Frans Willekens: Migration Scholar and Migrant

Liber Amicorum written on the Occasion
of his 80th Birthday on March 5, 2026

Edited by Nico Keilman & Leo van Wissen

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Nico Keilman • Leo van Wissen
Editors

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Colophon

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Greetings from Andrei Rogers

In the early 1970s Frans wrote me from Africa after reading one of my books. In 1975 I moved from Northwestern University to Vienna to work at IIASA , the International Institute for Applied Systems Analysis. Frans joined me there and was by far one of my best students, a top gun. We published many important articles and a 17 volume collection of reports. Frans was a delight to work with. Frans won the Mendel Sheps award recognizing his work in Metholodogy in Spatial Analysis. I am sending my best of wishes to Frans.

Andrei Rogers

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1 Frans Willekens: The demographers' demographer

Leo van Wissen and Nico Keilman

Abstract

This introductory chapter gives a brief overview of the impact Frans Willekens' work has had on demography world-wide. We sketch his contributions to theory and methodology. Four distinct perspectives in his scientific work are illustrated: structure versus process, macro versus micro, analysis versus synthesis, and certainty versus uncertainty. Finally, we outline his activities as a teacher of demography, supervisor of young scholars, and as an organizer of demographic education.

On the 5th of March 2026 Frans Willekens turns 80. It is an excellent opportunity to honor him on this occasion with a Liber Amicorum, written by friends and colleagues. The 22 contributions to this book signify his enormous influence on the development of the discipline of demography, and the role he played as inspirator, supervisor, mentor, role model or friend for many young scholars. It is impossible to cover all of his achievements and his impact in a few introductory pages. In 2018, Frans obtained a Honorary Doctoral Degree of the Warsaw School of Economics. The laudatio by Irena Kotowska, and the reviews by Jakub Bijak, Ewa Fratczak and Marek Kupiszweski in the book that was published on the occasion of this event, contain important additional reflections about Frans' contributions to demography (Kotowska & Chloń-Domińczak 2018). On a more personal note, the reflections of the authors in this book about Frans provide additional details to color the picture.

Frans is highly regarded by his peers for his invaluable contributions to demographic theory and methodology. On a fundamental level, he provided many researchers with the necessary basis for their research. To the non-academic world he is less well-known. Societal debates that involved demography he left to others. To our knowledge he never ventured on TV to express his opinion on migration, aging, or other demographic topics. You might therefore say that he is very much a demographer's demographer. A scholar, dedicated to the further development of the field of demography, to the advantage of many who followed in his footsteps, whose audience primarily consists of his demographic peers.

That he would rise to such prominence as a demographer was not quite clear at the start of his academic career. Although during his study he followed classes in economics and sociology, he obtained a master's degree in Agricultural Engineering, with specialization Tropical Agriculture, at the University of Leuven, in 1970; not exactly the most straightforward route to becoming a demographer. Fortunately for the demographic discipline he met Andrei Rogers while being employed at the Technological Institute at Northwestern University, Evanston, Illinois, USA. His dissertation, entitled "Analytics of multiregional population distribution policy", was supervised by Andrei Rogers who invented the field of multidimensional models in demography, but Frans took over the baton and developed the concept of heterogeneous populations much further both from a methodological and theoretical perspective. The dissertation was the spark, but his collaboration with Andrei Rogers in the Migration and Settlement project at IIASA, Laxenburg, Austria in 1975-1978, as testified by various authors in this book, ignited the fire of a broad new field of study, which defined to a large extent his academic career. It developed from multiregional to multistate modeling, applicable to the study of changes in heterogeneous populations with interacting states, in domains such as households and families, health or working life. It reflected the societal changes in western countries that took place in the 1970s, with its strong emphasis on individualization and the increased diversity in life courses. These societal changes inspired an important theoretical development in demography, the Second Demographic Transition (Van de Kaa 1987, Lesthaeghe 2014), and more broadly, the life course paradigm shift in social science. Frans defined this paradigm shift in four dimensions: (a) from structure to process, (b) from macro to micro, (c) from analysis to synthesis, and (d) from certainty to uncertainty (Willekens 1999*a*).

Since Frans has worked on the frontier of almost all these dimensions, we will use this multidimensional life course paradigm shift in this introduction to shed light on Frans' academic career.

The macro-micro perspective has clearly had his attention since long. Populations change because people change (Willekens et al. 2017): they move from one country to another, they change from being single to living together, or from unemployed to employed, etc. The analysis of these processes of change (events or transitions, depending how they are defined) is at the heart of demography. This view defines individuals as agents able to make choices among a set of alternative options. These ideas, which go back to at least 1988 (Willekens 1988), culminated in a IUSSP conference in 2015 in Rostock titled "The science of choice. How to model the decision-making process?"; see Willekens et al. (2017). This also explains his continuous interest in the estimation of models of change. For instance, loglinear and logistic regression models (Bishop et al. 1975), which became popular in the 1970s and 1980s, were ideal instruments to estimate transitions between system states, e.g. Willekens (1983). They could also be given a micro interpretation of the probability that a certain person, conditional on his characteristics, would choose one alternative among a set of feasible alternatives, as defined by the context. These models are formulated in discrete time, where a move is defined as being in state A at time t_0 and in state B at time t_1. Subsequent developments in statistics and econometrics proposed models in continuous time, such as the Cox proportional hazards model (Cox 1972) or other time to event models, which have become very popular in demography as well. Frans considered these methodological developments as central to his view of demography, where methodology and life course theory come together. This view culminated in his book “Multistate analysis of life histories with R” (Willekens 2014).

From analysis to synthesis is another major thread in Frans work and closely linked to the life course paradigm. "The life course [..] may be viewed as an outcome of a combination of a large number of elementary processes. The challenge is to detect the elementary processes and the rules linking them" (Willekens 1999*a*, p. 29). Analysis is concerned with the elementary processes governing the sequential stages in the life course, such as leaving home, living together, divorce, etc., but the complex dynamics at the individual level, and at the population level as the aggregate of these complex processes can only be revealed by applying the system of rules linking them together. It is therefore no miracle that microsimulation and agent-based modeling in demography had his attention since long. The EU-funded MicMac project, initiated and coordinated by Frans, of which a concise overview and technical description was given in Willekens (2005), was the first step in this direction. This project not only deals with microsimulation but reconciles the traditional macro-level approach in modeling and projections with micro-level behavioural heterogeneity in the life course. In his view, micro-simulation is a form of sampling from an underlying probability distribution, centred around the expected or mean value in the population, which is input for the macro-simulation model. Agent-based models are yet another step up the complexity ladder, where individuals not only follow behavioural rules but are interacting with each other, thus generating new and unexpected system behaviour. Examples of such complex models are Klabunde & Willekens (2016) and Willekens et al. (2017).

The transition from macro-level point-estimated based projections to micro-level probability sampling approaches also implies a move from certainty to uncertainty, the fourth dimension of the life course paradigm change. Projections of the size and composition of populations are uncertain, because we have insufficient understanding of the behaviour of individual actors. Existing behavioural theories have limited validity in time and space, may be strongly conditional, or may be faced with the difficult extrapolation of non-demographic exogenous variables (NRC 2000). In one view, this uncertainty is inherent and not just the result of our ignorance. Individuals make unpredictable choices with regard to partnership and fertility, health behaviour, migration etc.. Indeed, generally valid laws do not exist in social sciences — they are all partial and local, e.g. Boudon (1986). In another view, which goes back at least two hundred years to Laplace, imperfect understanding of demographic behaviour is temporary and could be partly remedied eventually through good research into human behaviour, leading to improved insight and better theory (Willekens 1990). This will help formulate accurate predictions. Whichever of the two views is correct, as of today we are unable to explain demographic behaviour well enough. When explaining is problematic, predicting is even more difficult, which is why demographers increasingly include measures of uncertainty in their predictions.

If there is one demographic component in which Frans showed continuous interest throughout his career it is migration. Out of the 203 academic publications in the list of publications in the final chapter of this book, 42, or more than one-fifth, have "Migration" in the title. This interest has undoubtedly to do with his first steps into multistate modeling with Andrei Rogers, which involved multiregional populations, and migration as the event or transition governing regional population change. Many applications of the models and theories out of his pen focus on migration. But migration has a clear disadvantage for researchers, compared to fertility or mortality: there are significant issues of availability and measurement (see the chapter by Jakub Bijak in Kotowska & Chłoń-Domińczak (2018) for a more elaborate overview of his contributions on this topic). His work in this area focused on the estimation of incomplete data, using entropy and generalized linear models, e.g. Willekens (1977, 1980, 1999*b*). In Willekens (1994) he set out a research agenda to arrive at a harmonized database for international migration statistics. Current developments in this field, such as the Human Migration Database at the Max Planck Institute for Demographic Research in Rostock, reflect the recommendations in that article.

Demography changes because demographers change, and change primarily comes about due to new cohorts entering a population. Therefore, the diffusion of new ideas is most effective if taught to new cohorts of students. In this respect, Frans has certainly left his mark. From 1989 until 2010 he was full-time professor in demography (later called Population Studies) at the University of Groningen, after temporary appointments in Utrecht and Brussels.[1] He supervised 39 PhD students, most, but not all of them in Groningen. Many of them currently occupy senior positions in Academia. His demographic teaching career started at the Interuniversity Program of Demography (IPD) in Brussels in the early 1980s, organized by Ron Lesthaeghe. A few years later he set up the Postdoctoral Programme in Demography (PDOD), a collaborative training programme of Dutch universities for students in demography, that run from 1989 to 1995. This training programme foreshadowed already the structure of the curriculum of the European Doctoral School for Demography EDSD, of which Frans is one of the founding fathers. The EDSD, a joint collaborative and voluntary effort by 17 European demographic institutes, offers a full-time one-year PhD training programme for 15 to 20 students. It started in 2005, and celebrated its 20th anniversary in 2025.

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[1] From 1971 to 1973 he was Assistant professor in the department of agricultural economics at the National University of Zaire, Kinshasa. We do not know if he taught demography there already.

As director of NIDI, between 2003 and 2010 he supervised the transformation from a policy oriented to an academic research institute, which was required since the institute had come under the umbrella of the Royal Netherlands Academy of Sciences KNAW in 2003.

In sum, his theoretical and methodological contributions to demography reflect the significant societal changes of his time. His achievements have been fundamental, not only for demography, but to the wider community of researchers studying social change. Frans is a demographer's demographer, but his research interests and achievements have contributed to a large extent to the life course paradigm shift in demography and social sciences following the major societal changes of his time, fuelled by individualization. He provided a solid methodological and theoretical basis for this paradigm change, that opened up multiple avenues for other researchers focussing on migration, family or household dynamics, the labour market, health, or other domains in life – a conclusion that will wholeheartedly be supported by the authors of this volume. And, talking about academic recognition, a few other things should be mentioned as well. In 1998 he became a regular member of the Royal Netherlands Academy of Sciences. In 2014 he received the Award for Population Studies from the European Association for Population Studies, and in 2020 the Mindel C. Sheps Award from the Population Association of America. Moreover, for his outstanding societal contributions he was knighted Officer in the Order of Orange Nassau (a high Royal Decoration), in 2011. Therefore, although we labeled Frans as a demographer's demographer, his societal impact, through his influence on the demographic discipline and the research of others, has been immense.


Franciscum Willekens
MAREK ROCK
REKTOR
FRANS WILLEKENS
DOKTOR HONORIS CAUSA SGH

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2 Third time lucky

Joop de Beer

My first memories of Frans Willekens go back to the early 1980s, when NIDI had its office in the building of Statistics Netherlands in Voorburg. At that time, I worked at the department of Statistical Methods of Statistics Netherlands. Frans and I exchanged thoughts about methods to project fertility. I was developing a statistical time series model to project age specific fertility rates. At the same time Frans was working on an apc model to project fertility rates. I was planning to write a dissertation and asked Frans to be my supervisor, but that turned out to be impossible because Frans was not yet appointed as professor. I still wrote the dissertation but as I was not satisfied with the result, I decided not to defend it.

Somewhere in the 1990s when Frans had become professor in Groningen, he approached me with the question whether I would consider doing a new attempt to write a dissertation. I agreed and decided to write a dissertation about uncertainty of population forecasts. However, in the early 2000s at Statistics Netherlands I was involved in a management development program and did not have enough time to finish my dissertation.

In 2004 when Frans had become director of NIDI, he approached me again. He asked me to join the institute as head of the department of Projections and Models. I agreed. Part of the deal was that I would write a dissertation. In my first years at NIDI the size of the staff of the department grew because researchers on migration and health migration were added. The increase in the size of the staff implied that I had to spend more time on management tasks than expected and had insufficient time to work on my dissertation. When Helga de Valk returned to NIDI to lead the new Migration department, I had more time to work on my dissertation and my third attempt to write a dissertation with Frans as promotor succeeded finally. The topic was the importance of transparency in preparing and publishing population forecasts.

This short overview is far from complete. Frans played a very important role throughout my professional career. We shared our interest in quantitative models for making population projections. I admired how Frans managed to combine the roles as director of the institute and as researcher in the project.

During more than 40 years Frans has been a big inspiration for me. I am very thankful for that.

3 A statistical vision for European migration statistics: Frans Willekens and his influences

Jakub Bijak

Abstract

This contribution focuses on challenges of measuring international migration in Europe and possible ways of addressing them through statistical modelling. A brief outline of the history of problems with migration measurement, and key areas in which the data fall short of expectations, is followed by a discussion of possible solutions that have been suggested so far. For those, particular focus is on statistical models that rely both on the patterns observed in migration systems, such as in Europe, and on critical reflection on measurement itself, highlighting the pivotal role of Frans Willekens in shaping the vision of such modelling endeavours.

3.1 Introduction

International migration involves some important and potentially consequential political, societal, and demographic processes. Given the high salience of migration, it may seem surprising that the knowledge base regarding the basic dimension – the size of flows – is severely lacking. Data gaps, low quality of statistical information, and comparability issues are all well documented (e.g. Poulain et al. (2006)) and hamper efforts to understand migration processes and systems, not to mention designing better policy solutions. In this context, the quest to improve international migration statistics, which has been taking place for over a century, is all the more important.

The aim of this contribution is therefore descriptive: against the background of challenges to measuring migration in Europe, to outline the line of reasoning, pursued and inspired by Frans Willekens, that has led to developing statistical models for migration systems. Such models would use both statistical properties concerning structures and processes, influenced by engineering, as well as substantive knowledge of migration as a social phenomenon, originating from social sciences. The focus is on migration data for Europe, which despite relatively good availability, at least compared to some other parts of the world, are still far from perfect.

In the remainder of this chapter, the problems with measuring international migration in Europe, recognised since the late 19th century, are outlined first. These problems provide the backdrop for the quest for solutions, visible both in one of the important threads of Frans Willekens' work, and more broadly in the logical sequence of research endeavours, cumulating in the development of a versatile statistical framework for estimating migration. Concluding remarks focus on the promising directions of further development of estimation methods, and on the potential for using them to construct future-oriented migration scenarios.

3.2 The problem: measuring migration in Europe

The history of recognising challenges with measuring migration dates back at least to the late 19th century, when the matter was discussed at the congress of the International Statistical Institute (ISI) in Vienna in 1891 (United Nations Department of Social Affairs 1949). In the ensuing century, international organisations, such as the League of Nations and later the United Nations, the International Labour Office, International Organization for Migration (IOM), the Organisation for Economic Co-operation and Development (OECD), Eurostat, or the ISI, have led efforts to streamline and harmonise efforts to produce robust statistics on international migration. These efforts have led to developing a set of recommendations, first in 1976, with the current version adopted at the end of the 20th century (United Nations Statistics Division 1998), and due for an update very soon (United Nations

2025). A fascinating story of early efforts to harmonise migration statistics across the world is offered by Kraly & Gnanasekaran (1987). Still, despite all the declarations, expressions of intent, and formal recommendations, problems with the quality, availability and international comparability of migration data stubbornly persist.

There are many reasons for this state of affairs, but the main ones result from different national systems for collecting migration data, and from imperfect tools used for that purpose. In many cases, the data are collected for different reasons rather than for measuring migration: these may be tax records, labour force surveys or mobile phone locators. The definitions in use can also vary depending on the country. Especially before 2009, European migration statistics were a mix of concepts and definitions, ranging from migrants being registered upon arrival, through stays of different durations (three months, six months, or a year), to intentions of permanent stay (Poulain et al. 2006). Statistics based on population registers exhibit known problems with undercounting, e.g. caused by unregistered migration, while for surveys, there are perennial questions about the validity of the sampling frames. Alternative sources, such as mobile phone or social media data, on their own do not correspond to established migration definitions (e.g. Rampazzo et al. (2021)).

These challenges have been met with many efforts to harmonise the statistics and develop more reliable estimates, sometimes backed up by legislation. In the European Union, the current legal basis is the Regulation 862/2007 of the European Parliament and of the Council of 11 July 2007 on Community statistics on migration and international protection (European Council 2007). This legislation requires statistics to be harmonised to a common definition, based on the 12-month duration-of-stay criterion, as stipulated in the United Nations Statistics Division (1998) recommendations. Importantly for the efforts to improve migration statistics, Regulation 862/2007 remains open for innovation: Article 9 allows using "other appropriate sources" for measuring migration, and states that "[a]s part of the statistics process, scientifically based and well documented statistical estimation methods may be used", as long as their quality is formally assured.

Despite these efforts, the current situation is such that the high political salience of migration is met with data imperfections or outright unavailability. Harmonisation efforts across Europe have improved data comparability, but at the expense of reduced availability – some EU countries do not supply harmonised migration data (Smith et al. 2024). Even within individual countries, there are many sources of migration data, which remain unused in the official estimations, such as surveys or alternative administrative sources, not to mention alternative digital data. The provisions of the Regulation 862/2007 regarding the use of statistical models remain largely underutilised. At the same time, recent advances in the EU's closest neighbourhood, such as the admin-based migration estimates developed in the United Kingdom (Office for National Statistics 2024) offer substantial promise of changing the methodological status quo. Any improvements in that area rely on robust statistical models, which have been developed since 1970s, as outlined in the next section.

3.3 A solution: statistical models for migration systems

Efforts to harmonise migration statistics through legislation, regulation and other administrative means, such as data exchanges, was one of the ways in which the challenges of migration data were being addressed. The other way was through the scientific advancements in the area of migration modelling and methodological developments underpinning them – in particular, paving the way for estimating migration flows based on incomplete information. The work of Frans Willekens, since the first reports in this area in the 1970s (Willekens 1977, Willekens et al. 1979), has created solid foundations for utilising such methods to infer the full matrices of flows by origin and destination based on aggregate (marginal) data available at the country level. This approach treated migration flows as elements of multi-country systems, with this systemic view allowing relying on tools and concepts such as entropy (Willekens 1977, 1999). It also used regularities across time, space and age to recover migration patterns in several different dimensions (Rogers et al. 2002).

A crucial methodological milestone was an article on "Monitoring international migration flows in Europe. Towards a statistical data base combining data from different sources" (Willekens 1994), outlining a plan for the research agenda in this area. This paper has presaged many developments of methods and approaches over the ensuing three decades, from the need to integrate multiple sources, to the use of Bayesian statistics to describe the estimation errors. At the symposium held in March 2016 in Rostock to mark Frans Willekens's retirement from the Max Planck Institute for Demographic Research (MPIDR), this paper was cited several times by different speakers as a crucial inspiration, being published well ahead of its time.

Indeed, only in the first decade of the 21st century, the ideas and research agenda laid out in the "Monitoring…" paper (Willekens 1994) began materialising in the form of tangible research projects, several of which included the Netherlands Interdisciplinary Demographic Institute (NIDI), led by Frans Willekens between 2003 and 2010, either as a lead institution or one of key partners. These projects included *Towards Harmonised European Statistics on International Migration* (THESIM), led by the Catholic University of Louvain and funded by European Union's 6th Framework Programme. THESIM focused on collecting metadata and studying the reasons behind discrepancies of migration statistics in Europe (Poulain et al. 2006).

Based on the THESIM results, Eurostat commissioned a consortium led by NIDI to carry out a proof-of-concept analysis for model-based estimation, in the project MIMOSA (MIgration MOdelling for Statistical Analyses). MIMOSA delivered complete sets of flow and stock estimates (De Beer et al. 2010, Bijak & Kupiszewska 2008), which, albeit still more mechanistic rather than statistical, offered crucial learning and inspiration paved the way for further developments. Frans Willekens played a pivotal role in these efforts: a discussion on errors of estimation at one of the MIMOSA project meetings proved critical in making a decisive step in that direction.

In addition, the research agenda for estimating migration was further sharpened through the work on regularities in migration patterns (e.g. Rogers et al. (2002)), culminating with the publication of a book, edited with James Raymer, summarising the state of the art in this area in the early 21st century (Raymer & Willekens 2008). The resulting research project IMEM (Integrated Modelling of European Migration, (Raymer et al. 2013), led by the University of Southampton, and involving NIDI alongside other partners, and funded by the New Opportunities for Research Funding Agency Cooperation in Europe (NORFACE) cross-funder partnership, was an important milestone on this line of research, and a methodological breakthrough.

In IMEM, for the first time, a fully coherent statistical framework for estimating migration was proposed that integrated different sources of data from the sending and receiving countries, information from the relevant metadata, and expert opinion (Wiśniowski et al. 2013). The estimates were produced by using a Bayesian hierarchical model, providing a fully probabilistic description of the estimates of migration flows within a system of 31 European countries (as well as from and to the rest of the world) in 2002–08, by origin and destination (Raymer et al. 2013), as well as age and sex (Wiśniowski et al. 2016). In parallel, theoretical work on translating migration measures between different durations of stay was advanced by Nowok & Willekens (2011).

The IMEM approach has proven to be very versatile, opening up research possibilities for integrating a range of different data sources, including traditional survey-based measures (Disney 2015, Wiśniowski 2017) as well as alternatives, such as the digital data (Rampazzo et al. 2021). The IMEM model itself was also later updated by Smith et al. (2024), with estimates extended to the period 2009–20, following the implementation of Regulation 862/2007. The model applications and adaptations were also extended beyond Europe, with examples including Asia-Pacific (Raymer et al. 2022) and South America (Aparicio Castro et al. 2024).

Parallel development efforts for global migration estimates, typically using the sizes of migrant populations (stocks) to estimate the migration flows, also share important similarities with the IMEM approach: statistical treatment, probabilistic outcomes and systemic view of migration (Abel & Sander 2014, Abel & Cohen 2019, Azose & Raftery 2019). Some of these models explicitly use IMEM estimates as benchmarks for Europe. Building on this, the MPIDR is currently working on a prototype of a Human Migration Database, for which IMEM and IMEM-inspired models constitute a cornerstone (Danko 2024). Of course, as even the best models produce estimates with relatively large uncertainty, much of European migration patterns remain to some extent uncertain. To that end, there are still gaps that need filling, either through more and better data, better understanding of processes, or both. Either way, the work started by Frans Willekens in the 1970s continues to inspire current efforts in this area nearly half a century later.

3.4 The future of measurement and measurement of the future

What might the future hold for the measurement of international migration? Already now, there are many new exciting methodological avenues that will no doubt be explored more fully, producing timelier estimates and ‘nowcasts’ by using non-traditional data sources. Mobile phone locators or social media are already used in innovative ways, in additional to information from population censuses, registers or surveys (see e.g. Wesolowski et al. (2013), Garcia et al. (2015), Lai et al. (2019), Rampazzo et al. (2021)). Still, true to the principles discussed above, the proposed methods and approaches require statistical and analytical rigour, in order to enable efficient borrowing strength between different data sources, and to help better understand data and patterns, by integrating different sources together in a purposefully designed way.

Moreover, the impact of reliable migration estimates, with their own uncertainty assessment, extends well beyond measurement of the situation now or in the past. Reliable, if uncertain, estimates are key foundations of any efforts on migration scenarios, forecasts, and broader preparedness efforts, which are in high political demand (European Commission 2020), but require solid evidence base to support them. To that end, the past estimates, if described with probability distributions, can directly serve as a basis for contingency planning taking into account the frequency and magnitude of rare events shaping migration processes (Bijak 2024).

In addition to his contributions to the methodology of estimating flows in migration systems, Frans Willekens has also left a lasting imprint on future-oriented studies of migration, with postulates for building better predictive models (Willekens et al. 2016), notably involving causal mechanisms (Willekens 2018), such as those based on agent-based simulations (Klabunde & Willekens 2016, Willekens et al. 2017). Still, given the inherent uncertainty involved in complex migration processes, these are just first steps on a long, but promising intellectual journey, which is likely to generate important research over decades to come.

Afterword

My earliest direct encounters with Frans took place in the mid-2000s: at meetings of a research project MIMOSA (Migration Modeling for Statistical Analysis) in The Hague, Charleroi and Warsaw; at migration modelling workshops organized by James Raymer in Southampton; and at various Eurostat gatherings across Europe. I then discovered that, (a) Frans's reputation for razor-sharp intellect, if anything, is understated, (b) we share many interests – migration – but also philosophical views on demography, statistics and modelling, and (c), being a direct consequence of (a) and (b), as an aspiring social scientist, I have A LOT to learn. This learning involved for example, in the 2010s, meetings on agent-based modelling in Rostock and Leuven (and conferences in Louvain-la-Neuve, for symmetry), collaboration on the IUSSP Panel on Microsimulations and Agent-Based Models in Demography, and co-editing a special issue of Population Studies.

I was all the more honoured to be asked to act as a reviewer of Frans's honorary doctorate at my alma mater – Warsaw School in Economics – in 2018. This gave me an excuse to look at Frans's early scientific writings, including some of the 1976 reports and papers, for which this year (2026) marks a golden jubilee. Later, we had an opportunity to collaborate directly, when Frans joined the team working on a European project QuantMig (Quantifying Migration Scenarios for Better Policy), which I led, to pursue our common interests in simulation-based models. Throughout the years, Frans was always generous with scientific advice and career mentoring, but also with fascinating research and life stories, which he shared, often with Maria, on various social occasions.

Warmest congratulations, Frans, on a wonderful career, and thank you.

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4 Herinneringen aan Frans: Willekens en Wiskunde

Luc Bonneux

Zowat alle vakken claimen dat ze het belangrijkste wetenschapsvak op aarde zijn, met mogelijk de bescheiden demografie als uitzondering. Dat vind ik dat dan weer het belangrijkste vak op aarde, na geneeskunde. Als je ziek bent, heb je liever een arts aan je bed dan een demograaf. Maar als onderdeel van de medische wetenschap is demografie onvervangbaar. Zij het graag genegeerd. Niets is meedogenlozer dan de sterftetafel. Terwijl epidemiologie steeds meer sterfte blijft voorkomen, als je epidemiologie gelooft, roeit de sterftetafel ongenadig iedereen uit. Altijd, steeds weer. Niemand overleeft. De verhalen over Elvis Presley en Jesus Christus zijn sterk overdreven. Er wordt enkel wat uitgesteld. Je mag de allerlaatste gezondheidsrages trouw opvolgen, je leven vullen met meditatie en gezondheidssapjes: de sterftetafel haalt je in.

Ik kwam bij de demografie en Frans terecht langs een achterpoortje. De afdeling Maatschappelijke Gezondheidszorg van de Erasmus Universiteit Rotterdam wilde de volksgezondheid vorm geven in Modellen, liefst met hoofdletter, als ondersteuning voor kosteneffectiviteit in de gezondheidseconomie. Dat was een puinhoop, de gezondheidseconomie nog meer dan onze plannen. Het ging zo ver dat de New England Journal of Medicine, het meest prestigieuze medisch wetenschappelijke blad, officieel verklaarde geen gezondheideconomische modellen meer te publiceren omdat de keuze van de parameters arbitrair en oncontroleerbaar was. Het eindresultaat van deze modellen kon gemakkelijk worden afgeleid uit de financieringsbron. De producenten ontdekten in hun modellen dat het middel best goedkoop was, ja: zelfs een koopje. De betalers ontdekten dat het middel te duur was, ja: zelfs de kosten niet waard. Het moet wel gezegd: de economie in het algemeen en de gezondheidseconomie in het bijzonder hebben sindsdien een hele weg afgelegd. Onder andere door leentjebuur te gaan spelen bij de evidence based medicine, met de opbouw van betrouwbare kennis door experimenteel onderzoek (de gerandomiseerde trial) en de samenvattingen ervan (de meta-analyse).

Eén van die wegbereiders was Frans Willekens. De wiskundige demografie, een soliede discipline ontstaan in de 19^{de} eeuw, had de sterftetafel verder uitgebreid tot de multistate stertetafel (of beter overlevingstafel). Wat een ontdekking! Je moet geen parameters uit je dikke duim zuigen! Je kan ze schatten op basis van gegevens! Feiten die je kan meten, tenminste in longitudinale studies die bevolkingen opvolgen! Al zat dat niet glad, je werd er snel nederig van: het aantal te schatten parameters vermenigvuldigt sneller dan konijnen per te schatten toestand. Waar de sterftetafel enkel rekening houdt met de overgang van levend naar dood, heeft een enkele extra toestand er al direct drie meer nodig: een overgang van gezond naar ziek, van ziek naar dood en terug van ziek naar gezond. Eén van de vele problemen is dat je dan veroordeeld bent tot prospectieve studies die grote aantallen mensen opvolgen, waarbij enkel associatie, nooit causatie valt aan te tonen. Zo vonden Mieke Reuser, Frans en ik in de Amerikaanse Health and Retirement Study dat het grootste verlies voor de volksgezondheid in de USA werd veroorzaakt door te weinig alcohol drinken. Zelfs ik was onvoldoende politiek incorrect om dat te publiceren. Terwijl er meer dan honderd prospectieve studies hetzelfde tonen (matig alcoholgebruik is geassocieerd met langer leven) wordt er tegenwoordig gekozen voor studies die net hetzelfde tonen, maar na langdurige marteling van de data met slecht begrepen methoden (Mendeliaanse randomisatie) het tegenovergestelde besluiten: matig alcoholgebruik is ongezond. Waar het voor iedereen blijkbaar evident is dat we alcohol drinken louter voor onze gezondheid. Een andere stresserende bevinding was dat Afro-Amerikanen korter leven zonder dementie en langer met. Op basis van de menselijke evolutie en de historische vermenging van menselijke genen geloof ik nooit dat dat “nature” is (de populaire racistische hypothese), maar “nurture”: slecht onderwijs en een kansarme jeugd. Maar ook dat blijft speculatie. Het toont de zwakheid van beschrijvende studies: oorzakelijkheid, en dus de mogelijkheid tot interventie, blijft beperkt.

Ik bleef een erg dwarse epidemioloog tussen demografen. De vijvertjes van het multidisciplinaire medisch wetenschappelijke onderzoek werden kleiner. Ik vond mijn Vak, het enige echte oudste vak ter wereld, geneeskunde (met meer nadruk op verzorgen en verlichten dan genezen), steeds aantrekkelijker en nam de vlucht. Feitelijk was dat een verspilling van onze gedeelde mogelijkheden. In de ouderengeneeskunde hervond ik het nut van vervlechting van epidemiologie, demografie en volksgezondheid in multistate lifetables. Op het einde van de rit vinden mensen het zelden erg om te sterven. Zeker Zeeuwen, mijn laatste werkplek, zijn het nuchterste volk op Aarde. Wat ze veel erger vinden dan een onvermijdelijk sterven is een vermijdbaar afhankelijk worden, hulp vragen voor alles en nog wat na een vol leven. Of ergste van al: inruilen van je heldere brein voor dementie en seniliteit. Niet het onvermijdelijke sterven, maar vermijdbare beperkingen bepalen wat we ons wensen voor een waardig levenseinde. En als we ze niet kunnen vermijden, dan toch bekorten. Dit weer oppakken en uitwerken zal niet meer voor mij zijn of Frans. Maar wiskunde is eeuwig, en met wiskunde de wiskundige demografie, dat bescheiden meidje voor veel werk. Misschien maak ik het nog mee, nieuwe artikelen over effectieve ouderenzorg met multistate life tables, waar ik in de methoden Frans Willekens weer vind.

Daar drink ik op. Op Frans' gezondheid!

5 Belgians and Dutch across the border

Peter Ekamper and Frans van Poppel

Abstract

The share of citizens of the European Union living in a European country other than that of their citizenship has increased over the last two decades. This chapter examines the situation with respect to Belgians and Dutch living elsewhere in Europe by using Eurostat data on their countries and regions of residence as well as demographic characteristics. The proportions of Belgians and Dutch living elsewhere in Europe are relatively low compared to other nationalities. Destination countries and demographic characteristics of Belgians and Dutch living elsewhere are quite similar.

5.1 Introduction

Over the last two decades the proportion of citizens of the European Union (EU) living in an EU country other than that of their own citizenship has increased (Arnholtz & Leschke 2023). Since the EU enlargement rounds of 2004 and 2007 mobility from the new EU member states in the east has grown substantially. After the Great Recession in 2009, mobility from the EU member states in the south also started showing a more upward trend. Mobility from the EU member states in the north and west is much lower, but has also been slightly increasing over time. How do the Low Countries, Belgium and the Netherlands, fit within these general trends? To what extent do Belgian and Dutch citizens live in European countries other than that of their citizenship? Which countries do they prefer and how do they relate to each other in this respect? Is there more mobility between the two neighbouring countries than mobility with other countries? And do demographic characteristics of Belgian and Dutch living in another EU country differ from each other or between destination countries?

According to Eurostat statistics around 330 thousand Belgians and around 600 thousand Dutch, i.e. people with Belgian or Dutch nationality, live outside their country of citizenship and elsewhere in Europe (Eurostat 2024). These are respectively 3.1 per cent of all the 10 million Belgian citizens and 3.5 per cent of all the 17 million Dutch citizens living in Europe. This puts the Belgians and the Dutch below the average for the European Union (EU): 4.7 per cent of all EU citizens do not live in their own country of citizenship, but in another country in Europe. Especially relatively large percentages of Romanians (16.5 per cent), Croats (14.1 per cent), Lithuanians (14.0 per cent), Bulgarians (13.9 per cent), and Portuguese (13.2 per cent) do not live in their own country. Romanians also form the largest group in absolute numbers: over 3.7 million Romanians live in another European country (of which a million in Italy), followed by Poles (2.6 million) and Italians (2.2 million). On the other hand, relatively low percentages of French (1.5 per cent), Germans (1.8 per cent), and Scandinavians (around 2 per cent) do not live in their own country of citizenship. Over the last two decades, both the numbers and percentages of Belgians and Dutch abroad have substantially increased (for both nationalities by roughly 80 per cent). In 2001 around 180 thousand Belgians (1.9 per cent) and around 340 thousand Dutch (2.1 per cent) lived elsewhere in Europe.

5.2 Belgians and Dutch across Europe

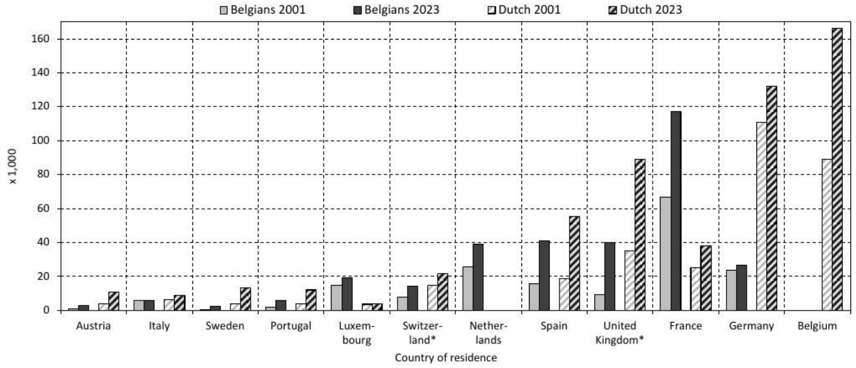
Belgians and Dutch living outside their country of citizenship mainly live in the neighbouring countries. Almost 62 per cent of the Belgians living elsewhere in Europe live in the four neighbouring countries of Belgium: 36 per cent in France, another 12 per cent in the Netherlands, 8 per cent in Germany, and 6 per cent in Luxembourg. Almost 50 per cent of the Dutch living elsewhere in Europe live in the two neighbouring countries of the Netherlands: 28 per cent in Belgium and

22 per cent in Germany. This makes Belgium the top destination for the Dutch and France the top destination for the Belgians (see Figure 5.1). However, over time the shares of all the neighbouring countries have declined for both countries. In 2001 still 72 per cent of the Belgians living elsewhere in Europe lived in one of the neighbouring countries, whereas 59 per cent of the Dutch did. Countries that have become more popular over time with the Belgians and the Dutch are the United Kingdom, Spain and (to a lesser extent) Portugal. For the Dutch the United Kingdom has been the third important destination over time. The share of Dutch abroad living in the United Kingdom increased from 10 to 15 per cent since 2001. For Belgians the share of those living in the United Kingdom increased even more over two decades: from 5 to 12 per cent. Spain and Portugal have become more popular destinations too. The number of Belgians living in Spain is nowadays actually somewhat larger than the number of Belgians living in the Netherlands, making Spain the second largest destination for Belgians. It is clear from Figure 5.1 that Belgium is a much more important destination for the Dutch than the Netherlands is for the Belgians, which will undoubtedly be affected by the distinctive regional difference between the Dutch-speaking Flemish in the north and the French-speaking Walloon in the south of Belgium. The Dutch community in Belgium is also relatively large from a Belgian perspective: Dutch people make up 10 per cent of all Belgian residents with a foreign nationality. In other countries, that percentage is much lower. In Germany for instance, only 1 per cent of all non-Germans have Dutch nationality. Belgians make up only 2.7 per cent of all residents of the Netherlands with a foreign nationality, but 6 per cent of all residents of Luxembourg with a foreign nationality.

5.3 Belgians in the Netherlands and Dutch in Belgium

Although Belgium is a much more important destination for the Dutch than the Netherlands is for the Belgians, with 166 thousand Dutch living in Belgium and 39 thousand Belgians living in the Netherlands, the regional distributions within the countries show some similarities. Figure 5.2 depicts the regional distributions of Belgians in the Netherlands and Dutch in Belgium at the NUTS-3 regional level (= 40 COROP regions in the Netherlands and 44 arrondissements in Belgium). Clearly the Dutch in Belgium are concentrated near the Belgian-Dutch border.

Figure 5.1: Number of Belgians and Dutch living in Europe outside their country of citizenship, by country of residence in 2001 and 2023.



Notes: Countries of residence sorted ascending by number of Belgians and Dutch combined in 2023. Most recent figures of Switzerland and United Kingdom refer to 2021. Source: Eurostat and ONS (UK).

Most of them, 39 thousand, live in the region of Antwerp, including the city of Antwerp, the second largest city of Belgium. Both in the regions of Turnhout (east of Antwerp) and Maaseik (east of Turnhout) live 25 thousand Dutch. In the region of Tongeren (south of Maaseik) live another 17 thousand Dutch. The concentration of Dutch is the strongest in the latter two regions: the percentage of Dutch is 6 times higher in Tongeren and 7 times higher in Maaseik than according to the Belgian national average. The four regions mentioned cover 64 per cent of all the Dutch living in Belgium. Very few Dutch live in the French-speaking Walloon region, especially in the Belgian-French border regions.

Belgians in the Netherlands are also strongly concentrated in the Belgian-Dutch border regions. Most Belgians in the border region, 8,400, live in the region of Zeeland Flanders (Zeeuws-Vlaanderen), an area west of Antwerp, due to the broad water of the Western Scheldt estuary easier accessible from Belgium than from the Netherlands. Another 4,100 Belgians live in the region of West-North-Brabant (north of Antwerp) and almost 3,200 Belgians live in the region of South-Limburg, the most southern region of the Netherlands in the east. All

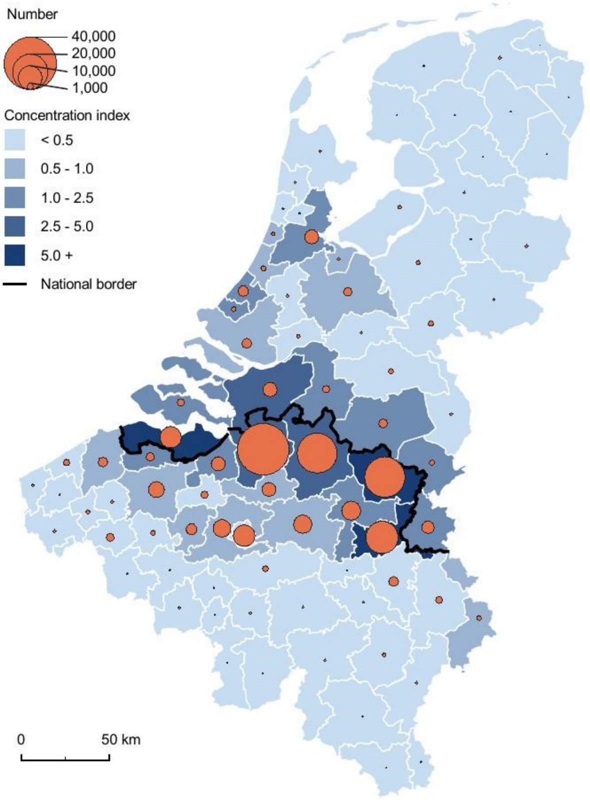
Dutch regions bordering to Belgium cover together 50 per cent of all the Belgians living in the Netherlands. Another 28 per cent of the Belgians live in the urbanized west of the Netherlands, like in Amsterdam, Rotterdam, and The Hague. Very few Belgians live in the north and east of the Netherlands. The concentration of Belgians in the Netherlands is by far the strongest in Zeeland Flanders (36 times higher than according to the Dutch national average).

5.4 Demographic characteristics

Although the number of men and women is more or less equally divided among all Belgians living elsewhere in Europe (49.7 per cent men versus 50.3 per cent women), there are large differences between countries. The share of women among the Belgians is particularly low in Finland, the Baltic countries, the Czech Republic, Slovakia, Slovenia, Bulgaria and Romania (ranging from less than a third to a tenth). Only in France, Italy, the Netherlands and the United Kingdom the share of Belgian women is higher than the share of Belgian men (52 to 56 per cent). There are also large differences between countries in terms of age distribution of the Belgians. The share of older Belgian people (aged 65+) is relatively high in Hungary, Italy, Portugal and Spain (22 to 34 per cent), but low in the Baltic countries, Scandinavia, and Ireland (less than 10 per cent). Especially in Italy and Spain the relatively high percentages of Belgians aged 65+ go together with relatively low percentages of young Belgians: only around 25 per cent of the Belgians in these countries is below the age of 40. In Luxembourg, Austria, Switzerland, Norway and Sweden the share of younger children (aged below 15) among the Belgians is relatively high (12 to 16 per cent), indicating an above average presence of families with young(er) children.

The demographic characteristics of the Dutch living elsewhere in Europe are quite similar to those of the Belgians. Although overall the share of men (51.8 per cent) among the Dutch is slightly higher than the share of women (48.2 per cent), the share of Dutch women is higher than that of men in France, Italy and the United Kingdom (51 to 55 per cent). As is the case for Belgians, the share of women among the Dutch is also particularly low in Finland, the Baltic countries, the Czech Republic, Slovakia, Slovenia, Bulgaria and Romania (14 to 27 per cent). Also, the differences between countries in terms of age distribution of the Dutch

Figure 5.2: Number and concentration index of Belgians living in the Netherlands and Dutch living in Belgium, by NUTS3 regions in 2023.



Notes: Concentration index = regional share of foreigners in population / national share of foreigners in population (calculated for each country separately). Source: Eurostat and Statbel.

are in line with those of the Belgians. The share of older Dutch people (aged 65+) is, like for Belgians, relatively high in Hungary, Italy, Portugal and Spain (24 per cent or more), but also in Germany (27 per cent). The share of Dutch elderly is also relatively low in the Baltic countries, Scandinavia, and Ireland (5 to 13 per cent). The share of younger Dutch children is relatively high in the same countries as is the case for Belgians. In addition to that, the share of younger children is highest for the Dutch residing in Belgium (almost 17 per cent), whereas the share of younger children is much lower among Belgians in the Netherlands (8 per cent). On the other hand, the share of Belgians in the Netherlands aged 15 to 40 is 38 per cent compared to 31 per cent for Dutch in Belgium; there are hardly any differences for the older age groups. Although the age distributions of Belgians and Dutch in France and the United Kingdom are not available from Eurostat, recent Dutch emigration data from Statistics Netherlands (2021-2023) show the Dutch emigrating to France are relatively old (compared to those emigrating to Spain) and the Dutch emigrating to the United Kingdom are relatively young (40 per cent in their twenties, 6 per cent aged 50+).

5.5 Demographic characteristics within the Low Countries

To what extent do demographic characteristics of the Belgians and Dutch living abroad within the Low Countries themselves differ at the regional level? Focusing on the most important areas of residence (see Figure 5.2), we do see differences between the Belgians living in the Netherlands near to the Belgian-Dutch border and those living in the urbanized west of the country. In particular in the border regions more to the east, the share of elderly Belgians (aged 65+) is relatively high (21 to 25 per cent). The picture of the most southern region of the Netherlands, South-Limburg, fits within that pattern with more than 18 per cent elderly Belgians, but is also characterized by almost 30 per cent Belgians in their twenties, most likely attracted by the international University of Maastricht. The border regions in the west, Zeeland Flanders and West-North-Brabant, accommodating most Belgians in the Netherlands, show more average percentages of elderly Belgians (around 15 per cent) combined with relatively high percentages of children below the age of 15 (around 12 per cent). This latter group is also overrepresented in the region of The Hague (14 per cent Belgian children below 15), a region that is home to many international organizations and attracts many expats. The regions of Amsterdam and Rotterdam have much younger age profiles, both showing relatively high shares of Belgians in their twenties (30 to 35 per cent). The share of elderly Belgians (65+) in the region of Amsterdam is rather low, with about 6 per cent. There are hardly any differences with respect to the share of men/women except for the region of Delft with 66 per cent Belgian men, primarily in their twenties, most likely attracted by the Delft Technical University.

The demographic profiles of Dutch living in the Belgian regions that accommodate the largest numbers of Dutch are quite similar. The regions of Turnhout, Maaseik, and Tongeren show slightly above average percentages of elderly (17 to 18 per cent aged 65+), around average percentages of the youngest age group (15 to 18 per cent aged below 15), and around average percentages of Dutch in their twenties (16 to 17 per cent). The region of Antwerp somewhat differs from the regions of Turnhout, Maaseik, and Tongeren with a lower share aged 65+ (13 per cent) and higher share aged below 15 (21 per cent). The percentages of Dutch aged 40+ and 65+ are in general much higher in the French-speaking Walloon part of Belgium, however the total number of Dutch in this part of the country is quite low.

5.6 Conclusions

The Belgians and Dutch may not be European front runners in trying their luck in another European country, but compared to their neighbours and Scandinavians, the Belgians and Dutch live abroad relatively more often. In the past two decades, the number of Belgian and Dutch people living elsewhere in Europe has also grown considerably. Belgium appears to be a much more important destination for the Dutch than the Netherlands is for the Belgians. The demographic characteristics of the Belgians and the Dutch living in EU countries other than that of their citizenship are pretty similar. The share of Belgian and Dutch women is higher than that of men in France, Italy and the United Kingdom. The share of Belgian and Dutch women is also particularly low in Finland, the Baltic countries, the Czech Republic, Slovakia, Slovenia, Bulgaria and Romania. The share of Belgian and Dutch people aged 65+ is relatively high in Hungary, Italy, Portugal and Spain, but relatively low in the Baltic countries, Scandinavia, and Ireland. The share of Belgian and Dutch children aged below 15 is relatively high in Austria, Switzerland, Norway and Sweden, indicating an above average presence of Belgian and Dutch families with young(er) children in these countries.

Afterword

Our first contact with Frans Willekens was in 1978 at the annual Chair Quetelet meeting in Louvain, dedicated to the Approche systémique en sciences de la population. At that time Frans had already a long migration history with positions in the Democratic Republic of the Congo, in the USA (Evanston Illinois), and in Austria (Laxenburg) as researcher at the International Institute for Applied Systems Analysis. Frans started to work at the then Netherlands Interuniversity Demographic Institute in The Hague, Netherlands in May 1980. He settled in a suburb of The Hague, a region where relatively many Belgians lived. Later on he became a professor at Groningen University, in the extreme north of the Netherlands, where he lived for several years, quite an exceptional place for Belgian citizens. Later on he returned to the region of The Hague. As varied as his geographic life course was his interest in demography. We worked together with Frans on census data on the variation in age at marriage after WWII, on multiregional population projections and on the construction of a database with mortality by age, sex and birth cohort over the period 1850-2000, that formed the basis for the Dutch part of the Human Mortality Database and various studies on long-term mortality trends.

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6 Wetenschap, gezelligheid en humor

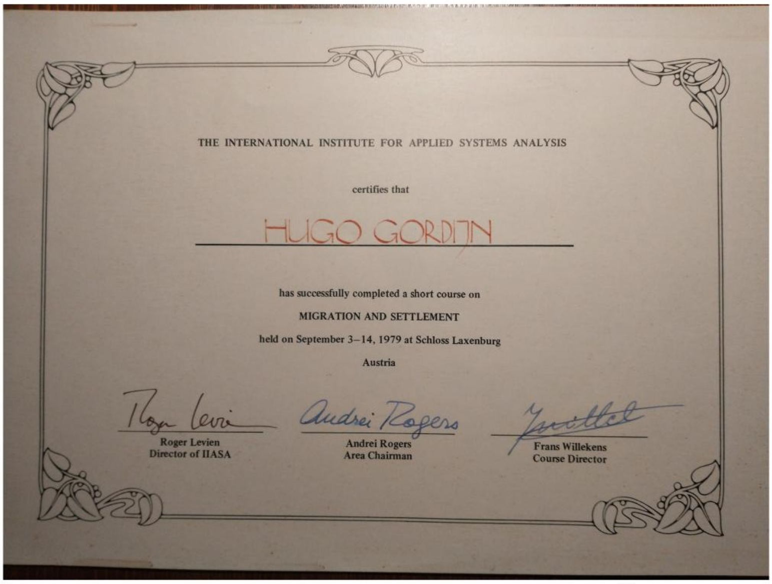
Hugo Gordijn

Frans gaf in 1979 een cursus Migration and Settlement aan het IIASA in Schloss Laxenburg. Ik was door IIASA-NL uitverkoren om de cursus te volgen. De bedoeling was de techniek van de Multistate Demography onder de knie te krijgen. Zo werd later in Europa vergelijkbaar onderzoek op migratiegebied uitgevoerd. In Nederland door Frans en Paul Drewe.

Frans was tijdens zijn lesuren über-serieus. Ik dacht in het begin dat hij wel 50 was, zo serieus kwam hij over. Ik was toen 29 jaar en had lang haar. Frans had hetzelfde kapsel dat hij zijn hele leven heeft gehad. Hij bleek pas 33. Mijn beeld werd snel bijgesteld. Na de lessen was het tijd voor uitstapjes met de cursisten. Frans bracht ons naar fraaie Heurigen in dorpjes als Guntramsburg en Munchendorf. Heurigen zijn traditionele Oostenrijkse wijncafé's, gelegen in schilderachtige wijngaarden. Daar werd het heel gezellig met Frans. Niet alleen keten, maar ook wist hij te vertellen over de klassenstrijd in Vlaanderen en de armoede vroeger in de Kempen.

Afgelopen april kwamen Erna en ik Frans en Mieke toevallig tegen bij de koffiemachine van het Martini-hotel in Groningen. Dat werd direct een heel gezellig ontbijt en we kregen weer een staaltje van zijn humoristische gevatheid. Ik zat een beetje op te scheppen over de door mij gevolgde opleiding tot Wilgenknotter. Dat ik gecertificeerd ben voor het omzagen van bomen tot een omtrek van een meter. Nou Hugo, zei Frans, ik heb niet zo'n diploma. Ik doe dat gewoon !

Nou Frans, ik hoop je nog vaak te kunnen ontmoeten !



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7 A new look at indirect estimation techniques

Ralph Hakkert

Abstract

In their essence, indirect estimation methods fit demographic models to observable data. However, rather than being implemented through standard statistical fitting methods, they have generally made use of standard tabulations, simplifying assumptions, shortcuts, and numerical workarounds, to guarantee easy computability, which was imperative at the time when they were designed. Now that the need for such resources has diminished, due to the increased accessibility of powerful computer software, it would be beneficial to return to the original models, to see how they can be estimated more transparently, extended to more complex situations, and combined to obtain integrated sets of estimators.

In the early 1990s, Frans Willekens (mostly) and I (in what I hope can be considered a supporting role) headed an IUSSP Working Group on Demographic Software, to make an inventory of the demographic software existing at the time and to evaluate the quality of its algorithms, effectiveness and user-friendliness. At the time we (or at least I) had some expectations about the future of this area that in hindsight may seem rather naïve. On the one hand, I expected to see the development of some sort of unified demographic analysis program along the lines of SPSS, SAS or BMDP - the dominant statistical packages at that time - which would bring all the methods of the standard demographic repertory under one roof. On the other hand, I expected that the standardization resulting from such a development would stimulate a revision, integration and extension of the existing methods, particularly indirect estimation methods, much like what had happened with the development of the Generalized Linear Models of statistics in the early 1970s (Nelder & Wedderburn 1972). However, the integration and generalization of methods did not materialize and the development unified programs for analysis only to a rather limited extent.

In hindsight, one might point at several factors to explain this:

- While statistical packages cater to the need to process large amounts of data in a standardized fashion, most demographic methods operate on data that have already been condensed, thus making them much more amenable to manual analysis. Those applications that do involve the manipulation of large amounts of data, such as data editing (CSPro) or, to a lesser extent, population projections, have typically been the ones where software development has been most successful.

- Most statistical methods are based on a unified mathematical theory of the behaviour of random variables. Some of the methods used in demography also employ fundamental mathematical properties, such as the ergodicity underlying stable population theory, but many are based on observed empirical regularities that are periodically revised, such as model life tables.

- The application of demographic estimation methods often depends on ad hoc judgment calls which are difficult to implement in automated software procedures. This is why Moultrie et al. (2013) prefer the relative adaptability of Excel spread sheets over the constraints of black box applications such as Mortpak.

- The field of demography as a whole may be too small to support the kind of vigorous software development that has occurred in statistics, especially in the commercial domain.

Whatever the reasons, the fact is that relatively few general purpose software packages of demographic methods are still widely used today. Apart from a number of population projection packages such as Spectrum/DemProj and DAPPS/RUP, the best known are the PASEX package developed by Eduardo Arriaga (Arriaga 2014) for the US Bureau of the Census and the Mortpak package of the UN Population Division (UN Population Division 2013). More important than the extent of their usage – at least for the purposes of this chapter - is that even the latter are little more than collections of disparate procedures that have been implemented much in the same way as they were originally formulated, without taking advantage of the digital environment to optimize, integrate and extend them.

That is not to say that the advantages of the computer environment for demographic analysis have not been exploited, but they have been so mostly for the development of specific fields of analysis that require large data bases or complex algorithms. The most relevant are those that were developed organically, in tandem with the research methodologies that they are meant to support, such as life-course analysis or household demography. Another example is the new stochastic projection methodology implemented by the United Nations Population Division (UN Population Division 2024), which depends greatly on the possibility to simulate large numbers of random draws from the same Bayesian parameter set. A remaining challenge is the publication of software that will help NSOs in disaggregating these national level stochastic projections into sub-national ones, e.g. using the methodology developed by Yu et al. (2023), which is based on the same concept, or the alternative methodology recently proposed by Wiśniowski & Raymer (2025).

Meanwhile, indirect estimation methods have remained mostly frozen in time, despite the revisions of specific aspects of these methods during the last decade or two (Moultrie et al. 2013). Most of these methods date back to the 1970s and early 1980s when computational resources were much more limited than they are today. This forced the designers of these methods to implement them in such a way that they could accommodate the most common or easily applicable constraints or assumptions (e.g. constant fertility) and avoid complex algorithms that might have limited their usefulness to practitioners in developing countries.

This computational environment, however, has changed drastically due to the advent of much more powerful and flexible programming tools: first Excel and more recently R, which Frans was one of the first to adopt to streamline the analysis of complex demographic problems Willekens (2014). These provide the user with much greater control over how exactly to conceptualize the problem, how to set realistic constraints and how to estimate its free parameters. Algorithmic limitations, which once were a major challenge, have now become much easier to deal with, thanks to numerical approximation methods such as the Solver resource in Excel or the optim and optimize procedures in R. In addition, as programming languages such as R or Python and their user-developed modules are within the public domain, access to complex algorithms and libraries has been greatly democratized, even in developing countries.

Rather than merely reprogramming the existing methods in the new environment of Excel or R, as is now being done (e.g. Riffe (2023)), it may be time to take a look at the algorithms themselves and assess whether their original implementations still make sense in today's computational environment. This new look should recognize indirect estimation methods for what they are: models of past demographic dynamics whose observable outcomes can be fitted to demographic models, in order to estimate some of the parameters involved in the process while making reasonable assumptions about the remaining ones. By eliminating some of the computational baggage of the traditional implementations, it becomes easier to focus on the essence of the methods, extend them to a broader set of underlying conditions, and integrate them with others.

More specifically, the model fitting approach suggested here involves the following modelling steps:

1. Define a model to connect the underlying demographic process with its observable outcomes, in terms that are sufficiently general to cover all the relevant situations. For example, the model should allow for alternative assumptions regarding past fertility and mortality, rather than assuming - for reasons of parsimony and computational convenience – that fertility has been constant in the past, in order to estimate infant and child mortality.

2. Define any relevant parametrizations, such as model life table families or standard fertility schedules that apply to the model. In the traditional implementations the options are somewhat limited in this regard as the estimation models have been specified for a limited range of standards: the Princeton or United Nations model life table families and the Brass, Coale-Trussell or Relational Gompertz fertility models. However, other options (e.g. the Indepth model life tables formulated by Clark et al. (2009) and different

fertility standards for the relational models of fertility and mortality should also be possible.

3. Determine the number of free parameters to be estimated and the number of reliably observable outcomes. In most circumstances the system will be under-determined, so certain assumptions must be made about the remaining parameters. These can be the same as in the traditional implementations, but other options should also be possible.

4. In case the system is over-determined or contains data of different levels of reliability, a penalty structure should be defined in order to express how admissible deviations of the predicted values from the observed data are considered to be.

5. Finally, the free parameters should be estimated, either by explicitly solving the resulting equations or by minimizing the penalty defined in 4. This should be done using efficient numerical procedures, rather than out-dated workarounds that were designed to avoid numerical difficulties that nowadays are no longer applicable.

Hakkert & Menezes (2024) list the advantages of proceeding in this manner:

- Directness: The traditional implementations of the methods typically need to make a separation between the underlying theoretical relationships, expressed by demographic models and relationships, and the standard tabulations, regression equations, and other operational tools needed to make the parameters of these models computable. The model fitting approach allows a greater approximation between model parameters and the procedures for estimating them.

- Intuitiveness/Transparency: Those of us who have taught indirect estimation methods know how difficult it is to keep the focus on the underlying rationale of these methods rather than becoming absorbed by their operational aspects (the “cookbook”). The model fitting approach makes it easier to both explain and apply the methods in the context of their theoretical models and relationships, provided that students are familiar with R or some advanced features of Excel.

- Flexibility: The standard tabulations, regression equations, and other operational tools of the traditional approach mentioned above need to be tailored to specific model variants (e.g., model life table families). In practice, this constrains the number of variants that can be implemented. The model fitting approach is much easier to adapt to alternative model assumptions.

- Extendibility: The flexibility of the model fitting approach also makes it easier to extend, not only in terms of alternative model variants, such as model life table families, but also in terms of additional parameters, e.g. to express changes in the age pattern of fertility. In the traditional formulation of the methods, such extensions would also be theoretically possible, but at the cost of making their execution operationally very cumbersome and confusing.

- The model fitting approach is also more precise in the sense that it better represents the theoretical models underlying the estimation methods. Whether the estimates obtained will be closer to their actual values, however, depends on the adequacy of the model and the choice of the constraints imposed in modelling steps 2 or 3. If the user makes incorrect assumptions in the specification of the estimation model in 1, obviously using a more efficient algorithm in 5 will not undo the bias in the resulting estimates.

A final advantage, which is not mentioned by Hakkert and Menezes because their examples are purely illustrative and mostly limited to alternative implementations of the existing models, is that the model fitting approach provides a theoretical basis for integrating different methods into composite estimators.

One of the illustrative examples provided by Hakkert and Menezes is the Relational Gompertz technique for fertility estimation. They point out that the standard implementation of this method, as described by Moultrie et al. (2013), is needlessly complicated by the linearization of an optimal fit problem which required such a transformation in the early 1980s, when the method was developed, but which nowadays can be resolved directly by using the function optimization resources of R. This dispenses with the need to use transformations and unintuitive auxiliary functions. Rather than fitting a linearized Gompertz transformation of successive cumulative fertility values, the approach is to fit the age-specific fertility curve directly by using the function optimization features of R or Excel. This requires the optimization of four parameters: 1. The Total Fertility Rate (TFR); 2. The location parameter α of the Relational Gompertz model; 3. The dispersion parameter β of the same model; and 4. The P/F ratio needed to correct the systematic under- or over-statement of the F series that expresses current fertility.

They demonstrate that fitting the data points F1-F6 and the data points P1-P3, that express cumulative fertility, through the minimization of deviations from the model yields a TFR estimate of 3.03, almost identical to the one obtained using the traditional implementation of the method (3.05), as described by Moultrie et al. (2013). It should be noted that the algorithm used for the estimation of the parameters makes no use of the particularities of the Relational Gompertz model. The underlying model might just as well be a classical Brass polynomial or a Coale-Trussell fertility function (UN Population Division 1983) and the fitting process would be the same. Thus the method has the merit of unifying the estimation strategies of the different methods. However, apart from the reassuring finding that the results are almost identical and the conceptual and didactic advantages of a direct and unified estimation strategy, the example does not, in and of itself, seem to justify a radical restatement of the method.

What makes the use of the direct fitting approach attractive, however, is that it can be extended to more complex situations with greater ease than the traditional implementations. The standard application 4-parameter does not provide a satisfactory fit to the P4-P7 data points. To remedy this, a fifth parameter can be added, namely the annual change of the TFR. This is the implementation of the method whose results are shown in Figure 7.1, based on a model in which the TFR declines by a factor 1.0248 each year, converging to a current value of 2.62. This provides an excellent fit to 11 data points (excluding P2, F6 and F7).[1]

Of course adding additional parameters comes with a risk, as there is a danger of over-fitting. Therefore, adding a fifth parameter is best done in situations where an independent estimate of this parameter is already available, to calibrate the model for this non-standard model constraint. Alternatively, the model could be extended to the two-census case with up to 12 parameters: TFR1, TFR2, $\alpha 1$, $\alpha 2$, $\beta 1$, $\beta 2$, P1/F1, P2/F2 and in addition the profile of the changes of TFR, α, β and P/F between censuses: linear, convex or concave. Two-census methods as such are

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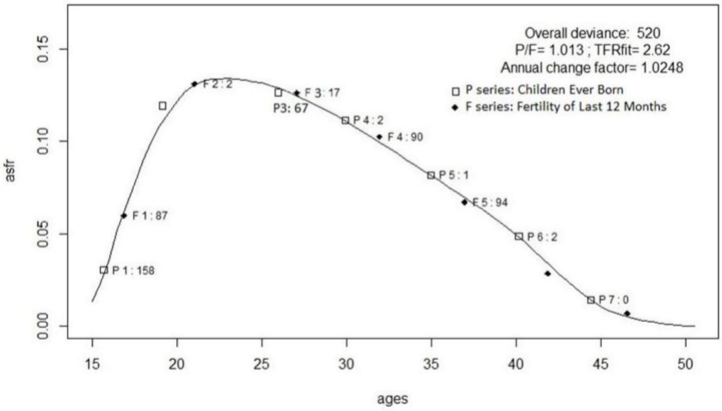
[1] For the details of the fitting procedure, including the meaning of the deviances in Figure 7.1, the reader is referred to the original article.

Figure 7.1: Application of the alternative fitting procedure for the Relational Gompertz fertility model to the 2018 census of Guatemala, with 5 instead of 4 free parameters.



Note: The numbers behind the data points refer to their deviances from the trend.
Source: Hakkert & Menezes (2024, Figure 2.)

nothing new and in the case of the Relational Gompertz method there is a standard implementation known as the Synthetic Relational Gompertz method (Moultrie et al. 2013, Chapter 10). The approach proposed here, however, has much greater flexibility, even recognizing that one would rarely want to treat all 12 values listed above as free parameters to be estimated at the same time.

The possibility suggested in the previous paragraph is not explored by Hakkert and Menezes. It constitutes the next step in a process currently being developed, to take full advantage of the direct fitting approach by generalizing the traditional implementation of these and other methods to more complex situations that involve additional data. The following step in this process would be to bring the estimation of different demographic measures together into an integrated estimation model. It would make sense, for instance, to integrate the estimation of fertility with that of infant and child mortality in a way that guarantees that the exact same evolution of the fertility function(s) is used to estimate both fertility and infant and child mortality. The Own Children method for fertility estimation and the orphanhood method for adult mortality estimation could also be subsumed into this integrated strategy.

Obviously, the crucial and most challenging step in the development of such an integrated estimation strategy in terms of the modelling steps outlined earlier is step 1), the definition of the underlying model that links the assumed demographic dynamic to its observable outcomes. This is relatively easy in the case of constant fertility and mortality with the standard data on children ever born, children surviving, data of the birth of the last child and paternal and maternal orphanhood, but becomes more complex as more degrees of freedom are introduced and more data are considered, including data from more than one census. The crucial decision is how much complexity to allow for. One does not want the estimation model to be overly restrictive, but introducing too many degrees of freedom may make it too unwieldy for the average user to operate and require too many parameters to estimate reliably.

Options that should be available include:

- Different model life table families and fertility models, including not only the Princeton and United Nations variants, but also some of the others suggested earlier under modelling step 2;
- Different options for the profile of change of certain parameters (linear, and various degrees of convexity or concavity);
- The option to include certain non-standard data, when available, such as the average age of mothers at the time of birth of their first child;
- Definition of a penalty structure as suggested under modelling step 4 that reflects the degree of confidence that the user has in different observations (e.g. the expected under-enumeration of children aged 0), to automatically reconcile the results through the proper weighting of data with varying reliability levels.

Some other options, however, may not be realistic. While non-monotonous profiles of change in the fertility and mortality parameters do occur, accounting for them may not be possible, at least not in the one-census case. The usual assumption of no correlation between the mortality of mothers and their children could, in theory, be replaced by a correlation parameter, but in practice such a parameter would be difficult to specify and even harder to estimate. Similarly, it may not be feasible to include parameters to quantify the correlation between levels of fertility and mortality.

Regardless of the details, the task of setting up such a complex model and linking it to the observable outcomes cannot be left to the average user. It requires the development of a standard software, in which users can simply choose the relevant assumptions, in a way that is sufficiently flexible, yet does not overwhelm them with too many options. Formulating a comprehensive model for implementation in a user-friendly software is a task of some complexity, but with the help of the powerful programming tools that are now available, it should be well within the realm of possibilities. The development of such a software is currently underway.

Afterword

Although my academic work in Brazil and my later postings for UNFPA never brought me together with Frans as a colleague in the same institution, I have known him for more than forty years. We worked together in the IUSSP Working Group on Demographic Software, which I originally proposed, but which I was unable to execute as I was living in Angola at the time, where even making a simple phone call abroad was a major challenge. Frans graciously accepted the responsibility for the working group and executed it better than I could ever have. Otherwise Frans has always been a bit of an intellectual mentor to me, who steered me in the direction of multi-state demography and R, among other things. His combination of academic excellence with personal simplicity and accessibility has always been an inspiration to me.

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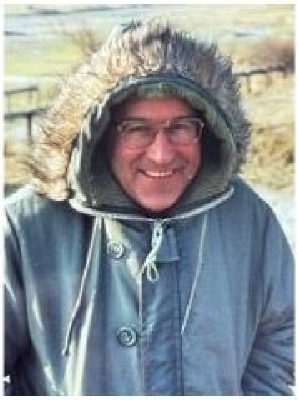
8 Not love at first sight

Inge Hutter

Dear Frans,

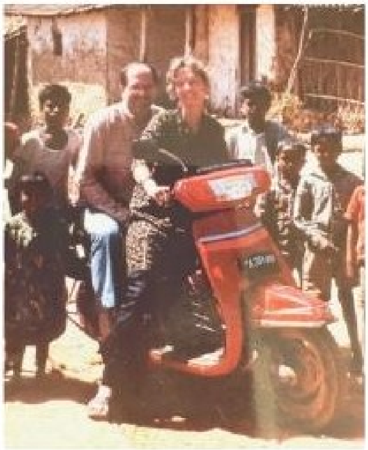
Well, it wasn't exactly love at first sight but . . . reflecting on our relationship at this time of your 80th birthday, I can only conclude that we must have been quite important for each other, in our work and beyond. The first time I met you was in 1989 in New Delhi, India, in the IUSSP conference where late Rajiv Ghandi gave a welcoming speech. Just before travelling to India, we were informed that you would become our new professor of demography in Groningen. We met briefly in the conference: I just had started my PhD research and after the conference would travel for the very first time, with Harrie van Vianen, to Dharwad.



In first instance, I didn't dare to expect too much from you as my promotor, given our different working fields in demography. And the very cold away-weekend at Schiermonnikoog where you / we decided that our field would not be called 'non-western' anymore. Given my work in India, I expected to have little space. By the way, in the years to follow there have been - more than ever - researchers from all over the world at PRC.

My first impressions, however, did not last. We slowly got to know each other better. What made us tick and be so complementary to each other?

Maybe it worked out so well because we were so different? I developed my focus on anthropological demography, wishing to know the story behind the (demographic) figures through qualitative research. In this sense, we continued the line of demography in Groningen: analytical (Harrie van Vianen) and social demography (Bert van Norren): hence we were complementing each other.



In 1992, you paid a visit to me in Dharwad where I conducted my fieldwork. You went with me to the villages, met the women, families and communities. You had no problem taking the back seat of my scooter.

You participated in my interviews with pregnant women and told me after the first day that you thought I didn't keep enough distance in my contacts with the women and their children. I was - you said - emotionally too involved with them. I came home, in Arya's place, and was angry!! Because . . . well, anthropology . . . establishing rapport, and how can one not be involved in such a personal research topic, in such poor circumstances? But the next day: revenge. We interviewed, again together, a pregnant woman with a very cute daughter of 2 years old. And you. . . were not keeping distance at all!! The girl approached you, the two of you obviously liked each other, and within 5 minutes she was sitting on your lap! On the tape, I still can hear myself saying: 'what did you say yesterday evening to me . . . . keep some distance???'.

We got to know each other much better during that stay in Dharwad. We had some heavy Kingfisher beer together, visited for the first time my best friends Arya and Vasant. Maybe you also met my young neighbor Ajay then as well? We discovered similarities: of growing up in small villages in de Kempen and in Drenthe; the two of us being first-generation-students; and above all . . . both knowing what really is important and valuable in life: solidarity with those who have less!

We did so many things at PRC. You started PRC and the first Master programme Population Studies. The PRC logo, a painting made by Arya, is still present in 2025. We visited with PRC and Russian colleagues my home village Oosterhesselen and a nearby farm. For me unforgettable: bringing work back to my birthplace.

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We celebrated Sinterklaas, other important days and PhD defenses with the PRC group. We always made ‘stukjes’ for each other. Once, you were Prince Willem Alexander and me Maxima after the PhD defense for Willem Jan. We had many diners in your and Mieke’s place. There was always fun and laughter, as I see when scrolling through the many photographs we took.

You too supported the workshops with the University of Southampton and the plan of Monique Hennink and me to start joint workshops on qualitative research. The workshops lead to the two jointly written editions of the Sage book on Qualitative Research Methods.

I can write about so many more memories. But for now, Frans: thank you so much for all your support, you believing in me – although I worked in such a different field - and for just being there in an important part of my work and life in Groningen.

I wish you and Mieke a long happy life, it was great to meet the two of you in Mol in the summer of 2025.

9 Willekens en de Koninklijke Academie van Wetenschappen: Hoe lang is "voor het leven"?

Dick van de Kaa

Halverwege de twintigste eeuw was WOII lang genoeg geleden om de toenemende bezorgdheid over de snelle groei van de wereldbevolking tot een geschikt onderwerp voor bespreking op een internationale conferentie te maken. Die eerste Wereldbevolkingsconferentie vond in 1954 te Rome plaats en bleek zozeer aan de behoefte van regeringen te voldoen dat hij over een reeks van jaren door vier soortgelijke bijeenkomsten werd gevolgd.

Voor Nederland had de conferentie een opmerkelijk, zij het onbedoeld effect. De delegatie, waarin een aantal zeer krachtige persoonlijkheden uit academische kring een plaats had gevonden, rapporteerde dat de beoefening van de demografie in Nederland de vergelijking met andere geïndustrialiseerde landen niet kon doorstaan. Snelle actie was noodzakelijk om de geconstateerde achterstand weg te werken. Gelukkig dienden zich daartoe goede mogelijkheden aan. Er bestond een wettelijke voorziening die het voor Nederlandse universiteiten aantrekkelijk maakte om samen te werken bij het open leggen van een nieuw terrein van onderzoek. Universiteiten konden daartoe een zogenaamd 'interuniversitair' instituut oprichten waarin elke deelnemende universiteit in gelijke mate bijdroeg en één van de deelnemers als penvoerder optrad. Voor de vorming van een interuniversitair demografisch instituut bleek grote belangstelling te bestaan.

De Sociaalwetenschappelijke Raad van de KNAW, met Professor E.W. Hofstee als voorzitter, zette zich ervoor in. Dr. Gunther Beijer, secretaris van de Raad en Drs. J.C. van den Brekel van het CBS, werd verzocht een formeel voorstel te ontwerpen. De administratieve afhandeling van de aanvraag verliep voorspoedig en in juni van 1970 kon het NIDI worden opgericht. Het kreeg een krachtig bestuur, met Hofstee als voorzitter, en een breed samengestelde Raad van Advies. Ook werd ervoor gezorgd dat de nog aan te trekken wetenschappelijke staf, waar nodig een introductie bij departementen en andere potentiële nuttige contacten zou krijgen.

De verdere uitbouw van het instituut verliep minder voorspoedig. Als consequentie van een onverwachte bezuinigingsronde was het beschikbaar komende budget veel kleiner dan in het vooruitzicht gesteld. Mede daardoor kon de rekrutering van stafleden maar zeer beperkt plaatsvinden. Kandidaten voor de functie van directeur konden nog wel worden opgeroepen. De demograaf Dr. D.J. van de Kaa, die in Nieuw-Guinea had gewerkt, werd geselecteerd en kwam terug uit Australië om de functie te aanvaarden. Er was daarnaast nog voldoende ruimte om de in Utrecht promoverende socioloog Dr. Hein Moors aan te trekken. Enig verdere soelaas werd verkregen toen, nagenoeg direct aansluitend aan zijn benoeming tot directeur, Van de Kaa door voorzitter Dr. P. Muntendam werd aangetrokken als wetenschappelijk secretaris van de Staatscommissie Bevolkingsvraagstuk. Die constellatie maakte het mogelijk dat Drs. Gerard Frinking uit Canada terugkwam om de instituutsstaf te versterken.

Overigens bleek al na korte tijd dat er bij de instelling van de Staatscommissie geen, of in elk geval onvoldoende, rekening was gehouden met een duidelijk verschil in opvatting tussen departementen over taak en werkwijze. Terwijl sommige beleidsmakers meenden dat het moest gaan om een commissie die bevolkingspolitieke adviezen zou uitbrengen, waren andere departementale vertegenwoordigers van oordeel dat de nadruk moest liggen op het doen van wetenschappelijk onderzoek. Toen de stroming die voor het doen van onderzoek opteerde aan het langste eind trok, kreeg de noodzaak tot financiering daarvan onvoldoende aandacht. Dat had, vanzelfsprekend, vergaande consequenties voor de werkwijze van de commissie, de mogelijkheden tot het verstrekken van onderzoeksopdrachten en de tijd die het onderzoek zou vragen.

Het had evenzeer belangrijke gevolgen voor het functioneren van het pas opgerichte NIDI. Directeur en staf werden intensief betrokken bij de planning van het demografisch onderzoek op nationaal vlak. Contacten met internationale zusterinstituten moesten worden gelegd en onderhouden, en publicaties moesten worden opgezet en tot reeksen uitgebouwd. De staf kon, afhankelijk van de taken en opdrachten, heel langzaam verder worden versterkt. De Belgische onderzoeker Dr. Ir. Frans Willekens, werd in 1980 benoemd tot adjunct-directeur en bleek zich snel thuis te voelen. Na een succesvol hoogleraarschap in Groningen kwam hij als directeur terug naar het NIDI. In 1998 onderging zijn relatie met de Academie een verandering: Hij werd verkozen tot lid.

Leden van geleerde genootschappen worden meestal voor het leven benoemd. Dat wil zeggen dat de benoeming tot lid voor onbepaalde tijd is en er geen einddatum voor de geldigheid van de benoeming is voorzien. Het lidmaatschap komt in principe pas tot een einde met het verscheiden van de benoemde. Voor zo'n regiem is in het geval van een Academie van Wetenschappen veel te zeggen. Benoemingen geschieden immers niet 'op krediet' maar op basis van verdiensten. Die kunnen als blijvend worden gezien ook al zouden door nieuw onderzoek de door de betrokkene verkregen inzichten later zijn achterhaald.

Wat bij het formuleren van geldigheidsbepalingen nog wel een rol kan spelen is de wijze van financiering van het genootschap. Bestaat die uit de bijdragen van leden dan kan bepaald zijn dat het lidmaatschap eindigt met het stoppen van de contributieafdracht. Bestaat die uit een overheidssubsidie dan is men in hoge mate van de opstelling en regelingen van die overheid afhankelijk. Stoppen de subsidies dan wordt de instelling wellicht opgeheven of drastisch verkleind zoals in 1851 het geval was met het Koninklijk Instituut voor Wetenschappen en Schoone Kunsten (KIWI), de voorganger van de huidige Koninklijke Nederlandse Academie van Wetenschappen (KNAW).

Gewone leden van de Koninklijke Academie zijn en worden voor het leven benoemd. De duur van het lidmaatschap wordt derhalve bepaald door zowel de leeftijd bij benoeming als de leeftijd bij overlijden. Veranderingen in een of beide variabelen bepalen wat 'voor het leven' inhoudt. Bij gevolg zal het met de tijd enigszins kunnen fluctueren (Van de Kaa 2008).

Om de huidige situatie te kennen en te begrijpen kunnen we de sterfgevallen in een bepaalde periode bezien. Voor de jaren 2007 – 2016 bij voorbeeld zijn dat er, zo wil het toeval, precies 100. Daaronder waren 46 leden van de Afdeling Letterkunde en 54 van de Afdeling Natuurkunde. De jaarlijkse variatie was, zoals men bij kleine aantallen mag verwachten, aanzienlijk: in 2007 overleden maar 6 leden, in 2010 stierven er 17. De gemiddelde leeftijd bij overlijden was 84,7 jaar. Het gemiddelde van de leden van de Afdeling Natuurkunde blijkt met nagenoeg 85 jaar iets hoger te zijn dan dat onder de overleden leden van de Afdeling Letterkunde, 84,3 jaar. Geconstateerd kan worden dat onder Academieleden de gemiddelde leeftijd bij overlijden nu al heel dicht ligt bij de leeftijd van 86 jaar die volgens het in DEMOS gepubliceerde onderzoek van Van Dalen en Henkens door de Nederlanders als een 'mooie' leeftijd wordt gezien (Van Dalen 2017).

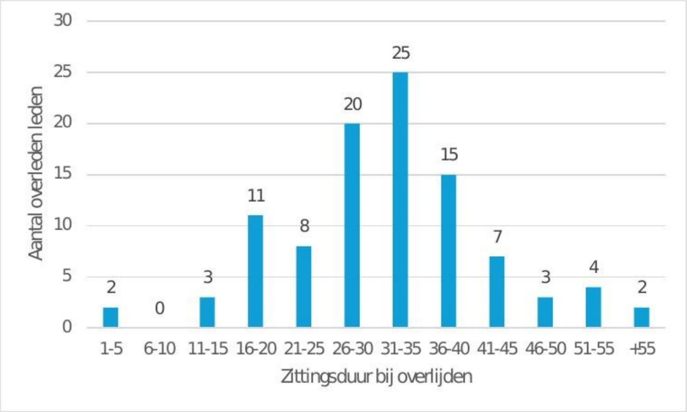
Overigens blijkt tussen leeftijd bij benoeming en leeftijd bij overlijden volstrekt geen relatie te bestaan. Ook is opmerkelijk dat tijdens het decennium een trend in de tijd niet valt te ontdekken. De hoogste gemiddelde leeftijd bij overlijden was bijna 88 jaar in 2009; de laagste gemiddelden scoorden 2007 en 2011 met niet meer dan, respectievelijk, 80,2 en 80,1 jaar.

Het enige vrouwelijke lid dat in het aangeduide decennium overleed was de filosofe E.M. (Else) Barth; zij overleed in 2015 toen ze 86,4 jaar oud was. Slechts één lid was jonger dan 60 bij zijn overlijden (de computerdeskundige Stamatis Vassiliadis, 55,7 jaar in 2007) en ook maar 1 lid nauwelijks ouder dan 60 jaar (Piet Rietveld, econoom, 60,7 jaar in 2013). Ouder dan 100 jaar werd alleen de bekende oud-president van de Hoge Raad C.W. (Cees) Dubbink (100,5 jaar in 2014). Van alle overleden Academieleden was maar 23 procent jonger dan 80 jaar bij zijn overlijden, nagenoeg hetzelfde percentage (24) was ouder dan 90 jaar.

Hoe lang is 'voor het leven' voor deze overleden leden nu wel geweest? Welnu, de zittingsduur heeft per lid zeer gevarieerd (Figuur 9.1). Voor de zojuist genoemde twee jong overleden leden was het maar 2 jaar; voor twee anderen liep het op tot bijna 57 jaar (Emile den Tex, petrologie/mineralogie, 56,6 jaar en Jan de Boer, theoretische fysica, 56,7 jaar). In driekwart van de gevallen heeft de zittingsduur meer dan 25 jaar bedragen, in de helft van de gevallen meer dan 30 jaar. De zittingsduur die het meest voorkwam, namelijk in 25 van de 100 sterfgevallen, was 31-35 jaar. Het gemiddelde over alle sterfgevallen gemeten beliep 31,5 jaar.

Bij een groep geleerden die pas in het voorbije decennium overleden komt het onbekend zijn van geboorte-, benoemings- of overlijdensdatum niet voor. Maar niet ieder benoemd gewoon lid bleef ook tot zijn of haar dood een actief lid. Een enkeling kan hebben bedankt uit onvrede met het beleid of over een bestuurlijke beslissing. Doch bedanken vereist een uitgesproken stellingname en daartoe hebben in het verleden maar weinigen zich geroepen gevoeld. Het aftreden

Figuur 9.1: De verdeling van de in de jaren 2007-2016 overleden gewone leden van de KNAW naar zittingsduur bij overlijden.



van gewone leden was en is heel ongebruikelijk en statistisch niet van belang. Dit ook al omdat er een simpeler keuze bij conflict, onvrede of teleurstelling was en is: eenvoudigweg niet meer ter vergadering komen. Ook voor leden die de last van het lidmaatschap te zwaar valt ligt die weg open. Men kan gevoeglijk aannemen dat bij heel hoge zittingsduren de actieve rol ruim voordien zal zijn uitgespeeld.

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10 A Journey of Mentorship

Samir KC

My first day in the Netherlands, away from Nepal (excluding a couple of visits to India), was at Frans' home in Groningen, where I was dropped off from the train station. I waited for Frans, who would take me to my rented apartment in Haren, just outside Groningen. That was my first encounter with him, and the first lesson I learned at his home was that in Europe, if you are offered tea or coffee, it will only be offered once. Following Nepali customs, I declined the tea, expecting a second invitation that never came. As I watched everyone sipping their tea, I found myself wondering if I would be asked again. This taught me an invaluable lesson about European customs, applicable not only to tea and coffee but to many other situations: if you want something, it's best to say yes at the first instance.

Another memory I often share is how I initially called Frans 'Sir' and 'Professor' out of respect for the hierarchy practiced in many cultures. He kindly encouraged me to call him by his first name. Making that shift was challenging for me. I learned that it is possible to show respect while using someone's first name. My initial respect for him stemmed purely from his position as my supervisor, but as I got to know him better, my admiration became genuine. I am deeply grateful for his teachings and mentorship throughout my life. Even though he could be strict and intimidating academically, he showed immense compassion and care for his students. I distinctly remember him saying that his office door was always open for me, meaning I didn't need an appointment to meet him. This experience has significantly influenced my behavior and how I communicate with my mentees, students, and colleagues. I continue to uphold an open-door policy in my office, which now extends to my online presence.

I learned about Event History Analysis and Multistate Demography from Frans, with the latter being the primary foundation of my work over the past 20 years. My PhD research was based on this multistate model, which I have applied in studying population dynamics in my current research. Sometimes, I wonder what I would be doing if I hadn’t met Frans. He was incredibly patient with me during my PhD, often guiding me back on track when I strayed from my topic. I remember being scolded for poor English in one of my drafts, which embarrassed me and made me worry about his opinion of me. However, once the meeting concluded, he returned to being the Frans I knew and helped me financially during that time when I was facing issues with my funding. I still wonder if I ever returned the money he lent me.

After completing my PhD, I had many opportunities to reconnect with him, often consulting him before making significant decisions. He has written reference letters for me with great patience. My last visit was in Groningen for a meeting, where I fortuitously bumped into Frans and Maria, who were there for a farewell event for a colleague. This coincidence made me reflect on the role of chance and fate in our lives. In conclusion, my journey with Frans, beginning with all the unlikely events in Nepal, and the fact that he remains just a phone call away, feels like destiny. I consider myself very fortunate to have you as my supervisor, mentor, and now, a friend. In response to your invitation to visit your home, my family and I hope to see you and Maria soon.

Thank you, Frans.

11 The accuracy of probabilistic household forecasts

Nico Keilman

Abstract

Scoring functions are used to evaluate the accuracy of the oldest known probabilistic household forecast, namely the one computed in 1999/2001 by Alders and De Beer for the Netherlands 1995-2050. I employ three different scoring functions: a variance-based score, the Dawid-Sebastiani score, and an interval score. All three indicate lower quality when forecast duration increases, as could be expected. The scores are very similar for men compared to women, except for lone parents and for institutionalized - men in these two population sub-groups are more difficult to predict than women. More generally, the findings suggest that frequent household positions (pair, child, alone) score better than infrequent ones (lone father, male living in institution).

11.1 Introduction

When I came to NIDI in 1982, I had done some work on population projections for marital status at Statistics Norway. Frans proposed that I extend this to projections of households. We wanted to model households with a focus on the dynamics, i.e. household formation and dissolution. This would be a step forward, compared to the static headship rate approach that was common at that time. We found out that a multistate approach would be feasible. Jan van Dam and I took the

MUDEA computer program, written by Trix Hummelinck and Frans, and adapted it to a program that could deal with household events, and the interrelationships between members of the same household. Evert van Imhoff generalized our proto-type LIPRO model to a very general multistate projection model and a versatile and user-friendly PC program that could handle both internal and external consistsency requirements. Since the end of the 1990s, the perspective has shifted from deterministic to probabilistic household forecasts, and also more generally to probabilistic multistate forecasts. But it was Frans who initiated this whole line of demographic research.

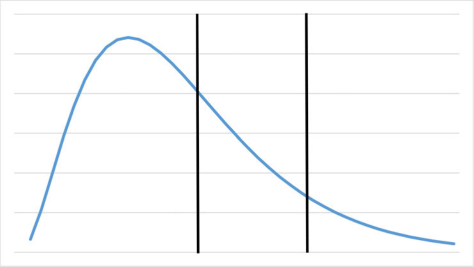
Household forecasts are valuable for planning purposes in connection with the housing market, consumer durables, and energy use. Since the future is uncertain, and some household developments are more likely than others, such forecasts should be computed probabilistically (UNECE 2017). Probabilistic household forecasts have a history of 25 years. It started with the pioneering work of Alders and De Beer (AdB henceforth; see De Beer & Alders (1999), Alders (2001a,b) and was followed by others (Jiang & O'Neill 2004, Scherbov & Ediev 2007, Alho & Keilman 2010, Christiansen & Keilman 2013, Keilman 2016, 2017, Wilson 2013a,b). The aim of this chapter is to evaluate how well these forecasts predicted actual household developments. I will assess the household forecast of AdB, for which detailed outcomes are available for the period 2000-2050. I analyse how fast forecast accuracy deteriorates when forecast lead time increases, and which household variables are easier to predict than others. Insight in these issues may be helpful for the users of the probabilistic forecast, who have to plan under uncertainty.

I will use so-called scoring functions, which measure the distance between a predictive density or distribution for a certain forecast variable, and its actual value observed after the forecast was computed. This is useful when the aim is to compare competing forecasts of the same population development by different forecasters, or forecasts of different variables at any given time, or forecasts of one variable at different forecast lead times. There is a large statistical literature on scoring functions, and the tradition goes back to at least Brier (1950). Nonetheless, only a few applications to *population* forecasts are known of (Keilman 2020), and none for household forecasts.

11.2 Scoring functions

Many different scoring functions have been proposed, e.g. Gneiting & Raftery (2007), Jordan et al. (2019). Most of these emphasize bias and precision, but in different ways. Take the example of the predictive distribution or density of the number of one-person households in 2020 as predicted in 2000, together with the actual number as observed in 2020. The first principle ("closer is better"), obviously, is that an observed value close to the expected value or median of the distribution (small bias) gives a good score; cf. Figure 11.1.The second principle ("sharper is better") is that a good score results when the actual outcome was predicted with small variance (high precision); cf. Figure 11.2, which shows two different predictive densities compared with the same observation. The idea behind this principle is that a forecaster who predicted with small variance takes a larger risk of missing the actual value and hence should be rewarded, compared to the forecaster who predicted with large variance. One is penalized for being vague.

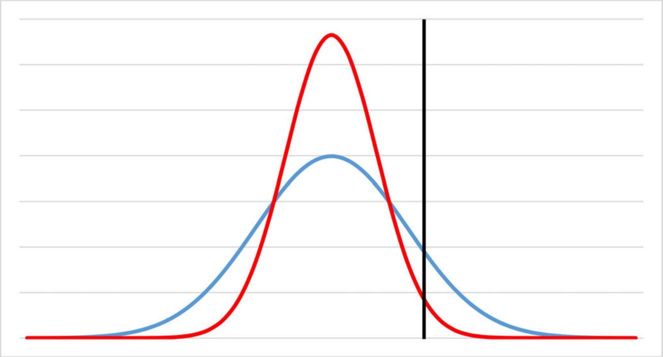
Figure 11.1: Blue curve: predictive density for one-person households in 2020 computed in 2000. Black lines: two possible actual values in 2020.



Thus the predictive distribution may be right on target, but have a very wide prediction interval, or it may have a narrow prediction interval and not cover the target. A scoring function characterizes such different situations.

A probabilistic forecast may be made available in three different forms. First, as an interval forecast, that is, as prediction interval with a pre-specified coverage probability (e.g., 67 or 80 or 95 per cent). Second, in the form of moments of the predictive distribution, for instance the expected value and the variance. Finally, as a full probability distribution, sometimes an analytical expression, but

Figure 11.2: Blue and red curve: predictive densities for one-person households in 2020 computed in 2000. Black line: actual value in 2020.



most often as a sample obtained by simulation. Different scoring functions have been developed for each of these three cases (Gneiting & Raftery 2007, Gneiting & Katzfuss 2014). AdB published their forecasts in terms expected values and prediction intervals, not full probability distributions. In the analysis below I shall use three functions: a variance-based scoring function, the Dawid-Sebastiani score, and a scoring function for prediction intervals; see Keilman (2020) for a discussion.

Write X for the variable to be predicted, with probability distribution $F(x) = Pr[X < x]$, expectation μ, and variance σ^2. The predictive density is $f(x)$. Let y be the *ex-post facto* observed empirical value of X. I use negatively oriented scoring functions: a low score implies a good forecast, interpreting a scoring function as a cost function (a positively oriented scoring function would reflect a reward).

The variance-based scoring function, written as VS, is defined as

$$VS = \sigma^2 + (\mu - y)^2.$$

VS reflects the variation in X around y. It rewards both accuracy – when y coincides with μ, the forecast is of optimal quality – and sharpness – a small variance gives a good score, irrespective of how far off the forecast was. *VS* is called the Predictive Model Choice Criterion by Gneiting & Raftery (2007).

The Dawid-Sebastiani scoring function *DSS* is

$$DSS = \log(\sigma^2) + (\mu - y)^2/\sigma^2.$$

DSS has its background in the log score (Gneiting & Katzfuss 2014), defined as -log(*f(y)*). This scoring function can be computed when the predictive distribution is available in analytical form. When *y* has a normal distribution N(μ, σ^2), the log score simplifies to ½[log($2\pi\sigma^2$) + $(\mu - y)^2/\sigma^2$]. *DSS* ignores the constants ½ and log(2π). It can be used for any predictive distribution when only its expectation and variance are known, but not the whole distribution.

The Interval Scoring function is defined as follows. Assume that we have the forecast outcome as a central prediction interval $[l, u]$ with $\Pr[l < X < u] = (1 - \alpha), 0 < \alpha < 1$. In other words, the lower and upper endpoints l and u of the prediction interval are the predictive quantiles at levels $\alpha/2$ and $(1 - \alpha/2)$, respectively. Then, the Interval Scoring function (*IS*) is

$$IS = \alpha(u - l), l \leq y \leq u,$$

$$= \alpha(u - y), y < l,$$

$$= \alpha(y - l), y > u.$$

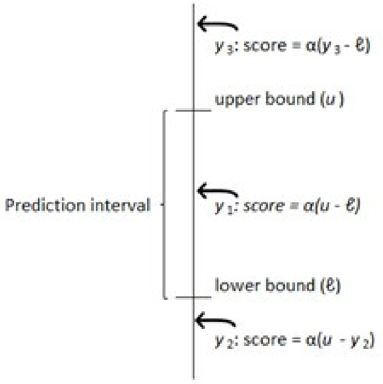
In words: when the prediction interval (PI) covers *y*, the score equals α times the width of the PI. When *y* falls below the lower bound, the score is α times the distance from *y* to the upper bound of the PI, and vice versa when *y* is larger than the upper bound (see Figure 11.3).

11.3 Comparison of *VS*, *DSS*, and *IS*

DSS is similar to *VS* but gives different weight to the variance of the predictive distribution. A low variance leads to a good score as long as $\sigma > |\mu - y|$ (Keilman 2020). Whereas *VS* always rewards predictive distributions with low variance, *DSS* does so if the observation *y* is less than one standard deviation away from the expectation of the predictive distribution. Both reward predictions with little bias.

For a given α, *IS* rewards narrow intervals and penalizes observations far

Figure 11.3: Scoring function *IS* for prediction interval. Scores for three different outcomes: observation inside the prediction interval (y_1), below the lower bound (y_2), or above the upper bound (y_3).



away from the PI. For a given interval, it rewards small α. It does not reward an observation close to the mean or the median of the distribution, if the PI captures the observed value. *IS* is an improved version of the Interval Score of Gneiting & Raftery (2007), which does not reward small α for a given PI (Keilman 2020).

When comparing scoring functions, the notion of a proper scoring function may become important. Assume that the actual value y comes from a distribution $G(y)$. Before we have seen y, the scoring function $S = S(F, G; Y)$ is a random variable in Y with expectation $E_Y[S(F, G; Y)]$. Now imagine a situation in which the forecaster knows, by some unknown mechanism, that y will be generated by G, and computes the prediction based on G. A scoring function S is called *proper* when a prediction based on any distribution $F(y) \neq G(y)$ does not score better than one based on $G(y)$, or $E_Y[S(G, G; Y)] \leq E_Y[S(F, G; Y)]$. Thus, a proper scoring function stimulates the forecaster to be honest.

When predicting future events, one does not know G, and the distinction between proper and improper scoring functions is of theoretical value. However, this property is important in model calibration when the forecaster selects one of several competing models using scoring functions and a hold-out sample of observations. It is also useful in an *ex-post facto* comparison of predictions for different variables, as in our application.

Whereas the Dawid-Sebastiani scoring function DSS is proper, this is not the case for the variance-based scoring function VS (Gneiting & Raftery 2007).

As to the interval score IS, its expected value is

$$E_Y[IS] = \alpha(u - l), l \leq y \leq u,$$

$$= \alpha(u - E_Y[Y|y < l]), y < l,$$

$$= \alpha(E_Y[Y|y > u] - l), y > u.$$

If the prediction interval covers the actual value, the expected score is independent of the distribution $F(x)$, and the interval score is proper. Otherwise, the expected score depends on the conditional expectations for the tails. In those cases, IS is not proper, because it is always possible to find a distribution F with conditional expectations closer to the interval bounds than $G(y)$. This means a lower score, even when $G \neq F$.

Based on these considerations, DSS is more attractive than VS or IS.

11.4 The probabilistic household forecast of AdB

AdB developed a method for probabilistic household forecasting and applied it to data for the Netherlands. Their approach combines an independently computed probabilistic cohort-component forecast (population broken down by age and sex) with random shares. The shares distribute each age-sex specific forecast result stochastically over six sub-populations defined by household positions. Uncertainty parameters ((co-)variances) were not estimated from data but based upon subjective reasoning. AdB used the following six household positions:

- Living alone
- Living with partner
- Child in parental home
- Lone parent
- Other private household position
- Institutionalized

Based on these household positions for individuals, numbers of private households are easily computed, provided one knows the average household size of persons who have household position "other".

Results were published for selected years in the period 2000 – 2050, with 1995 as the jump-off year (Alders 2001a). The outcomes suggest an almost certain increase in the number of private households from 6.5 million in 1995 to 8.3 million in 2030, with a 95 per cent PI that ranges from 7.0 to 9.7 million. The increase will flatten out after 2030. A large part of the growth in private households is caused by a strong growth in the number of one-person households: from 2.1 million in 1995 to 3.4 million in 2050. The lower limit of the 95 per cent PI falls slightly below 2 million to 2035, and somewhat more steeply for later years. This means that the increase in the number of one-person households is not entirely certain. One can estimate that the probability for this to occur is between 2.5 and 16.7 per cent, because the 67 per cent PI has a lower bound well above 2 million in 2035. A strongly ageing population causes many more persons who live alone, in particular elderly men. This effect is stronger than the ongoing reduction in the sex gap in life expectancy, which leads to fewer widows.

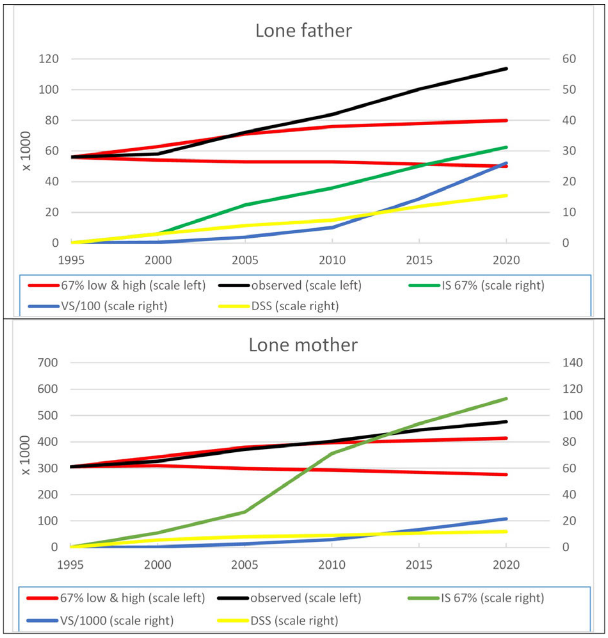
Small changes are expected in numbers of persons who live with a partner (7.9 million in 1995, 8.8 million in 2050) and children who live at the parental home (4.5 million in 1995, 4.8 million in 2050), although the corresponding PI's are wide. Persons who live in an institution are difficult to predict. Alders (2001a) expects that the numbers first will decrease (from 248,000 in 1995 to 159,000 in 2020), followed by an increase caused by population ageing (to 230,000 in 2050). However, the prediction intervals are very wide (for instance, ranging from 50,000 to 500,000 for the 95 per cent PI in 2050).

11.5 Did the AdB household forecast hit the targets?

I assessed the goodness-of-fit of predictions for men and women in the following five household positions: living alone, living with partner, living in parental home, lone parent, and living in an institution. Alders (2001a) reported predicted numbers, as well as the upper and lower bounds of the 67 per cent and the 95 per cent PI's, for the years 2000, 2005, 2010, 2020, 2030, 2040, and 2050. I have estimated results for 2015 by linear interpolation between 2010 and 2020.

For each variable, I took the predicted number as the expectation of the predictive distribution and estimated its standard deviation by assuming normality. A first estimate was the width of the 67 per cent interval divided by two, a second one was the width of the 95 per cent interval divided by 3.92. The two estimates differed slightly, so I used the average of the two as the final estimate of the standard deviation.

Figure 11.4: Observed numbers, 67 per cent prediction intervals, and three different score functions for predictions of lone fathers and lone mothers. Note: different scales.



I plotted observed numbers of men and women in each household position, the associated 67 per cent PI, as well as the scores *VS*, *IS*, and *DSS*, for the years 1995(5)2020. These plots are not very informative: the PI's widen up over time and the scores increase more or less regularly in all cases. This is what one could expect. The PI's capture the observed values, with two exceptions: lone parents and persons in institutions; see Figures 11.4 and 11.5.

Numbers of lone parents were predicted to stabilize between 2010 and 2020, after a slight initial growth (Figure 11.4). In contrast, observed numbers increased continuously, such that the 67 per cent PI's did not capture them after 10-15 years. The reason for this under-prediction is not entirely clear. Shares for persons living alone and for lone parents were modelled combined (Alders 2001b), and numbers of lone parents were singled out from the combined numbers at the final stage of the simulations. I find that observed numbers of one-person households agree very well with the stochastic predictions: observations fall inside the prediction intervals, often very close to the expected values. One possible explanation for the under-prediction of lone parents is that the forecasters assumed lower levels of divorce and separation than what was observed ex post. Children born by women in a LAT-relationship may also be a factor. In any case, expected numbers of lone parents were much higher in later household forecasts, e.g. Van Duin & Loozen (2009), Van Duin & Stoeldraijer (2011).

Figure 11.5 shows men and women in institutions. The predictions trended downwards, but the actual numbers for men turned out to increase starting in 2005. The consequence was that the number of men in institutions fell outside the 67 per cent PI – after 2015 even outside the 95 per cent PI (numbers not shown here). The small numbers involved make it difficult to compute an accurate forecast.

Even if the prediction intervals for lone parents and for persons in institutions were relatively wide already, here we see that they were not wide enough.

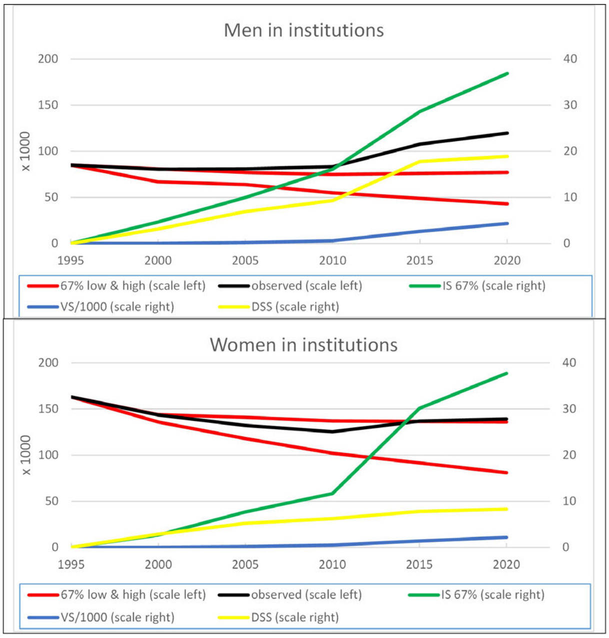
11.6 Which household positions are easy to predict?

The three scoring functions employed here cannot be used to compare predictions for various household positions. The reason is that the scoring functions are not dimensionless: dimensions are "persons" for the Interval Score and "persons squared" for the Variance-based Score. The dimension of the Dawid-Sebastiani Score is unclear: its first term has dimension "logarithm of persons", whereas the second term is dimensionless. The numbers in various positions are very different, ranging from a low 259,000 persons in institutions in 2020 (of which 120,000 men) to a high 8.6 million who live with a partner. A fair comparison requires scoring functions that are homogeneous of order zero. I scaled the three scoring functions as follows:

$$VS^* = VS/\mu^2$$

$$DSS^* = DSS - \mathtt{log}(\mu^2)$$

Figure 11.5: Observed numbers, 67 per cent prediction intervals, and three different scoring functions for predictions of men and women living in an institution.



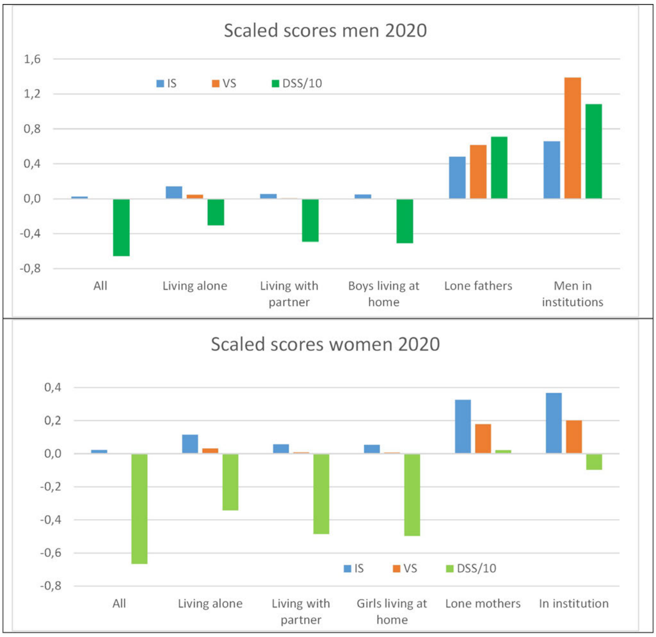
$$IS^* = IS/\mu$$

With these corrections, the scoring functions become insensitive for a proportional increase or reduction in population size. Moreover, the scaled DSS is still proper, because any proper scoring function S remains proper after a linear transformation $S^* = a + bS, b > 0$ (Gneiting & Raftery 2007). Here we have $a = -\texttt{log}(\mu^2)$ and $b = 1$.

Figure 11.6 plots the scaled scores for men and women in 2020. Results for the Dawid-Sebastiani score DSS are divided by a factor 10, to enhance comparison with the other scores. A low score reflects a forecast of good quality, as mentioned above. This principle still holds after scaling. Thus, the negative DSS-scores we find for many household positions imply better forecasts than the few forecasts with positive scores.

I attach more weight to DSS, which is proper, than to the improper VS and IS. Nevertheless, all three scoring functions show very clearly that it is more difficult to predict lone parents and persons in institutions, compared to the other household

Figure 11.6: Scaled scores for men and women by household position, 2020. Note: different scales.



positions. Note also that the scores are worse for men in institutions and for lone fathers, compared to women in these two household positions. This suggests that population sub-groups of small sizes are more difficult to predict accurately than larger sub-populations.

An obvious question is whether one would have reached the same conclusion when the forecast would have been deterministic - in other words, in case one would only have the expected value of the predictive distribution. I computed the absolute percentage error (APE) of the predictions for men and women in five household positions. APE is defined as $100.|E[X] - y|/y$. This led to two conclusions.

First, for some variables, the time pattern of the APE is a bit irregular. This is because predictions $E[X]$ are smooth extrapolations of observed patterns, whereas actual numbers may be irregular, for instance caused by business cycles or by policy changes. On the other hand, when we evaluate the probabilistic forecast by a scoring rule, the time trend of the score is more regular, because the variance of the predictions increases smoothly and the prediction intervals become wider.

This counteracts a possibly irregular pattern of the distance between expected and actual value.

Table 11.1 gives an example for girls who live at the parental home. If one only had a point prediction $E(X)$ and would inspect the APE, one might conclude that the forecast becomes more accurate from around 2010. However, the scaled DSS, which takes the increasing prediction variance into account as well, shows that this is not correct. Other household positions with a more or less fluctuating time trend in the APE are men living alone (for which the signed error $(E[X]-y)$ went from positive to negative during the projection period) and boys living with parents (numbers not shown here).

Table 11.1: Girls living with parents, 1995 - 2020. Predictions, actual numbers, and measures for prediction errors (predictions and actual numbers in 1000s)

Year	Prediction	Actual	APE	DSS^*
1995	2078	2078	0	-
2000	2089	2089	0.0	-9.4
2005	2169	2140	1.4	-7.1
2010	2198	2120	3.7	-5.6
2015	2188	2117	3.3	-5.3
2020	2177	2157	0.9	-5.0

Second, the earlier conclusion that small population groups are more difficult to predict accurately than large populations was confirmed. Table 11.2 shows very clearly that the relative bias in predictions of lone parents and persons in institutions is much larger than for the other three household positions. A similar conclusion was reached earlier when still another set of deterministic family and household projections was evaluated (Keilman 2018): "projection errors for couples and one-person households can be limited to about ten percent or less even after 25 years, if projection parameters are chosen carefully. For families that are less important numerically, for instance one-parent families, projection errors can be one order of magnitude larger."

Table 11.2: Absolute percentage error, 2020

	Men	Women
Living alone	2.5	4.0
Living with partner	2.5	2.9
Child living at home	2.4	0.9
Lone parent	42.8	27.1
Institutionalized	53.2	26.0

11.7 Conclusions

Scoring functions, proposed by statisticians since the 1980s, are useful when we wish to evaluate the accuracy of probabilistic forecasts. Only a few applications to demographic forecasts are known, none to household forecasts. Here I evaluate the accuracy of one of the oldest probabilistic household forecasts, namely the one computed in 1999/2001 by Alders and De Beer for the Netherlands 1995-2050.

I used three different scoring functions: a variance-based score (*VS*), the Dawid-Sebastiani score (*DSS*), and an interval score (*IS*). All three indicate lower quality when forecast duration increases, as could be expected. The scores are very similar for men compared to women, except for lone parents and for institutionalized - men in these two population sub-groups are more difficult to predict than women. More generally, the findings suggest that frequent household positions (pair, child, alone) score better than infrequent ones (lone father, male living in institution). Thus, when resources are limited, more attention could be given to accurate predictions of small groups. The alternative is to construct wider prediction intervals, which, however, may make the forecast uninformative.

Acknowledgements

Joop de Beer and Leo van Wissen gave useful comments on an early version.

Afterword

I graduated in Applied Mathematics from Delft University of Technology in September 1977, and had my first job in a research group on population forecasting at Statistics Netherlands. In addition to learning demography, I attempted to apply my fresh knowledge about systems analysis, modelling, simulation, and statistics to the new field of population forecasting. Soon I discovered that I wasn't the first person with this type of interest. A Belgian scholar named Willekens had recently written a paper on exactly this topic, and presented it in 1978 at the Chair Quetelet meeting dedicated to the Approche systémique en sciences de la population in Louvain, Belgium (see also the chapter by Ekamper and Van Poppel). I was even more surprised to learn that he worked at NIDI, which was located in the same building as Statistics Netherlands (!). We turned out to have common interests, and when NIDI had a vacancy in 1981 I applied immediately - and was fortunate enough to be hired by the institute. After Frans had accepted a part-time professorship at the University of Utrecht, I decided to do my PhD research under his supervision. For many years, Frans has had a strong influence on my academic career, for which I am immensely grateful to him.

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12 Professor Frans Willekens - some reflections

Irena E. Kotowska

How to express adequately my gratitude to Professor Frans Willekens in a strictly limited contribution? And how to capture its different dimensions?

Firstly, as researchers involved in population studies we continue to benefit from his impressive achievements in methodology of population studies and shifts in research perspectives, which have changed demography as a discipline and its position among social sciences. His contributions to scientific collaboration and proper education of new generations of researchers in Europe have strengthened population studies in Europe and their position on a global scale.

Secondly, I deeply appreciate the support given by Frans Willekens to scholars at the Institute of Statistics and Demography (ISD) in Warsaw, and other activities important for our integration into the demographers' community in Europe. Our direct contacts started forty years ago with the stay of Janina Jóźwiak at NIDI in 1985 to work with Frans on multistate modeling. He was the Deputy Director of NIDI, and Dirk Van de Kaa was the Director. In 1987 Frans visited Warsaw for the first time. He returned every year in the period 1987-1990 to teach on population projections within the UNFPA programme initiated by Professor Jerzy Z. Holzer, the Director of ISD. Other ISD demographers also benefitted from scholarships offered by NIDI. Despite the fact that it was a hard time for Poland, these years of close contacts were constitutive not only for selecting scientific interests of scholars, but also for our efforts to mark the position of the Institute at the international level. Since the beginning of the 1990s, the ISD increasingly participated in research and other activities aimed at strengthening of demography in Europe, as well as integration of the European demographers' community (cooperation with European Association for Population Studies, European Doctoral School of Demography, Population Europe). Frans was continuously supportive in any personal requests for scientific advise as well as institutional involvements of the ISD.

Finally, Frans Willekens occupies an exceptional position in my professional biography. He influenced my scientific choices when I started in population studies in the mid-1980s. Our disputes about the university and science management benchmarks and values crucial to preserve in our professional activity and beyond were constructive for me at that time of university reforms in Poland and searching for future configurations of research. The next years brought many contacts and proved our common understanding of crucial topics for demographic research and education in Europe. I tried to follow this thinking in my activities at the ISD and beyond. I am proud of our friendship, important for me in subsequent stages of my life course.

In May 2018, by conferring the honorary doctorate of the Warsaw School of Economics on Professor Frans Willekens, our academic community expressed their deep appreciation for his outstanding scientific achievements and huge contributions to progressing demographic research and education in Europe, as well as their gratitude for his support for the efforts of the Institute made towards the development of population studies in Poland, and especially for enhancing the position of the ISD at the international level.

13 The new fertility postponement wave in Europe and North America between 2010 and 2019, and the East-West contrast

Ron Lesthaeghe and Krystof Zeman

Abstract

Using a life-cycle perspective of cohort fertility, a clear distinction could be found concerning the degree of postponement among young adults prior to age 30 between the Nordic, Western and Southern European countries, the USA and Canada (the "West") on the one hand, and the Central and Eastern European countries (the "East") on the other. Generally, the former exhibit a new postponement wave whereas the latter do not. This resulted in a new overall period fertility decline in the West, and a new trend toward convergence with the lower fertility in the East.

The chapter explores a set of possible explanations for this East-West duality: advancing education, more conservative gender relations resulting in earlier marriage in the East, job insecurity and housing problems, and changing "tastes" associated with cultural factors such as the legitimation of a child-free life option and "open future" considerations connected to a care-free interim period. The concentration of the fertility decline in the 2010-2019 decade in the young adult phase also explains why the classic policy measures (length of parental leaves, childcare and pre-school facilities, children allowances and tax deductions) have little impact during this younger life-cycle phase of postponed parenthood. Young adults face

other issues before a stable union can be established, required for starting a family with children.

13.1 Introduction

It is well known by now that many European countries and also Canada and the US have witnessed a marked fertility reduction during the decade 2010-2019, i.e. prior to the Covid epidemic (Bloom et al. 2023, Solaz et al. 2024, OECD 2024). But new puzzles emerge. For instance, why are the declines so pronounced in the Nordic countries which have the most generous family policies and the most liberal gender relations? Why is the decline considerably stronger in the West than in the Central and Eastern European (CEE) countries? And what is behind the convergence of Period Total Fertility Rates (PTFRs) of the former group of countries of earlier higher fertility (US, Nordic countries, Low countries, UK and Ireland) to those with long standing PTFR values below 1.5 children? How large is the new postponement wave? And do we have an idea of what the driving forces could be of the new fertility decline in a large set of countries and not in others? In answering these questions, we adopt a life-cycle perspective. This enables us to specify the nature of changing challenges faced during the different life-cycle phases of successive cohorts, and on policy responses adopted so far. In other words, via the life-cycle lens we can focus on longitudinal developments concerning the postponement and recuperation phases of generations, and on the need for shifting policy responses.

13.2 Fertility analysis focussing on life-cycle stages

To document the fertility evolution in the 2010-2019 decade we shall use the life-cycle approach, with four distinct stages arranged in a longitudinal fashion (Lesthaeghe 2018). The “Life-Cycle Sensitive Total Fertility Rate” (LCS-TFR) for a certain year t is defined as the sum of four segments of age-specific rates, namely

1. earlier teenage fertility, measured 5 years earlier, i.e. f(<20, t-5);
2. young adult fertility, indexed at time t, i.e. f(20-29, t);

3. mature adult fertility, ten years later, i.e. f(30-39, t+10);
4. older age fertility, fifteen years later, i.e. f(40+, t+15).

This very simple approach approximates the behaviour of groups of generations as they pass through the four life cycle stages. The computation only requires a re-arrangement of the classic time series for age-specific rates, which are traditionally summed up to yield the PTFRs. However, it avoids the pitfall of lumping together the behaviours of generations that, at the extremes, are 30 years apart, and went to very different slices of history.[1] The inputs are the most readily available ones for a large number of countries, and this is the second advantage of the use of the LCS-TFR. Furthermore, and this is the third and main advantage, the comparison of the four fertility segments permits the easy and fast following up of the evolution of the "postponement transition". In this fashion one can follow the postponement phase prior to age 30 over time, and inspect the subsequent degree of catching up after that age, i.e. during the mature adult phase of cohorts. Finally, the accuracy of the LCS-TFR can be checked by plotting the outcomes for a large set of countries against the true Cohort Total Fertility Rates (CTFR). This test was performed by Krystof Zeman and is being shown here in Figure 13.1. It is obvious that the LCS-TFR is a vast improvement over the postponement distorted PTFR. Obviously, for the more recent years, the rates beyond age 30 will not be available, but, on the basis of the extent of further postponement during the young adult phase, one will get a good grasp of what the size of recuperation fertility will have to be in order to replicate the values of the latest available completed LCS-TFRs.

13.3 The demographic meaning of the four life-cycle phases

The teenage phase captures individuals during their secondary schooling. However, it also is the locus of lasting social problems caused by dropping out and possibly substance abuse. As this is more a male than female set of issues, the growth of a lowly educated male group produces mismatches on the later "cohabitation/marriage market" and may results in the growth of a group of single men

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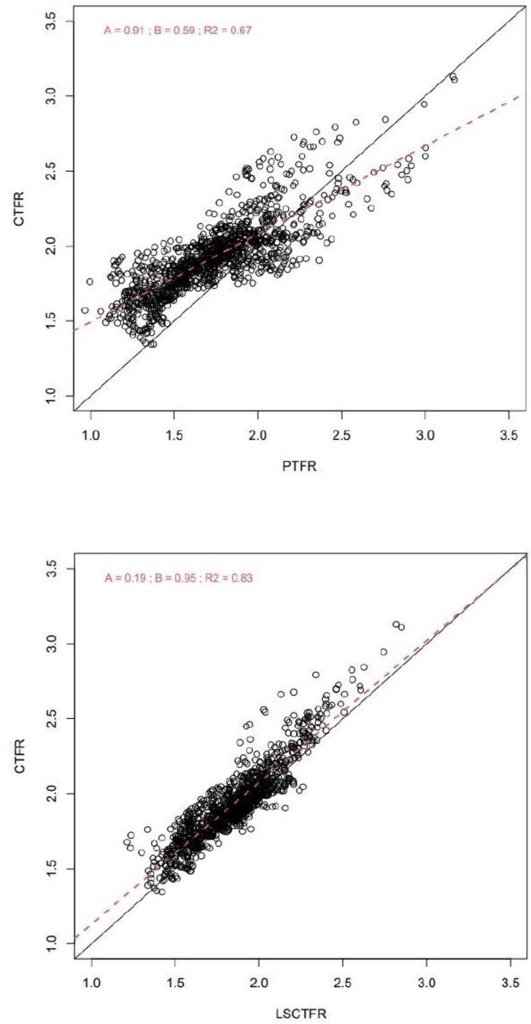
[1] Obviously, the LCS-TFR is not being proposed as a substitute for more accurate and/or more sophisticated fertility measurements. Also, the cut-off points can be adapted to other fertility patterns, such as the younger schedules in Latin American countries, e.g. pre 18 (t-5), 18-24 (t), 25-34 (t+10), 35+ (t+20). For a considerably more sophisticated analysis of the postponement – recuperation sequence in fertility, see Sobotka et al. (2011).

Figure 13.1: Scattergrams depicting the relationship between the Period Total Fertility Rate (PTFR) and the Cohort TFR (CTFR) (top), and between the Life-Cycle Sensitive TFR (LCS-TFR) and the Cohort TFR (CTFR) (bottom). Source: Vienna Institute of Demography Human Fertility database.



who are unable to find a partner. On the female side, low educated women too may be left behind in partnering (Sturm & Van Bavel 2024), or worse, an accidental teenage pregnancy curtails subsequent life chances.

The young adulthood phase contains the period of continued higher education, and as the study period is being prolonged, so is, in most instances, the time of being single. Being single can take the form of solo living, of co-residence with parents, or with other singles in co-housing. The age of ending studies has been steadily advancing in many countries, thereby producing a further increase in ages at couple formation and first parenthood. Graduation is followed by issues connected with the entry into the labour force. When problematic, for instance as a result of employment insecurity, chances for the formation of a stable partnership drop, leading to further postponement. When unproblematic, an independent income will spur on independent living and a search for a suitable partner. Conversely, this new economic independence may also lead to an accentuation of "keeping an open future", thereby avoiding irreversible commitments. Instead, there is in this instance an interim period of enjoying the great variety of gratifications offered by living in affluent consumer societies. Also, educated women may become more choosy as far as partners are concerned and move into a longer "trial cohabitation phase" before engaging into a stable partnership and subsequent marriage.

When stable couple formation is on the horizon, so is the search for more adequate housing. Hence, during this life-cycle phase housing availability and rental prices, strongly affected by inflation, become a crucial issue conditioning the establishment of a new independent household.[2] To sum up, the observed fertility postponement in this life cycle phase may have to do with the lagged formation of stable partnerships and to job and housing challenges, and not only with delayed parenthood and fertility preferences as such. The mature adult phase is characterized by consolidating the various life-cycle choices emerging during the previous phase. This occurs in tandem with more economic and housing security. Once in a stable union, these choices include progression to parenthood (versus opting for a "child free life") and progression to higher parities. On the other hand union break ups produce more time lost for procreation. It is also the life-cycle phase of reduced fecundity especially after age 35. In other words, this

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[2] A historical factor is at work here given the western custom of establishing nuclear households and avoiding extended ones with more than one married couple under the same roof. The latter were more common in Eastern Europe and the Balkans.

is the phase of fertility recuperation after the postponement period in the previous young adult phase. The question is whether or not fertility in these two phases keep each other in balance to produce a level trend on cohort final offspring versus a further drop in quantum.

The policy interventions facilitating the work-family balance deal with fertility once progression to parenthood comes on the horizon, not with the earlier phase of couple formation. We are referring here to pregnancy leave, maternity and paternity leaves, availability of child-care facilities, kindergarten enrollment, child allowances and tax deductions, availability of part-time work, etc. These supports, which are most developed in the Nordic countries, are not addressing the partnership, job and housing bottlenecks of the young adult phase of persons in their twenties.

Finally, more equity concerning gendered shares of housework has repeatedly been reported to support progression to parenthood and to higher parities during the fertility starting and recuperation phases. However, the "double female emancipation" (Goldscheider et al. 2015), i.e. at work and at home, has not been able to stem the steep drop of pre-30 fertility in the Nordic countries.

The ultimate correction phase after age 40 essentially deals with attempts to finally becoming a parent or to provide a sibling for an existing child. More often than not, long postponement leads to more medical interventions (Assisted Reproductive Technology, ART), but on the whole such assisted pregnancies are not numerous enough to raise the Cohort Total Fertility Rate (CTFR) to a significant extent (Beaujouan et al. 2023).

13.4 The post 2010 fertility decline observed through the life-cycle lens

The graphic representation of cumulated fertility according to the four life-cycle phases shows the importance of the postponement prior to age 30 and the size of subsequent recuperation after that age. The total is the Life-Cycle Total Fertility Rate (LCS-TFR), which is an excellent approximation of the real CTFR. The ongoing postponement, which can be followed to at least t=2019 for f(20-29,t) in the data set, illustrates the importance of the size of recuperation fertility needed to reach the more stable LCS-TFRs as they existed prior to 2009. In Figure 13.2 we have illustrated this for Belgium and The Netherlands and various other countries, starting with t=1999 for f(20-29,t).[3] Also, note that a dotted horizontal line at the LCS-TFR value of 1.5 is added so that one can readily see how much recuperation at the older ages would be needed to restore cohort fertility to that level.

The results of f(<29), defined as f(<20, t-5) + f(20-29,t), are reported in Table 13.1 for 32 countries, both in absolute numbers and in terms of percentage change between 2010 and 2019. The countries are grouped in larger regions. In the text further on, we shall continue to use the label "West" for Northern, Western and Southern countries together plus the US and Canada, and "East" for the Central and Eastern European countries (CEE). Data for Japan, South Korea and Taiwan are only shown for comparison.

The following conclusions can be drawn.

1. The overall fertility decline witnessed in the 2010-2019 decade has a major component in the form of a drop in teenage + young adult fertility. In other words, there has been no end to postponement. Instead, this decade is characterized by a new postponement wave.

2. The Baltic, Central and Eastern European countries have weathered the storm far better than those in the West, Canada and the USA included. Croatia is, however, a major exception among the CEE countries as it exhibits a large drop in young adult fertility.[4] On the whole there is a new East-West contrast, but the respective PTFRs have become more similar by 2019.[5] In other words, the convergence of PTFRs to values closer to the 1.4 to 1.6 range hides the East-West contrast in evolution with respect to the degree of the new fertility postponement.

3. The 2010-2019 postponement is particularly marked in several Nordic countries. Their generous family policies could not stop the overall fertility decline, because the new postponement is produced at an earlier life cycle phase where stable partnership formation, finding jobs and affordable

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[3] The full set going back two or three decades can be obtained from Krystof Zeman at Krystof.zeman@oeaw.ac.at.

[4] Croatia fits the western Mediterranean pattern. But it is unclear why it is an outlier in the set of CEE countries.

[5] The reductions of f(<30) in excess of 20 percent are all in the West-group, with Croatia being a CEE exception.

Figure 13.2: Cumulated fertility in the four life-cycle stages, 1999-latest. Various Western countries (Nordic, Western and Southern Europe, USA and Canada). Source: Vienna Institute of Demography, Human Fertility Database.

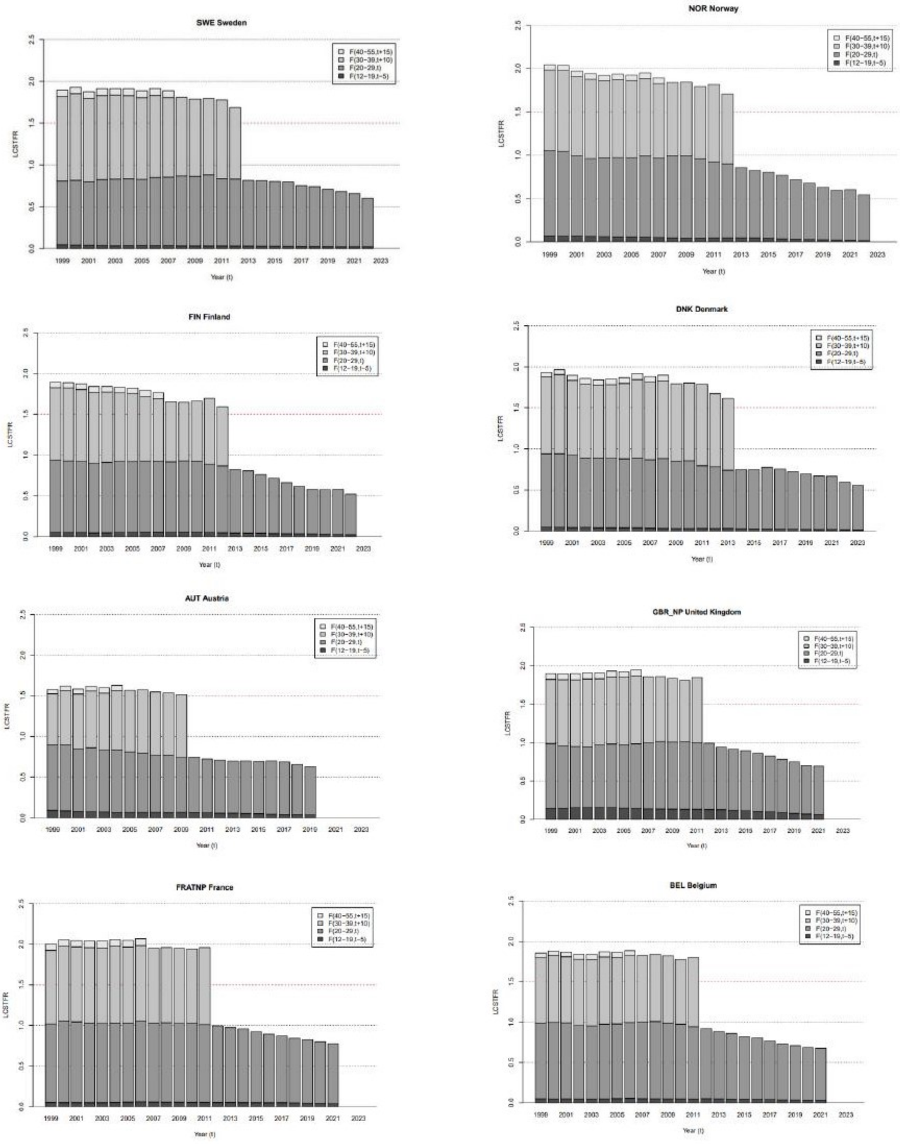

Figure 13.2: Cumulated fertility in the four life-cycle stages, 1999-latest (continued).

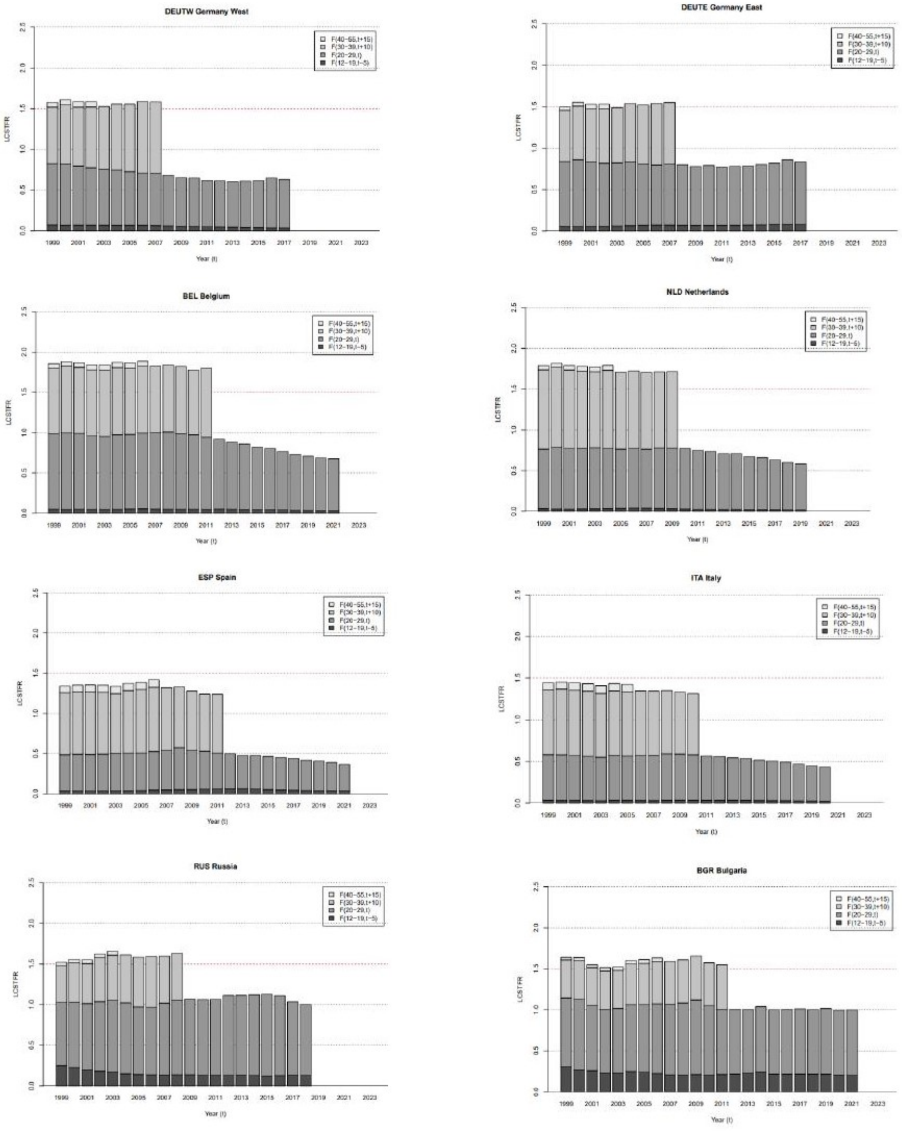

Figure 13.2: Cumulated fertility in the four life-cycle stages, 1999-latest (end).

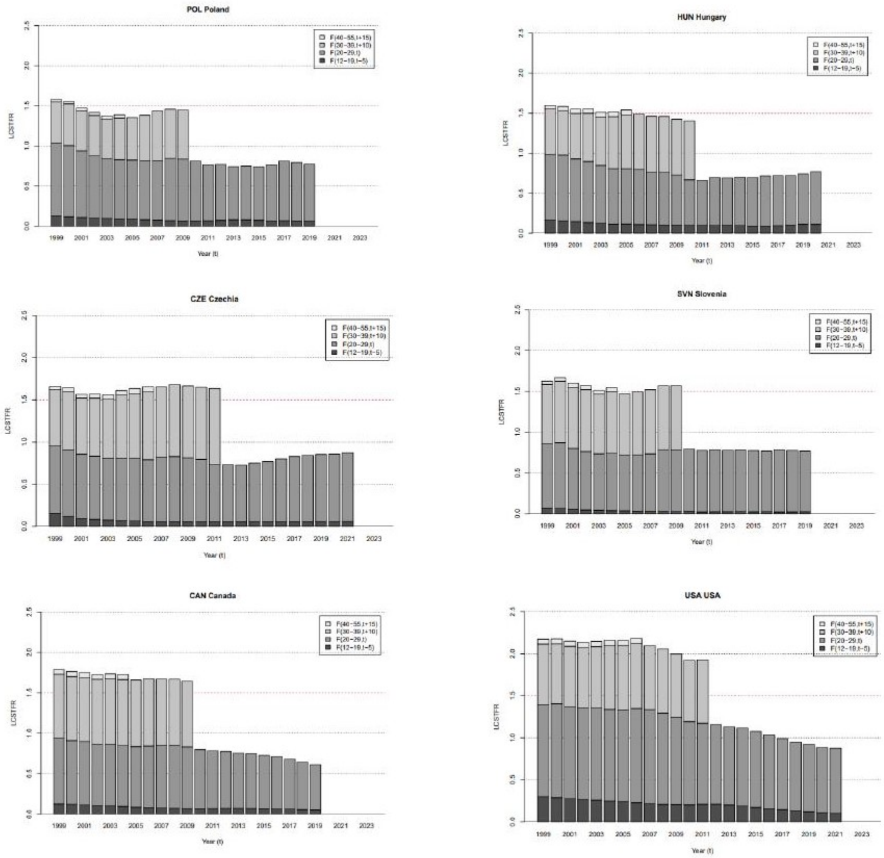

Table 13.1: Comparison of $f(< 29)$ across countries, 2010–2019

Country	$f(< 29)$ 2010	$f(< 29)$ 2019	PTFR 2019	Difference 2019-2010	% change 2010-2019
Western Europe					
- Belgium	0.97	0.71	1.60	-0.26	-27%
- France	1.03	0.83	1.83	-0.20	-19%
- United Kingdom	1.01	0.75	1.63	-0.26	-26%
- Ireland	0.79	0.55	1.71	-0.24	-30%
- Netherlands	0.77	0.58	1.57	-0.19	-25%
Northern Europe					
- Denmark	0.86	0.70	1.70	-0.16	-19%
- Finland	0.92	0.58	1.35	-0.34	-37%
- Iceland	1.13	0.80	1.74	-0.33	-29%
- Norway	0.96	0.63	1.53	-0.33	-34%
- Sweden	0.88	0.71	1.71	-0.17	-20%
German-speaking					
- Austria	0.75	0.63	1.46	-0.12	-16%
- Switzerland	0.61	0.49	1.48	-0.11	-18%
- Germany*	0.67	0.65	1.57	-0.02	-3%
- Southern Europe					
- Spain	0.53	0.41	1.23	-0.12	-23%
- Italy	0.58	0.45	1.27	-0.13	-23%
- Portugal	0.71	0.56	1.44	-0.16	-22%
Central Europe					
- Czechia	0.79	0.85	1.75	+0.06	+8%
- Estonia	1.00	0.81	1.66	-0.19	-19%
- Croatia	0.89	0.68	1.47	-0.21	-24%
- Hungary	0.67	0.74	1.49	+0.08	+11%
- Lithuania	0.94	0.79	1.61	-0.14	-15%
- Latvia*	0.80	0.89	1.69	+0.09	+11%
- Poland	0.81	0.78	1.41	-0.04	-5%
- Slovenia	0.80	0.77	1.61	-0.03	-3%
Eastern Europe					
- Bulgaria	1.05	1.02	1.58	-0.03	-3%
- Belarus*	1.06	0.93	1.45	-0.13	-12%
- Russia*	1.06	1.00	1.58	-0.06	-6%
North America					
- Canada	0.80	0.61	1.47	-0.18	-23%
- USA	1.19	0.92	1.70	-0.27	-22%
Other					
- Japan	0.64	0.52	1.34	-0.11	-17%
- Republic of Korea	0.48	0.22	0.92	-0.25	-53%
- Taiwan	0.43	0.38	1.05	-0.04	-10%

Note: * Last observation is 2017 for Latvia and Germany, and 2018 for Russia and Belarus.

housing are more central concerns. At that stage, parenthood and further procreation are not yet on the horizon among many young adults.[6]

4. Also the other Western and the three Southern European countries have major declines in fertility before age 30. The Nordic, Western European countries and the two North American ones have declines starting from higher levels, whereas the Southern ones started from already much lower levels in 2010. Only Germany seems to be the exception with a smaller change until 2017 (see also Bujard et al. (2022).

5. The postponement in the USA is a novelty as far as sheer size is concerned. It takes the US PTFR to below replacement level (PTFR = 1.65 in 2022).[7] This evolution marks the end of "American exceptionalism" in this respect. The US is also catching up with respect to increasing premarital cohabitation, parenthood among cohabitants, and lowering teenage fertility, so that it now produces a more classic "second demographic transition" profile (Lesthaeghe 2020).

6. The stronger the postponement in the 2010-2019 decade, the higher recuperation fertility has to be after age 30 to reach the LCS-TFR levels of the years prior to 2010. Fertility drops of 0.200 or more in the first two life cycle phases (see Table 13.1) form a major challenge, and may well cause a further reduction in LSC-TFRs when the cohorts reach age 40 or 45 (Beaujouan et al. 2023). Given the record of older adult recuperation fertility so far in the West (see Figure 13.2), the extra recuperation fertility may not materialise.

7. Last but not least, further increases in childlessness could also be expected (Sobotka 2017, Beaujouan et al. 2017).

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[6] A similar observation can be made for France and Belgium, which also have comprehensive policies re the work-family balance.

[7] In fact, six states had PTFRs in 2022 below 1.50: all five New England ones plus Oregon. Idem for Washington DC. Only a single state had a PTFR just over 2.0: North Dakota. Even Mormon Utah no longer made it to that level.

13.5 What are the causes of the new East-West divide? An exploration

The division between the stronger postponement versus the weak or no postponement countries essentially follows the former split between the western and the previously Communist countries. In what follows we shall examine six possible explanatory avenues that may account for the East-West contrast.

1. A first candidate is the still prevailing East-West difference with respect to the institution of marriage: the Eastern half is more conservative and this is reflected in various facets. Marriages are still occurring at younger ages, and cohabitation is considerable less prevalent than in the West. This also fits with the more conservative gender roles in most CEE countries (European Institute for Gender Equality (EIGE) 2023, Lomazzi 2022) [8] and the far lower degree of sexual permissiveness (Gelissen 2022). Equally striking is that attitudes toward childlessness are more conservative in the East than in the West (Szalma et al. 2025). Hence, these aspects may, at least partially, explain why there are more married couples in the age bracket prior to age 30 in the East who are already in the procreation phase and move faster to parenthood. This argument also implies that in the western half (not including the US) young adults take more time in forming stable couples before moving into the procreation stage. Persons could be remaining single on their own or in a parental household, in serial cohabitation, or in a trial cohabitation phase for a longer period. Note that Southern European countries (Italy, Spain, Portugal, Greece) and also Ireland have 70 to 82 percent of persons 20-29 still residing with parents, which produces a long delay in couple formation. However, it should be noted that these figures for Slovenia, the Slovak Republic and Poland are also of the order of 65 to 74 percent (OECD 2024), but marriage follows considerably faster upon home-leaving in these countries. This contrasts strongly with the very low

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[8] The European Gender Equality Index (EIGE 2023) shows a clear East-West contrast with only a tiny overlap: of the 13 countries in the West, 11 have scores of 70 or more (Italy and Portugal have less), whereas all 11 in the group East have scores below 70. The Gender Role Attitude GRA scores measured in the European Values Studies and reported by Lomazzi display a similar picture; of the 14 countries in the West, 11 have scores above unity (exceptions are Austria, Portugal and Italy), against only one of the 14 countries in the Group East (Slovakia).

prevalence of still living with parents in the Nordic countries amounting to merely 10 to 20 percent. These countries obviously have many more cohabiting couples. Ideally, the Nordic populations should have an advantage in having much longer exposures of living in couples, but they are presently increasingly failing to use this exposure advantage for procreation. On the whole, earlier schedules of marriage and parenthood in the East explain a part of the East-West contrast in the evolution of f(<30) between 2010 and 2019. Evidently, the mature adult phase comes earlier in the East, whereas the full SDT-package retards it in the West.

2. A second, and common, reason for further fertility postponement is rising enrollment in education in the age groups 20-24 (mostly full-time) and 25-29. The OECD provides enrollment rates in these age groups for full and part time students together, and for both in public and private schools; see OECD (2023). The results span the period from 2010 to 2021. Some East-West contrast emerges from the set of countries listed by the OECD. The overall increase for all European and the US plus Canada amounts to a modest 2 percentage points. The largest increases in the age group 20-25 emerged in Spain (+11 percentage points) and Ireland (+14). Eight more countries had enrollment increases of 5 percentage points or more. Hence, ten countries were in the West[9], and only one, i.e. the Czech Republic (+6), was in the CEE group. By contrast, six countries had enrollment reductions, four in the East (Estonia, Lithuania, Poland, Hungary) and two Nordic ones (Finland and Iceland). The overall picture is, however, not entirely consistent with the East-West fertility postponement contrast, and this is largely due to the evolution in the Nordic countries. In Finland and Iceland, the drop in f(<30) cannot be explained by any extension of schooling. Furthermore, the prolonged schooling argument is also very weak for Sweden (zero enrollment increase) and Norway (+2 percentage points only). The results for the age group 25-29 are mixed. The OECD total is as good as constant (+1 percentage point), and those with an increase

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[9] The western countries with 5 or more percentage points increases are: Austria, Belgium, Denmark, France, Germany, Ireland, Spain, Switzerland and the UK. The Czech Republic and Croatia were the only Central European ones in this category. Declines were found in Estonia, Hungary, Lithuania, Poland, Iceland, Finland and the USA. The Lithuanian decline was by far the strongest (-13 percentage points).

over 3 percentage points are five West and two Baltic countries. However, declines are found for 8 countries with an even split between East and West. The conclusion is that the expansion of education can be of significance in a few West countries, but nor in the Nordic ones, and also not in most CEE countries.

3. Another common explanation given for the new postponement points to employment insecurity (Matysiak & Vignoli 2024) In their comprehensive meta-analysis Alderotti et al. (2021) show that a main factor for starting parenthood is a stable employment status. Employment instability seems to have an increasing negative effect on starting parenthood over time and matters more for men. However, this negative effect is dampened in countries with strong social protection legislations, such as those in Nordic and several Western European countries. But can employment instability explain the observed East-West split concerning the new fertility postponement in the young adult phase? Firstly, labour market deregulations and the concomitant degree of job or income insecurity vary tremendously between countries. For instance, according to the latest OECD measurement of 2022 among respondents aged 25-54 (OECD 2023), job or income loss during the next two years were cited among the three most important future risks in less than 40 percent in the Netherlands, Switzerland, Norway, Belgium and Germany. By contrast, these percentages were above 60 in Italy, Spain and Portugal. Also, among the 21 countries (European + Canada and USA) in the 2022 OECD sample, the Baltic countries, Poland, Slovenia and Greece score noticeably higher than the western welfare states. Furthermore, countries in the CEE commonly have higher unemployment rates among persons younger than 30. Normally, they should all be scoring higher on employment insecurity in this age bracket too, and hence have the strongest new fertility postponement. Obviously, the opposite is true. Finally, according to these OECD measurements employment insecurity in the Nordic and western welfare states is evidently lower than in the US, which experienced the steepest drop in fertility since the Second World War. Alternatively, it could well be that countries should be considered separately so that not the level but the national trend in income insecurity could be the determining

factor.[10] Evidently more research will have to go into these questions before employment insecurity can be considered as the across the board explanation for the recent postponement phase in the West and not in the East. In short, the job or income insecurity argument is not a prime candidate to account for the East-West split concerning the 2010-2019 fertility postponement.

4. Stable couple formation and parenthood typically require adequate housing. This may be a temporary dwelling, but their availability and rental costs may have become an increasingly pressing problem, particularly in urban settings. Housing shortages and inflation could have produced a pattern of "housing insecurity". But again, would this be a less pressing issue in the eastern half of Europe? Would the housing issue be that much more dramatic in the Nordic countries? Eurostat (2024) provides figures of the evolution of house prices, rents and construction costs between 2010 and 2021. House prices were up 37 percent in the EU, and mostly in Estonia, Latvia, Slovakia, Hungary (East) and in Luxembourg, Austria, Iceland, Denmark, and Switzerland (West). By contrast, prices were stable in Spain, France and Germany. Prices dropped in Bulgaria, Romania, Hungary, Poland, Italy and Cyprus. Rents were up by 16 percent, and mostly in Estonia, Lithuania and Ireland. The inflation change ran roughly parallel to the increase in rents, i.e. 17 percent for the EU as a whole. Increases larger than 25 percent were recorded in Hungary, Romania, Estonia and Lithuania. By contrast, Greece and Cyprus but also Ireland had less than 10 percent inflation in the period 2010-2021. Construction producer prices rose by 25 percent in the EU, but most in Hungary, Romania, Latvia and Lithuania (over 50 percent). Again, with respect to these indicators, there is no clear East-West split, and, if anything, countries in the eastern half of Europe were worse off. In short, the East-West split witnessed in the evolution of fertility postponement during the young adult phase cannot be matched by the evolutions on the housing market. In fact, the amount of fertility postponement should be as strong or stronger in the CEE countries, and this is obviously not so. But the earlier caveat is equally applicable in

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[10] A recent Swedish study shows mixed results: an unemployment experience was unrelated to fertility intentions in the Gender and Generations surveys (GGS) of 2012 and 2023, and the relationship between fertility intentions and current unemployment insecurity was inconsistent with opposite results in the two GGS waves.

this context: housing conditions can constitute a relevant factor in specific countries. However, they cannot be used to explain the East-West difference in fertility postponement.

5. One should also note that combinations of structural factors need to be considered, rather than falling back on single factor explanations. Possibly, OECD indicators could be candidates for the exploration of such interacting combinations in specific countries.

6. Another line of thought concerns future fears about the fate of children and possibly about the ecology. The Pew Research sample of 2021 to 2022 reveals vast differences concerning the issue of "children now growing up will be worse off financially than their parents" (reported in OECD (2024). The two Central European countries in the Pew Research sample score very low on this fear, with less than 30 percent. By contrast the Southern European countries, and also Australia, Canada, the US and France score much higher, i.e. between 70 and 80 percent. The sample of countries is too small, but at least suggestive of the fact that there could be an East-West split in this respect. The "fear for the future" argument needs further study, including fears about the ecology. Furthermore the fear for the spreading of armed conflict may be an emerging factor after 2020, but this has to our knowledge not been picked up by the literature.

7. Last but not least, one may consider more cultural explanations, as for instance in line with the Second Demographic Transition (SDT) theory. The Inglehart index (Inglehart & Welzel 2005) of proportions stressing "self-expression" in the mid-1990s already displayed a very clear East-West split: all western and northern countries had scores between 0.65 and 0.95, with the Nordic countries in the vanguard.[11] There were simply no Central and East European cases in this interval. Closer to fertility is the fact that proportions of young women declaring to want a "child-free life" seem to be increasing. The "child-free life" option is certainly being de-stigmatised and has become an acceptable alternative (Miettinen & Szalma 2014, Szalma

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[11] "Self-expressive values" in Inglehart and Welzel capture the shift from collective discipline to individual autonomy, to cultural diversity and to self-realisation. These are precisely the props of the Second Demographic Transition (SDT) (Surkyn & Lesthaeghe 2004).

et al. 2025, Minkin et al. 2024). But equally importantly, the interim period of keeping an “open future”, free of irreversible commitments, is a very attractive proposition in consumer oriented “leisure societies”. The adagios are: “the more serious stuff can wait till later”, and, “enjoy life while you’re young and unburdened”. These rising hedonistic tendencies (cf. Leijen et al. (2022) are of course a recipe for further progression of fertility postponement. Moreover, in this context the current family policies are simply “not applicable”, no matter how generous they may be. They simply do not address the partnership, employment and housing bottlenecks during the young adult phase, nor do they take a major shift in tastes and preferences into account. These policies are essentially applicable and helpful during the fertility recuperation phase. This is yet another reason why the current overall “sudden” fertility decline after 2010, driven by falling fertility during the young adult phase, is not enigmatic in the Nordic countries .

13.6 Conclusion

The life-cycle perspective of fertility revealed that there has been a new postponement wave in the decade 2010-2019. The drop in young adult fertility exhibits a clear East-West split, with CEE countries exhibiting less or no postponement. By contrast, countries which by 2010 still had the higher period fertility levels (Nordic, Low Countries, France, UK and Ireland, US) exhibit the steepest drops in fertility prior to age 30. This brings their PTFRs in the vicinity of the levels of formerly lower fertility countries. Ideally reductions of 0.200 or more in young adult fertility will need to be neutralized by extra rises in the older adult recuperation phase, so that drops in cohort total fertility can be avoided. But this could be too optimistic an expectation.

Given their gender egalitarian culture and more developed family policies, the new fertility postponement wave during the 2010-2019 decade came as a surprise in the Nordic countries. Earlier predictions of Nordic robustness to fertility declines were swiped away. One thing is certain: the new Nordic parenthood postponement cannot be explained by increases in education length and enrollment. Other reasons for this development may well be that Nordic policies supportive of fertility only operate when a solid partnership has been formed and when parenthood is being considered. But in the young adult age group this may not yet be the case, and other pre-occupations may be more pressing concerning job security, low cost housing availability, or other consumption and leisure aspirations. Furthermore, recent micro-level research in three Nordic settings (Denmark, Finland, Norway) has revealed that the most gender egalitarian couples are not the ones with higher fertility aspirations, but, by contrast, contain those with the strongest preference for a child-free life (Begall & Hiekel 2025).

As far as the explanations of the East-West duality in young adult fertility postponement are concerned, the CEE countries mostly have earlier ages at marriage, less cohabitation and lower percentages out-of-wedlock births. They also have systematically lower gender egalitarian scores than the West (European Gender Equality Index European Institute for Gender Equality (EIGE) (2023), Lomazzi (2022). This facilitates an earlier transition to a stable relationship and parenthood, as a classic pattern of gender relations requires less bargaining. Hence, the overall more traditional partnership formation pattern of the CEE countries can partially explain the East-West contrast in f(<30), and their faster progression to "full adulthood". Obviously, more traditional and uneven gender relations may have the opposite effect later on, i.e. once parity progression comes into view.

There are three further explanations for fertility postponement: (i) prolonged education, (ii) employment insecurity and (iii) housing problems. The education prolongation factor is generally more important in the West than in the East. The fertility declines in Ireland and Spain, for instance, could be accounted for by substantial hikes in education enrollment. By contrast, the Nordic young adult fertility decline cannot be put on the account of education expansion as there was little or none in the period under consideration.

The other two structural explanations based on employment and housing insecurity respectively do not replicate the new East-West fertility contrast. The CEE countries are not better off in these respects. More often than not, the opposite holds. Possibly the expectations about the future of children matters more, and also the SDT explanation based on an interim unburdened consumerist period during the young adulthood ages remain in the running, especially in the more affluent societies.

There is a major caveat. The focus on the East-West postponement contrast, as done here, does by no means preclude that the structural explanations based on changing employment and housing insecurity could have a significant but specifically national effect in accounting for the decline from 2010 to 2019. It is, however imperative that the focus of further research is not on PTFRs as a whole, but on f(20-29), where the crucial structural and cultural prerequisites for progression to parenthood are being articulated. Finally, one cannot dismiss the effect of changing "tastes" and the further expansion of individual discretion in these respects. The obvious example is the rise of the preference for a child-free life. Consumerism and enjoying leisure are firmly on the list too, especially in the wealthier countries where more young people can afford these, and where job uncertainty is dampened by welfare state provisions.

The future for a trend reversal in fertility postponement seems to be further away than ever: the youngest cohorts raised with the social media explosion and with overall regression in school results, are not exactly well prepared for assuming adult commitments in the next decade.

Afterword

Beste Frans, Dear Frans,

I'm doing this in English because not only me but all the former IPD students and colleagues in Brussels would like to thank and honour you for being such a great and dedicated teacher ! What a great time this was when the first floor of the oval building (the "delice de dieu" box) on the VUB Etterbeek campus was filled with a worldwide sample of English accents. And with all these great individual persons behind these accents. I have missed them a lot, and I know you have too !

In addition, what a pleasure it has been to have you as a colleague during all these years including these during which you were at NIDI and in Groningen. Technical mastership and predelection for behavioural models were among your hallmarks that were widely appreciated by the field. Your mark on migration research is a lasting one too.

Hence, many big thanks, Frans, and all the best for Mieke and yourself in the coming years.

From one octogenarian to another,

Ron Lesthaeghe

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14 My friendship with Frans Willekens

John F. Long

I first met Frans in 1979 when I attended a short course that he and Andrei Rogers were presenting at IIASA. I had just accepted a position directing population projections activities at the U. S. Census Bureau and was intrigued by their classes in multistate demography. Frans made those classes interesting and was able to combine the technical training with a gift for forming a network of demographers from a wide variety of nationalities into a cohesive intellectual network.

I kept in touch with Frans after my return home. With Frans encouragement and support, we were able to develop close ties between government statistical officials and demographers in academic research to address complex forecasting issues. Frans was a visiting fellow at the U. S. Census Bureau and I was able to work at NIDI on short projects. During this period, the field of multidimensional population forecasting made major advances both in academic and official statistical circles – in no small part due to Frans' efforts.

As time went on, our interests broadened. I became chief of the Population Division at the U. S. Census Bureau and Frans took on more responsibilities and expanded his research interests.

We kept in touch professionally and met at many international professional meetings. Along the way, Frans and Maria became great friends of my wife Anamaria and me. We celebrated life events as our children grew. Frans and Maria even "attended "our 50th wedding anniversary in 2020 when Covid-19 converted that into a Zoom event.

Through it all, Frans remains an intellectual mentor, a valued colleague, and a close friend.

15 The first cohort of master students in demography and PhDs at the Population Research Center

Hideko Matsuo

Life is full of transitions and doing a master's and PhD in Groningen for me was certainly one of them. Back in the mid-1990s, I had a strong interest in pursuing a PhD. I graduated with my first master's in the US and had UN assignments in Low and Middle Income Countries (LMICs). I wanted to get solid quantitative skills and build up expertise in population research. I learned about the launch of the English Master in Demography program in Groningen. I soon got in contact with Frans and faxed him a letter (yes it was fax at that time). My original interest was to develop a research proposal on the subject of internal migration in the city of Shanghai. In the winter of 1998, I started enrolling in Frans' life history analysis course, and then Sergei's visual basic-based quantitative course as a trial which I, to be honest, somewhat survived, so then reapplied to formalize this training, by enrolling in the master's program. In this path, I reworked the research proposal turning the original Chinese proposal into a cross-national partnership and fertility research on Japan and Netherlands. The master's program (consisting of demographic theory, data collection, multistate modelling, demographic policy, population health modules, and research seminars) provided a solid foundation for the PhD demographic research resulting in a master's thesis co-supervised by Inge. This initial period was dedicated to sharpening the PhD research proposal: research questions (Frans always says!) and hypothesis, state of the art, novelty, feasibility, data source, methodology, work plan and table of contents, etc. which were all crucial components to start this PhD journey. Along with all these courses in master's in demography (1999-2001), I grew together with my Dutch and international cohort mates.

The experience at Groningen was very special and remains even vivid today. As the first cohort of master students in demography I was fully engaged in the globally oriented training of early career demographers, in the educational and research program. This consisted of seminars, academic events, and external research trips keeping Europe, Asia and LMICs in mind. Research activities were always accompanied by dining, a crucial component in socialization, including frequent meals at Frans' home where Maria had to cook large quantities. Also scientifically in the short period during the years 1999-2003, we traveled together, including to the US-PAA conferences preparing posters, presentations, etc., being directly exposed to frontier research. Our PAA trips visiting Atlanta, and Minneapolis provided great opportunities to present at scientific sessions. This was also accompanied by social activities visiting cities: I recall vividly visiting live blues in Minneapolis. Interactive social events were a crucial part of the PRC. All PhD defenses culminated in a big event characterized by scientific and social aspects, defending the PhD research before the jury committee, and ending with extended dinners. Here Dutch tradition continued ("stukje" choreographed and well-practiced) making the performance of singing, dance, etc., shedding light on the hidden talents of colleagues.

I believe the years of 1999-2003 coincided with important transition moments for Frans too. After 10 years of a professorship in Groningen, he took up an assignment to become the director of NIDI in 2003 resulting in de-facto Frans' departure from PRC. The first cohort of master's students of 1999 defended their PhD sequentially during that year. The rest of his excellent scientific trajectories are well-known to us: a subsequent scientific position as a research director of MPIDR resulting in international research collaboration published, awarded, and training in population modeling, multistate demography, in many PhD dissertations.

I have remained in close contact with Frans and Maria through professional and private encounters. Professionally, I got to follow his academic visits to UC Louvain-la-Neuve, KU Leuven taking forms of seminars including agent based modelling (ABM) or meeting him at EPCs. He was invited to organize the plenary session (leader) on methodology at the European Society of Historical

Demography (ESHD) in Leuven (2016), on the theme of "Innovating Historical Demography: The World and Europe".

Frans always used to say, 'In research, you never walk alone but you walk together' and that symbolizes what he has achieved in training and research, advancing the frontier of demographic research and beyond. These magnificent outputs are observed in his big garden in Mol, a beautiful tree where Maria and Frans originally planted the gift from PRC more than two decades ago during one of those social events. The small tree is now big, spreading over the terrain but also strongly and solidly rooted in the middle of the garden. The tree symbolizes the impact he has made and does not stop there. Indeed, and perhaps, also in life you never walk alone but you walk together. I am very proud to be one of the students of Frans studying at Groningen.

I like to end the essay by revisiting the text that we read together at the (another!) party of Frans' sabbatical leave to Leuven in 2001 organized by PRC.

Robert Frost: "The Road not Taken"

Two roads diverged in a yellow wood,
And sorry I could not travel to both
And be one traveler, long I stood
And looked down one as far as I could
To where it bent in the undergrowth;

Then took the other, as just as fair,
And having perhaps the better claim,
Because it was grassy and wanted wear;
Though as for that the passing there
Had worn them really about the same.

And both that morning equally lay
In leaves no step had trodden black.
Oh, I kept the first for another day!
Yet knowing how way leads on to way,
I doubted if I should ever come back.

I shall be telling this with a sigh
Somewhere ages and ages hence:
Two roads diverged in a wood, and I—
I took the one less traveled by.
And that has made all the difference.

Yes, Groningen was one of the two roads diverged in a wood, and I took the road that was less travelled by. Now I can truly say that for all that has made all the difference to me and to us all.

16 Lessen van leermeester Frans Willekens

Claartje Mulder

Ik heb niet bij Frans Willekens gestudeerd, heb geen scriptie bij hem geschreven, ben niet bij hem gepromoveerd, ben nooit collega van hem geweest aan dezelfde universiteit of hetzelfde instituut, en heb nooit samen met hem gepubliceerd. En toch beschouw ik hem als een van de belangrijkste leermeesters en inspirators die ik heb gehad. Hoe dat zo, dan? Wel, als een van mijn docenten aan de PostDoctorale Opleiding Demografie (voorloper van de European Doctoral School of Demography EDSD), heeft hij een vormende rol voor mij gespeeld. En ook daarna heb ik van alles van hem geleerd. Ik vat een paar belangrijke lessen samen.

Gebeurtenissenanalyse (event history analysis, hazard models) is een belangrijke techniek voor het analyseren van het optreden van gebeurtenissen. Frans heeft mij ingewijd in de wereld van de gebeurtenissenanalyse en mij daar enthousiast voor gemaakt. Ik herinner me de fascinatie voor deze techniek: o wauw, dit wil ik gaan gebruiken. Ik gebruik de techniek nog altijd regelmatig.

Migratie is instrumenteel gedrag. Migreren doe je niet zomaar: het dient om een ander traject in de levensloop te faciliteren. In mijn zoektocht naar een theoretisch kader voor mijn proefschrift was dit inzicht, dat Frans mij bijbracht, een cruciale eye-opener. Het is een simpel inzicht, maar juist de simpele inzichten zijn soms het meest inspirerend.

De rol van parallelle carrières kan de vorm aannemen van status-afhankelijkheid of gebeurtenis-afhankelijkheid. Het was Frans die mij het belang van het onderscheid tussen status-afhankelijkheid (state dependence) en gebeurtenis-afhankelijkheid (event dependence) heeft bijgebracht. Dit onderscheid heeft mij de inspiratie ge-

geven voor mijn allereerste wetenschappelijke artikel, in European Journal of Population 1993, geschreven samen met Michael Wagner. Het had een methodische insteek: de ondertitel was *a method for studying synchronized events*. Dat durfde ik zomaar, als jonge promovendus. Misschien heb ik die durf ook wel bij Frans opgedaan.

De senior trakteert. Bij de sociale bijeenkomsten rondom de PDOD was Frans altijd aanwezig. Daar deed hij een boekje open over wat er achter de schermen gebeurt in de wetenschappelijke wereld. En als er betaald moest worden, trok hij de portemonnee. Ik heb dit opgevat als een belangrijk symbool. Als senior ben je niet alleen een wetenschappelijke mentor voor promovendi, maar ook een sociale.

Ge kiest niet uw problemen, maar ge kiest wel hoe ge ermee omgaat. Deze zin, die Frans in mijn herinnering letterlijk zo heeft uitgesproken, was voor mij een heel belangrijke levensles. Korter dan zo kun je de belangrijkste lessen van de stoïcijnen, Stephen Covey en vele anderen niet samenvatten.

Groningen is zo gek nog niet. Het was Frans die mij, samen met Inge Hutter, enthousiast maakte voor een hoogleraarspositie in Groningen. Mede dankzij hem heb ik mijn geliefde Amsterdam achter me gelaten voor een provinciestad die weliswaar niet alles heeft wat de hoofdstad heeft, maar waar het leven aangenaam langzamer gaat, de omgeving rustiger en groener is en de omgangsvormen vriendelijker zijn.

Frans, heel veel dank voor alle levenslessen en inspiratie. Je weet niet half hoe belangrijk je voor me bent geweest.

17 "The beauty of demography", and an effort to sell this to the public

Nico van Nimwegen

The term “beauty of demography” is vintage Frans Willekens, a demographer who is passionate about our discipline. We used it (in Dutch “de pracht van demografie”) in a family chronicle that was published at the occasion of the 40th anniversary of NIDI.[1] Frans was director of NIDI, and I was his deputy. In search of a way to celebrate this event it was decided to commission a literary work by a professional writer that would highlight the leading theme of NIDI’s scientific work, the Life Course. The book would be a sort of birthday present in reverse, a present from NIDI to Dutch society, and I vividly remember our first discussion with the free-lance journalist and aspiring essayist, Truska Bast, who had been recommended by a bestselling colleague novelist.

Not surprisingly the author knew nothing about demography and was overwhelmed when Frans explained the many ramifications of state-of-the-art life course research, its rich data sources and methods, its linkages to population dynamics and not to forget its multiple causes and consequences. NIDI colleague Frans van Poppel and I also added our bits to this brief but intensive lecture on NIDI’s takes on life course demography, no doubt raising the stakes (and anxieties) for the author. In the end our question to her was clear: how best to highlight and open this beauty of demography as we see it at NIDI in a literary way to a large

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[1] Truska Bast, En zij die na ons komen. Kleine kroniek van drie Nederlandse families. Nieuw Amsterdam, 2010.

audience? Not afraid to muddy the waters with some more questions, we added if it would also be possible to include some background statistics to the novel for some context, and add some historical perspective as well and what about a longitudinal approach and some core bibliography?

To cut a longer story short, we did manage not to scare the author too much! Subsequent discussions with the publisher made it clear to us that we had to make up our minds: either we would commission a work of literature and go with the literary publisher, or we should write a scientific publication ourselves (and find of course another publisher). Our choice was unanimous and so Truska set out to write a great chronicle of three Dutch families, retracing their life events and linked lives over almost a century, painting a vivid picture of societal and family change in the Netherlands. The book was well received and did fine in book sales as well. Did it open the beauty of demography to the public? We like to think so (and yes, we managed to convince the publisher to add a few pages that we wrote ourselves on the beauty of our trade).

All this to say that Frans, as a passionate demographer, has always been open to novel approaches and new insights. He is also persistent and creative in his efforts to share his love for our trade with others, as a leader, educator, mentor, and colleague. It has been a privilege to witness and be part of this from close, living our motto “never a dull moment”!

All the best Frans!

Afterword

NIDI is our common ground; we were colleagues here from the early 1980s when Frans was Deputy Director. After Frans left NIDI our paths kept crossing. We were re-united when Frans was appointed NIDI Director and led the institute from 2003-2010 and, in my turn, I was his deputy director until his retirement. Currently we are both Honorary Fellows at NIDI.

18 Estimating origin-destination patterns of migration

James Raymer

Abstract

Multiregional demographic models require information on the spatial patterns of migration by age and sex. While these models have been shown to produce more accurate and less biased population projections, a major hindrance to their application has been the absence or poor quality of data on migration flows by origin, destination and other characteristics. Starting in the late 1970s, Frans Willekens developed a range of models to estimate or update migration flows for the purpose of spatial population analysis. In this paper, I review this work and then demonstrate how iterative proportional fitting and log-linear models can be applied to estimate patterns of internal migration, using data from Australia. The paper ends with a discussion highlighting the importance of Willekens' contributions to migration estimation and usage of multiregional demography as a framework for understanding spatial population change.

18.1 Introduction

A long-standing problem in demography is the analysis and projection of subnational areas. Most countries in the world do not contain an abundance of data that are available and reliable. Even for those that have data and sophisticated administrative data systems, their national statistical offices may struggle to make sense of the differing patterns and 'randomness' that occurs when analysing or projecting populations in small geographic areas. Typically, the most challenging aspect of any subnational analysis is understanding the contributions that migration makes towards population change. For this, international and internal migration data are needed. Moreover, some details about the migrants, such as their origin, destination, age, sex and/or other characteristics (e.g., education level) are often required.

During the 1970s, Willekens worked with Andrei Rogers as a researcher to apply and further develop the field of multiregional demography, following the publication of several books introducing the ideas and mathematics to regional planners and demographers (Rogers 1968, 1971, 1975, Willekens & Rogers 1978). While still working on his PhD in Urban Systems Engineering and Policy Planning at Northwestern University, he followed Rogers to the International Institute for Applied Systems Analysis (IIASA) to conduct research on spatial population dynamics in the Human Settlements and Services Area. One of the main objectives was to apply multiregional demography to project subnational populations across a wide range of countries, which required origin-destination flows of migration by age and sex as inputs. This led Willekens on a path towards pioneering methods to estimate migration flows and their characteristics using entropy maximization, iterative proportional fitting, gravity models and log-linear models (Willekens 1977, 1982, 1983, Willekens et al. 1979).

My own research has been greatly inspired by Willekens' research on estimating migration flows. Indeed, my efforts in the indirect estimation of internal migration (Raymer & Rogers 2007), estimating international migration in Europe (Raymer 2007, Raymer, De Beer & Van der Erf 2011, Wiśniowski et al. 2016), combining census and registration data to estimate detailed migration flows in England (Raymer et al. 2007, Smith et al. 2010, Raymer, Smith & Giulietti 2011), projecting and forecasting internal migration (Raymer et al. 2006, 2017, 2020), and estimating international migration flows in the Asia-Pacific region (Raymer et al. 2019, 2022, Shen et al. 2024) are all direct extensions of Willekens' original ideas and models. In all of these efforts, migration data are represented as cross-classified tables of counts by origin, destination, age, sex, and other characteristics. Each of these tables contains structures that are both essential and not-so-essential to the migration patterns. Log-linear models and iterative proportional fitting are the techniques that I have most used to bring together various data structures that have been observed or inferred. In this contribution, I interchange the two models as they produce identical results.

18.2 Review of Willekens' work on modelling migration patterns

Willekens pioneered the modelling of migration flows for use in subnational population projections. Early developments contributed towards the application of multiregional demography to compare and contrast demographic changes occurring across 139 regions in 17 countries as part of the Migration and Settlement Task led by Andrei Rogers at the International Institute of Applied Systems Analysis in Laxenburg, Austria (Rogers & Willekens 1986).

18.2.1 Estimation

When attempting to apply multiregional demography, one of the main obstacles was the absence of origin-destination-age-sex tables of internal migration. Often only partial information was available such as total in-migration or total out-migration (or even worse, just net migration totals). To overcome data limitations, Willekens searched for methods that could infer the origin-destination flows based on aggregate data. For example, as described in Willekens (1977), age and sex patterns of migration between the nine Belgian provinces were not available from the 1970 census data. However, he was able to obtain some published age and sex patterns of total out-migration and total in-migration, from which he could then infer the age and sex patterns for origin-destination flows. In Willekens et al. (1979), models were assessed using data from Austria and Sweden before using them to infer the internal migration patterns in Bulgaria.

Not only did Willekens show us how to estimate detailed patterns of migration and compare the results using empirical examples, he provided the mathematical theory underlying the models and clarified the relationships between different and competing spatial interaction models (Willekens 1977, 1982, 1983, 1999, Willekens et al. 1979). The spatial interaction models included entropy maximization, proportional adjustment (also known as iterative proportional fitting, RAS algorithm, raking, and matrix scaling), gravity models, log-linear models and the

EM algorithm. Finally, Willekens explained how spatial interaction models could be used to create complete and consistent data systems for migration flows by combining data from different sources, including expert judgements, using the US Census and European migration as examples (Willekens 1994, 2019).

18.2.2 Forecasting

Willekens also made contributions to migration forecasting. Specifically, he showed the importance of identifying key structures in migration flow tables and designing forecasting methods specific to each structure. For example, in Willekens & Baydar (1986), generalized linear models (GLMs) were used to forecast internal migration in the Netherlands based on data gathered from 1958 to 1982. Here, they showed that the spatial patterns of migration, after controlling for overall levels of migration, were remarkably stable. They used a multiplicative model that distinguished the overall level, generation, and distribution of migrants (Willekens & Baydar 1986, p. 207), i.e.,

$$m_{ijt} = N_t w_{it} p_{ijt} \tag{18.1}$$

where N_t is equal to the total number of migrations during year t (i.e., overall level component), $w_{it} = m_{it}/N_t$ or the probability that a migration originates from region i during year t (i.e., generation component), and $p_{ijt} = m_{ijt}/m_{it}$ or the probability that a migration originating from region i ends in region j during year t (i.e., distribution component). To produce forecasts, a time series model can be specified for each component. In my own research, I borrowed from these ideas and expanded on them to project internal migration in Italy (Raymer et al. 2006), test different time series forecast models for internal migration in Australia (Raymer et al. 2020), and to produce indirect estimates of international migration in the Asia-Pacific region (Raymer et al. 2022).

18.3 Illustration: Estimating detailed patterns of internal migration in Australia

In this section, iterative proportional fitting is used to estimate internal migration for specific country of birth groups in Australia. For the purposes of illustration, internal migration patterns across eleven regions for persons born in Australia, China or India are examined. The data were obtained from the 2021 Census from the Australian Bureau of Statistics and are presented in Table 18.1. The Australian internal migration data is measured using census questions on place of current residence by place of residence five years prior to the census. These data represent transitions from one region of residence to another and exclude those who died during the five-year interval and those under the age of five years at the time of the census.

The models we test for each population group include the quasi-independence model, a log-linear with offset model that uses 1981-1986 and 2011-2016 migration data from the 1986 and 2016 Censuses, respectively, and a log-linear with offset model that uses 2016-2021 Australia-born migration data to estimate the corresponding data for persons born in China or India. In each case, we assume the in-migration and out-migration totals are known. The models are assessed in Section 18.3.4 using the coefficient of determination (R^2) and Chi-square (χ^2) statistics.

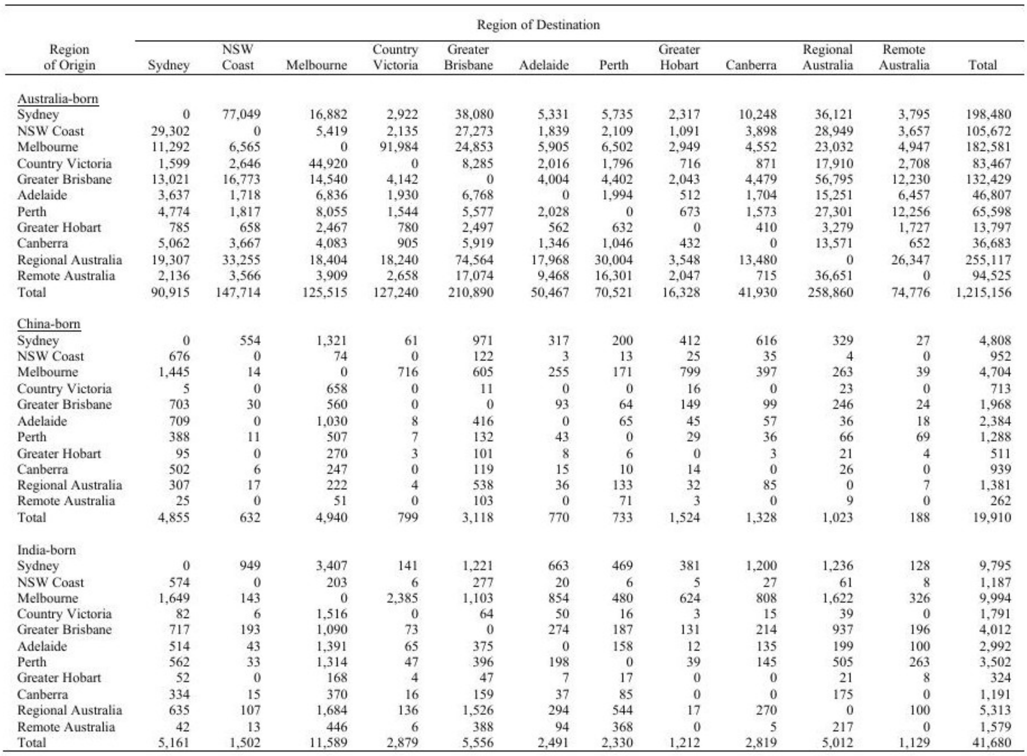
18.3.1 Log-linear with offset model: quasi-independence

Migration flow tables differ from other categorical tables in that they are square tables with diagonal elements that contain movements within the region and/or persons who have not moved. To focus on cross-border patterns, which are captured in the off-diagonal elements of the table, diagonal elements are often removed with the cells either left blank or replaced with structural zeros. A standard independence model predicts migration for all cells based on the marginal totals in the table. This model in log-linear format is specified as:

$$ln(\hat{n}_{ij}) = \lambda + \lambda_i^O + \lambda_j^D, \tag{18.2}$$

where $\hat{n}_{ij}$ denotes the estimated migration from origin i to destination j, λ is the overall effect, λ_i^O is the main effect for origin, and λ_j^D is the main effect for destination.

Table 18.1: Internal migration by regions of origin and destination for persons born in Australia, China or India, Australia 2016–2021.



	Region of Destination											
Region of Origin	Sydney	NSW Coast	Melbourne	Country Victoria	Greater Brisbane	Adelaide	Perth	Greater Hobart	Canberra	Regional Australia	Remote Australia	Total
Australia-born												
Sydney	0	77,049	16,882	2,922	38,080	5,331	5,735	2,317	10,248	36,121	3,795	198,480
NSW Coast	29,302	0	5,419	2,135	27,273	1,839	2,109	1,091	3,898	28,949	3,657	105,672
Melbourne	11,292	6,565	0	91,984	24,853	5,905	6,502	2,949	4,552	23,032	4,947	182,581
Country Victoria	1,599	2,646	44,920	0	8,285	2,016	1,796	716	871	17,910	2,708	83,467
Greater Brisbane	13,021	16,773	14,540	4,142	0	4,004	4,402	2,043	4,479	56,795	12,230	132,429
Adelaide	3,637	1,718	6,836	1,930	6,768	0	1,994	512	1,704	15,251	6,457	46,807
Perth	4,774	1,817	8,055	1,544	5,577	2,028	0	673	1,573	27,301	12,256	65,598
Greater Hobart	785	658	2,467	780	2,497	562	632	0	410	3,279	1,727	13,797
Canberra	5,062	3,667	4,083	905	5,919	1,346	1,046	432	0	13,571	652	36,683
Regional Australia	19,307	33,255	18,404	18,240	74,564	17,968	30,004	3,548	13,480	0	26,347	255,117
Remote Australia	2,136	3,566	3,909	2,658	17,074	9,468	16,301	2,047	715	36,651	0	94,525
Total	90,915	147,714	125,515	127,240	210,890	50,467	70,521	16,328	41,930	258,860	74,776	1,215,156
China-born												
Sydney	0	554	1,321	61	971	317	200	412	616	329	27	4,808
NSW Coast	676	0	74	0	122	3	13	25	35	4	0	952
Melbourne	1,445	14	0	716	605	255	171	799	397	263	39	4,704
Country Victoria	5	0	658	0	11	0	0	16	0	23	0	713
Greater Brisbane	703	30	560	0	0	93	64	149	99	246	24	1,968
Adelaide	709	0	1,030	8	416	0	65	45	57	36	18	2,384
Perth	388	11	507	7	132	43	0	29	36	66	69	1,288
Greater Hobart	95	0	270	3	101	8	6	0	3	21	4	511
Canberra	502	6	247	0	119	15	10	14	0	26	0	939
Regional Australia	307	17	222	4	538	36	133	32	85	0	7	1,381
Remote Australia	25	0	51	0	103	0	71	3	0	9	0	262
Total	4,855	632	4,940	799	3,118	770	733	1,524	1,328	1,023	188	19,910
India-born												
Sydney	0	949	3,407	141	1,221	663	469	381	1,200	1,236	128	9,795
NSW Coast	574	0	203	6	277	20	6	5	27	61	8	1,187
Melbourne	1,649	143	0	2,385	1,103	854	480	624	808	1,622	326	9,994
Country Victoria	82	6	1,516	0	64	50	16	3	15	39	0	1,791
Greater Brisbane	717	193	1,090	73	0	274	187	131	214	937	196	4,012
Adelaide	514	43	1,391	65	375	0	158	12	135	199	100	2,992
Perth	562	33	1,314	47	396	198	0	39	145	505	263	3,502
Greater Hobart	52	0	168	4	47	7	17	0	0	21	8	324
Canberra	334	15	370	16	159	37	85	0	0	175	0	1,191
Regional Australia	635	107	1,684	136	1,526	294	544	17	270	0	100	5,313
Remote Australia	42	13	446	6	388	94	368	0	5	217	0	1,579
Total	5,161	1,502	11,589	2,879	5,556	2,491	2,330	1,212	2,819	5,012	1,129	41,680

To prevent the model from considering the diagonal elements, we need to tell the model to not include flows where i is the same as j, or places in the table that migration does not occur. We can do this by adding an offset to the above log-linear model:

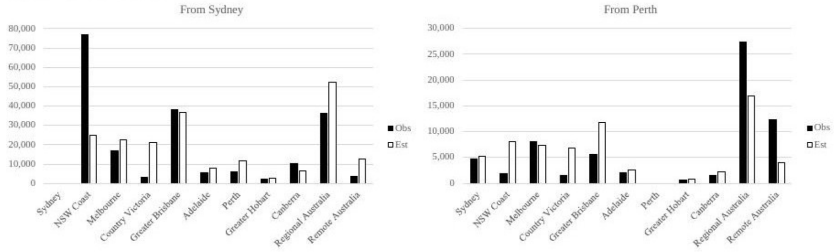
$$ln(\hat{n}_{ij}) = \lambda + \lambda_i^O + \lambda_j^D + ln(m_{ij}), \tag{18.3}$$

for $i \neq j$, where $i = 1, \ldots, R, j = 1, \ldots, R$, m_{ij} is the offset, and R is the number of regions in the table. To estimate the quasi-independence model, the offset is specified to include the same values in all of the off-diagonal cells (typically the value of 1). This model assumes independence but excludes cells where $i = j$. The quasi-independence model is discussed in Willekens (1983, pp 199-200), and Agresti (2002, pp. 423-428).

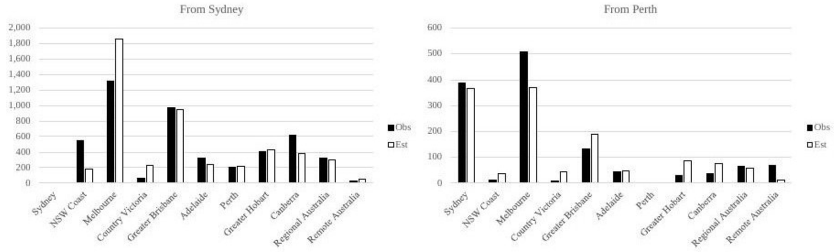
In Figure 18.1, we compare the observed migration transitions from the cities of Sydney and Perth to other cities and regions in Australia with the corresponding estimated transitions using a quasi-independence log-linear model. As the model does not include any spatial interaction information, it tends to underestimate transitions between neighbouring regions (e.g., Sydney and NSW Coast, and Perth and Regional and Remote Australia). This is because the only information used is total out-migration and total in-migration.

Figure 18.1: Comparison of observed internal migration flows from Sydney and Perth with estimated flows using a quasi-independent log-linear model: Persons born in Australia, China or India, 2016-2021.

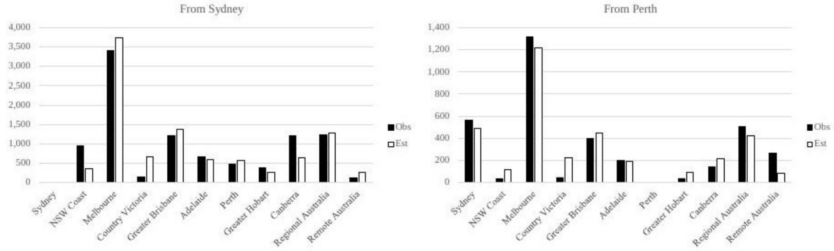
A. Born in Australia



B. Born in China



C. Born in India



18.3.2 Log-linear with offset model: historical data

The offset in Equation 18.3 can also be used to incorporate auxiliary information, such as a historical table of migration from a previous census or a table of migration obtained from another data source. To illustrate the use of auxiliary information, internal migration transitions for persons born in Australia and China are estimated using historical census data on their migration patterns. In this case, two historical matrices were used as offsets: migration that occurred during the 1981-1986 period and migration that occurred during the 2011-2016 period.

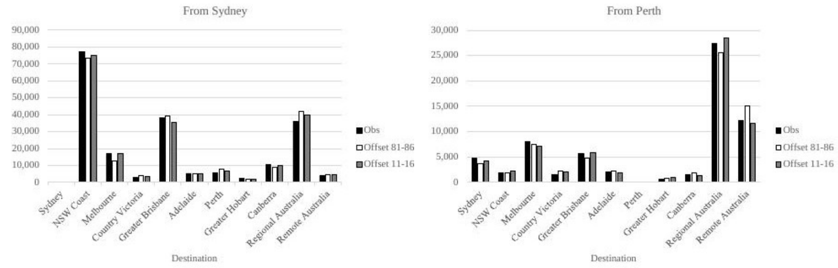
The results of the log-linear models with historical data used as offsets are presented in Figure 18.2 for migration from Sydney and Perth, along with the corresponding observed values. Here, we see that the estimates for the Australia-born migration transitions closely resemble the observed patterns with only a slight improvement exhibited by the model using the 2011-2016 migration transitions as an offset. For China-born population, on the other hand, the model that used the 2011-2016 transitions as an offset produced estimates that were much closer to the observed patterns than the model that used 1981-1986 as offset. This is not surprising considering the great changes that have occurred with the China-born population over time. In 1986, there were very few persons living in Australia that were born in China relative to 2016.

18.3.3 Log-linear model that uses Australia-born data as an offset

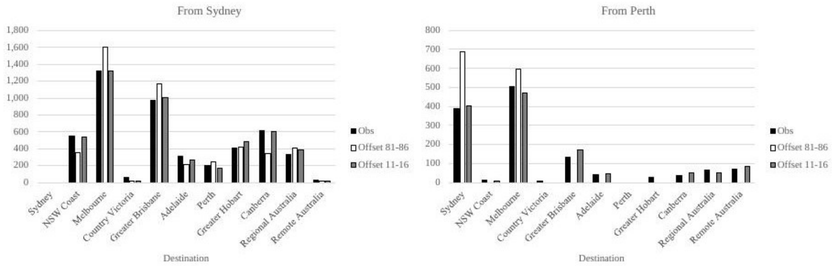
As a third illustration, the internal migration patterns of persons born in China or India during the 2016-2021 period are estimated using (1) the observed totals of in-migration and out-migration and (2) an offset representing the spatial patterns of migration of persons born in Australia during the same time period. This approach may be useful if detailed information is unavailable for specific population groups. Of course, here the assumption is that the spatial patterns of migration for the total population, or in this case the majority population, are similar to those for minority populations. The results from the log-linear models using the 2011-2016 migration transitions of the Australia-born population as an offset to predict the 2011-2016 migration transitions for the China-born or India-born populations are presented in Figure 18.3. Here, we see there are some noticeable differences, such as migration from Sydney or Perth to Greater Brisbane, that suggest that the spatial

Figure 18.2: Comparison of observed internal migration transitions from Sydney and Perth with estimated transitions using historical data as offsets: Persons born in Australia or China, 2016-2021.

A. Born in Australia



B. Born in China



patterns of migration for the population born in Australia are substantially different from the populations born in China or India.

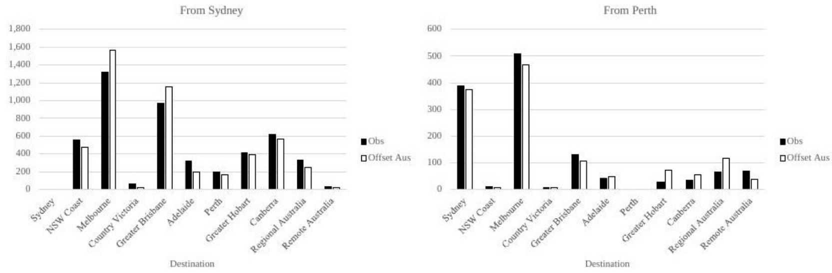
18.3.4 Summary

In Table 18.2, the coefficient of determination (R^2) and chi-square (χ^2) goodness-of-fit indicator are presented to assess the various log-linear with offset models used to estimate the spatial patterns of Australia-born, China-born and India-born internal migration in Australia during the 2016-2021 period. Clearly, the quasi-independence model does not perform as well as models that use either historical data or other birthplace group data as offsets. Still, the quasi-independence models do explain about 50-80 percent of the variation in the observed data.

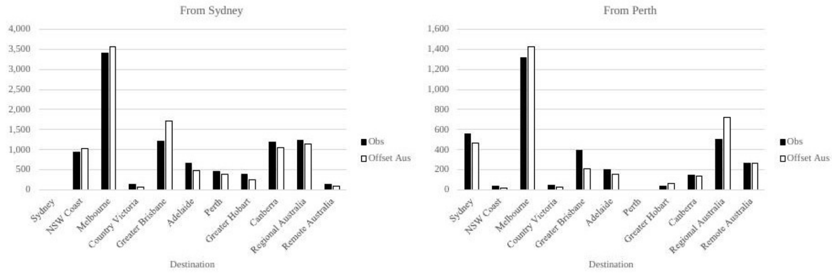
For the models that use historical data, using more recent data as an offset resulted in considerably better fits. For the Australia-born patterns, there was a

Figure 18.3: Comparison of observed internal migration transitions from Sydney and Perth with estimated transitions using Australia-born data as offsets: Persons born in China or India, 2016-2021.

A. Born in China



B. Born in India



small improvement in the R^2 values from 0.99 to 1.00; there was a more noticeable effect when using the χ^2 measure, which decreased from 19,112 to 4,632. For the China-born patterns, the R^2 increased from 0.86 to 0.98 and the χ^2 decreased from 4,922 to 1,114. In the 1980s, there were relatively few persons born in China living in Australia; migration from China increased greatly after the year 2000.

For the models that used Australia-born migration patterns to estimate the spatial patterns of China-born internal migration, the results were much better than the models that assumed quasi-independence and used the 1981-1986 patterns as offsets – but not quite as good as those that used the recent historical data (i.e., 2011-2016 migration patterns) as offsets. This makes sense as origin-destination flows of migration are fairly stable over short periods of time, and we normally expect migrants to have more concentrated residential distributions than persons born in the country – and, consequently, somewhat different spatial patterns of internal migration.

Table 18.2: Goodness-of-fit indicators for log-linear with offset models used to estimate the spatial patterns of 2016-2021 migration transitions.

		Model			
Goodness-of-fit indicator	Birthplace	Quasi-Independence	1981–86 offset	2011–16 offset	Australia-born offset
R^2	Australia	0.49	0.99	1.00	—
	China	0.79	0.86	0.98	0.95
	India	0.80	—	—	0.94
χ^2	Australia	728,204	19,112	4,632	—
	China	7,728	4,922	1,114	1,490
	India	11,893	—	—	3,091

18.4 Discussion

In this short paper, I have focused on the contributions Willekens has made towards modelling origin-destination flows of migration for the purposes of demographic analyses. Illustrations using Australian data on internal migration data of persons born in Australia, China or India allowed us to examine how one could model the observed patterns using three different types of auxiliary data: (1) assuming quasi-independence, (2) using historical data, and (3) using data from the majority population group.

Modelling origin-destination patterns of migration is highly relevant today as both internal and international migration are known to greatly influence population change — yet our data for integrating these flows into our population models and forecasts are still greatly limited (Willekens 2016). Moreover, as countries are increasingly turning to administrative data to augment or replace traditional data gathered by censuses and surveys, we need models that allow us to combine migration data from different sources to both strengthen the quality of the information, as well as to overcome data measurement issues, including inadequate coverage or missing data. Fortunately, Willekens has set the foundation for how we can systematically bring this information together in a meaningful way for both analyses of migration and for spatial population estimation.

Afterword

I was introduced to Frans Willekens in 1997 by Andrei Rogers soon after starting a Master of Arts degree in the Department of Geography at the University of Colorado Boulder. Andrei Rogers supervised both of our PhDs but many years apart. Since our first meeting, we have remained in close contact and collaborated on several research projects that have resulted in workshops, journal articles and a co-edited book. Throughout my academic career, he has mentored and inspired me.

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19 Learning Multistate Population Analysis through Working with Frans Willekens

Philip Rees

Abstract

The chapter celebrates the 80th birthday of Frans Willekens by describing our collaboration in understanding the role that the measurement of migration has in the design of sub-national population forecasting. It also suggests further research questions about the interaction between migration and climate change which Frans might wish to address in his eighties.

19.1 Introduction

Frans' career in demographic research spans five decades. I will touch on just a small part of his stellar output in this review.

This chapter is divided into three further sections. The second examines our collaboration in the 1970s and 1980s, identifying our research innovations and assessing the extent they have been built into demographic practice or not. The third section describes the improvements made to multistate population analysis through linking it with demographic accounts. The fourth section speculates about what research questions Frans might wish to work on in his eighties.

19.2 Multiregional/Multistate Population Modelling

19.2.1 The Origins of Multiregional Population Modelling

The term “Multiregional” was applied in the 1970s and 1980s to the modelling of regional populations within countries. It has since been applied to countries or to other population characteristics such as marital or health status and renamed more generally as “multistate” modelling.

Andrei Rogers first developed the multiregional population model as a projection tool in the late 1960s at the University of California at Berkeley (Rogers 1968). At Northwestern University, Evanston, Illinois, the model was extended and refined in collaboration with doctoral students Frans Willekens, Jacques Ledent and Luis Castro. In the early 1970s, the team moved to IIASA when Andrei became Leader of the IIASA Population Programme. There Andrei and Frans led the Migration and Settlement Study which aimed to demonstrate the international applicability of multiregional demographic analysis. They recruited demographic researchers from each of the 17 countries which were funders of IIASA.

19.2.2 Spatial Population Analysis, 1977 and 1978

Frans had noticed that Alan Wilson and I had published several papers linking the multiregional methodology to population accounting, summarised in book form (Rees 1977). In the next year, Frans and Andrei published an IIASA Research Report, Willekens & Rogers (1978), also named Spatial Population Analysis (SPA), but with the crucial addition of Methods and Computer Programs. When Frans asked me to join the Migration and Settlement project and author the United Kingdom (UK) national report, I accepted immediately.

19.2.3 The Migration and Settlement Project: Comparing across 17 Countries

My task was to supply the necessary UK demographic inputs to his software for implementing multiregional population projections. Frans provided encouragement and guidance on what data were needed and how to interpret the results. Willekens & Rogers (1978) provided a full description of the multiregional model, a detailed specification of the data inputs and the code for implementation. It serves as a shining example of how to document a methodology.

19.2.4 The UK Case Study

The data needed for the UK Migration and Settlement Case study (Rees 1979) were transcribed from official published tables of official statistics into the format for the Computer Programs and prepared as a set of punched cards. Frans fed the cards into the IIASA mainframe computer, ran the code and returned results to national collaborators. They were funded to attend meetings to discuss the results. It was a surprise that my UK case study (Rees 1979) was the first report in the IIASA series, as there was keen competition between the 17 authors. Thank you, Frans!

19.3 Improving the multistate population projection model

19.3.1 Clarifying the Distinction between Migration as an Event and as a Transition

Migration is the demographic event of moving from one usual residence to another. If the moves are within the subnational units of interest, they don't contribute to population change for that unit. However, households or individuals may make several moves that cross subnational unit boundaries. Full records of migrations as events are available from population or administrative registers. An alternative measure of migration uses the migrant's location at a census and their location at a previous point in time. Courgeau (1973) first made this distinction. Rees & Lomax (2020, Fig. 1) provide a time-space diagram that illustrates the different definitions of migration. Use of both measures were made possible in the Spatial Population Analysis code (Willekens & Rogers 1978, p. 49-53).

19.3.2 Adding International Migration to the Multistate Demographic Model

Three aspects of the multistate population model used in the Migration and Settlement project were raised in the UK report: the roles of international migration, time interval for measuring migration and method for computing out-migration. International migration was largely ignored or treated as the net difference between total population change and natural increase. Although international migration flows are much smaller than those within countries, their economic and political significance is much larger. Raymer & Willekens (2008) edited an important collection of papers on the estimation of international migration across Europe by researchers which include methods for filling this gap (Willekens 2008).

19.3.3 Demographic Accounts and Projection Models Based on Migrant Transitions

Population accounts report on the components that change the population stock over an interval of time. They derive from the work of Richard Stone, an economist who developed the system of National Economic Accounts, vital to the management of national economies. Late in his career Stone used that knowledge to build demographic accounts applicable to monitoring change in school systems by grade (Stone 1971). Note that population accounts that link population at the start of a time interval with that at the end and require input of international migration flows (immigration and emigration or net international migration). Population accounts guarantee consistency of stocks and flows. Rees (1977, Chapter 12) link the Stone, Rogers and Rees-Wilson multistate models. The latter was built using census data on migration based on a question about where a respondent was living at a fixed date prior the census, which generates a transition measure of migration. For projection, rates of inter-regional migration were computed using the start population in a time interval, classifying both the population and migration by age at the start of the interval. This model was used again for the 2001-based projections of UK local populations classified by sex, and age and ethnicity (Rees et al. 2012).

19.3.4 Development of Population Accounts and Projection Models based on Migration Events

In 1981, Frans invited me to spend time at NIDI to help develop a population model based on migration events for use in projections of Dutch populations. This involved some re-thinking of the transition model. The population at risk for births, deaths and migration needed to be the person-time exposure in a time interval. Willekens & Rogers (1978) achieved this through matrix inversion of the migrant transition rate matrix. A simpler solution, when the migration measure was based on event counts, was as follows. At the start, compute migration rates using the start population to project the end of interval population. Then substitute the average of the start and end populations in a time interval, iterating the calculation until the difference between previous and current result was negligible (Rees 1981, 1983). This procedure has since been used extensively by Tom Wilson in his projection models for Australian regions and large and small and in a recent collaboration applying his model, SYNPOPP, to forecast the population of local authority populations in England (Rees & Wilson 2023).

In the Migration and Settlement Study (Rogers & Willekens 1986), Frans and I collaborated to describe projection models based on alternative migration measures (Rees & Willekens 1986). Prior to this, I had used invented migration histories to prove that the same results could be obtained using either event or transition data (Rees 1985) if the right model was used. Frans later provided an overview of population accounts in a 2019 symposium held to mark my retirement (Willekens 2011).

Has this distinction between migration measures and matching projection models been adopted by national statistical offices or local authorities in their population projections? Experience in both the UK and Australia suggests that this occurs only when the researchers and government officials engage in the co-production. For example, discussion with a colleague in the UK Office of National Statistics during a conference, I persuaded him to request event data from the NHS Patient Register (Demographic Spine), to match better to the model used by ONS in their subnational population estimates and projections.

19.3.5 Estimates of International Migration using Expanded Population Accounts

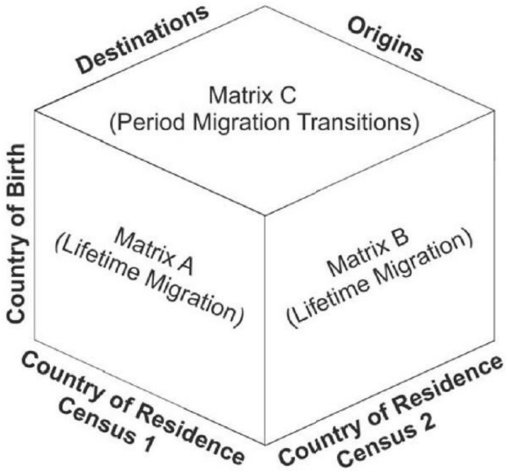
International migration has become of increasing political interest at both country and world scales. Most high-income countries receive substantial numbers of immigrants. Emigration from the Global South has increased because of poverty, conflict and climate change. Leaders of right-wing political parties have become more extreme in their opposition to immigration, failing to recognize the benefits of new workers, carers of the elderly, researchers and entrepreneurs. This debate was not helped by a lack of sound estimates of immigration and emigration for all countries.

This gap has been filled by important work by Guy Abel (University of Hongkong, IIASA). With colleagues he has systematically developed and extended a database of bilateral (inter-country flows) built from UN collections of member state census tables that classify the population by country of current residence and country of birth. The tables are populated by counts of lifetime migrants, a third measure of migration, the use of which was pioneered by Anglo-German scholar Ernst Ravenstein (Ravenstein 1885). Although country of birth has been widely used as a migration measure once censuses became available, it conceals when the migration to the current country of residence migration took place. Ravenstein (1889) used lifetime migration as a variable to track international migration in the late 19th century, when it was probably reasonable to assume only one migration event per lifetime transition.

After nearly 13 decades when only lifetime migration measures were used to estimate international migration, Abel (2013) proposed a method to estimate transitions between countries specific to a time interval using a UN database of country of birth by country of current residence tables from the censuses of member states. The method involves expanding the space of demographic accounts to three dimensions to estimate origin-destination migrant transitions in the time interval between successive censuses (Figure 19.1). Assumptions are made about the likely migrant numbers classified by the three dimensions, arrays A, B and C. The assumed flows are constrained to the marginal numbers in Matrix A (lifetime migration at the first census) and Matrix B (lifetime migration at second census) using either iterative proportional fitting or log-linear models. The estimates are then summed over country of birth to yield a Matrix C that estimates origin to destination migrant flows, also termed bilateral flows, between censuses.

Abel & Sander (2014) summarized the methodology for a wider audience and showed how a circular plot (Circos) borrowed from Genetics could be used to represent flows of migrants between regional groupings of countries. Because censuses are usually spaced about 10 years apart, values for mid-interval populations were interpolated so that the results could be used, when refined, in the Wittgenstein World Population and Human Capital model which used five-year

Figure 19.1: A three dimensional array of population flows by country of birth, country of residence at a first census and country of residence at a second census



Source: Drawn by the authors, based on a model by *Abel* (2013).

Note: Source: Rees & Lomax (2020, Figure 3).

age and time intervals for 195 countries (Lutz et al. 2014, 2018).

Abel (2022) and Abel & Cohen (2022) added gender to the estimates of international bilateral flows. Abel & Cohen (2019) and Abel & Cohen (2022) used a variety of different assumptions for the initial values of the ABC array that were tested and the best model adopted. The estimation model was extended by Rikani & Schewe (2021). This innovation recognized the importance of the diaspora effect (people migrate to countries where fellow nationals have migrated in the past). Yildiz & Abel (2024) added a decomposition by age generating emigration rates by origin, destination and country of birth. Kluge et al. (2024) brought together all these additions to the original Abel model to generate migrant flows by origin, destination, country of birth, age, gender and education with links to projected GNP/capita and scenarios based on Shared Socioeconomic Pathways (O'Neill et al. 2017, Wikipedia 2025). A new update of the Wittgenstein world projections is published in KC et al. (2024), with data available from the Wittgenstein Data explorer (Wittgenstein Centre 2024).

Alternative estimates of international migration flows were made by Azose & Raftery (2018), revising the Abel and Cohen bilateral flow estimates by including estimates of return and onward migration. This was an attempt to convert the migration flows of Abel and Cohen based on transition measures of migration into estimates of all moves. (Kluge et al. 2024, p. 355) comment that "these estimates ... are based on internal migration flows and leave room for improvement". Just three studies of internal migration from the 1970s from high income countries are used (Rees (1977) was one such study). However, internal migration differs from international in being rarely constrained by legal barriers. Azose & Raftery (2018) claim that they have generated "true" international migration flows. This is unlikely.

Dennett (2016) does a thorough comparison of the Abel (2013) estimates with IMEM estimates of international migration within Europe (Raymer et al. 2013) and between a set of industrialized countries (Kim & Cohen 2010). The European international migration estimates have been subsequently updated, using an improved version of the IMEM model (Aristotelous et al. 2022, Aristotelous 2023). Dennett suggests that migration flows in Abel estimates are radically underestimated compared to studies of countries with better data. He devises a method for correcting the Abel estimates to reflect these findings. Unlike Azose and Raftery, he stresses the uncertainty of all methods and avoids claims that they are the "truth".

A problem with both these critiques is that they lack clear links to event-based and transition-based migration measures as discussed earlier in the current chapter. Onward/Transit and Return migrations are important, particularly for the migration of international students, and better estimates are needed.

19.3.6 Understanding the Motivations of Migrants and the Drivers of Migration.

Just before the Covid-19 Pandemic, Frans joined the QuantMig project of the Horizon 2020 program led by Jakub Bijak (QuantMig 2024, Bijak 2024). In 2023, I was one of the two official reviewers of the project deliverables. Frans provided a superb survey of work on the factors affecting and motivations of international migrants (Willekens 2023*b*). He then followed by inventing a simulation of the drivers and constraints on international migration, using historical flow estimates as quotas for immigration into European countries (Willekens 2023*a*). Right wing politicians with a strong prejudice against immigrants would be shocked by such a model but it is more credible than their policy obsession with Net International Migrants, who do not actually exist, as Rogers (1990) pointed out.

19.4 An agenda for Frans in his eighties

If Frans is still enthusiastic about continuing his research and writing, here are some suggestions about research questions, small and large, that would welcome his attention and insight.

19.4.1 Is it sensible to assume constant fixed rates in a forecast except as a comparative scenario?

Most forecasters build in assumptions for mortality and fertility based on recent trends and some test their models using two intervals. The first is used to calibrate the model; the second is used to test the model. In high income countries, the trend of decreasing mortality is usually adopted and tested. Oeppen & Vaupel (2002) showed how the highest life expectancies among countries kept on increasing steadily from 1840 to 2000 and speculated that this would continue. This paper has persuaded many national statistical offices to assume mortality rates will continue to fall. Is this assumption tenable, given post the Covid-19 pandemic, when life expectancy improvement in many countries has stalled?

The use of fixed rates in internal inter-regional migration was critiqued by Plane (1993). He showed that continuing migration into attractive regions over time increase the costs of living there and migrants switch to other destinations. So, California has lost its golden image and Americans move to Texas or Florida. Statistics Canada built in a feedback effect that over time reduced the migrant flow into British Columbia. How should this effect be implemented more generally?

19.4.2 Which method should be adopted to include international migration in a national or subnational projection model?

If fixed transition rates are used between the rest of the world and a country and its regions, the flow of immigrants will be huge because the rest of the world population will be growing faster for most countries outside Africa. On the other hand, it is convenient to use emigration rates. In Kluge et al. (2024), emigration rates are used, based on a model that includes country of birth and the attraction of diasporas of fellow nationals and origin-destination income differences. Should a fully specified gravity model be used?

19.4.3 How should climate change be incorporated as a driver of international migration?

The world faces the growing existential challenge of climate change. Climate change will alter the direction of population change in new ways. A variety of approaches and outcomes is summarized in Van Wissen (2024). However, there is still a void to be filled which is the connection between climate change and international migration. One qualitative scenario is set out in Vince (2022). Frans has always enjoyed a methodological challenge. Perhaps he will accept the task.

Afterword

Happy Birthday, Frans. Congratulations on reaching your ninth decade of life. It has been a privilege to work with you from time to time over the last six decades. Our collaborations in the 1970s and 1980s challenged me to become a better demographer. In the 1970s, you worked on the Migration and Settlement Study directed by Andrei Rogers at IIASA (Rogers & Willekens 1986). Key outputs from the project were 17 case studies, applying multiregional demographic analysis to the populations of IIASA member countries. I contributed the UK report. Using your skills as an international research diplomat, you supervised the work with aplomb.

Over the four decades from 1980 to 2020, Frans produced a stream of peer reviewed research. Our life courses crossed again in the 2020s. Frans took on the job of managing editor of the online journal Comparative Population Studies (CPoS), published by the Federal Institute for Population Research. I had pioneered the role of external editing for CPoS in 2019. This role became essential in 2020 as the Covid-19 pandemic swept the world. From 2021 to 2023 Frans participated as partner in the EU QuantMig Horizon project led by Jakub Bijak (QuantMig 2024, Bijak 2024). He linked the literature on choice theory and migration decision making in a couple of "monograph-sized" reports. I was privileged to be one of two reviewers of the project.

Frans was an excellent collaborator to work with in the 1970s and 1980s, supportive and very well organized. I am sure he will continue to contribute into his eighties, health permitting. I was privileged to learn from our collaborations.

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20 Estimating net international migration by age and sex from the Human Mortality Database

Tianyu Shen, Qing Guan and Vladimir Canudas-Romo

Abstract

The demographic balance equation combines fertility, migration, and mortality to calculate population growth. If an unknown value exists, it can be derived from the other components based on the equation's perfect mathematical relation. Similarly, age-specific cohorts exhibit a perfect mathematical relation between younger and older population counts due to mortality and migration. This relation can be used to estimate net international migration from population and mortality counts. We present net international migration estimates by age and sex for populations in the Human Mortality Database (HMD). Age-sex patterns and time trends of these estimates are analyzed across populations. Recent decades show mostly smooth patterns across age, with some populations exhibiting irregularities. We also compare our HMD net migration results with other international migration flow estimates, revealing high similarity, especially for total net migration.

20.1 Introduction

Population estimates are critical for policymakers, urban planners, and researchers across various fields. To accurately capture population trends, demographers require reliable data on three key components: fertility (births), mortality (deaths), and migration flows. While vital statistics on births and deaths have been relatively well-documented in many countries and widely used in research (Canudas-Romo et al. 2024, Shen et al. 2023), migration flow data have long been a weak link in demographic analysis, often criticized for their incompleteness and lower quality (De Beer et al. 2010, Raymer et al. 2019, 2022, Guan et al. 2022, Shen et al. 2024). In the absence of comprehensive multi-regional international migration flow data, net international migration statistics remain crucial for uni-regional population estimation and projections, such as those conducted by the United Nations (2024). These statistics, while not providing the full picture of migration patterns, offer valuable insights into the overall impact of population movements on a country's demographic landscape.

The Human Mortality Database (Human Mortality Database 2025) has established itself as a gold-standard source of mortality and population data, covering numerous populations with high-quality, standardized statistics. The same group has further developed the Human Fertility Database (Human Fertility Database 2025). However, no complementary database on comprehensive migration information exists, particularly for long time series. This omission has limited the potential for in-depth historical analysis of migration patterns and their effects on population dynamics.

Extracting net international migration statistics from the HMD present a unique opportunity to address this gap. These data are particularly informative and useful for several reasons. Firstly, they provide a source of information to understand migration patterns over extended time periods, especially in the absence of detailed immigration and emigration statistics or reliable covariates to estimate them for historical periods. Secondly, these migration statistics are effectively leveraged as side products of the well-established demographic data already present in the HMD. Finally, the net international migration estimates help maintain consistency with other demographic measures and benefit from the rigorous data quality standards of HMD.

The concept of cohort net international migration estimates is not new to demographic literature. However, the extraction of these estimates from the HMD data represents a significant contribution to the field. These net international migration estimates can be used in various ways, including enhancing historical demographic analyses, improving population projections, and providing a benchmark for comparing and validating other migration data sources. The methodology behind these estimates relies on the demographic balance/accounting equation, which combines fertility, migration, and mortality to calculate population growth. This mathematical relation allows for the derivation of unknown components when other elements are known (Preston et al. 2001). At the age-specific level, a similar relationship exists between population counts at different ages accounting for mortality and migration between those ages.

The net international migration estimates by age and sex for HMD populations offer a unique resource for demographic research. Analysis of these data reveals age-sex patterns and time trends of net international migration across countries, with recent decades showing mostly smooth patterns across age groups, though some populations exhibit notable irregularities. To analyse and interpret these new estimates further, we compare our results with other sources of estimates, including the Integrated Modelling of European Migration project (IMEM, Raymer et al. (2013)) and EUROSTAT in Europe, age- and sex-specific migration flows in the Asia-Pacific region (Shen et al. 2024), and World Population Prospects 2024 (United Nations 2024) and international migration flow estimates across the globe of Abel & Cohen (2022). This comparative analysis not only highlights the potential of the HMD-derived net international migration data but also reveals limitations in both this approach and other existing estimates, underscoring the ongoing challenges in accurately measuring and analysing migration patterns.

20.2 Data

The Human Mortality Database primarily covers industrialized low mortality countries with reliable and consistent census and vital statistics data. The database includes detailed mortality and population statistics for over 40 populations across Europe, North America, and parts of the Asia Pacific region. The time span of the data varies by country but often extends back to the early 20th century or even earlier, depending on the availability of historical records. The HMD's coverage focuses on nations with high-quality vital statistics systems, which in theory ensures that the mortality and population estimates are both reliable and comparable across countries and time periods.

Even in the highest standard data, the HMD involves a few common conversions and standardization procedures depending on input structure of the raw data, including splitting death in a year at an age into Lexis triangles, splitting 5 years age group into single year ages and converting census with 5-year interval into single year population estimates. Deaths in older ages are also smoothed. There are also other country-specific adjustments to the population estimates, death and birth statistics. These adjustments might lead to significant bias in net international migration as it is usually a small proportion of the population change.

Several other datasets are available to understand trends and changes in international migration flows. Table 20.1 presents the coverages of these datasets. In Europe, Raymer et al. (2013) estimated international migration flows (IMEM) across 31 European countries from 2002 to 2008, providing net migration disaggregated by five-year age groups and sex. QuantMig (Aristotelous et al. 2022) extends the time series from 2009 to 2019 based on the IMEM methodological framework. eurostat2024 offers net international migration data covering the period from 2013 to 2022. Outside Europe, other datasets, such as those in the Asia-Pacific region, are available in the Human Mortality Database (HMD). Shen et al. (2024) estimated origin-destination migration flows by age and sex in the Asia-Pacific from 2000 to 2019, so only a few countries overlapped with HMD. Except for the United Nations (2024), the other datasets are by sex. IMEM, EUROSTAT and Shen et al. (2024) also provide estimates by age. Notably, these estimates focus on period data rather than cohort analysis. However, this chapter produces a unique dataset on cohort net international migration statistics, that is data unavailable elsewhere.

20.3 Methods

Net international migration estimates are here computed as the residual term from the balance equation. Similar to the HMD Methods Protocol (Wilmoth et al. 2021), we first construct the Lexis parallelogram of the net international migration in one year, t, as

Table 20.1: Comparison of datasets on demographic information by characteristics and country coverage.

Dataset	**HMD**	**UN WPP**	**Abel & Cohen**	**EUROSTAT**	**IMEM**	**Shen et al.**
Year	Various	1950–2023	1990–2015	2013–2022	2002–2008	2000–2019
By sex	Yes	No	Yes	Yes	Yes	Yes
By age	Yes	No	No	Yes	Yes	Yes
Country*	AUS, AUT, BEL, BGR, BLR, CAN, CHE, CHL, CZE, DEU, DNK, ESP, EST, FIN, FRA, GBR, GRC, HKG, HRV, HUN, IRL, ISL, ISR, ITA, JPN, KOR, LTU, LUX, LVA, NLD, NOR, NZL, POL, PRT, RUS, SVK, SVN, SWE, TWN, UKR, USA	AUS, AUT, BEL, BGR, BLR, CAN, CHE, CHL, CZE, DEU, DNK, ESP, EST, FIN, FRA, GBR, GRC, HKG, HRV, HUN, IRL, ISL, ISR, ITA, JPN, KOR, LTU, LUX, LVA, NLD, NOR, NZL, POL, PRT, RUS, SVK, SVN, SWE, UKR, USA	AUS, AUT, BEL, BGR, BLR, CAN, CHE, CHL, CZE, DEU, DNK, ESP, EST, FIN, FRA, GBR, GRC, HKG, HRV, HUN, IRL, ISL, ISR, ITA, JPN, KOR, LTU, LUX, LVA, NLD, NOR, NZL, POL, PRT, RUS, SVK, SVN, SWE, UKR, USA	AUT, BEL, BGR, CHE, CZE, DEU, DNK, ESP, EST, FIN, FRA, GRC, HRV, HUN, IRL, ISL, ITA, LTU, LUX, LVA, NLD, NOR, POL, PRT, SVK, SVN, SWE	AUT, BEL, BGR, CHE, CZE, DEU, DNK, ESP, EST, FIN, FRA, GBR, GRC, HUN, IRL, ISL, ITA, LTU, LUX, LVA, NLD, NOR, POL, PRT, SVK, SVN, SWE	AUS, CAN, HKG, JPN, KOR, NZL, TWN, USA

Note: * "Country" = Available country or area (ISO alpha-3).

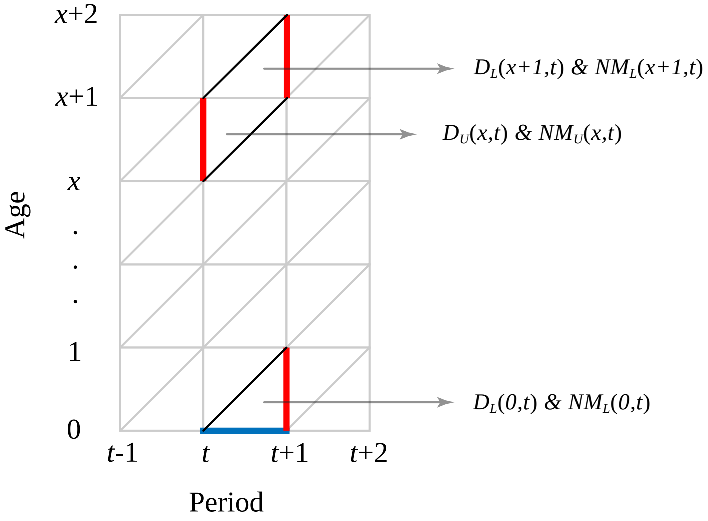
$$NM_U(x,t) + NM_L(x+1,t) = P(x+1,t+1) - P(x,t) + D_U(x,t) + D_L(x+1,t), \tag{20.1}$$

where $NM_i(x,t)$ is the net international migration in a Lexis triangle ($i = U$ or L for Upper and Lower), $P(x,t)$ is population at the beginning of time t and $D_i(x,t)$ are the deaths during age x to $x+1$ and time t to $t+1$ in the Lexis triangle i. The Lexis parallelogram in Figure 20.1 (upper part) focuses on the event in one time period across two ages. To be consistent with the notations in the HMD Methods Protocol, $D_U(x,t)$ and $NM_U(x,t)$ represent the upper triangle at time t and age x, while $D_L(x+1,t)$ and $NM_L(x+1,t)$ are the lower triangle in Figure 20.1 at time t and age $x+1$, both for the cohort born in year $t-x-1$.

To divide the parallelogram of net migration into Lexis triangles and compute net international migration by age, we simply assign half of the value in a Lexis parallelogram to each Lexis triangle, as similarly done by Willekens & Baydar

(1984). As part of a sensitivity analysis, alternative proportions for disaggregating the Lexis triangles were explored, though the effects are generally minimal. Further details are available from the authors upon request.

Figure 20.1: Lexis diagram depicting population counts and the estimation of net international migration in one year. $B(t)$ are the births at time t, represented by the blue horizontal bold line at age 0, the red vertical bold lines represent the population counts at each age and time $P(x,t)$, and the triangle i includes deaths and net migration denoted as $D_i(x,t)$ and $NM_i(x,t)$ at age x and time t.



Since the upper parallelogram of Figure 20.1 does not start from birth, we need a second equation to calculate the first Lexis triangle at age 0 using the number of births in the HMD and illustrated in Figure 20.1 (lower part),

$$NM_L(0,t) = P(0,t+1) - B(t) + D_L(0,t), \tag{20.2}$$

where $B(t)$ are the births at time t, represented by the blue line at the bottom. After obtaining these Lexis triangles, we can freely construct the net international migration by cohort or by period for each country and sex.

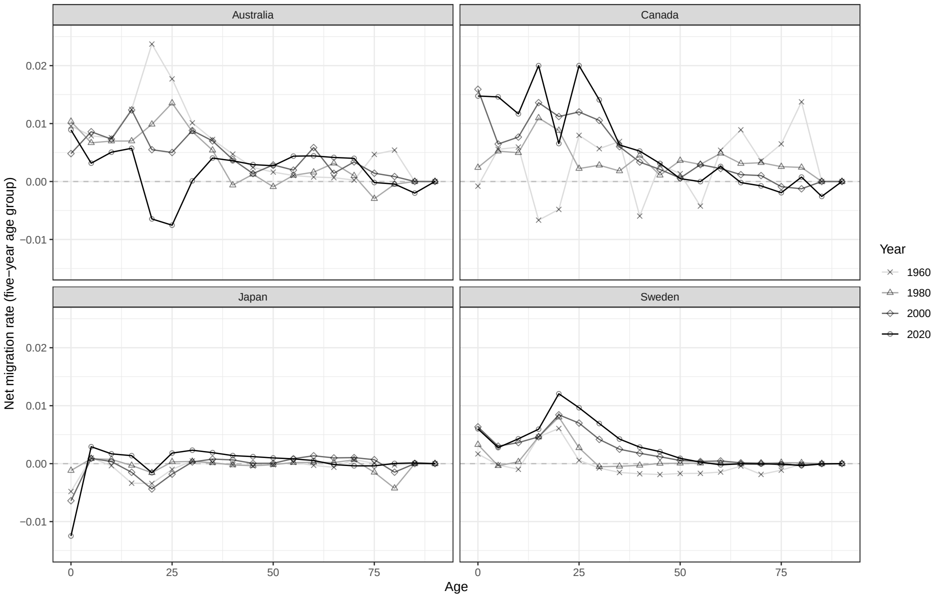
20.4 Results

The results have the same structure as the HMD, where we have the net international migration of single year and single age by period or cohort and by sex. A net migration database of number of international migrants can be found on GitHub (https://github.com/tyaSHEN/netmig), allowing readers to explore and interact with the full data. In this chapter, we present period and cohort age patterns of net international migration for four selected countries in different continents: Australia (1921-2021), Canada (1921-2022), Japan (1947-2022), and Sweden (1751-2023). For better comparison across countries in the figures, we compute the age-specific rate with the size of net migration divided by the exposure, for either period or cohort. As exemplified in Figure 20.1, combining upper and lower triangles allowed us to create squares for period values, and parallelograms for cohort measures. Period rates were then constructed with the size of net migration from five consecutive squares at a specific year and using the HMD exposure in that given year. Cohort rates used the size of net migration of five parallelograms and extracting the cohort exposure from the HMD data. The net migration rate is a synthetic demographic indicator that facilitates standardized comparison but should not be interpreted as a literal measure of per-capita migratory risk.

Figure 20.2 illustrates the single-year net international migration rates from 1960 to 2020, presented at twenty-year intervals and aggregated into five-year age groups for smoother trends. For Australia, Canada, and Sweden, the highest net migration rates were observed among children (ages 0–10) and young adults (ages 20–30), suggesting a net gain of migrants primarily from families and working-age individuals. In relative terms, Australia exhibited significantly higher net migration rates in earlier years, whereas Sweden experienced lower rates that have increased in recent years. Notably, the 2020 line for Australia shows a sharp decline in net migration for individuals around age 25, reflecting the impact of strict border closures during the COVID-19 pandemic. In contrast, Canada experienced a smaller dip at ages 20–25, while Sweden showed no comparable net loss in migration during this period. Japan displayed high negative net international migration rates in the 0–4 and 15–24 age groups, reflecting a net loss during those periods. However, in more recent years, Japan has transitioned from being a migration-sending to a migration-receiving country, as highlighted by Hollifield

& Sharpe (2017).

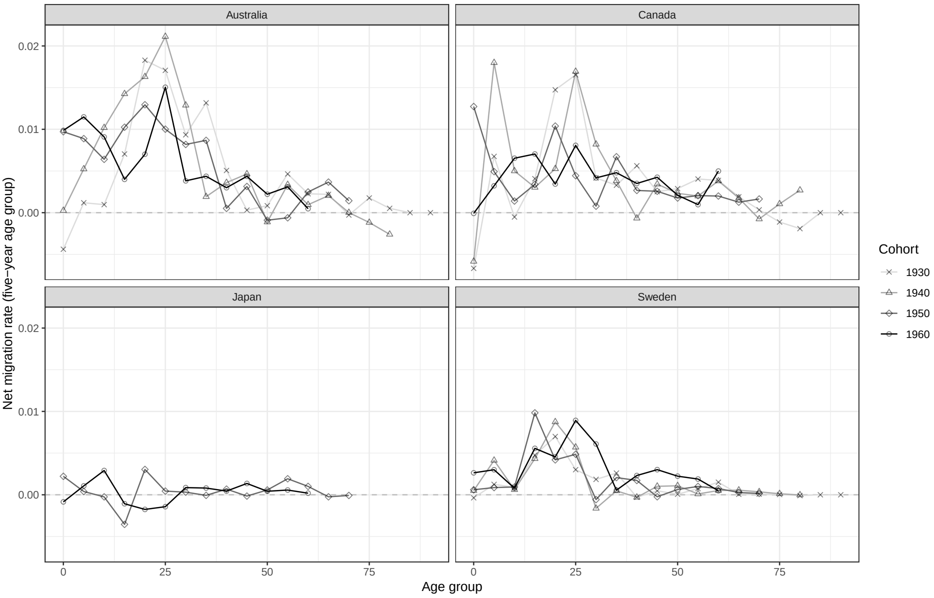
Figure 20.2: Net international migration rate in five-year age group for total population in selected countries, 1960 to 2020.



Unlike other data sources, the HMD enables the examination of cohort-specific net international migration rates. Figure 20.3 illustrates net international migration for individuals grouped by five-year age cohorts across four countries, covering birth cohorts from 1930 to 1960. Australia shows the most significant migration rate, with the 1940 cohort reaching approximately 2 per cent of the population around age 25, followed by a gradual decline as the cohorts age. Sweden exhibits a similar age-related pattern but with lower intensity, peaking at approximately 1per cent of the population in the mid-20s. Canada presents a more volatile migration pattern, with multiple peaks, including high migration rates in early childhood for the 1940 and 1950 birth cohorts. In contrast, Japan's net migration rate is relatively low compared to the other countries. Across all countries except Japan, there is a pattern of peak migration during the 20s and early 30s, mirroring the trends observed in the period-based net international migration rates shown in earlier figures.

Table 20.2 presents the correlation coefficients comparing net migration esti-

Figure 20.3: Cohort net international migration rate in five-year age group for total population in selected countries, cohorts 1930 to 1960.



mates from various leading demographic data sources. This analysis is restricted to populations with available HMD data allowing comparison across estimates, which is shown in Table 20.1. Correlations are evaluated at three levels of granularity: total migration, sex-specific migration, and age-and-sex-specific migration, using five-year age groups up to 85 and older. Overall, the table highlights remarkably strong positive correlations (>0.80) across most sources, reflecting high consistency in migration estimates. Notably, the UN WPP and Abel & Cohen (2022) estimates exhibit an exceptionally high correlation of 0.95 because of the strong methodological relationship. EUROSTAT also demonstrates consistent agreement with other datasets, maintaining correlations above 0.96 even when disaggregating by age and sex, indicating similar data sources with HMD. In comparison, the relatively low correlation between HMD and IMEM is partially attributed to the correction in the definition of migration employed by IMEM, which differs from that used by EUROSTAT. While most correlations remain robust across different levels of disaggregation, the correlation between estimates of Shen et al. (2024) and those of the HMD shows some variation between total migration (0.94) and age-and-sex-specific estimates (0.66), suggesting potential differences in their methodological approaches for detailed demographic breakdowns.

Table 20.2: Correlation of the net migration between the different databases

	Level of disaggregation	HMD	UN WPP	Abel & Cohen	EUROSTAT	IMEM
UN WPP	Total	0.89				
	By sex	-				
	By age and sex	-				
Abel & Cohen	Total	0.88	0.95			
	By sex	0.87	-			
	By age and sex	-	-			
EUROSTAT	Total	0.98	0.98	0.84		
	By sex	0.97	-	0.83		
	By age and sex	0.96	-	-		
IMEM	Total	0.88	0.86	0.90	-	
	By sex	0.87	-	0.89	-	
	By age and sex	0.83	-	-	-	
Shen et al. (2024)	Total	0.94	0.96	0.97	-	
	By sex	0.91	-	0.95	-	
	By age and sex	0.66	-	-	-	

Note: The correlation is calculated for five-year age groups. We use the estimates from pseudo-Bayesian method in Abel & Cohen (2022). Since the estimates are aggregated over five-year intervals, the number of net migrations is the same within each five-year period. The highest age group is 85 and older. The correlation is computed only for the countries with available data in the HMD across all datasets (see Table 20.1). "-" indicates that no correlation is available, either because there are no overlapping countries (or years) between the two datasets or because the level of disaggregation is unavailable for one or both datasets.

20.5 Discussion and Conclusion

This study applies the demographic balancing equation at the age-specific level to estimate international migration patterns across multiple countries and time periods. By leveraging high-quality population and mortality data from the Human Mortality Database (HMD), the method provides a consistent framework for deriving net migration estimates where direct data are incomplete, inconsistent, or unavailable.

Our findings reaffirm longstanding demographic insights (e.g., Castro & Rogers (1979): net migration typically peaks during young adulthood—particularly in the 20s and early 30s—reflecting transitions related to education, labor market entry, and family formation. These patterns are remarkably consistent across countries with sustained migration inflows, such as Australia and Canada, while countries like Japan exhibit distinct profiles, including episodes of negative net migration.

Importantly, validation against available international migration flow data confirms the robustness of the total net migration estimates produced through this approach.

While our method focuses on net migration, it is important to recognize that this is the net result of two separate processes—immigration and emigration—each of which may have different age structures and underlying drivers. Consequently, the age profile of net migration should not be interpreted as representing a single flow. Rather, it reflects the demographic impact of international migration on a population's structure. This is especially relevant in countries where immigration and emigration peak at overlapping ages.

The importance of net migration by age is also evident in recent work by Raymer et al. (2023), who model immigration and emigration separately in order to construct net migration age schedules for all countries in the UN World Population Prospects. This reinforces the fact that net migration by age is not just a residual artifact, but a critical input for global demographic estimation and projection. Unlike their method, which provides model-based estimates, our approach offers a more empirically grounded alternative based on observed demographic changes.

As with any residual method, our estimates reflect not only migration but also potential inconsistencies in the underlying data. Errors in census coverage, age misreporting, or vital registration may contribute to the residual, particularly at very young and older ages. To minimize these effects, we restrict our analysis in this Chapter, to countries in the HMD without documented data quality warnings. While this does not eliminate potential bias, we expect any remaining distortions to be relatively minor in the context of HMD's rigorous data curation standards. In conclusion, this study demonstrates the utility of residual-based estimation for uncovering age- and sex-specific migration trends in the absence of direct flow data. The approach is broadly applicable across settings and time periods, supporting demographic research and policy planning.

Future work may expand the scope to additional populations and explore integration with socioeconomic data to better understand the drivers behind observed patterns.

Afterword

We dedicate this net-migration concept paper to Frans Willekens, PhD supervisor of Vladimir Canudas-Romo and an exceptional mentor. As PhD students of Vladimir Canudas-Romo and James Raymer, we—Qing Guan and Tianyu Shen—are part of the growing academic lineage shaped by Frans. More than a guide, Frans embodies the generosity and wisdom that every student hopes to find in an academic mentor. Arriving at the University of Groningen felt like stepping into a United Nations gathering, with students from across the globe, many mentored by Frans. Some of the most memorable moments were the warm gatherings hosted by Maria and Frans Willekens at their home, where hospitality matched the intellectual generosity. It has been an honour and a privilege to be trained by Frans.

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21 Including level of education in regional population estimates using hybrid loglinear models

Leo van Wissen

Abstract

The term hybrid loglinear model was introduced by Frans Willekens and Nazli Baydar in 1985 (Willekens & Baydar 1985), as an extension of the class of loglinear models for the analysis of contingency tables. The term hybrid refers to nonstandard forms of loglinear models. This model is used here to estimate the population by age, sex, NUTS3 region and level of education. Educational attainment is only available without age detail at the NUTS2 level at the European scale. An aggregated logit model, based on a small set of predictors of regional educational attainment is used to estimate a prior distribution at the NUTS3 level. Using Iterative Proportional Fitting we fit this prior distribution to known marginal totals at the regional and national scale, following the principles set out in Willekens' paper from 1980.

21.1 Introduction

Whereas traditionally age and sex were the defining dimensions of a population, the recognition of variation in demographic behavior resulted in the introduction of more dimensions of interest, such as country, region, household position, and more recently also education. The cross-classification of the population using multiple dimensions leads to a large number of cells in the contingency tables describing these populations, which may be the reason that many view demography as a data-hungry activity, for which you have to be a data-fetishist to enjoy working with it.[1] Because the data demands for these large tables are substantial, a common problem in this type of analysis is incomplete data: there is partial information available, but not for every cell. Demographers have developed or adopted various methods to deal with these problems. Few know however, that Frans Willekens has been at the forefront of these developments in the seventies and eighties. This is quite understandable as a result of his involvement in the development of multidimensional demographic methods at the time, for which these methods were very well suited.

In this contribution I will present a method to estimate the NUTS3 population of European countries by age, sex and level of education using partial available information from various international statistical sources. The method is well known and already described in the comprehensive paper by Frans in 1980 in Sistemi Urbani, entitled "Entropy, multiproportional adjustment and the analysis of contingency tables"; see (Willekens 1980). The usefulness of this approach is still undisputed, as my contribution demonstrates, and my paper is a tribute to his original paper, which, strangely enough, was only cited 49 times, according to Google Scholar.

In the next section a short overview of the method is presented. In section 22.3 the estimation problem is explained. The loglinear model formulation is introduced in section 22.4. Section 22.5 presents an aggregated logit formulation to estimate a crucial missing interaction between region and educational attainment, that is not present in the given partial information. Next, in section 22.6, the estimated model for the Netherlands is applied and tested for the case of Norway. Section 21.7 gives some results at the European level, and section 21.8 concludes.

21.2 The analysis of contingency tables: an overview

In demographic research, contingency tables are very common. Contingency tables of the counts of the number of persons by age and sex are the bread and butter of every demographic analysis of populations. The two-way table by age and sex can be extended to include other dimensions of demographic interest, such as position in the household, country or region of residence, or education. The number of

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[1] At least, some researchers do enjoy this activity, and a high concentration of such persons is to be found among the authors of this LA.

cells in such multiway tables multiplies with every additional dimension included. Loglinear models were developed in the 1970s by Bishop et al. (2005) to deal with these complex discrete multivariate distributions. They provided the statistical background for the analysis of such distributions. Frans was among the first to discover the added value of this approach in demographic analysis. He wrote a comprehensive overview in his 1980 article in Sistemi Urbani referred to above, in which he showed that many existing models for the analysis of interaction between multiple variables could be brought under this umbrella. These earlier approaches included for instance the iterative proportional fitting procedure introduced in demography by Deming & Stephan (1940) for combining census with sample information, the Fratar-Furness method (Fratar 1954) in transportation science to update a spatial interaction table to known marginal totals, Stone's RAS method (Stone 1962) for updating input-output tables in economics, entropy maximization (Wilson 1970) in spatial interaction models, information minimization (Kullback 1959), and linear programming (Nijkamp 1975). A central element in this general approach is iterative proportional fitting (IPF), which can be viewed as a method to find a multivariate distribution that is as close as possible ("adds as little as possible information") to a given prior distribution, given a set of marginal constraints. The method is since then widely accepted in demography, and well-suited to estimate the cell counts of an incomplete contingency table where only partial information is available, in the form of marginal and certain interaction totals. This is exactly the problem to be addressed in this contribution.

21.3 The estimation problem

In the project PREMIUM_EU[2], a regional demographic database at the NUTS3 level for all EU27 countries was built, that includes age (by 5-year age categories, with the upper age category 85+), sex, and level of education. There are, although the exact classification changes regularly, more than 1200 NUTS3 regions. Information about age (5-year age categories) and sex is available through the Eurostat REGIONS database. The European Joint Research Centre JRC has harmonized these data, which resulted in a time series at the NUTS3 level starting in 1990.

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[2] The research on which this contribution is based was conducted as part of the Horizon Europe project PREMIUM_EU (Grant Agreement number: 101094345).

The research problem that we try to solve here is to expand this table of three dimensions (region R, sex S, age A) with a fourth dimension: educational attainment E, in three categories: Low, Middle and High educated. For the Netherlands for example, having 40 NUTS3 regions (so called COROPs) this table contains 40x3x2x18 = 4320 cells. The level of education is not available for most European countries at the NUTS3 level. Eurostat provides information on level of education at the NUTS2 level[3] but not broken down by age[4]. More detailed information of educational attainment is provided at the national level by the Wittgenstein Centre for Demography and Human Capital WIC. The available partial regional information is summarized in Table 21.1. As already mentioned, Eurostat collects annual information about the population by age and gender for each NUTS3 region[5]: $R \times S \times A$. In the PREMIUM_EU project the years 2010, 2015 and 2020 are used. Educational attainment is a more problematic dimension. WIC has made estimates for all countries in the world of the population by sex, age and level of education, but not for regions within countries. There is some information at Eurostat/JRC, based on the ongoing European labor force surveys: The population of working age (between 15 and 75 years) by sex and educational attainment, at the NUTS2 level. The notation in the first column of the table will be explained below.

Table 21.1: Data resources for estimation

Notation	Source	Description
$R \times S \times A$	Eurostat/JRC	Population by age (0-5, ..., 85+) and gender for each NUTS3 region
$S \times A \times E$	WIC	Educational attainment by age (0-5, ..., 100+) and gender
$R2 \times S \times E$	Eurostat/JRC	Population 15–75 by gender and educational attainment for each NUTS2 (R2) region

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[3] There are currently 244 NUTS2 regions in the EU. NUTS3 regions are a subdivision of NUTS2 regions.

[4] After the analysis for this chapter was finished, Eurostat released the data of the Census of 2021, which contains a table at the NUTS2 level by broad age groups and sex. It was too late to include this table in the current estimation.

[5] This information is even available at the finer detailed regional level of the LAU (Local Area Units).

21.4 Model specification

The problem can be specified as follows, using the modelling language that was introduced in the programming language GLIM (an acronym for Generalized Linear Interactive Modelling) in the 1970s (Aitkin et al. 2005). In this modelling language a contingency table with dimensions sex S and age A can be written as $S \times A$. If we only have the marginal totals of age and sex, we can estimate a table $S + A$, assuming independence between both dimensions. The formulation of independence between the two dimensions in a loglinear formulation is given by:

$$\log \hat{M}_{ij} = \mu + \mu_i^A + \mu_j^B$$

where $\hat{M}_{ij}$ is the expected value of cell (i, j) in the two-way table under the assumption of independence of factors A and B, and the coefficients are given by:

$$\mu = \frac{1}{IJ} \sum_{i,j} \log \hat{M}_{ij}, \mu_i^A = \frac{1}{J} \sum_j \log \hat{M}_{ij} - \mu, \mu_j^B = \frac{1}{I} \sum_i \log \hat{M}_{ij} - \mu. \qquad (21.1)$$

If μ is determined, only I-1 coefficients of factor A can be estimated, and one is redundant, and similarly for factor B. Usually, the constraint that all coefficients sum to 0 is used, but other designs can be imposed as well, for instance that the coefficient of the first or last category of the factor is 0. Note that the parameters are estimated from the expected values $\hat{M}_{ij}$. This means that the expected values under the model have to be estimated first, and from these expected values the parameters are derived. The sufficient statistics to estimate the expected values are the marginal totals implied by the specified main and interaction effects. For the model of independence (21.1) these are the row- and column totals of the $A \times B$ table.

By comparing the expected values $\hat{M}_{ij}$ with observed values M_{ij}, the hypothesis of independence can be tested, using the well-known Chi-square test, with appropriate degrees of freedom: in this case $I \times J - 1 - (I - 1) - (J - 1)$. However, many contingency tables of data suffer from overdispersion, which heavily inflates the test statistic. Moreover, many tables are based on register or census data of the whole population, not samples. Therefore, the value of the test statistic is only indicative of the fit of the model.

If the hypothesis of independence is rejected, an interaction term is necessary. In a two-way table this leads to a saturated model, with the number of coefficients equal to the number of observations (cells) in the table. The model of interdependence is $A \times B$, or, in a loglinear formulation:

$$\log \hat{M}_{ij} = \mu + \mu_i^A + \mu_j^B + \mu_{ij}^{AB}$$

and the interaction term in this model is estimated as:

$$\mu_{ij}^{AB} = \log \hat{M}_{ij} - \mu - \mu_i^A - \mu_j^B.$$

This example readily extends to more than two dimensions. Our table to be estimated has four dimensions, with cell entries M_{ijkl}, where i is the index for region, j for sex, k for age and l for education. The available partial information allows only to estimate a model with restrictions on many parameters.

$$R \times S \times A \times E \approx R \times S \times A + S \times A \times E + R2 \times S \times E$$

This is a hybrid loglinear model, since $R2$ is an aggregate of NUTS3 regions and therefore not a standard factor in a loglinear model. In parametric form the model reads:

$$\begin{aligned} \log \hat{M}_{ijkl} = \quad & \mu + \mu_i^R + \mu_j^S + \mu_k^A + \mu_l^E + \mu_{ij}^{RS} + \mu_{ik}^{RA} + \mu_{jk}^{SA} + \\ & \mu_{jl}^{SE} + \mu_{kl}^{AE} + \mu_{kl}^{R2E} + \mu_{ijk}^{RSA} + \mu_{jkl}^{SAE} + \mu_{jkl}^{R2SE} \end{aligned} \tag{21.2}$$

Note that in this hierarchical model, if a higher dimensional interaction is included, the lower-level interactions between these variables are also included. It is clear that the crucial interaction at the NUTS3 level is missing. Although $R2 \times S \times E$ provides some information between the regional dimension and the level of education, it does not differentiate between NUTS3 regions within a NUTS2 region. This is most clearly seen if we observe a single sex-age combination, say 25-30 Females. For this group we have the distribution over the regions R in a country, as well as the nation-wide level of education E. The interaction $R2 \times S \times E$ assigns values of educational attainment to each NUTS3 region based on the corresponding NUTS2 regional context, and for all ages 15-75. As a result, all 25-30 aged Female categories in the NUTS3 regions of the same NUTS2 region will be assigned the same values. We therefore need an $R \times E$ interaction term (i.e., at the NUTS3 level), and possibly such interaction term could also be age- or sex-dependent. This information exists only for specific countries, but not European wide. To fill in this missing interaction we need a model that predicts the educational distribution of each NUTS3 region as a function of regional characteristics. This model, an aggregated logit model (a member of the family of loglinear models), is explained in the next section in some detail. The estimates of this model generate a distribution of level of education as a function of the regional characteristics. We include this term $R \times E$, or, if it is age and sex-specific $R \times S \times A \times E$, in the model as an *offset*. An offset is a covariate in the model with a fixed parameter value of 1. This could be specified as:

$R \times E \times S \times A \approx R \times S \times A + E \times S \times A + \{R \times E \times S \times A\}$

where the notation $\{..\}$ is used to denote the offset. This offset can be interpreted as prior information to be included in the estimation. The parametric form of this model is:

$$\begin{aligned} \log \hat{M}_{ijkl} &= \mu + \mu_i^R + \mu_j^S + \mu_k^A + \mu_l^E + \mu_{ij}^{RS} + \mu_{ik}^{RA} + \mu_{jk}^{SA} + \\ &\quad \mu_{jl}^{SE} + \mu_{kl}^{AE} + \mu_{ijk}^{RSA} + \mu_{jkl}^{SAE} + \log \check{M}_{ijkl}. \end{aligned}$$

As will be explained in the next section, we include the $R2 \times S \times E$ table as a covariate in the estimation of the prior information $\log \check{M}_{ijkl}$. The formula has one intercept, four main effects, five two-way interactions, and two three-way interactions. This formulation makes clear that because of the partial information available, neither the two-way interaction μ_{il}^{RE}, nor the three-way interactions μ_{ijl}^{RSE} and μ_{ijl}^{RAE} are included (i.e., these are set to zero). Instead, the prior distribution $\check{M}_{ijkl}$ contains an approximation of the interactions between these factors, derived from the logit predictions to be discussed below. Iterative Proportional Fitting (IPF) starts with the prior distribution $\{R \times S \times A \times E\}$, which is scaled in a number of rounds to fit it to the marginal totals $[R \times S \times A]$ and $[E \times S \times A]$, until convergence is reached.[6]

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[6] The IPF model was programmed, not in Fortran (which would have been suitable given the timing of the origin of the approach), but, since all data are stored in Excel files, in an almost equally

21.5 The aggregated logit model to estimate the regional distribution over educational attainment

An aggregated logit model is equivalent to a loglinear model. In a loglinear model such as equation (21.2) there is no dependent or independent variable. The model estimates a multivariate discrete distribution. But we can designate one factor, say education, as the dependent variable, and estimate its value, conditional on the value of the other factors. For instance, we could model the probability that a person living in region i, with sex j and age k will have educational attainment l. This probability is

$$Prob_{l|ijk} = p_{l|ijk} = \frac{M_{ijkl}}{\sum_{l'} M_{ijkl'}}. \tag{21.3}$$

Substitution of (21.2) in (21.3) gives:

$$p(l|ijk) = \frac{\exp(\mu^{SE}_{jl} + \mu^{AE}_{kl} + \mu^{SAE}_{jkl} + (\log \check{M}_{ijkl}))}{\sum_{l'} [\exp(\mu^{SE}_{jl'} + \mu^{AE}_{kl'} + \mu^{SAE}_{jkl'} + (\log \check{M}_{ijkl'})]}. \tag{21.4}$$

All terms not related to E cancel out. The p can be either interpreted as the probability of having a certain educational level, or as population shares. In the current approach the interpretation of shares is more to the point. The μ-terms describe differences in educational attainment between age- and sex categories, based on the national distribution from the WIC table $S \times A \times E$. By using data from countries that have all variables R, S, A and E, we can model the prior distribution $\log \check{M}_{ijkl}$ with a set of region-specific explanatory variables. The estimated coefficients of such a model can then be applied to predict the value of the prior distribution for other countries without a complete $R \times S \times A \times E$ - distribution, but with the explanatory variables. We present the results of the estimation for the Netherlands, as an example of a country with all variables available. We estimate the following model on Dutch data:

$$p(l|ijk) = \frac{\exp(\mu^{SE}_{jl} + \mu^{AE}_{kl} + \mu^{SAE}_{jkl} + \sum_m \beta_{jkl,m} X_{i,m})}{\sum_{l'} [\exp(\mu^{SE}_{jl'} + \mu^{AE}_{kl'} + \mu^{SAE}_{jkl'} + \sum_m \beta_{jkl',m} X_{i,m})]}, \tag{21.5}$$

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old-fashioned language Visual Basic, which was introduced by Microsoft in 1993.

where $\sum_m \beta_{jkl,m} X_{i,m}$ is a linear sum of m region-specific variables $X_{i,m}$, with weights $\beta_{jkl,m}$.

The educational attainment data, by region, sex and age (i.e. the observed table $E \times R \times S \times A$) for the Netherlands come from the Statline database of Statistics Netherlands. Statistics Netherlands provides information for 10-year age categories (15-25, … 65-75). We use the 2015 and 2020 data for the estimation. Table 21.2 gives an overview of the explanatory variables used in the model. Note that the educational attainment at the NUTS2 level is used as a predictor in this model.

Table 21.2: Explanatory variables of the regional NUTS3 share of the population by educational attainment

Variable	Description
Educ15–75	Share of the population aged (15–75) by educational attainment and sex
%Hightech	Share of employment in professional, scientific and technical activities; administrative and support service activities
Econ_index	The economic index as calculated in Arnold (2024). It is a composite index of regional product per capita, and unemployment

The model was estimated using R function glm as a hybrid log-linear model including all available terms $R \times S \times A$ and $E \times S \times A$, plus quantitative predictors of the regional educational attainment distribution. Table 21.3 shows the deviance fit for a number of nested models for 2015 and 2020. It gives an impression of the contribution of the explanatory variables to the overall fit between observed and predicted regional educational attainment shares.

Table 21.3: Model fit of aggregated logit estimates of educational attainment in NUTS3 regions in the Netherlands

Model	Deviance (2015)	Df	Deviance (2020)	Df
1: $E \times R \times S \times A + E \times S \times A$	298666	936	321639	936
2: Model 1 + Educ15–75	234582	933	240933	933
3: Model 2 + %Hightech	207490	931	232546	931
4: Model 3 + Econ_index	184016	929	183516	929

Table 21.3 shows that the three explanatory variables have a substantial effect on the model outcomes. The economic index, one of the dimensions of the regional development concept, is the strongest variable. Further interactions of these variables with age and sex do not add much to the fit. This means that the β_{jkl}'s can be simplified to β_l.

The parameter estimates β_l of these three explanatory variables are given in Table 21.4.

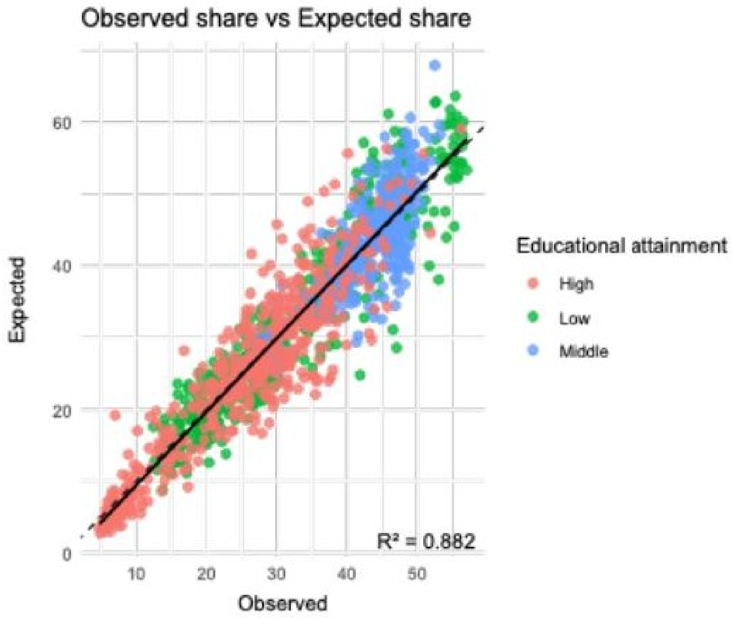
Table 21.4: Parameter estimates of explanatory variables in 2015 and 2020

	2015			2020		
Variable	Low	Middle	High	Low	Middle	High
Intercept	3.145	3.035	(ref)	3.176	3.430	(ref)
NUTS2 Educ 15–75 (/10000)	-0.15	-0.12	(ref)	-0.25	-0.15	(ref)
%Hightech (/100)	0.255	(ref)	0.818	0.638	(ref)	-2.162
Econ_index	-0.178	(ref)	1.684	0.004	(ref)	2.760

The most important variable is Econ-index. The higher the economic index of a region, the higher the share of highly educated, as expected. In 2015 it also correlates negatively with the share of low educated. The percentage of employed in the Hightech sector is positive for the low, and mixed for the share of high educated: positive in 2015 but negative in 2020. The effect of the NUTS2 educational distribution is marginal and negative for low and middle educated shares, relative to the high educated shares at the NUTS3 level. This implies that on average higher shares of low or middle educated at the NUTS2 level correlate with lower shares at the NUTS3 level. Including interaction effects with either age or sex does not greatly improve the fit of the model, while making it substantially more complicated.

Using these parameter estimates, a prior distribution $\log \hat{M}_{ijkl}$ can be estimated. Figure 21.1 shows the expected and observed shares based on the 2015 data. The figure shows a decent fit (R^2 is 0.88 for 2015, and similarly 0.87 in 2020).

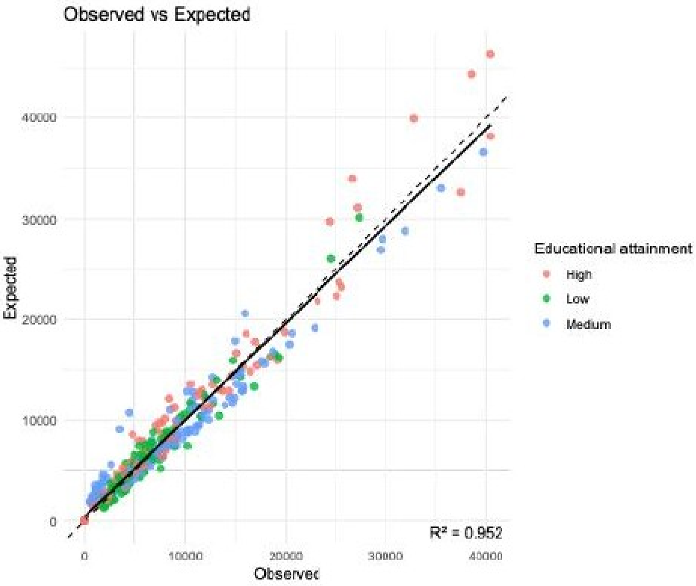
Figure 21.1: Observed and expected shares of levels of education for NUTS3 regions by age and sex, 2015, in the Netherlands.



21.6 How well does this prior distribution work for other countries?

We use the estimated values of the logit model for the Netherlands to construct the prior distribution for Norway. The estimated values can be compared with the observed counts, which are available from Statistics Norway. Norway has 11 NUTS3 regions, and Statistics Norway publishes data on regional educational attainment for 6 age categories. In total there are therefore 11x2x6x3 = 396 cell counts. Figure 21.2 shows the fit of the resulting model. Each dot represents observed and expected shares of low, middle and high educated for each combination of region, age and sex. The fit is very satisfactory. Of course, this does not indicate that the model can be transferred to any country. The Netherlands and Norway are both North-western European countries with a highly educated population. Nevertheless, as an illustration we used the model estimates, to estimate the level of education by age, sex and NUTS3 region for all European countries.

Figure 21.2: Observed and Expected counts of low, middle and high educated by age, sex and region, Norway, 2015



21.7 Some results at the European level

The variables Econ_index, %Hightech and NUTS2, together with the estimated coefficients from the Dutch logit model will generate a prior distribution $\{R \times E\}$ for each country. Unfortunately, data for Austria, Germany and Spain are not available in the Eurostat Regions database. For all other countries, the educational distribution, by NUTS3 region, age and sex can be estimated. Figure 21.3 shows the resulting pattern for highly educated 25-30 years old women in 2015.

21.8 Conclusion

Frans Willekens was the first to provide an integrated overview of the various methods that existed in the 1970s in such diverse fields as transportation science, economics, and geography to estimate missing values in a multi-way contingency

Figure 21.3: Estimated share of high educated women aged 25-29 in NUTS3 regions in Europe in 2015

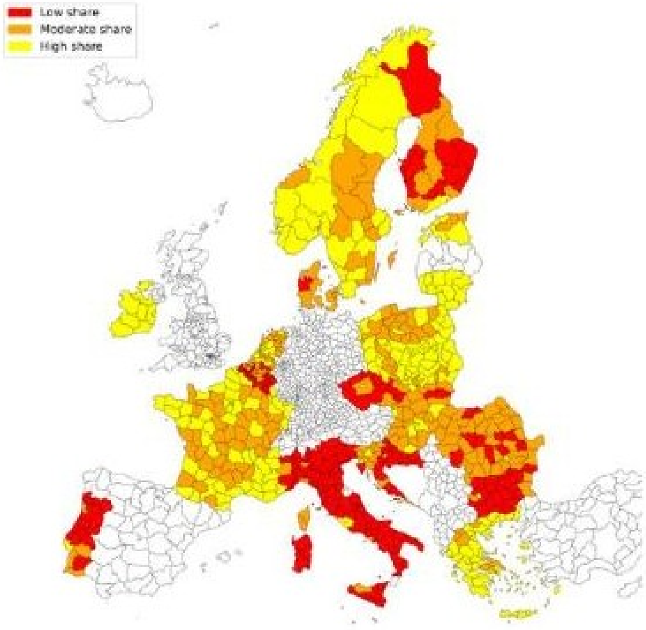


table. The method of Iterative Proportional Fitting is used today by many demographers for filling in the cells of such tables. Few know that Frans was at the heart of the introduction of this family of techniques in the discipline. Loglinear models for the analysis of contingency tables have become less popular these days than in the 1970s and 1980s. Logit models, where one of the variables is explicitly treated as the dependent variable, such as discussed in Section 22.5, are closely related and can easily be derived from the results of a loglinear model of a contingency table. Nevertheless, detecting the most informative interactions in a multidimensional distribution has its own merits, and should be in every demographer's toolbox. In this contribution we show that the method is still very useful, and can accommodate hybrid forms such as used here, by including prior distributions of interactions between variables, itself the result of a separate modelling strategy.

Today alternative methods exist, such as Bayesian analysis or machine learning techniques. It would be interesting to compare the outcome of such models with the more traditional approach in this chapter. The advantage of the current method is that it is transparent. The fit of the model for the two countries where the predications could be compared with observations, The Netherlands and Norway, is quite satisfactory.

Acknowledgements

Nico Keilman gave useful comments on an early version.

Afterword

I came to know Frans when I started my PhD in 1981. Multiregional population models were quite new at the time, and I (together with Annemarie Rima) made extensively use of these new methods. My PhD involved the specification, estimation and projection of a regional household and housing market model, for which it was necessary to copy - by hand - published tables of the 1971 Dutch census, to combine it with housing market survey information, and to program everything in Fortran on a main frame. These multiregional models were very data hungry, and population registers or surveys at that time were totally insufficient to provide the information on a cell-by-cell basis. Frans saw the potential of loglinear models to estimate the missing information for such data-hungry models, and I thankfully made use of his ideas. Since then, a lot has changed: there is much more detailed information available, today's personal computers are much more powerful than the large mainframes of the eighties, and there are new techniques and much more powerful programming languages to choose from. Still, the problem of incomplete information remains, which is partly due to the increased ambitions of researchers. These ambitions, for some reason, always keep ahead of what is possible.

Since that first encounter between a PhD student and a leading demographer, we have stayed in frequent contact: at NIDI, where I started working in the early 1990s, and at the University of Groningen, where I developed, stimulated by Frans, the field of the Demography of Firms. Much later, in 2010, I followed in his footsteps as his successor as Director of NIDI. Under his directorship the institute developed a strong academic character, which turned out to be a very important asset to survive the difficult period of budget cuts in 2013 through the affiliation with the University of Groningen. So, NIDI owes a lot to Frans, but clearly my career would have been quite different without him as well. Many, many thanks Frans.

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22 The ProFamy Multistate Extended Cohort-Component Method for Household and Living Arrangement Projections

Yi Zeng, Zhenglian Wang and Qiushi Feng

Abstract

We first review the importance of household and living arrangement projections. We then summarize basic ideas, data needed, assessments, and applications of the ProFamy method and software for household and living arrangement projections. Next we mention assessments of the accuracy for the ProFamy method, and we list several empirical applications of the approach. After this we discuss the user-friendly R software package DemoRates, which can be used for estimating rural/urban (or race)-age-sex-specific standard schedules and demographic summary measures. Finally, we argue that it is useful and feasible to extend the ProFamy approach to probabilistic household and living arrangement projections, in which the population size/structure projection outcomes are in line with those of probabilistic population projections released by the United Nations Population Division (UNPD).

22.1 The Importance of projecting household and living arrangements

Forecasting household structures and living arrangements plays a critical role in socioeconomic and welfare planning. In the United States and Europe, for instance, many welfare programs are specifically designed for single-parent households—especially those headed by single mothers (Maldonado & Nieuwenhuis 2015). To plan effectively and allocate resources, policymakers need reliable projections of the future number of such households, their characteristics, and how many children will be living in them (Casey & Maldonado 2012).

Beyond disability status, household composition is one of the most important factors influencing the type and amount of care older adults receive (Francesca et al. 2011). Knowing how many older adults are living with spouses, partners, or adult children helps governments prepare for the realities of aging populations around the world (Zeng, Land, Wang & Gu 2013).

In fact, changes in the number, size, and structure of households can have a bigger impact on energy use and environmental sustainability than overall population growth (Bradbury et al. 2014). The reason is that households — not individuals — make most decisions about consuming resources like electricity, gas, water, and transportation. For example, in the United States, household vehicles use about 68 per cent of all the energy consumed by road traffic (United Nations Department of Economic and Social Affairs 2007). In many developing countries, indoor and outdoor air pollution is closely related to household energy use, especially where clean fuels are scarce (International Energy Agency 2004, Dalton et al. 2008).

Trends like rising divorce rates, increased migration, and changing cultural expectations around multi-generational living are leading to smaller households and increasing numbers of them worldwide (Gu et al. 2015). Consequently, relying only on population growth to forecast energy demand risks severely underestimating future needs—especially as population growth slows or populations even decline in many nations (Keilman 2003, United Nations 2024, Zeng et al. 2021).

Market research for home-based products and services often depends on projections of household size and living arrangements. Housing development and real estate planning, for instance, rely heavily on knowledge of future numbers and types of households (Smith et al. 2008, 2012). Similarly, projections of household trends help financial institutions anticipate demand for home loans (Zhu 2021), and guide manufacturers of durable goods—like furniture, appliances, and vehicles—on what to produce and in what quantity (Feng et al. 2011, Prskawetz et al. 2004).

22.2 Overview of the ProFamy multistate extended cohort-component method for projecting households and living arrangements

Thanks to innovations in multistate demography (Willekens et al. 1982, Land & Rogers 1982), Zeng et al. (1998) introduced the ProFamy model, and later expanded it (Zeng et al. 2006, Zeng, Land, Wang & Gu 2013) as a two-sex multistate cohort-component approach for projecting households and living arrangements. Note that ProFamy is both a model and a software package. It projects the number of people by age, sex, marital/union status, and numbers of co-residing children or parents. From that, it builds projections of household types and sizes. For example:

- A widowed man over age 80 who lives alone is counted as a one-person household.
- An unmarried women aged 30–34 who lives with three children and no co-residing parents is counted as a four-person, two-generation household.
- A married or cohabiting couple living with two children and no parents is counted similarly.
- A household with a married couple, three children, and two co-residing parents forms a seven-person, three-generation household.

These examples show how ProFamy extends the traditional cohort-component model by simultaneously projecting households by type, size, and sex or age of its reference person, alongside the number of individuals disaggregated by sex, age, marital/union status, and the number of co-residing parents and children. In this respect it follows the work of others, who computed future numbers of households of various types from future numbers of persons by household status or living arrangement, e.g. the PRIMOS model of Heida and Gordijn (Heida & Gordijn

1985) or the LIPRO model of Van Imhoff and Keilman (Van Imhoff & Keilman 1991, Keilman & Van Dam 1987). The ProFamy projections of population by age and sex remain fully consistent with those generated by the standard cohort-component method, provided both use identical fertility, mortality, and migration inputs.

Additionally, ProFamy yields a wide range of household and living arrangement outcomes. Importantly, it addresses major limitations of the conventional headship-rate method, which lacks linkage to demographic rates, provides limited household typologies without size details, and focuses narrowly on household "heads" while ignoring other members. It also ensures internal consistency across sex, age, and relationship types by using a “harmonic mean” approach (Keilman 1985). For instance, it guarantees that the number of new marriages among men matches those among women, and that numbers of children who leave (or return to) the parental home each year are balanced against numbers of parents who experience a change in the number of co-residing children (Zeng et al. 1998).

Figure 22.1: A model of four marital statuses (left) and seven combined marital/union statuses (right)

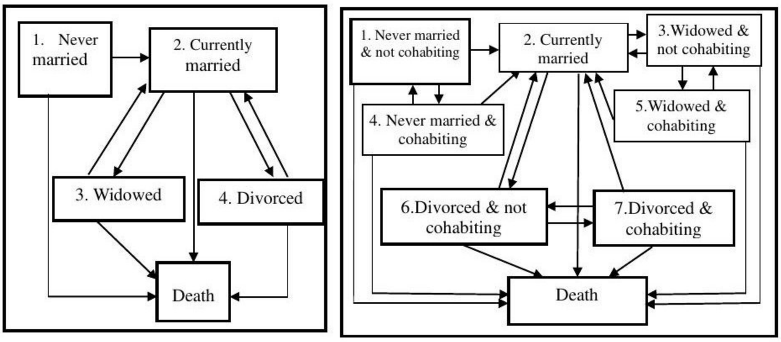

Figure 22.1 shows the two options the ProFamy user has for selecting marital status or combined marital/union status. In countries where cohabitation is widespread, a model with seven marital/union statuses will be appropriate. For other countries one may prefer an approach based on four marital statuses. Two other options the user has is to distinguish persons and households (i) in rural areas from those in urban areas, and (ii) according to race (two, three or four categories allowed). Unless mentioned otherwise, the remainder of this text assumes that the

four marital status option has been chosen, and no distinction by urban or rural area or by race.

As Willekens (2010) noted, one of ProFamy's biggest strengths is its reliance on standard demographic data sources, such as demographic surveys, censuses, vital statistics, and population registers. This makes it a powerful tool for analyzing how trends in marriage, divorce, fertility, mortality, and migration shape family and household structures over time (Willekens 2010).

Compared to a cohort-component model that uses common demographic data, the additional data preparation for ProFamy is relatively light. As shown in Table 22.1, it mainly requires estimates of age-parity-specific occurrence/exposure (o/e) rates of marital and non-marital fertility and of fertility of cohabiting women, age- and sex-specific o/e rates of marriage/union formation and dissolution, age- and sex-specific o/e rates for leaving the parental home, as well as total rates of marriage/union formation and dissolution (cf. below). These can be estimated using data from standard demographic surveys, censuses (for instance, home-leaving rates from two adjacent census micro data files and the intra-cohort iterative method, see Coale (1984, 1985), Stupp (1988), Zeng et al. (1994)), vital registration, or population registers, using ProFamy or the DemoRates package (Section 22.4).

Keyfitz (1972) has stressed that over-reliance on extrapolated age- and sex-specific rates can produce erratic results. A more effective strategy is to use standard age-sex schedules (see Section 2 of Table 22.1) and focus on projecting changes in key summary indicators (Section 22.3). This approach has been validated in several studies (Brass 1974, Coale et al. 1983), showing that changes in a few summary measures often determine the overall accuracy and realism of projections. The sex-specific total rates of marriage and of marriage dissolution are defined as sums of the age-sex-specific occurrence-exposure rates of marriage and marriage dissolution from the lowest age to the highest age at which the respective events occur (like the definition of total fertility rate).

The ProFamy approach with national age-sex-specific standard schedules is suitable both for national forecasts and for state, county, or city-level projections (Smith et al. 2012, Zeng, Land, Wang & Gu 2013, Zeng et al. 2014). It can even be applied to other countries with similar demographic patterns (Zeng et al. 2000).

Table 22.1: Data required for ProFamy and population projections

Data needed for the projections	**ProFamy**	**Population projection (sex and age only)**
1. Baseline population of starting year of projection at a certain regional level		
Either: (a) Micro data file from census or population register with the following variables: sex, age, marital status, relationship to householder, living in private or institutional household; Or: (b) Tabulations of age-sex-specific distributions for the variables mentioned under (a).	✓	✓
2. Sex-age-specific standard schedules, estimated by DemoRates R package using data from vital registration system, population registers, demographic surveys or census.		
(a) Sex-age-(and marital-status if possible)-specific mortality rates;	✓	✓
(b) Age-specific fertility rates;	✓	✓
(c) Sex-age-specific rates of in-migration and out-migration;	✓	✓
(d) Age-parity-specific o/e rates of marital and non-marital fertility;	✓	
(e) Sex-age-specific o/e rates of marriage and marriage dissolution;	✓	
(f) Sex-age-specific net rates of leaving the parental home.	✓	
3. Demographic summary measures in the baseline year and selected future years		
(a) Total fertility rates;	✓	✓
(b) Sex-specific life expectancies at age 0;	✓	✓
(c) Sex-specific general rates of in-migration and out-migration;	✓	✓
(d) Sex-specific total rates of marriage and marriage dissolution.	✓	

Note: When projection results are required by rural/urban area (or race), data types (a)-(b) in Section 1, (a)-(f) in Section 2, and (a)-(d) in Section 3 of the table need to be distinguished by rural/urban (or by race). Similarly, when the model includes seven marital/union states (cf. Figure 22.1), data for all statuses except "currently married" and "death" should be specified for cohabiting and non-cohabiting separately. The decision is based on the actual demographic situation and data availability of the country/region under study.

22.3 Evaluating and applying the ProFamy method

As stated before, ProFamy projects numbers of persons by age, sex, marital/union status, and numbers of co-residing children or parents. In addition, persons living in a private household are distinguished from those who live in an institution. This means that a person of a given age and sex may be in one of many possible states at a certain point in time. The mathematical expressions for such multistate models are complicated, because people may experience several competing events. For instance, an unmarried woman aged 23 who cohabits at time t may change marital status (marry her partner), break up the consensual union, get a child, leave her partner and return to her parental home, leave the country, or die before time $(t+1)$. Matrix expressions are required for an exact solution to these competing risks. However, an ingenious computational strategy originally due to Bongaarts (1987) simplifies the model equations considerably. ProFamy assumes (a) that births occur throughout the first and second half of the single-year age/time interval, and (b) that marital/union status changes, leaving parental home, migration, and death occur in the middle of that interval. The consequence is that the model can be expressed in terms of scalar equations – matrices are not necessary.

A second characteristic of ProFamy is its judicious choice of independence assumptions. For instance, marital/union status transitions depend on age, sex, and race, but are assumed to be independent of parity and co-residence status with parents and children. Fertility rates depend on age, race, parity, and marital/union status, but not on co-residence status with parents and children. Mortality rates are age, sex, race, and marital/union status specific, but are assumed to be independent of parity, co-residence status with parents, and children. These and other independence assumptions reduce the number of input parameters considerably. More details about the model expressions and the independence assumptions are given in Zeng et al. (2006).

Given these simplifying assumptions, it is important to test the validity of the model. In-sample tests of ProFamy show that the approach is reliable when forecasting household and living arrangements. For example, projections for the U.S. and China from 1990 to 2000 showed small forecast errors when compared with 2000 census data (Zeng et al. 2006, 2008). In a study comparing ProFamy projections to 2000 census results for all 50 U.S. states and D.C., 63 per cent of absolute percentage errors were under 3 per cent, and only 7 per cent of these errors were above 10 per cent of the observed values (Zeng, Land, Wang & Gu 2013). Similar accuracy was found in projections for all 31 provinces in China. ProFamy has also been validated at the county level, such as in Southern California, where projections from 2000 to 2010 aligned well with 2010 census counts (Feng et al. 2020).

ProFamy and its user-friendly software have been used worldwide—in countries like the U.S., Canada, China, Austria, Germany, Brazil, Mexico, Sri Lanka, Pakistan, and Iran. Applications include:

- Racial differences in U.S. household projections (Jiang & O'Neill 2007)
- Impacts of household trends on housing markets and policy in the U.S. (Smith et al. 2008, 2012)
- Forecasting U.S. home energy use and carbon emissions (Dalton et al. 2008, O'Neill & Chen 2002, O'Neill & Jiang 2007)
- Trends in private car ownership in the U.S. and Austria (Feng et al. 2011, Prskawetz et al. 2004)
- Fertility policy, elder care, and retirement policy in China (Zeng 2007, 2011, Zeng et al. 2008, Zeng, Chen, Wang & Land 2013, Zeng et al. 2014, Feng et al. 2018)
- Household projections in Germany, Brazil, and Mexico (Hullen 2000, 2003, Tirza 2017, Landy 2017)
- Fiscal impacts of changing households in Sri Lanka (Gruen 2020)
- Residential energy use projections in Pakistan and China's Hebei province (Zeng et al. 2021)

The method has also been adopted at local levels. For example, the Southern California Association of Governments (SCAG) has used ProFamy since 2009 to produce detailed, updated projections every two years. These projections support planning for housing, transportation, energy, senior care, and other social services (Feng et al. 2020). As of November 2024, the ProFamy software has been downloaded by 287 scholars from 39 countries, as well as by institutions like the World Bank and UNFPA.

22.4 The DemoRates package for estimation of age-sex-specific standard schedules and demographic summary measures

One challenge in producing detailed household projections is the lack of standardized age-specific rates for events like marriage, divorce, and fertility by parity. While such rates aren't readily available in many countries, they can be estimated using common demographic surveys, vital registration, censuses, or population registers (Zeng et al. 2012). The difficulty lies in the technical work needed to calculate and smooth these rates using traditional statistical tools. To simplify this task, DemoRates has been developed (Feng et al. 2024, Wang et al. 2024), an easy-to-use R package included in the free ProFamy software suite (http://www.profamy.com.cn). DemoRates enables researchers to estimate and smooth simultaneously the essential age-specific demographic rates for household projections.

22.5 Extending ProFamy to probabilistic household and living arrangement projections

The demographic future of any country is uncertain, but some developments are more likely than others. Therefore, population and household projections are best computed probabilistically, with results available as statistical predictive distributions.

Probabilistic household projections have a history of at least 25 years, which started with the work of Alders and De Beer (De Beer & Alders 1999, Alders 2001*a*,*b*). It was followed by many others (Jiang & O'Neill 2004, Scherbov & Ediev 2007, Alho & Keilman 2010, Christiansen & Keilman 2013, Keilman 2016, 2017, Wilson 2013*a*,*b*). Many of these probabilistic household projections (PHPs) are based on the following idea. Starting from a probabilistic population projection (PPP), each age-sex group of the population at some time in the future is broken down into several marital/union status categories, for instance the seven categories in Figure 22.1. This breakdown is performed stochastically, using "random conditional probabilities" (Alders and De Beer), or "random shares"

(Alho, Keilman, Christiansen), or “random propensities” (Wilson).

The ProFamy research team is conducting research to develop probabilistic household and living arrangement projections (PHPs) methods and user-friendly software, building on the United Nations Population Division’s (UNPD) PPPs that are available for each country. In summary, our approach is first to construct four time series models, for (i) total fertility (TFR), (ii) the sex-specific life expectancy at birth (e0), (iii) the total marriage rate (TMR), and (iv) the total divorce rate (TDR). Next, we construct prediction intervals for the population broken down by four marital statuses (Figure 22.1), in addition to age, sex, whether living with parents or not, or in a private or institutional household. The prediction intervals are obtained by simulation, accounting for the correlations through optimized random combinations of TFR(t), e0(s,t), TMR(t), and TDR(t); more specifically,

1. Optimized random-combinations of the 20 per cent highest TMR(t), the 20 per cent highest TFR(t), the 20 per cent lowest e0(s,t), and the 20 per cent lowest TDR(t);
2. Optimized random-combinations of the 20 per cent second highest TMR(t), the 20 per cent second highest TFR(t), the 20 per cent second lowest e0(s,t), and the 20 per cent second lowest TDR(t);
3. Optimized random-combinations of the 20 per cent middle TMR(t), the 20 per cent middle TFR(t), the 20 per cent middle e0(s,t), and the 20 per cent middle TDR(t);
4. Optimized random-combinations of the 20 per cent second lowest TMR(t), the 20 per cent second lowest TFR(t), the 20 per cent second highest e0(s,t), and the 20 per cent second highest TDR(t);
5. Optimized random-combinations of the 20 per cent lowest TMR(t), the 20 per cent lowest TFR(t), the 20 per cent highest e0(s,t), and the 20 per cent highest TDR(t).

The processes of home-leaving and entering an institution are assumed to be non-random. The final step is to split up predicted age-specific numbers of persons in each of the three marital status categories (never-married, divorced, and widowed) into two groups: cohabiting or not cohabiting. The shares that distinguish cohabiting from non-cohabiting persons are deterministic.

We have constructed time series models for marriage and divorce trends in China (1951–2020), the U.S. (1961–2020), and the UK (1951–2020) using the BayesRates R package. We have also used the BayesProj package to project these trends probabilistically through 2100 (Zeng et al. 2024, Liu et al. 2025, Zhang et al. 2024). Looking ahead, we plan to do the same for several other countries — including Brazil, Indonesia, Iran, Malaysia, Pakistan, the Philippines, Saudi Arabia, Singapore, Sri Lanka, Thailand, and Vietnam – with the help from local scholars.

22.6 Conclusion

The extended ProFamy method offers a practical and effective way to expand existing UN probabilistic population projections into full-scale probabilistic household and living arrangement projections. These can offer crucial insights for planning around aging populations, sustainable development, housing, residential energy, and social services. Our goal is to collaborate closely with UNPD and other global partners to make these projections more inclusive and informative for policy and planning worldwide.

Afterword

With Professor Frans Willekens' strong support and encouragements, based on Zeng's one-sex general-family-status life table model, Zeng et al. (1998) initially proposed and Zeng et al. (2006) and (Zeng, Land, Wang & Gu 2013) further developed ProFamy multistate cohort-component methods. The name of "ProFamy methods/software" was proposed by Professor Frans Willekens. ProFamy software for household and living arrangement projections was mainly developed by Zhenglian Wang. She was Visiting Research Scholar at NIDI in the early 1990s, and received a lot of guidance from Professor Frans Willekens. Qiushi Feng (who received his PhD degree in 2009 and did post-doc research on applications of ProFamy methods/software with Yi Zeng's supervision at Duke University) and Zhenglian Wang co-led the development of the DemoRates R package for input data preparations and analyses of household and living arrangement projections, using ProFamy methods/software.

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This book was written by friends and colleagues to honour Frans Willekens on the occasion of his 80th birthday on the 5th of March 2026. The 22 contributions to this book signify his enormous influence on the development of the discipline of demography, and the role he played as inspirator, supervisor, mentor, role model or friend for many young scholars. The book gives examples of research by colleagues and former students, who could build on Frans Willekens' invaluable contributions to demographic theory and methodology. Moreover, the authors' reflections about Frans provide additional details to colour the picture of a scholar one could call "a demographer's demographer".