labour force curve.
Asymmetry	The ratio of the maximum upward to the maximum downward rate of change: MURC/MDRC

Table 3 Correlations between six metrics of migration age profile for 25 countries

Migration metric	Intensity at peak	MURC	MDRC	Breadth of peak	Age at peak	Asymmetry
Intensity at peak	1					
MURC	**0.96**	1				
MDRC	**−0.92**	**−0.87**	1			
Breadth of peak	**0.95**	**0.88**	**−0.82**	1		
Age at peak	−0.34	−0.47	0.26	−0.19	1	
Asymmetry	0.04	0.23	−0.23	0.19	−0.45	1

Note: Refer to Table 2 for definitions of the measures. Values greater than 0.80 or lower than −0.80 are in bold.
Source: As for Table 1.

curve begins its rise in the mid-teenage years, the rate of ascent in countries where migration peaks at a later age is more gradual, an effect mirrored by the slower descent of such curves. In consequence, MURC displays a modest negative association with age at peak, $r = -0.47$, while the relationship between age at peak and MDRC is positive but weak with $r = 0.26$. Countries where migration peaks late exhibit no consistent evidence of a faster or slower MDRC. Figure 4 illustrates this relationship: countries such as Colombia and Peru, where migration peaks early, at around age 20, exhibit a more asymmetrical labour force curve than countries such as Costa Rica and Mexico, where migration peaks later, at around age 30.

It is notable that the strength of these associations can be traced directly to the shift from exponential coefficients to the MURC and MDRC as measures of the slope of the labour force curve. For instance, the correlation between intensity at peak and rate of ascent is 0.96 when the rate of change is measured by MURC, but this drops to just 0.46 when the exponential coefficient is used. Similarly, the correlation

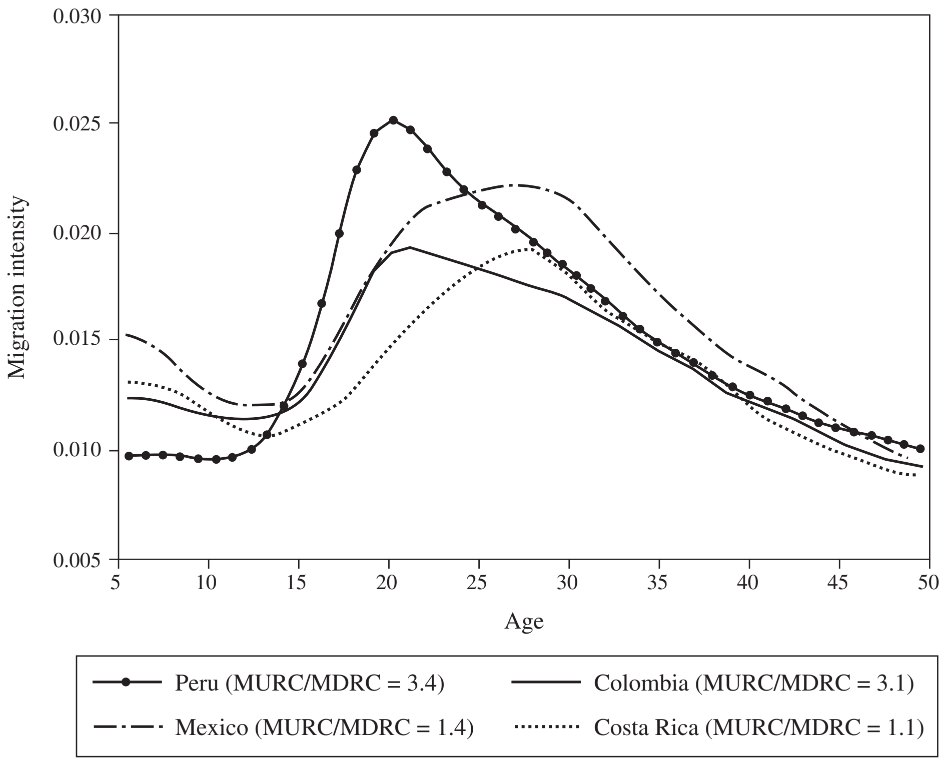

Figure 4 Age profiles of migration for selected countries showing different degrees of asymmetry around the age of peak migration
Note: Kernel-based smoothing. MURC/MDRC is the ratio of the maximum upward and downward rates of change; the higher the value the more asymmetrical the curve.
Source: IPUMS database: Peru (2002–07), Colombia (2000–05), Mexico (1990–95), and Costa Rica (1995–2000).

between intensity at peak and rate of descent is −0.92 if the MDRC is used, but only −0.56 when using the exponential coefficient.

To tease out the underlying structure of the age profiles, we subjected the six measures listed in Tables 2 and 3 to factor analysis, using observations from our sample of 25 countries. An orthogonal rotation was used to ensure that the resulting factors were not correlated (Basilevsky 2008). Two factors were retained based on the Kaiser Criterion that their eigenvalues be greater than one. (The Kaiser Criterion ensures that a factor accounts for at least as much variance as a single variable. The average of all eigenvalues being one, the factor analysis will extract factors with eigenvalues greater than the average value. Eigenvalues may be thought of as indicators of the variance explained by a factor.) The results are displayed in Table 4 and provide a clear picture of how the migration measures contribute to the two factors. Factor 1, Migration Concentration, captures the degree to which migration activity is concentrated around the peak age of migration, as reflected in high factor loadings on MURC, MDRC, breadth of peak, and intensity at peak. This factor explains 63 per cent of the variance between countries. Factor 2, Age Selectivity, captures the degree to which migration is age selective; it is a combination of age at peak and of asymmetry in the labour force curve and explains 26 per cent of the variance between countries. It is instructive to note the relatively small proportions of the variance which are unique to each measure of migration, with the exception of age at peak. The latter explains 30 per cent of the variance not shared with other measures in the overall factor model.

The strong correlation between MURC and MDRC, breadth of peak, and intensity at peak, and the inclusion of these four measures in the same factor suggest that only one of the four is needed to capture the concentration of migration activity around the peak. We recommend using intensity at peak as the summary measure of migration concentration since this can be readily gauged from smoothed data, which are best obtained via kernel regressions. In addition, intensity at peak has more intrinsic meaning than either of the rate-of-change measures or breadth of peak. For similar reasons, we recommend retaining age at peak as the key measure to summarize the age selectivity of migration. The age at which migration peaks can be deduced directly from a graph or table of age-specific migration rates. In addition, age at peak accounts for 30 per cent of the variance, the largest proportion of the variance not shared by other measures. A second factor analysis based only on intensity at peak and age at peak revealed that these two variables alone accounted for 67 per cent of the total variance between countries. This confirms that between them these two measures encapsulate the main features of the labour force curve and can provide a parsimonious summary of the way this curve varies from country to country. The proposed measures have the additional benefit of not requiring the use of any curve-fitting procedures while also sidestepping the issues related to the estimation of parameters.

As noted earlier, several previous studies have used age at peak and intensity at peak as summary measures of migration age profiles. In addition to providing an analytical foundation for this choice, our analysis has allowed us to add a clear understanding of the way these measures regulate two key features of the labour force curve. First, as the intensity of the peak increases, the slopes of the labour force curve progressively steepen. Second, as the peak age of migration increases, the upward slope of the labour force curve flattens and the symmetry of the curve around the peak age becomes more marked.

Table 4 Factor loadings of six metrics of migration age profile for 25 countries

Migration metric	Factor 1 Migration Concentration	Factor 2 Age Selectivity	Unique variance
Intensity at peak	**0.99**	0.10	0.01
MURC	**0.94**	0.30	0.03
MDRC	**−0.96**	0.12	0.07
Breadth of peak	**0.94**	0.03	0.12
Age at peak	−0.30	**−0.78**	0.30
Asymmetry	0.07	**0.90**	0.18
Proportion of total variance	0.63	0.26	

Note: Orthogonal rotation with Kaiser Normalization. Refer to Table 2 for definitions of the measures. Values greater than 0.75 or lower than −0.75 are in bold.
Source: As for Table 1.

6. Research application

In order to uncover the age structure of migration we normalized the migration data available to us. To compare migration dynamics meaningfully across countries it is essential, however, to take into account overall migration levels. To that end, we used a three-dimensional scatter plot to compare the migration profiles of the 25 countries we were studying—plotting our two recommended measures against the overall levels of migration in each

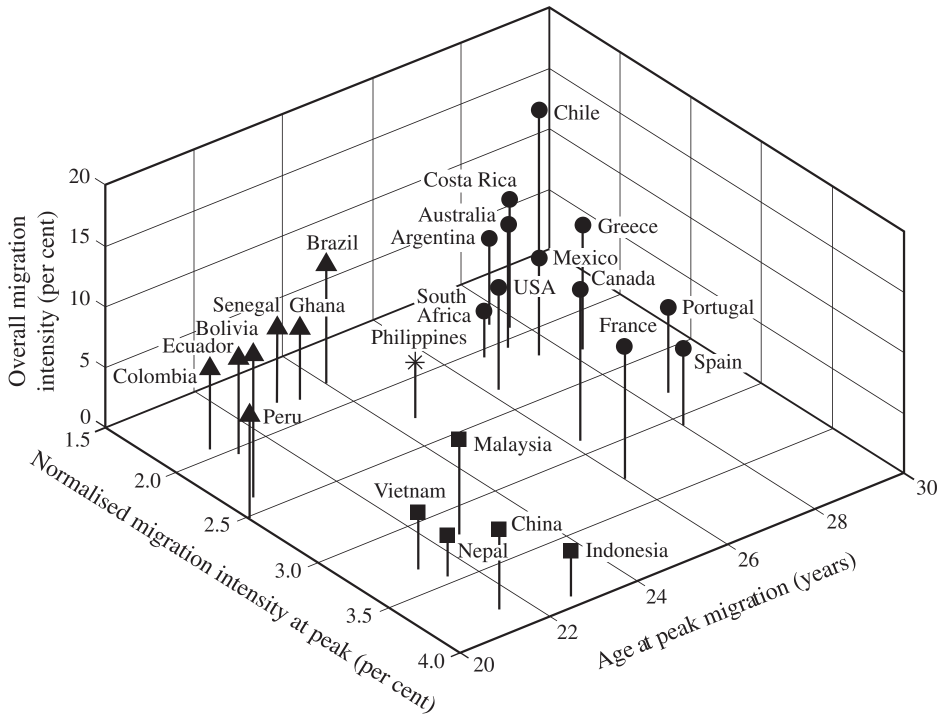

Figure 5 Age at peak, normalized intensity at peak, and overall migration intensity for 25 sample countries, indicating clusters of countries with similar age profiles of migration

Note: Overall migration intensity refers to the migration rates across the entire population. Clusters were defined according to a three-solution *k*-means cluster based on variables normalized to unit variance. The Philippines were excluded from the cluster analysis because their migration age patterns differ from those of the other sample countries in the same region, and also from patterns seen in the other major world regions. *Source*: IPUMS database.

country. Figure 5 displays normalized intensity at peak on the x-axis, age at peak on the y-axis, and overall migration intensity on the z-axis. The data points represent intensity at peak and age at peak for each country, while the vertical lines extending from the $x-y$ plane represent overall migration intensity.

Figure 5 demonstrates that the three measures shown provide a highly effective framework which can differentiate between the age profiles of migration seen in countries around the world. A k-means cluster analysis revealed three regional clusters within our 25 countries: a South-East Asian cluster, characterized by a strong concentration of migration activity in the early 20s and a comparatively low overall migration intensity; an industrialized-economy cluster, featuring a peak at older ages, dispersion of migration across the age spectrum, and high overall migration intensity; and a cluster of Latin American countries distinguished by a younger age at peak migration and greater dispersion of migration across the age spectrum. The diversity of migration age profiles within Latin America had been identified previously (Bell and Muhidin 2009). However, our comparison of a large number of countries within the region revealed that migration age patterns in Latin America differ according to the level of human development, as measured by the Human Development Index (HDI). In countries with a high HDI, such as Chile and Argentina, migration activity is concentrated in the late 20s, whereas in countries with medium HDI, including Bolivia and Colombia, migration peaks at an earlier age. The age profile of Ghana is similar to that of Senegal with a moderate peak in the mid-20s, but with only three African countries in our sample we were unable to draw conclusions about this region as a whole. Figure 5 also reveals that, despite strong regional clustering, the migration age patterns of a few countries, such as the Philippines, can differ substantially from those of their neighbours within the same region.

The differences in the overall level of migration intensity evident in Figure 5 can be traced, at least in part, to variations in the spatial scale at which migration has been measured within each country. Such differences are a product of the modifiable areal unit problem (MAUP) which plagues all geographical studies (Wrigley et al. 1996). We sought to minimize issues of comparability by drawing our data from countries in the IPUMS database which measure internal migration over 5-year intervals, 1-year age groups, and minor administrative units, but the number of the latter still varies widely from one country to another. Migration intensities have been shown to increase with the level of spatial disaggregation (Courgeau 1973), so differences in the number of divisions within each national territory are likely to account for some of the variations between nations observed along the vertical z-axis in Figure 5. The age profile of migration appears to be largely independent of scale however. Rogers and Castro (1981) found that the shape of the age profile of local mobility in the USA closely matched that of longer distance migration, and Bell and Muhidin (2009) reported a similar finding by comparing the age profiles of migration between minor administrative units in 19 countries with those of migration between major administrative units in the same countries. The explanation of the differences between both individual countries and clusters of countries in age at peak and intensity at peak seen in Figure 5 must therefore be sought in more substantive variations in the key factors driving mobility among young adults: patterns of education, economic opportunities, housing and labour market structures, family and household formation, and cultural norms. Further analysis is required to assess the relative influence of these determinants in different countries.

7. Conclusions

The rigorous cross-national comparison of population mobility calls for robust statistical indicators. The work reported here endeavoured to refine the utility of model schedules, one of the pre-eminent, long-standing tools used for migration analysis, and to advance the suite of measures proposed by Bell et al. (2002) for use in the comparative analysis of internal migration.

Model migration schedules represent a powerful conceptual tool and provide a useful device for exploring the relationship between age and migration. They have the singular strength that they capture the full variation in the propensity to migrate that occurs across the age profile. They are also applied widely in other areas, such as the development of inputs to population projections. However, model schedules face a number of limitations in relation to the estimation of their parameters and to their interpretation, particularly in regard to the slope of their constituent curves. We have argued that the maximum rate of change provides a more accurate measure of these slopes than is given by their exponential coefficients, and have proposed two new measures, the maximum upwards rate of change, or MURC, and the maximum downwards rate of change, or MDRC, to capture the upward slope and the downward slope of the labour force curve, respectively. We have demonstrated that these measures ensure more consistent discrimination between countries whose migration profiles display different shape characteristics. The proposed measures can be calculated without estimating model schedules, simply by taking the difference in migration intensity between two consecutive ages, repeating this sequentially across the relevant age range, and identifying the age at which the maximum rate of change occurs. While similar measures could also be computed by taking the first derivative of the model migration schedule, the proposed approach ensures that the results are not prejudiced by problems of parameter variability, sensitivity, or instability.

By pooling the measures of the slopes of the labour force curve with four other measures used in previous comparative research, we have shown through correlation and factor analysis that the complexity of the age profile of migration can be reduced to two principal characteristics, each of which is closely associated with other features of the age profile, and which can be adequately summarized by two discrete indicators: the age at which migration peaks and the intensity of migration at that peak. The intensity of the peak shapes the slopes demarcating the labour force curve: as intensity increases, the upward and downward slopes progressively steepen, a relationship that only crystallizes when the slopes are expressed via the rate of change. At the same time, the age at which peak migration occurs governs the symmetry of the labour force curve, the latter increasing steadily as age at peak rises. Computed across a sample of 25 countries, factor analysis shows that these two metrics account for 67 per cent of inter-country variance. Plotting age at peak against intensity at peak provided striking evidence of systematic regional variations in the age profile of internal migration among countries around the world. Our results confirm the distinctive migration age pattern among the countries of South and East Asia, which are characterized by relatively young age profiles with high migration peaks. These stand in clear contrast to the lower-intensity profiles of the more developed countries, which have peaks at older ages. Latin America, on the other hand, appears to fall into two distinct clusters differentiated by their age at peak migration, which may reflect international differences in culture or in levels of human development. At the same time, it is clear that there is also significant variation in the age profiles of migration of countries within the same region.

The way migration is measured differs greatly from country to country and not all nations collect information on movements within their borders (Bell et al., 2014). In consequence a comprehensive, global table of age profile indicators may be out of reach. Further work, with a more extensive sample of countries, is needed to verify that the two preferred measures identified here account for most of the inter-country variance. By extending the scope and depth of our comparative research, we aim to provide further insights into the similarities and differences in patterns of migration within countries, and to uncover the migration age patterns of hitherto under-researched regions, such as Africa and the Middle East.

Building on the statistical refinements outlined in this paper, the ultimate aim of our research programme is to establish the extent of international variation in four aspects of mobility: in the intensity of migration, in the distances covered, in the spatial impact of the migrant flows, and in the connectivity between countries, regions, or areas created by migration. In addition, we wish to achieve a greater understanding of the causes and consequences of these variations. Measured across a large number of countries, we anticipate that the linking of our age at peak and intensity at peak measures to a range of other summary socio-economic indicators will advance the understanding of migration to a level equivalent to that already attained by those considering other components of population change.

Notes

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Appendix A

Steps to obtain the maximum upward rate of change (MURC) and the maximum downward rate of change (MDRC) of the labour force curves, using data for Brazil 1995–2000 and for France 2000–06 as examples.

This appendix provides worked examples of the computation of MURC and MDRC for the age profiles of migration in Brazil in 2000 and France in 2006. We first smoothed the observed migration age profiles using kernel regressions. We then calculated MURC by identifying the age range, calculating the difference in migration intensity (proportion of individuals who moved) between each pair of consecutive ages sequentially across this age range, and selecting the maximum value. We identified the MDRC in the same way, calculating the maximum rate of change on the downward slope of the labour force curve. Table A1 displays the smoothed migration intensity and rate of change at each year of age from 5 to 40. The bold values are the MURC and MDRC for each country. Figures A1 and A2 are graphical representations of these data.

Table A1 Normalized migration intensity and rate of change by age, Brazil and France

	Brazil, 2000		France, 2006	
	Normalized migration intensity * 100	Rate of change	Normalized migration intensity * 100	Rate of change
5	1.368		1.515	
6	1.354	−0.014	1.453	−0.062
7	1.329	−0.025	1.374	−0.080
8	1.299	−0.031	1.287	−0.087
9	1.270	−0.028	1.203	−0.083
10	1.248	−0.022	1.128	−0.075
11	1.231	−0.017	1.060	−0.068
12	1.219	−0.013	0.999	−0.061
13	1.215	−0.004	0.946	−0.053
14	1.224	0.010	0.909	−0.037
15	1.251	0.026	0.920	0.011
16	1.297	0.046	1.044	0.124
17	1.365	0.067	1.345	0.301
18	1.450	0.085	1.799	0.454
19	1.545	**0.095**	2.279	**0.480**
20	1.638	0.093	2.663	0.383
21	1.717	0.079	2.908	0.245
22	1.773	0.057	3.043	0.135
23	1.805	0.032	3.126	0.083
24	1.815	0.009	3.198	0.072
25	1.805	−0.010	3.261	0.063
26	1.783	−0.022	3.288	0.027
27	1.755	−0.028	3.255	−0.033
28	1.722	−0.033	3.157	−0.098
29	1.685	−0.037	3.008	−0.148
30	1.645	−0.040	2.830	−0.179
31	1.601	−0.043	2.640	**−0.190**
32	1.555	−0.046	2.449	−0.190
33	1.507	**−0.048**	2.264	−0.185
34	1.459	−0.048	2.085	−0.179
35	1.415	−0.044	1.913	−0.171
36	1.376	−0.039	1.754	−0.160
37	1.338	−0.039	1.609	−0.144
38	1.296	−0.042	1.482	−0.127
39	1.252	−0.044	1.370	−0.112
40	1.210	−0.042	1.271	−0.099

Appendix B

Table B1 Year of data collection and type and number of administrative units for which data were collected in countries used to test new measures for the cross-national comparison of age profiles of internal migration.

	Year data collected	Smallest type of administrative unit between which age-specific migration could be identified	Number of administrative units for which data collected
Africa			
Ghana	2000	District	110
Senegal	2002	Department	45
South Africa	2001	Municipality	52
Asia			
China	1990	Prefecture	347
Indonesia	2000	Regency	180
Malaysia	2000	District	136
Nepal	2001	District	75
Philippines	2000	Municipality	1,610
Vietnam	1999	District	663
Latin America			
Argentina	2001	Department	324
Bolivia	2001	Province	112
Brazil	2000	Municipality	1,540
Chile	2002	Municipality	178
Colombia	2005	Municipality	1,104
Costa Rica	2000	Canton	81
Ecuador	2001	Canton	128
Peru	2007	Province	195
North America			
Canada	2001	Census District	280
USA	2000	States	51
Mexico	1995	Municipality	2,456
Europe			
Greece	2001	Municipality	1,033
Portugal	2001	Municipality	308
France	2006	Department	101
Spain	1991	Municipality	366
Oceania			
Australia	2006	Statistical Division	61

Note: All migration data were measured over a 5-year interval by collecting individuals' place of residence 5 years before the collection year.
Source: IPUMS database for all countries, except for Australia and Turkey, for which data were obtained from the Australian Bureau of Statistics and the Demographic and Health Survey, respectively.

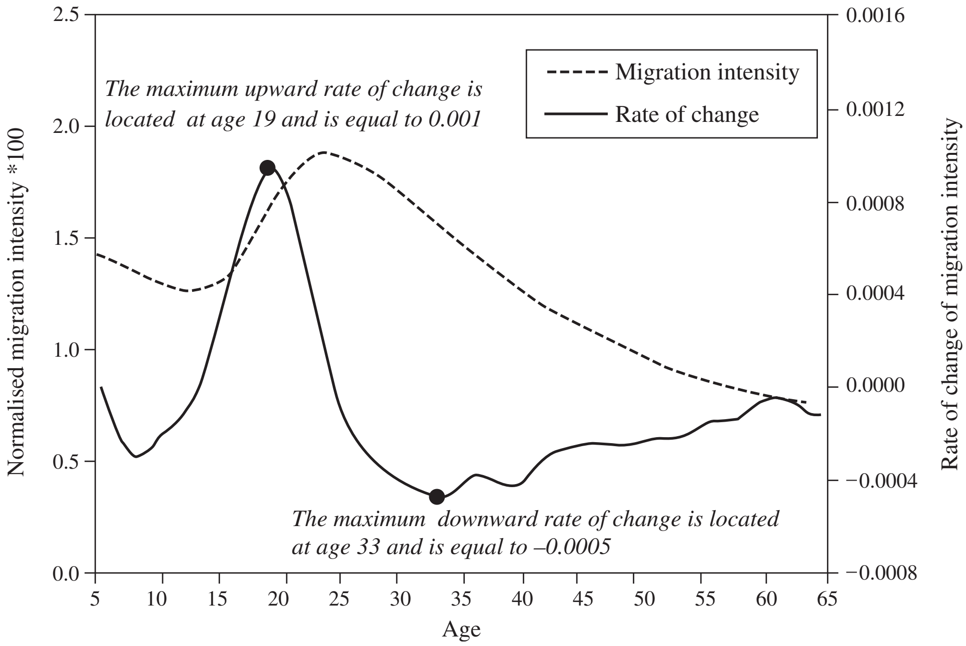

Figure A1 Migration intensity and rate of change by age, Brazil, 2000
Note: Migration intensities were smoothed using kernel regressions.
Source: IPUMS database.

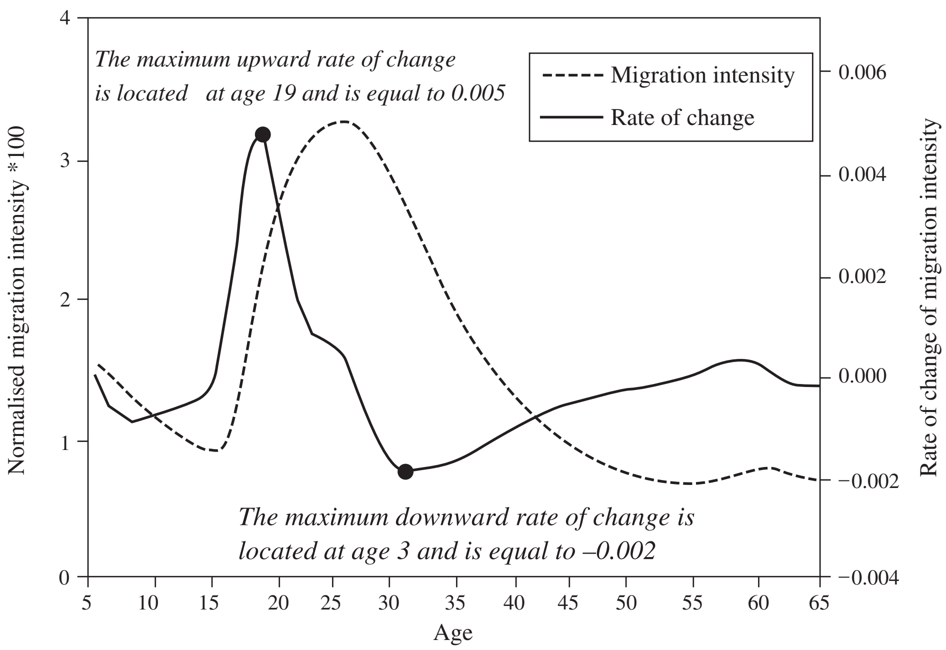

Figure A2 Migration intensity and rate of change by age, France, 2006
Note: Migration intensities were smoothed using kernel regressions.
Source: As for Figure A1.