The MIMOSA model for estimating international migration flows in the European Union[1]

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Introduction

MIMOSA (MIgration MOdelling for Statistical Analyses) is a three-year project funded by Eurostat intended to support the development and application of statistical modelling techniques for the estimation of missing data on migration flows and foreign population stocks. The project is being coordinated by the *Netherlands Interdisciplinary Demographic Institute* (NIDI) and involves experts on migration statistics from the *Central European Forum for Migration and Population Research* (CEFMR), *Southampton Statistical Sciences Research Institute* (S3RI) and *Université Catholique de Louvain*. This paper presents the modelling approach adopted by the MIMOSA project to estimate international migration flows between countries in the European Union. The aim is to account for the many differences in definitions, quality and sources of available migration data and to estimate the missing data.

The study of international migration in the European Union (EU) is currently hindered by data availability, quality and consistency. Harmonization of data collection processes and the data they generate is not even close to being realized (Poulain et al. 2006). Our understanding of population change and migration policy is therefore currently limited. So, how does one overcome these obstacles to obtain an overall and consistent picture of the migration patterns occurring within Europe? This research seeks to answer this question by developing a methodology to (i) harmonise and correct for inadequacies in the available data and (ii) estimate the missing patterns. In particular, a categorical data analysis approach is applied to the structures in the migration flow tables, representing the gross flows of immigration and emigration and the associations (or interactions) between countries. The resulting estimates provide valuable insights into the overall picture of population movements, as well as suggest areas for further improvement in the modelling approach. It should be noted that this research is in many ways a first attempt and that the results we present are by no means final. International migration in the European Union lacks a solid foundation from which completely reliable estimates can be made. However, our approach does produce reasonable results that can be used for improving our understanding of population movements in the European Union and as inputs for population planning and policy making. Also, the results can also be compared with the reported data, which may be useful for identifying problems in the data.

A brief overview of international migration data issues in the EU

The process of obtaining consistent international migration flow data involves overcoming several major data-related obstacles (Kelly 1987). Mainly, this involves combining information obtained from independent sources that may (i) contain different conceptualisations of migration and (ii) provide varying levels and qualities of available data (including historical time series). The following paragraphs briefly describes the issues, focusing on the different timing criterions used to measure migration, unreliable data and missing data. For a more detailed account of the data issues of international migration and various migration typologies, refer to Champion (1994), Kelly (1987), Kraly and Gnanasekaran (1987), Poulain (1994, 1995), Poulain et al. (2006), Raymer and Willekens (2008), United Nations (2002) and Willekens (1994, 1999).

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The timing criterion used to identify international migrants varies considerably between countries (Kupiszewska and Nowok 2008). For population register data, international migration may refer to persons who have lived in a different country as much as three months, six months, or one year. For census or survey data, the entry date of international migrants is not known, only that they lived outside the country one-year or five years prior to the census or survey date. More research is needed to reconcile the different timings used to collect or model migration data, as well as between different collection systems. At present, only a small body of literature exists on this subject, and all of it is focused on different timings of *internal migration* data obtained from censuses and surveys (i.e., Kitsul and Philipov 1981; Liaw 1984; Long and Boertlein 1990; Rogers et al. 2003a; Rogerson 1990). An examination of the effects of different timings on the levels of international migration flows obtained from population registers, residence permit databases or border crossing surveys has not been carried out for the purposes of studying international migration.

The effect of timing criteria on levels of migration obtained from registers, residence permit databases or border crossing surveys is illustrated in Figure 1. The 'permanent' migration criterion, representing a move in which the migrant essentially gives up his or her residence rights, has been used commonly in former Soviet Union countries in Central and Eastern Europe, explaining their very low reported flows (Nowok 2008). The 'last country of residence' represents the absence of a timing criterion and refers to persons who ever lived abroad without a fixed time constraint. Here, we assume that the net effect of migration is positive over time resulting in a very big 'flow.' In between these two extremes are all sorts of possible definitions (or combinations of them), including the United Nation's recommended one-year definition. The diagram assumes the level of a particular migration flow is affected by timing criterion used to determine immigrants and emigrants. Note that the relationships between different timings may, in fact, be non-linear, as Long and Boertlein (1990) show for different timings of internal migration data (i.e., 1-year versus 5-years) collected in the United States. Also, the actual spacing between definitions could be different from what is expressed in the diagram; although, the relative rankings should remain the same.

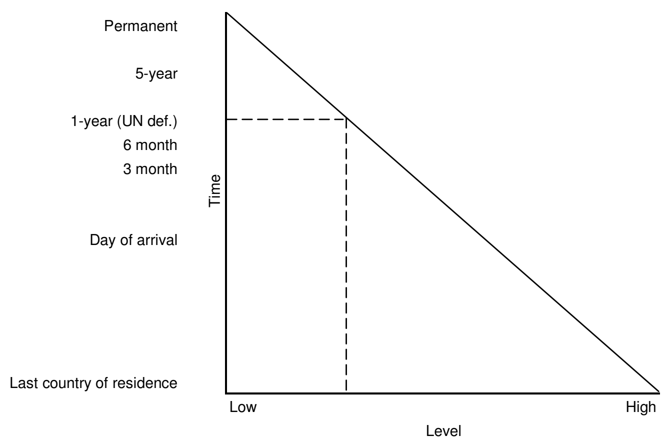

Figure 1. Conceptual framework for adjusting international migration flows due to different timings

International migration statistics also suffer from unreliability, mainly due to under-registration of migrants and data coverage (Nowok et al. 2006, pp. 211-214). This is often caused by the collection method or by non-participation of the migrants themselves (see Kupiszewska and Nowok 2008). Emigration data are particularly problematic because migrants may not notify the population register of their movement or may produce statements that are based on intentions. Surveys, such as the United Kingdom's International Passenger Survey, are particularly problematic for providing international migration data as the sample size must be very large in order to provide sufficient detail for analyses. Without a relatively large sample size, unexpected irregularities in the data are likely to appear, such as in the country-to-country-specific flows.

The types of missing data found in European international migration data consist primarily of data not collected or provided by statistical agencies. There are many different types of missing data. For example, flows for certain countries may be missing for particular years or entirely. The reported flows are likely to have missed some groups of persons, for example, illegal migrants who do not participate, for obvious reasons, in a particular survey or register with the local residence authorities. Furthermore, migration data may be available only for the total population, not for more detailed demographic, socioeconomic or spatial characteristics required for a particular study.

Data used in this study

This study focuses on international migration between 31 European countries (EU plus Iceland, Liechtenstein, Norway and Switzerland) during 2002, 2003, 2004 and 2005. Flows from and to the rest of the world are also included. The data come from Eurostat. No other data were collected. Most of the available data represent flows by previous / next country of residence for both immigration and emigration.

The various definitions used by the 31 countries in our study to measure immigration and emigration are set out in Table 1. Here, we find that not only are there differences between countries but also within countries. In fact, a particular immigration or emigration flow may be an aggregation of flows (e.g., native and non-native) representing more than one migration definition. For example, the immigration total for Finland is a combination of the non-Finish who have been in the country for 12 months and that of returning Fins, counted from the moment they re-entered the country. Using information on timing criteria drawn from Chapter 8 in THESIM (Poulain et al. 2006) and an internal MIMOSA report, a relative ranking is set out in Table 1. Six timing categories are identified: instant, 3 months, 6 months, 12 months, permanent and unknown. Discrepancies appear to occur more frequently in the immigration data, some of which are fairly large. For example, Latvia and Finland move from 12 month timing on migrants from other EEA countries to an instant timing on nationals. Fewer and smaller jumps are made when comparing emigration timing criteria of those from other EEA countries and nationals leaving a given country.

Methodology

This section briefly describes the methodology used to obtain harmonised estimates of international migration between countries in the European Union (note, much of the detail is left out for space reasons). There are two important stages. The first harmonises the available data by using a relatively simple iterative procedure and a set of countries whose patterns are considered reliable. The second stage estimates the missing marginal data and associations between countries by using the available data, pooled over time, and covariate information. Both stages are set within a multiplicative framework for analysing migration flows.

Multiplicative framework

There have been several recent papers focusing on analysing and estimating migration structures found in categorical tables cross-classified by origin, destination and age (Raymer et al. 2006; Raymer and Rogers 2007; Rogers et al. 2001, 2002a, 2002b; 2003b). This (mathematical) approach has direct linkages with the log-linear (statistical) model approach. The multiplicative component model for an origin (O) by destination (D) table of migration flows is specified as

$$n_{ij} = (T)(O_i)(D_j)(OD_{ij}) \quad i \neq j$$

where n_{ij} is an observed flow of migration from origin i to destination j. There are four multiplicative components in total: an overall level, two main effects and one two-way interaction component. The description and estimation centres on these components rather than on the flows themselves. The components are calculated with reference to the total level in the migration flow tables. T denotes the total number of all migrants in the system: $T = n_{++}$. The main effect components, O_i and D_j, represent proportions of all migration from each origin and to each destination, i.e., $O_i = n_{i+} / T$ and $D_j = n_{+j} / T$. The two-way interaction component represents the ratio of observed migration to expected migration (for the case of no interaction) and is calculated as $OD_{ij} = n_{ij} / [(T)(O_i)(D_j)]$. The OD_{ij} component represents the association or "connectedness" between origins and destinations.

Table 1. Timing criterion used by various countries in the European Union

Timing	Immigration		Emigration	
	Other EEA	Nationals	Other EEA	Nationals
Instant		*Belgium*		*Belgium*
		Estonia	*Estonia*	*Estonia*
		Finland		
	Germany	Germany	Germany	Germany
	Ireland*	Ireland*	Ireland*	Ireland*
	Italy*	Italy*		
		Latvia		
	Luxembourg*	Luxembourg*	Luxembourg*	Luxembourg*
	Spain	Spain	Spain	Spain
3 months	Austria*	Austria*	Austria*	Austria*
	Belgium		*Belgium*	
	Estonia			
	Hungary	*Hungary*	*Hungary*	*Hungary*
	Slovenia	Slovenia	Slovenia	Slovenia
6 months	Denmark	Denmark	Denmark	Denmark
	Iceland*	Iceland*		
			Latvia	Latvia
	Lithuania	Lithuania		Lithuania
	Netherlands	Netherlands	Norway	Norway
	Norway	Norway		
12 months	Cyprus	Cyprus	Cyprus	Cyprus
	Czech Rep.			
			Italy	Italy
	Finland		Finland	Finland
	Latvia			
			Lithuania	
			Netherlands	Netherlands
	Portugal		*Portugal*	*Portugal*
	Sweden	Sweden	Sweden	Sweden
	Switzerland	*Switzerland*	*Switzerland*	*Switzerland*
	UK	UK	UK	UK
Permanent		Czech Rep.	Czech Rep.	Czech Rep.
	Malta*	Malta*	*Malta*	*Malta*
	Poland	Poland	Poland	Poland
	Romania*	Romania*	Romania	Romania
	Slovakia	Slovakia	Slovakia	Slovakia
Unknown	*Bulgaria*	*Bulgaria*	*Bulgaria*	*Bulgaria*
	France	*France*	*France*	*France*
	Greece	*Greece*	*Greece*	*Greece*
			Iceland*	Iceland*
	Liechtenstein	*Liechtenstein*	*Liechtenstein*	*Liechtenstein*
		Portugal		

* Only partial data exists between 2001 and 2004
Italics: No data exists between 2001 and 2004

The multiplicative component model is useful framework for estimating migration flows because it makes a distinction between an overall level, main effects, and interaction effects in contingency tables with parameters that can be used to guide the estimation process. This means that one can focus on modelling the underlying structures of migration flows via each multiplicative component, which allows the modeller to better identify errors in reported and adjusted data. Finally, this model can be extended to include other categorical variables, such as age groups, sex, or nationality. This modelling framework has been used, for example, to project future age-specific migration patterns in Italy (Raymer et al. 2006) and to construct missing origin-destination associations for migration between countries in

Europe (Raymer 2007, 2008). The procedure adopted for this paper can be viewed as a direct extension and improvement to earlier attempts made by Raymer (2007, 2008).

Iterative procedure for harmonising the available data

Following the work of Poulain (1994, 1999), van der Erf and van der Gaag (2007) proposed a simple procedure to harmonise available migration data. It represents an iterative technique that relies on reliable receiving country or sending country data to revise the corresponding less reliable data. This technique assumes that the user knows the relative reliability of the various sources in the migration flow tables. Also, expert knowledge is often required to make further corrections to the reported data, such as whether the unknown data should be allocated evenly across all origins or destinations. The resulting adjustments to the reported data may, in some cases, be substantial.

The method works from two corresponding migration flow tables representing flows provided by the receiving country and flows provided by the sending country. The first step is to identify the data that are believed to be reliable and in line (more or less) with the recommended definitions of the United Nations (1998). For the 2002-2005 annual migration flows provided by Eurostat, we used Denmark, Finland, Norway and Sweden's immigration and emigration data as our base for the iterative procedure. The second step is to make relative judgements on the remaining data according to their reliability. The iterative process works from relatively good data to relatively poor data, so it is important that the rankings of the countries reliability are carried out with care.

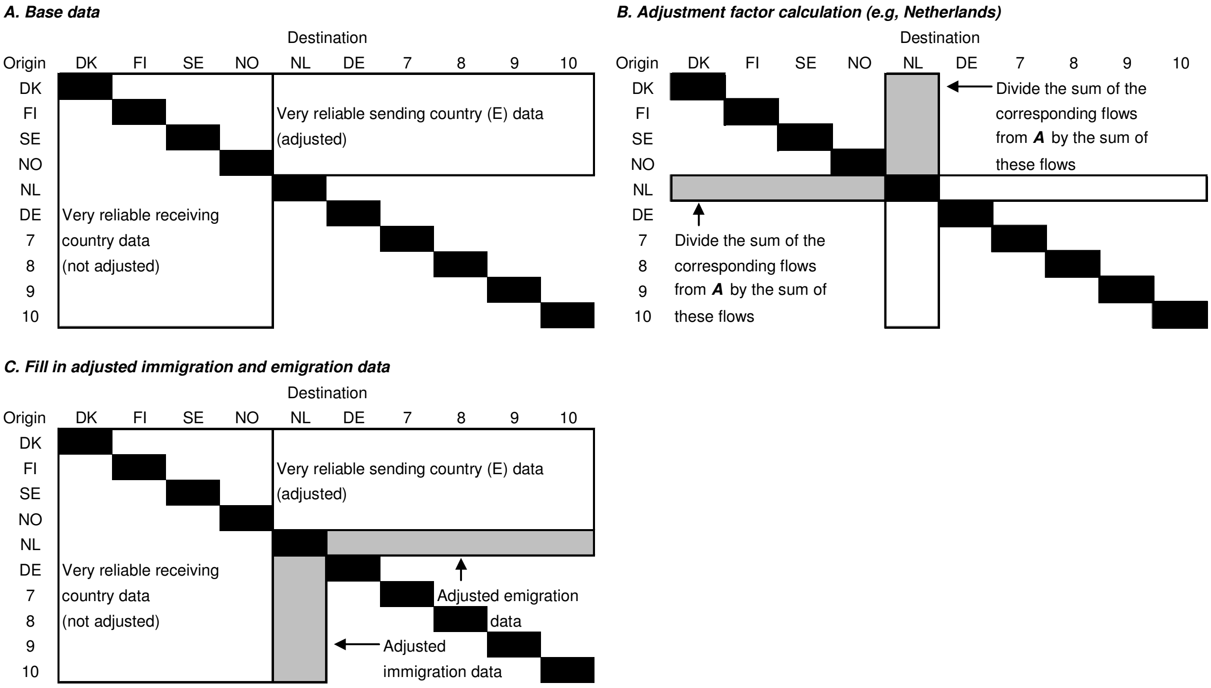

Figure 2. Illustration of iterative procedure to harmonise available migration flow data

The following explains in more detail how the iterative process works (see also Figure 2 and Table 2). First, the 2002-2005 immigration flows reported by Denmark, Finland, Sweden and Norway are simply fixed and do not change throughout the estimation process. We assume these data are accurate and reliable. The corresponding emigration data were adjusted based on average comparisons with the receiving data, both across countries and over time (i.e., 2002-2004). Combined together, these two sets of flows represent the base data (See Figure 2A). The second step of the procedure is to calculate correction factors for, say, Netherlands' immigration and emigration flows based on comparisons with the corresponding base data (see Figure 2B). The last step adds the adjusted Netherlands flows to the migration flow table (see Figure 2C). These flows are then considered fixed and used as a reference for the next country (e.g., Germany). The process continues until there are no more comparisons possible. The calculated adjustment factors for immigration and emigration are set out in Table 2. Note, Poland, Romania and Slovakia's reported data were not used as the adjustment factors were over 25 and deemed to large to consider the data reliable.

Table 2. ***Adjustment factors for receiving country (I) and sending country (E) migration data, 2002-2005***

Country	I	E	Country	I	E
Denmark	**1.000**	1.081	Latvia	6.990	7.433
Finland	**1.000**	0.994	Lithuania	3.624	3.314
Sweden	**1.000**	1.055	United Kingdom	1.059	1.048
Norway	**1.000**	1.122	Slovenia	0.779	0.816
Netherlands	0.960	0.795	Italy	2.027	2.523
Germany	0.758	0.792	Luxembourg	1.256	1.218
Czech Republic	4.464	6.700	Austria	0.804	1.095
Spain	0.821	2.839	Iceland	0.947	0.976
Cyprus	0.738	2.883			

Estimating the missing data

Margins of EU matrix (T, O_i and D_j) and flows from / to rest of world

The adjusted data were used as the basis for estimating the missing data. The available totals of immigration and emigration were split into two categories: migration from / to the 31 European countries and from / to the rest of world. Simple OLS regression models for the available data pooled over time (i.e., 2002-2004) were used to estimate the natural logarithms of migration to European countries, migration from European countries, migration to rest of world and migration from rest of world (n = 59). The variables used to predict these flows were population size (in thousands, natural logarithm), the ratio of 65+ year olds to 20-64 year olds, life expectancy of females, relative GDP, percent refugees of foreign-born population, percent urban, percent foreign-born (natural logarithm) and dummy variables for Germany (European matrix) and the new EU accession countries (rest of world). The estimated coefficients and adjusted R^2 (coefficient of determination) values are set out in Table 3. All four models performed well with all adjusted R^2 values over 0.9. Most of the variables were significant with some exceptions, e.g., percent foreign-born was not significant for predicting immigration and emigration within the European matrix. Finally, by combining the adjusted and estimated European marginal totals, the T, O_i and D_j multiplicative components were obtained.

Associations of European matrix: OD_{ij}

The next step estimates the missing associations between origins and destinations. The expected flows (denominator) are obtained by using iterative proportional fitting to the adjusted and estimated European matrix marginal totals, where structural zeros are placed in the diagonal elements. The origin-destination associations for the available data are then calculated by dividing the adjusted flows of migration from i to j by the expected flows. The missing origin-destination associations may be estimated by using OLS regression, where the dependent variable is the natural logarithm of OD_{ij} (n = 2540). The predictors for this model are contiguity (1 = neighbours, 0 = non-neighbours), new EU accession countries (1 = accession, 0 = non-accession), language family (1 = same language family, 0 = different language family), after 2004 (1 = 2004 and 2005, 0 = 2002 and 2003), natural logarithm of GNI PPP ratios, natural logarithm of distance, natural logarithm of foreign-born OD_{ij} associations and natural logarithm of trade OD_{ij} associations. The estimated coefficients are set out in Table 4.

Table 3. ***Estimated coefficients for regressions on available immigration and emigration flows from / to EU matrix and rest of world***

Variable	Immigration B	t	Sig.	Adj. R^2	Emigration B	t	Sig.	Adj. R^2
A. EU matrix								
(Constant)	-4.9000	-1.6802	0.0990	0.9119	9.5455	4.1967	0.0001	0.9355
ln of Population (in 1000)	0.7448	11.9010	0.0000		0.6998	14.3387	0.0000	
65+ / 20-64 years	-0.0415	-1.4781	0.1455		-0.0582	-2.6547	0.0106	
life expectancy (females)	0.0848	2.2626	0.0280		-0.0867	-2.9651	0.0046	
GDP (relative)	0.0062	3.1971	0.0024		0.0063	4.1116	0.0001	
% refugees of foreign-born	-0.0467	-3.7380	0.0005		-0.0377	-3.8666	0.0003	
% urban	0.0273	3.7797	0.0004		0.0333	5.9243	0.0000	
ln of % foreign-born	0.0499	0.4114	0.6825		-0.1320	-1.3958	0.1688	
Dummy variable for DE	0.7422	2.8628	0.0061		1.1528	5.7011	0.0000	
B. Rest of world								
(Constant)	-8.4355	-1.9840	0.0526	0.9636	28.3149	5.0110	0.0000	0.9113
ln of Population (in 1000)	1.0910	22.7613	0.0000		0.9424	14.7935	0.0000	
65+ / 20-64 years	-0.0574	-2.3774	0.0212		-0.0891	-2.7779	0.0076	
life expectancy (females)	0.1179	2.3527	0.0225		-0.3052	-4.5827	0.0000	
GDP (relative)	-0.0087	-5.1765	0.0000		-0.0127	-5.7010	0.0000	
% refugees of foreign-born	-0.0040	-0.3504	0.7275		-0.0298	-1.9415	0.0577	
% urban	0.0188	2.9673	0.0046		0.0036	0.4257	0.6721	
ln of % foreign-born	0.1726	1.7728	0.0822		0.6918	5.3451	0.0000	
Dummy variable for EAST	-0.3584	-1.4596	0.1505		-1.9921	-6.1042	0.0000	

Table 4. Estimated coefficients for regression on available origin-destination associations within the EU matrix

Variable	B	t	Sig.	Adj. R^2
(Constant)	0.4697	1.5630	0.1182	0.4073
contiguity	0.3398	4.0653	0.0000	
new accession countries	0.7157	3.7117	0.0002	
language family	0.4348	4.9863	0.0000	
after 2003	0.1340	3.2068	0.0014	
ln of GNI PPP ratios	0.1088	5.5536	0.0000	
ln of distance	-0.1097	-2.6194	0.0089	
ln of foreign-born OD associations	0.2262	14.4113	0.0000	
ln of trade OD assocations	0.2950	11.9247	0.0000	

Estimated flows: $\hat{n}_{ij}$

Finally, the set of available and estimated OD_{ij} components were combined together and used to produce (unconstrained) estimates of origin-destination-specific migration flows for the entire matrix, i.e., $\hat{n}_{ij} = (T)(O_i)(D_j)(OD_{ij})$, where T, O_i and D_j are obtained from the marginal totals estimated in the previous modelling objective.

Results

The results show that migration within the EU steadily increased from 2.39 million persons in 2002 to 2.67 million persons in 2005, whereas the migration from and to the rest of the world remained around the same levels, i.e., 2.23 million immigrants and 1.11 million emigrants (on average). In total, there were 4.58 million persons who migrated in 2002, 4.81 million persons in 2003, 4.93 million persons in 2004 and 4.87 million persons in 2005. The net migration from rest of world amounted to 1.1 to 1.2 million each year during the four years. As for immigration and emigration totals, the top 20 flows are set out in Figure 3. Here, we see that the Germany, Spain, Italy, United Kingdom and France were the main receivers of migrants during the four year period, however, with no particular pattern. For emigration totals, Germany and the United Kingdom were consistently the largest senders of migrants. Surprisingly, Romania was estimated to be the next largest sender with over 200 thousand migrants during 2003, 2004 and 2005.

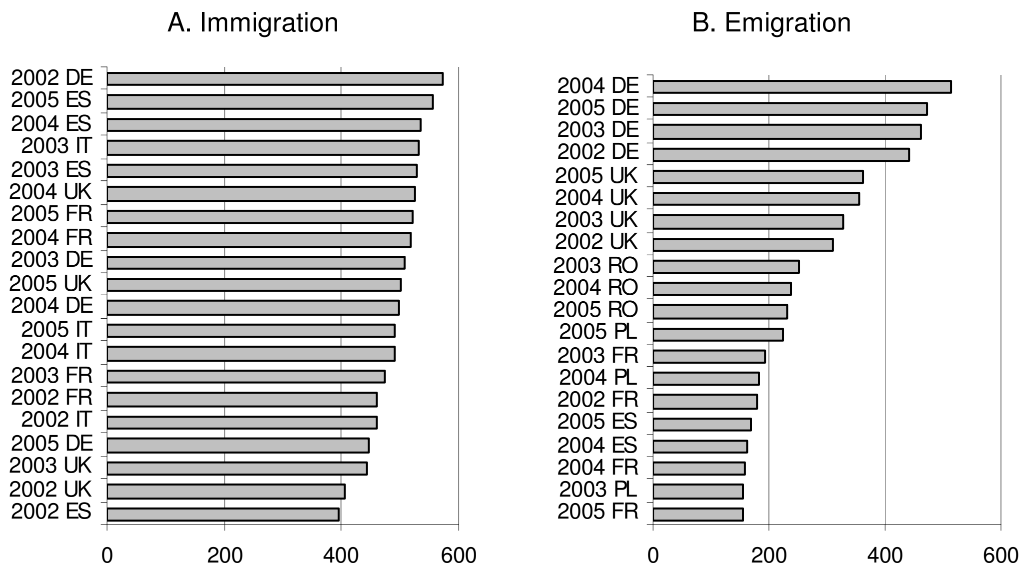

Figure 3. Top 20 estimated immigration and emigration countries, 2002-2005

The estimated origin-destination-specific flows can also be analysed. For example, in 2002, emigrants from Poland (Figure 4) chose Germany and the rest of the world as their first and second top choices. In 2005, the United Kingdom was the second most attractive destination. The estimated patterns of migration from France, on the other hand, showed the importance of migration from the rest of the world, which declined from around 100 thousand before 2004 to around 80 thousand after 2004. The other top destinations for migrants from France were large countries, such as Germany, Italy, the United Kingdom and Spain.

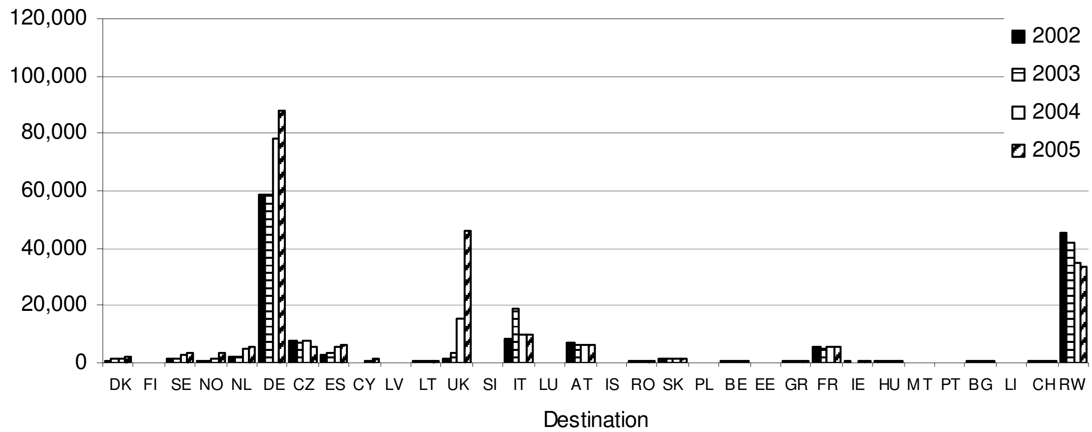

Figure 4. Estimated emigration flows from Poland, 2002-2005

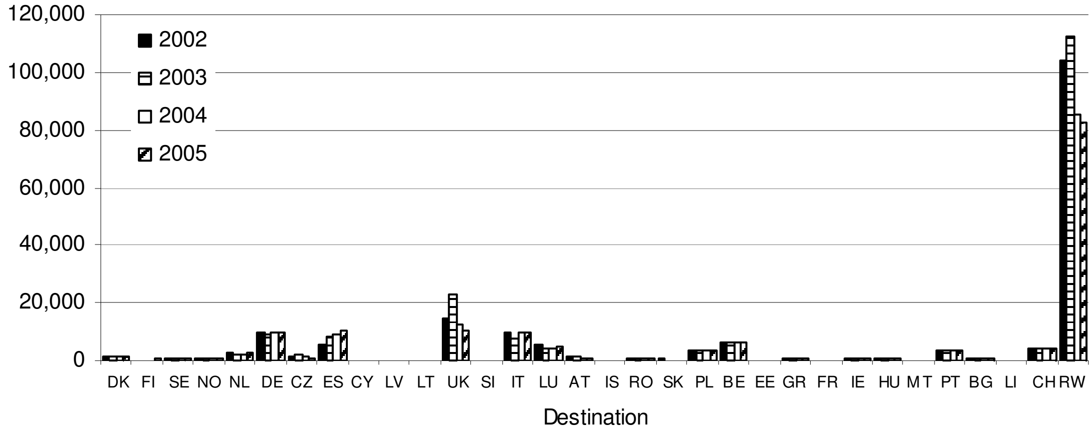

Figure 5. Estimated emigration flows from France, 2002-2005

Summary

This paper has set out a general methodology for obtaining harmonised estimates of international migration between countries in the European Union. It is difficult to assess a particular methodology since the true answers are unknown. However, we believe we have made an important first step to obtaining reliable and consistent estimates of international migration between European countries. Migration estimation is a complicated task but an important one. The multiplicative component procedure simplifies the process by allowing the user to maintain control during the estimation. The quality of international migration may vary substantially, not only by country, but also year by year. Until we have a strong base to work from, the estimation of migration will require a strong user interface.

References

Champion AG (1994) International migration and demographic change in the developed world. *Urban Studies* 31(4/5):653-677.

Kelly JJ (1987) Improving the comparability of international migration statistics: Contributions by the Conference of European Statisticians from 1971 to date. *International Migration Review* (Special Issue: Measuring international migration: Theory and Practice) 21(4):1017-1037.

Kitsul P and Philipov D (1981) The one-year / five-year migration problem. In *Advances in multiregional demography*, Rogers A, ed., pp. 1-33, RR-81-6, International Institute for Applied Systems Analysis, Laxenburg, Austria.

Kraly EP and Gnanasekaran KS (1987) Efforts to improve international migration statistics: A historical perspective. *International Migration Review* (Special Issue: Measuring international migration: Theory and Practice) 21(4):967-995.

Kupiszewska D and Nowok B (2008) Comparability of statistics on international migration flows in the European Union. In *International migration in Europe: Data, models and estimates*, Raymer J and Willekens F, eds. Chichester: Wiley.

Liaw K-L (1984) Interpolation of transition matrices by the variable power method. *Environment and Planning A* 16:917-926.

Long JF and Boertlein CG (1990) Comparing migration measures having different intervals. Current Population Reports No. 166, U.S. Census Bureau, Washington, DC.

Nowok B (2008) Evolution of international migration statistics in selected Central European countries. In *International migration in Europe: Data, models and estimates*, Raymer J and Willekens F, eds. Chichester: Wiley.

Nowok B, Kupiszewska D and Poulain M (2006) Statistics on international migration flows. In *THESIM: Towards Harmonised European Statistics on International Migration*, Poulain M, Perrin N and Singleton A, eds., pp. 203-231. Louvain: UCL Presses.

Poulain M (1994) Internal mobility in Europe: The available statistical data. Working Paper No. 17, Conference of European Statisticians, Commission of the European Communities (Eurostat), Mondorf-les-Bains, Luxembourg.
Poulain M (1995) Towards a harmonisation of migration statistics within the European Community. In *Demographic consequences of international migration*, Voets S, Schoorl J and de Bruijn B, eds., pp. 11-25. The Hague: Netherlands Interdisciplinary Demographic Institute.
Poulain M (1999) International migration within Europe: Towards more complete and reliable data? Working Paper No. 37, Conference of European Statisticians, Statistical Office of the European Communities (Eurostat), Perugia, Italy.
Poulain M, Perrin N and Singleton A, eds. (2006) *THESIM: Towards Harmonised European Statistics on International Migration*. Louvain: UCL Presses.
Raymer J (2007) The estimation of international migration flows: A general technique focused on the origin-destination association structure. *Environment and Planning A* 12:371-388.
Raymer J (2008) Obtaining an overall picture of population movement in the European Union. In *International migration in Europe: Data, models and estimates*, Raymer J and Willekens F, eds. Chichester: Wiley.
Raymer J, Bonaguidi A and Valentini A (2006) Describing and projecting the age and spatial structures of interregional migration in Italy. *Population, Space and Place* 12:371-388.
Raymer J and Rogers A (2007) Using age and spatial flow structures in the indirect estimation of migration streams. *Demography* 44(2):199-223.
Raymer J and Willekens F, eds. (2008) *International migration in Europe: Data, Models and Estimates*. Chichester: Wiley.
Rogers A, Raymer J and Newbold KB (2003a) Reconciling and translating migration data collected over time intervals of differing widths. *The Annals of Regional Science* 37(4):581-601.
Rogers A, Willekens FJ, Little JS and Raymer J (2002a) Describing migration spatial structure. *Papers in Regional Science* 81:29-48.
Rogers A, Willekens FJ and Raymer J (2001) Modeling interregional migration flows: Continuity and change. *Mathematical Population Studies* 9:231-263.
Rogers A, Willekens FJ and Raymer J (2002b) Capturing the age and spatial structures of migration. *Environment and Planning A* 34:341-359.
Rogers A, Willekens FJ and Raymer J (2003b). Imposing age and spatial structures on inadequate migration-flow datasets. *The Professional Geographer* 55(1):56-69.
Rogerson PA (1990) Migration analysis using data with time intervals of differing widths. *Papers of the Regional Science Association* 68:97-106.
United Nations (1998) Recommendations on statistics of international migration. Statistical Papers Series M, No. 58, Rev. 1. Statistics Division, Department of Economic and Social Affairs, United Nations, New York.
United Nations (2002) Measuring international migration: Many questions, few answers. Population Division, Department of Economic and Social Affairs, United Nations, New York.
van der Erf R and van der Gaag N (2007) An iterative procedure to revise available data in the double entry migration matrix for 2002, 2003 and 2004. Discussion Paper, Netherlands Interdisciplinary Demographic Institute, The Hague.
Willekens F (1994) Monitoring international migration flows in Europe: Towards a statistical data base combining data from different sources. *European Journal of Population* 10:1-42.
Willekens FJ (1999) Modeling approaches to the indirect estimation of migration flows: From entropy to EM. *Mathematical Population Studies* 7(3):239-278.