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1. Introduction

A small research group within MPIDR works on agent-based modeling (ABM) of international migration. This note presents the approach to ABM. The aim is to clarify how ABM relates to demographic modeling in general and previous research. The aim is also to position the proposed research in the context of international migration research.

ABM aims at modeling the mechanisms and causal pathways that generate the phenomena we want to explain or predict. In order to accomplish that goal, the attention is shifted from factors to actors¹. To explain and predict population dynamics (e.g. migration), ABM identifies key actors (individuals, institutions) in the population and uses hypotheses on their behaviour to infer the behaviour of the population. ABM is a logical next step in formal demography. It is an extension of micro-demography and a response to Keyfitz and Caswell's (2005, p. 512) call for new models that follow causal pathways in population dynamics.

Migration is approached as a life event. That abstract perspective makes the research useful, not only for the study of migration, but also for studies of other life events that shape the life course, such as union formation and dissolution, childbearing, labour force entry and exit and major health transitions. The life course is usually operationalized as a sequence of life events (event histories) or a sequence of stages or states and transitions between stages/states (multistate approach).

This note consists of seven sections. In the second section, I try to clarify what ABM adds to demographic modeling and formal demography. In Section 3, I clarify why the subject of international migration was selected. In Section 4, a perspective on international migration is presented that is interdisciplinary and facilitates agent-based modeling. In the fifth section, the main features of the envisaged agent-based model of international migration are presented. The model extends the model proposed in Willekens (2013a). The model includes diaspora as a major source of feedback effects. The sixth section covers the use of ABM in population projections.

2. Why agent-based modeling?

Agent-based models capture the mechanisms that generate the phenomena we want to explain or predict. What are the mechanisms that generate life events? Life events are outcomes of biological, psychological and/or social processes. The processes are developmental processes, characterized by stages. A fundamental characteristic of a developmental process is that the onset of the process is determined by other factors than its continuation, perpetuation or evolution. The onset of a process is triggered by an event, an experience or a developmental readiness. But a process may also occur by chance. An evolving process accumulates traits and experiences and inherits features from earlier stages. That accumulation, i.e. the history of the process, influences its future. That fact is usually referred to as cumulative causation and path dependence.

¹ For a discussion of causal modeling in ABM, see e.g. Elsenbroich (2012) and Epstein (2007). For a discussion of causal modeling in demography, see Courgeau (2012a) and Wunsch (1988). For a discussion of causal modeling in the social sciences, see Russo (2009). Since causality is stochastic, models of causal mechanisms need to be probability models. Courgeau's (2012b, chapter 5) call for a paradigm shift in demography with a greater emphasis on fictitious individuals whose behaviour is prescribed by probability models points in the direction of ABM (see also Courgeau's discussion of ABM [Courgeau, 2012b, pp. 256ff).

The research group approaches agent-based models as extensions of demographic models. Most demographic models describe phenomena at the population level, but some describe processes and outcomes at the individual level. Keyfitz and Caswell distinguish between macrodemography and microdemography. In microdemography, 'properties of individuals and their random variation are recognized as the source of change in population aggregates' (Keyfitz and Caswell, 2005, p. 398). The authors mention microsimulation methods as an example of microdemography. Keyfitz and Caswell make another statement that helps view microsimulation and ABM, as practiced in the proposed research, as a logical extension of demographic modeling. Vital rates and other transition rates are the parameters of all demographic models. These rates 'are, in the end, properties of individuals. But the population consequences of those rates become apparent only when they are linked together in a model that describes stocks and flows of those individuals.' (Keyfitz and Caswell, 2005, pp. 511-512). In demography, a typical microsimulation model generates events (deaths, births, migrations, marriages, etc.) in a population of fictitious individuals by sampling from theoretical distributions (waiting time distributions) with as parameters the vital rates and transition rates. Agent-based models extend microsimulation by incorporating biological, psychological and/or social mechanisms underlying event occurrence. At the individual level, the outcome of a microsimulation model and an ABM is the occurrence (or non-occurrence) of a life event. By relating event counts to risk sets, transition rates may be computed for an entire population or for a group of people with similar characteristics. Or (multistate) event history models may be used to estimate transition rates. Transition rates may be used in demographic modeling, including cohort-survival projection models and microsimulation. (e.g. MicMac). ABM is fundamentally different from statistical modeling. Statistical modeling focuses on the relationship between variables and patterns in data. Transition rates are estimated from data. Agent-based models focus on (causal) mechanisms or processes underlying observed patterns. The mechanisms that link individual behaviour and observed outcomes at the population level are stochastic and should therefore be modeled using stochastic process models. To be valid, the underlying mechanisms that generate the events should (1) be plausible or (most) likely and (2) give rise to observed outcomes. An important aspect of behaviour is interaction with other individuals (with other household members and peers, but also with distant individuals), institutions and the macro-context. Since plausible processes are generally presented as heuristics or theories of demographic behaviour, ABM contributes to construction and testing of heuristics and theories. ABM offers an opportunity to close the gap between theory and techniques in formal demography. As a point of departure the theory of planned behaviour (TPB) (Ajzen, 1991, 2012; Fishbein and Ajzen, 2010) will be used. This theory focuses on actions in specific contexts (important for prediction, see below). It predicts actions (in our research emigration and choice of destination) from intentions and perceptions of behavioural control. In that theory, predispositions, attitudes and traits are insufficient to predict actions. The perceived behavioural control (*self-efficacy* in Bandura's Social Learning Theory), which is the belief in one's capability to perform an action (e.g. to emigrate and go to the destination of choice) is a critical aspect of the theory and should therefore be a critical component of the ABM. The theory of planned behaviour is widely used in migration research (for a relatively recent overview and discussion, see Gubhaju and de Jong, 2009). The TPB is also widely used in demography (see De Bruijn, 1999, for an overview and a discussion). Recently the usefulness of TPB for understanding reproductive decisions was the subject of a debate (Testa et al., 2011).

The findings are of particular relevance for the research group, because reproduction and migration are two life events. Some necessary improvements in the TPB proposed in the debate are already considered in the proposed ABM, in particular the developmental nature of decision processes and their embeddedness in the life course. During the research, the TPB will be adjusted and extended to make it more appropriate to study the causal mechanisms underlying international migration. We will use the TPB as a heuristic framework rather than a theory to be tested (for the distinction, see Liebroer, 2011). The TPB helps identify the mechanisms underlying migration decisions (the building blocks) that need to be included in the ABM. A milestone in ABM in demography was the first MPIDR workshop on Agent-based Computational Demography of February 2001 (Billari and Prskawetz, 2003). Presentations at the workshop illustrate the micro-demographic perspective and the use of microsimulation as an aid in theory building. For the first time it became clear that ABM can offer an effective approach to closing the gap between theory and techniques in demography. The workshop, the second workshop on ABM in demography (Billari et al, 2006) and later publications demonstrate that ABM also enables the exploration of new processes that are difficult to model using conventional techniques, such as the emergence and evolution of social norms or a culture of migration, consequences of complex institutional arrangements, and integration, differentiation and polarization in a population. ABM is also a natural way to incorporate game theory in formal demography and demographic modeling. That is beyond the proposed research, however.

ABM has a long history. It started with Schelling (1971), who showed that residential segregation is an outcome of the tendency of individuals to associate with similar others (homophily). In demography ABM is used extensively to model partnerships (homogamy) (e.g. Billari et al., 2007; Zinn, 2012). It is used remarkably little in migration research except in studies of residential mobility (e.g. Heppenstall et al., 2012). One of the very few applications to international migration is the dynamic microsimulation model developed by Massey and Zenteno (1999) to explain the evolution of migration from Mexico to the United States. It is an ABM, although the authors do not refer to the model as an ABM. To my knowledge, the AMARC (Agent Migration Adaptation to Rainfall Change) model developed by Smith (2012) in his dissertation on Burkina Faso is the most extensive application to migration (outside of residential mobility) of an agent-based model. Smith uses the theory of planned behaviour and does extensive validity tests. Migration rates generated by the agent-based model are close to the rates estimated from survey data and destinations correlate well with observed data. For other applications, see Willekens (2013a). If ABM closes the gap between theory and techniques in demography, ABM offers an opportunity to use theory of demographic behaviour in population forecasting. The use of theory has been an issue since Keyfitz (1982) raised the question whether knowledge can improve forecasting. Keyfitz did not expect much help from theory because theories are usually too general, whereas forecasting needs specific theories, i.e. theories on how people behave in a particular context. Agent-based models are designed to formulate and test specific theories (or heuristics people use in particular situations). The research group will explore using ABM to improve migration and population forecasting.

3. Why international migration?

The public concern about international migration, its policy relevance and the unique scientific challenges are reasons for selecting international migration. In Europe, the public is told that immigration is needed to make up for low fertility. In other parts of

the world, emigration is a livelihood strategy and emigrants a factor in economic development and foreign policy. The political interest in monitoring and global governance of international migration has never been greater. In the globalization debate, migration has long been neglected or considered an unintended consequence, but it is now moving to a central position comparable to that of trade and investment. International migration research is not equipped to respond to these changes and to provide the evidence and mental frames for sound policies. In the past decade, the OECD², the EU³, the United Nations⁴ and the World Bank⁵ have greatly improved the empirical base for international migration research⁶. Impressive visualization tools have been developed to explore these data (Vertovec, 2012). Scientists have not yet produced the comprehensive conceptual and analytical frameworks that incorporate the many dimensions of international migration and that could serve policy-making, for at least two reasons. First, the research area is fragmented and compartmentalized, constraining the development of a comprehensive approach. Second, empirical research is handicapped by data deficiency (lack of harmonized measurements), inadequate micro-data, and high costs of data collection (to prevent selection bias, data should be collected in sending, receiving and transit countries; probability sampling is usually not feasible and replaced by snowball sampling and other non-random sampling techniques [see e.g. Beachemin and González-Ferrer, 2011]). The public interest in international migration and major scientific challenges are elaborated.

a. Public interests in international migration

International migration is an important factor of demographic change. The population of the European Union grows at a rate of 2.5 per thousand (2011) and 70 percent of that growth is due to (net) migration (and statistical adjustments). In 2003, when the rate of population increase was 4.4 per thousand, migration accounted for 95 percent of that change. In Germany, the population would decline at a rate of 2.3 per thousand (close to 200 thousand people per year) in the absence of immigration and emigration. The slight increase in 2011 (1.1 per thousand) was a result of immigration (at a rate of 3.4 per thousand). In 2001, the United Nations increased awareness of migration as a factor of demographic change by raising the question whether replacement migration could be a solution to declining and ageing populations (United Nations, 2001). More important than the impact of migration on total population size is its impact on

2 OECD International Migration Database <http://stats.oecd.org/Index.aspx?DatasetCode=MIG>
<http://www.oecd.org/els/internationalmigrationpoliciesanddata/oecdmigrationdatabases.htm>

3 Eurostat Migration and Migrant Population Statistics
http://epp.eurostat.ec.europa.eu/statistics_explained/index.php/Migration_and_migrant_population_statistics

4 United Nations Global Migration Database <http://esa.un.org/unmigration/>

5 World Bank Global Bilateral Migration Database <http://data.worldbank.org/data-catalog/global-bilateral-migration-database>

6 For an extensive overview of databases on international migration, see Borchers (2008).

population composition and the perceived consequences of increased population diversity for shared values and social and cultural identities. More important is also the concern about sustainability of the welfare state with entitlement programmes not sufficiently resilient to accommodate large numbers of, often self-selected, newcomers.

Globally, migration is an important economic factor. The number of international migrants (persons living in a country other than their country of birth) is 215 million, 3 percent of the world population (IOM, 2012). Migrants send home large amounts of money. The World Bank estimates that in 2012 officially recorded remittances to developing countries surpasses \$400 billion, a growth of 6.5 percent over the previous year. The Bank expects these flows to rise even faster in the coming years and surpass \$500 billion in 2015. The total amount of remittances is more than three times the Official Development Aid (ODA), which is about \$130 billion per year. Since 1995 remittances surpass the ODA flowing to the developing world. In many developing countries, emigrants are a major source of income, with official remittances exceeding 10 percent of GDP (World Bank, 2011). The World Bank estimates that the total remittances are much larger because of informal remittance channels and irregular migration. Diaspora of developing countries have been discovered as sources of capital, trade, investment and knowledge and technology transfers. In 2007, the World Bank launched its African Diaspora Program and recently the International Organization for Migration (IOM) published its *roadmap for engaging diasporas in development* (Agunias and Newland, 2012).

Diaspora are being discovered as engines of economic growth and partners in foreign policy. In 2011, US Secretary of State Clinton launched the International Diaspora Engagement Alliance and convened the first annual Global Diaspora Forum⁷. Much earlier, in 2004, the Indian Government established the Ministry of Overseas Indian Affairs (MOIA) to connect the Indian diaspora with its motherland⁸. In 2012 the MOIA estimated the overseas Indian community (non-resident Indians NRI and persons of Indian origin PIO) at 25 million (MOIA, 2012). In China, [Deng Xiaoping](#) stopped treating overseas Chinese with suspicion and started seeing them as people who could aid China's development with their capital and skills (particularly in the Special Economic Zones established at that time [1978-]). Today the Chinese government is calling the Chinese at home and abroad (estimated at 50 million) to unite⁹. The African Union sees the African diaspora around the world as an "integral part of the continent" and organized in 2012 the first Global Africa Diaspora Summit (<http://www.africa-eu-partnership.org/node/2643>). In 2012, Indonesia established the Indonesian Diaspora Network, "acknowledging the potentials of Indonesian diaspora as a social and economic force". The Indonesian government estimates the number of Indonesians living overseas at around 6 million¹⁰. The network organized its first

7 <http://diasporaalliance.org/featured/global-diaspora-forum/>

8 <http://moia.gov.in/>

9 http://english.gov.cn/2012-09/22/content_2230790.htm (Official Chinese Government's web portal)

10 <http://www.diasporaindonesia.org/media/news/news42.php>

Congress of Indonesian Diaspora (CID) in July 2012, which attracted 2000 Indonesians and people of Indonesian descent living abroad to the Los Angeles Convention Center. The aim of the congress was to “to inspire Indonesian diaspora communities to connect and to unite themselves into one big community and create a tangible force in order to achieve a better Indonesia.”

(<http://www.diasporaindonesia.org/about.php>).

The European Commission’s Global Approach to Migration, initiated in 2005 as the overarching framework for the EU external migration policy, sees the potential of diasporas, but is predominantly an instrument to prevent and reduce irregular immigration. The potential of diaspora as partners in development cooperation was recognized, however “The EU will continue to invest in leveraging the contribution of diaspora communities to development and endeavour to better utilize their knowledge and expertise.” (European Commission, 2011b, p. 18; see also European Commission, 2011a). The DIASPEACE research project in the EU 7th Framework Programme (2008-2011) sought to produce empirical knowledge on how diasporas in Europe from conflict regions help build peace in their home countries. In 2011, the EU started funding the “European-wide African Diaspora Platform for Development” (Africa-Europe Platform, www.ae-platform.org).

The growing importance of international migrants in economic development and foreign policy is also evident from the many supra-national initiatives. The Global Forum on Migration and Development (GFMD; www.gfmd.org) is a global platform, established in 2007, where governments of 160 countries meet to discuss ways to integrate migration in international development. The platform is led by governments but involves the United Nations and civil society. Governments are requested to ‘unlock the potential of migration for inclusive development. Coherent development policies that fully incorporate migration as an enabling factor are better equipped to maximize the benefits and minimize the downsides of migration.’ (Åkerman-Börje, 2012). The United Nations has its own platform to encourage ‘more coherent, comprehensive and better coordinated approaches to the issue of international migration.’ It is the Global Migration Group (www.globalmigrationgroup.org).

b. Scientific challenges

International migration is an active field of research but fragmented along disciplinary, geographic and other dimensions (Penninx et al., 2006, 2008; Willekens, 2009a; de Haas, 2011). It lacks an overarching conceptual, theoretical and analytical framework that accommodates old and new forms of mobility in a changing world and lacks the necessary empirical base for comparative research, impact assessment and forecasting. Migration research is less pronounced in policy debates than it could and should be. For instance, the EU migration policy, which was adopted in December 2005, considers different stakeholders including governments, non-governmental organizations (such as trade unions, churches and welfare organizations) and other private organizations in sending, receiving and transit countries. It considers various forms of movement, covers migration and development linkages, and addresses temporary migration and permanent settlement. It differentiates between migrants on the basis of skill level (see e.g. Frattini, 2007; European Commission, 2012). The political commitment in Europe and the world to move towards a global governance of international migration has never been greater and the sense of urgency is manifest. Scientists are challenged to produce scientific

frameworks that position international migration within the context of economic and social transformation and include policy options.

International migration research in Europe gained considerable momentum in recent years. There is a growing interest in theoretical research that encompass various types of spatial movement from travel to permanent change of residence, and that views migration in the context of globalization and socio-economic transformation. The fragmentation along traditional disciplines is gradually fading, in part as a result of increased networking¹¹. The empirical basis for migration research improved considerably, largely because of (1) funding by the European Commission (in particular Eurostat) following new legislation on international migration statistics (adopted by the European Parliament and the EU Council in 2007), (2) the establishment of migration database by OECD, World Bank and United Nations (see above), and (3) NORFACE¹². Micro-data on migration have been collected in numerous surveys¹³, but with the mentioned problems associated with sampling methods. The type of coordination found in other surveys in Europe, such as the European Social Survey, the Survey of Health, Ageing and Retirement in Europe (SHARE) and the Gender and Generations Survey (GGS) is still missing in specialized migration surveys.

The European Science Foundation (ESF) stimulated a comprehensive, interdisciplinary approach to the study of international migration. It invited a Forward Look proposal¹⁴. The first stage of the Forward Look was implemented. In September 2011, the first ESF Strategic Workshop "New approaches for researching the

11 For instance, the Network of Excellence IMISCOE (International Migration, Integration and Social Cohesion in Europe) (www.imiscoe.org), established in 2004 with EU funds. IMISCOE is a scientific network and should not be confused with the European Migration Network (EMN), which was launched in 2003 and formally established in 2008 to provide up-to-date information on migration and asylum to European Union institutions and Member States. The EMN is coordinated by the EU Directorate General of Home Affairs. The up-to-date information is provided by national contact points, appointed by Member States (see <http://emn.intrasoft-intl.com>).

12 NORFACE programme "Migration in Europe: social, economic, cultural and policy dynamics" (2009-) (www.norface.org/migration.html).

13 Specialized migration surveys include the survey Push and Pull factors of International Migration (1995-1996, funded by Eurostat and coordinated by NIDI), the National Immigrant Survey 2007 of Spain (National Statistical Institute), the survey Migration from Africa to Europe (MAFE) (2008-2010, funded by European Commission and coordinated by INED), the survey Return Migration to the Maghreb (MIREM) (2006-07, by the European University Institute, Firenze) and qualitative and quantitative data collection by the THEMIS project coordinated by the International Migration Institute at the University of Oxford and funded by NORFACE.

14 The goal of the ESF Forward Look was to provide directions for international migration research for the next 5 to 15 years. It should guide research councils and other funding agencies in setting priorities and research institutions and research teams in developing agendas that address the migration process in relation to economic and social change. Agendas would be developed in a series of workshops. The proposal was completed in 2009 (Willekens, 2009a). Because of uncertainties about future activities of ESF (a consequence of the establishment of Science Europe), Forward Looks were put on a hold. It is now clear that ESF may be terminated by the end of 2015 and no new Forward Looks will be funded, although strategic exploratory workshops will (<http://www.esf.org/about-esf/latest-esf-developments.html>).

determinants of migration processes” was held at the University of Oxford, organized by the International Migration Institute, University of Oxford. The workshop resulted in key research questions and comprehensive research approaches cutting across disciplines (Bonfiglio, 2012). One approach is to adopt a complexity science perspective and to view international migration flows as outcomes of actions of agents (individuals and institutions) and interactions between agents and macro-structures. The subsequent stages, including an exploratory study for a European Migration Survey, following the example of SHARE and GGS, did not make it. Although more databases on international migration are being established, empirical migration research is handicapped because of data deficiencies, e.g. lack of comparability and insufficient detail on migrant characteristics. The new EU legislation of 2007, which required Member States to make available to Eurostat migration data that are comparable across Europe, aimed at establishing a common framework for the collection of statistics on international migration. The legislation allowed Member States to combine data from different sources and to use “scientifically based and well documented statistical estimation methods” (for an overview of the legislation and how it came about, see Willekens and Raymer, 2008). That statement triggered innovative research on the use of models to harmonize existing data, infer missing data, and produce synthetic data bases that integrate the best information available, along the lines recommended by researchers (Willekens, 1994). Innovative methods have been developed to combine data from different sources (censuses, surveys and administrative data) and to find ways to incorporate expert knowledge on migration flows and their composition (de Beer et al., 2010; Rogers et al, 2010; Raymer et al., 2011; DeWaard et al., 2012). New data sources are being explored (Zagheni and Weber, 2012). Bayesian methods have been introduced in migration estimation (see e.g. Brierley et al., 2008; Congdon, 2008; Bijak, 2011; Wiś niowski, 2013). The ongoing IMEM (Integrated Modelling of European Migration) project, coordinated by James Raymer at the University of Southampton (and currently at Australian National University) and funded by NORFACE adopts a Bayesian view to correct inadequacies in migration data and to estimate missing flows. Microsimulation modeling has been proposed and used to aid harmonization of migration statistics (Nowok, 2010; Nowok and Willekens, 2011). The modeling of international migration added tremendously to our understanding of migration data and migration patterns in Europe. It produced data that are more reliable, consistent and comparable, but there is still a long way to go to produce migration data that serve public debate and policy-making (for a discussion, see also Skaliotis and Thorogood, 2007). Many questions remain in measuring international migration (see also United Nations, 2002).

The research that will be carried out by the MPIDR research group takes a different perspective. It will not focus on improving flow data by combining information from various sources using statistical techniques and modeling. It will focus on agent-based models to produce the migration patterns recorded in official statistics, administrative data and surveys. Comparison of simulation results and empirical data will raise the critical issue of migration definition and measurement. For simulation results and empirical data to be comparable, the definition of migration must be the same and the simulation model should be able to simulate the measurement method. If countries use different definitions and/or measurements of migration, or definitions change in time, an agent-based model will generate events (emigrations and immigrations) that may be consistent with migration definitions in some countries but not in other countries. Validity checks become close to impossible unless the agent-based model is

extended with a *data model*, which simulates different definitions and measurements of migration, building on work by Nowok (2010). For example, an agent-based model of emigration from Poland to Germany that passes the validity test with Polish official statistics will not pass the test with German official statistics of the migration flow, because Poland and Germany define and measure migration differently. Agent-based models do not solve the conceptual and measurement problems in official migration statistics. A data model may.

4. A perspective on international migration

Migration is inherently linked to the geography of opportunities or means of existence. Many opportunities that are valued by people have a physical location and an individual has usually no influence on the location. To get access to the opportunities, the individual has to move. Many types of relocation exist: travel, commuting, seasonal migration, circular migration, temporary migration, nomadism and permanent migration. The type of relocation selected is likely to depend on the individual's resources (capabilities; human capital [including earlier migration experiences]; social capital), facilitators (e.g. social network, information, migration agents/brokers) and inhibitors or barriers (e.g. costs, regulations, documents required, e.g. visa or residence permit, language barriers, limited portability of pension entitlements and social security). In short, migration is viewed as a way to get access to valued opportunities and a strategy that depends on agency and structure.

The decision to migrate depends on individual preferences, aspirations and expectations. It also depends on others (family members, peers, etc.) and on higher-level (meso and macro) structures. By migrating and maintaining contact (through remittances, information exchange, maintaining ties) or by inviting or supporting new migrants, an individual contributes to building networks and other structures that change the conditions for migration and influence subsequent migration. By migrating and adding to the immigrant population in receiving communities, an individual contributes to a public attitude towards immigrants, which may facilitate or inhibit future migration. These feedback effects help shape migration flows. Positive feedback effects and the cumulative causation (path dependence) they generate are responsible for the emergence of migration corridors, migrant networks (diaspora) and migration systems¹⁵.

The distinction between theories describing the initiation of international migration (pioneer migration) and theories explaining the perpetuation of migration flows and the emergence of migration corridors and migration systems was introduced by Massey et al. (1993) and became generally accepted in migration research. It is consistent with the traditional distinction between active and passive migrants. The distinction is an illustration of the distinction in systems theory between factors that trigger processes and factors that influence how processes evolve. Feedback mechanisms that give rise to the emergence of a migration system and their subsequent decline (de Haas, 2009; Bakewell et al., 2011) are the subject of the ongoing THEMIS¹⁶ project, coordinated by the International Migration Institute of the University of Oxford and funded by NORFACE.

15 Stark and Jakubed (2012) present an interesting model of the emergence of migrant networks between would-be emigrants. Individuals interested in emigration engage in cooperative agreements to finance the emigration. Since migrant networks have optimal sizes, multiple networks emerge.

16 Theorizing the evolution of European migration systems (THEMIS).

5. Agent-based model of international migration

The point of departure of the envisaged ABM is the model proposed in Willekens (2013a). The model simulates individual migration decision processes. In the model, the decision to emigrate consists of several stages (attitude, intention, planning, performance of behaviour) and is a simple operationalization of the Theory of Planned Behaviour. During each stage, an individual may become disappointed or discouraged by others, may no longer believe in the ability to emigrate and consider emigration no longer an option (withdraw). Random factors play an important role. The length of each stage and progression to the next stage are random variables, described by waiting time distributions and other probability distributions. Simulation is in continuous time. The model distinguishes skill levels. The model includes governments in receiving countries enacting immigration policies targeted at highly skilled and moderately skilled residents of sending countries. As a result of migration flows, migrant stocks emerge in destination countries. The model includes diasporas. The immigrant community in diasporas is an important source of feedback effects influencing migration decision of individuals in home countries. Several activities of a diaspora generate positive feedback effects enhancing migration flows, leading to the emergence of migration corridors and migration systems. The model reproduces empirical observations by the Gallup World Poll on migration decisions and the United Nations on migrant stocks (foreign-born population).

Of the people who consider emigration, very few ever leave the country. Gallup World Poll interviewed 750,000 adults in 150 countries since 2005. The report of the study "*The many faces of global migration*" (Esipova et al., 2011) reveals that 14 percent of the world's adults (15+) population (630 million) say they would like to emigrate permanently if they could. It is high in outmigration countries such as Ghana and Mexico. Educated people are more likely to desire to emigrate. Persons who can rely on help from friends and family in other countries when they need it are nearly three times more likely to say they would like to migrate (30 percent versus 11 percent). Only 8 percent of those who desire to emigrate are planning to do so and less than half (39 percent) of those planning to move say they have already started making preparations. It amounts to 0.5 percent of the world population. The United Nations estimates that today, 3 percent of the world population lives in a country other than the county of birth. International migration is highly selective. The Gallup finding is generally consistent with other studies that investigate intentions to migrate. Most people do not intend to emigrate and a considerable mismatch exists between intentions and behaviour^{17 18}.

The agent-based model envisaged distinguishes several stages in a decision process. A stage ends with a transition to a new stage, the endpoint (emigration) or interruption of the process (withdrawal or attrition from the population at risk of emigrating). A

17 See e.g. Fouarge and Ester (2007), reporting on the Eurobarometer 2005, indicating that 5 percent of Europe's population intend to move to another country within the next five years.

Van Dalen and Henkens (2008) linked survey data of 2004-05 and population register data in 2007 and found that in 2004-05 3 percent of the Dutch population had plans to emigrate in the near future and 14 percent of those who intended to emigrate left the country before 2007. See also Van Dalen and Henkens (2012).

18 The mismatch between intentions and behaviour is also observed in reproductive decision making (Testa et al., 2011).

probability model (time-to-event model) describes the waiting time to an event and the duration of a stage. A sequence of probability models describes the behavioural process. The age at emigration is the sum of random waiting times and the age distribution is a convolution of distributions. Institutions, collective phenomena and feedback mechanisms impact on the parameters of the probability models. They speed up or slow down the decision process and they affect the rate of withdrawal. The validity of the ABM is assessed by comparing age distributions of emigration generated by the ABM with empirical distributions and by comparing simulated directions of migration with observed migration flows.

The microsimulation model that is a fundamental part of the ABM simulates migration histories, i.e. sequences of migration. The outcome of a migration decision is a single emigration, but emigration experience will have an influence on subsequent emigrations (if any). Research shows that many migrants return or move on to a new destination within a relatively short period of time, in particular after job loss or divorce (Bijwaard and van Doeselaar, 2012; Bijwaard et al., 2013). Students are likely to move on after graduation unless a job or forming a family induces them to stay (Bijwaard and Qi Wang, 2013). In the proposed simulation model, life histories are simulated in continuous time (Willekens, 2009b). A few simulation models exist that simulate event occurrences in continuous time, among them the MicMac model (Gampe et al., 2009). The basic specification of the MicMac model and several modules of the MicMac software will be used in the proposed research. Recently, Wu and Birkin (2012) included a brief review of MicMac in their overview of microsimulation models and agent-based models. Similar to MicMac, the envisaged agent-based model simulates individual life histories in continuous time. It differs from MicMac in the input. MicMac generates life histories from age-specific transition rates (estimated from vital statistics or survey data). The agent-based model generates life histories from a model of behaviour. If the agent-based model is valid, the two approaches should give comparable results (see below, Section 6).

The life histories produced by the agent-based model will be stored in a life-history data file with one record per individual (person file). The proposed format is that of a *Biograph* data file. *Biograph* (Willekens, 2012, 2013b) is a package in R designed to facilitate the analysis of life histories. *Biograph* is expected to facilitate the analysis of simulated migration histories.

A number of survey data may be used to test the validity of the agent-based model, although none of the surveys include sets of questions specifically designed for an operationalization of the Theory of Planned Behaviour. The Gallup World Poll data may be considered to model the decision to emigrate. The MAFE data set has information on intentions (plans) and steps undertaken to emigrate for respondents in the sending countries and information on intentions and behaviour for immigrants in receiving countries. The MAFE project is coordinated by Chris Beauchemin (INED) (www.mafeproject.com). The MAFE final conference was held in December 2012.

Another option is to use data from the Mexican Migration Project initiated by Douglas Massey at Princeton University (<http://mmp.opr.princeton.edu/>). The THEMIS project, coordinated by Oliver Bakewell (International Migration Institute at University of Oxford) is collecting qualitative data and quantitative data in a selection of origin and destination countries (www.imi.ox.ac.uk/research-projects/themis). The NIDI emigration survey (Van Dalen and Henkens) is a longitudinal survey among persons who expressed an interest in emigration by visiting an emigration expo.

6. Projection

The use of behavioural theories in population projection is of particular interest to demographers (see e.g. Keyfitz, 1982; Sanderson, 1998; Chi, 2009; Willekens, 2011). ABM provides an effective way to incorporate theories of demographic behaviour into projection models. Linking ABM and population projection is a logical next step in efforts to improve forecasting.

Microsimulation has a long history in population projection (for a review and discussion, see van Imhoff and Post, 1998). Recently microsimulation has been used in tandem with population-level models such as the life table and the cohort-survival model (see e.g. Lubitz et al., 2003; Cai et al., 2010; Willekens, 2011). Extending the research to ABM is a logical step. The agent-based model may be linked to the projection model through the transition rates similar to the way microsimulation is linked to the life table and the cohort-survival model. Age specific transition rates are the parameters of demographic projection models. They are usually estimated from vital statistics or survey data. They may also be generated by a behavioural model that describes (causal) mechanisms underlying occurrences of demographic events. The age at which an event (emigration) occurs, provided it occur, is an outcome of the behavioural model. It is the age at onset of the decision process plus the lengths of the various stages of the process. From the information on ages at emigration, age-specific emigration rates may be derived¹⁹. Introducing these rates in a projection model and making a population projection give the demographic consequences of the behavioural theories operationalized in the ABM (an alternative is to use the demographic accounting equation, which adds immigrants to and subtract emigrants from the population at the beginning of a time interval). The emigration rates may also be used to test the (predictive) validity of the behavioural model. The ABM-based rates should be close to the rates estimated from vital statistics or survey data (for methods and illustrations, see Zinn, 2011; Willekens, 2011; Smith, 2012). A related validity test is to compare individual life histories generated by the ABM and life histories generated by applying age-specific transition rates.

An alternative approach is to predict individual life histories using sequences of decision processes. Migrants have different motives to return or move on, depending on the reason for their first emigration. Bijwaard (2010) and Constant et al. (2012) present models for predicting the migration dynamics over the life course. The models require longitudinal data.

7. Research group

The proposed research group consists of two or three postdocs, in addition to myself. In addition, I expect to engage actively with other research groups at the institute. Cooperation with the Statistical Demography Laboratory (Jutta Gampe) will be aimed at the development of cutting-edge methodologies and software. Cooperation with groups that study the human life course in search for path dependencies (e.g. early life experiences) and effects of institutions, policies, and systemic variables (e.g. aggregate economic constraints) will be aimed at improved understanding of the mechanisms underlying the occurrence and timing of life events and structuring of the life course. Viewing migration as a life event paves the way to improving our understanding of migration using insights from studies of other life events.

¹⁹ Applying the demographic approach of dividing event counts in an age interval by the duration of exposure [occurrence-exposure rates] or the statistical approach, by deriving the Nelson-Aalen estimator of the cumulative hazard, the Cox model or another transition data model.

Team

Postdoc A:

- Subject: Agent-based modeling of the emigration decision process.
- Objective: Develop a stochastic, agent-based model of Ajzen's theory of planned behaviour and incorporate the major determinants of international migration. Estimate the parameters of the emigration decision model (and destination model) from (longitudinal) data from one or two of the surveys mentioned in this report.
- The candidate's field of expertise should be multistate modeling with proven expertise in empirical research and statistical modeling with R, and with an interest in theories of migration.

Postdoc B:

- Subject: Demographic consequences of international migration: ethnic population projections.
- Objective: Use results (migration rates) of the ABM and other data to produce ethnic population projections *for one country of Europe*. The results are migration rates and the projection model to be used is MicMac (both the cohort-survival model [Mac] and the microsimulation model [Mic]). Explore the usefulness of ethnic population projections in diaspora policies. A problem is that people have mixed origins and multiple identities. Study how a selection of national statistical offices (including US, Canada, UK, Germany, France) handle this issue in demographic studies and projections. Cooperate with the Max Planck Institute for Religious and Ethnic Diversity to determine the classification of ethnicities that is most suitable for forecasting purposes. The research builds on research by Rees (2008) and Rees et al. (2012). Note that Eurostat does not collect statistics with a breakdown by ethnic group. National legislation and practice in a number of Member States prevent the collection and dissemination of information on ethnic group or religion.
- The candidate's field of expertise should be international migration with proven expertise in empirical research and statistical modeling with R, and with an interest in ethnic demography, migration forecasting and population projection.

Postdoc C:

- Subject: Agent-based modeling of recent migration flows between EU Member States
- Objective: Operationalize an ABM that replicates the migration flows between EU Member States that have recently been estimated (MIMOSA and IMEM projects)
- The postdoc works with official statistics (measurements and estimates) and MIMOSA and more recent estimates. Simulation methods will be used to produce comparable migration data, extending work by Nowok (2010).
- The candidate's field of expertise should be international migration between EU countries. He/she should have a proven expertise in empirical research and statistical modeling with R, and an interest in migration forecasting.

Small but highly focused workshops may be scheduled

a. *International migration: from intentions to behaviour*

The aim of the workshop is to identify the heuristics and theories that are sufficiently specific to be used in ABM. The Theory of Planned Behaviour (with the extensions listed above) provides the overarching framework. Alternative theories will be considered.

b. *Migration networks: their role in the emergence of migration systems*

The aim of the workshop is to discuss empirical research on mechanisms through which migration networks and diaspora contribute to the emergence of migration systems. Social network theory, which views networks as nodes and ties between nodes, provides a framework. In the workshop, contributions of game theory (cooperative games and competition between coalitions) will be explored.

c. *Modeling social networks and social capital*

The aim is to review and discuss design issues in social network models (see e.g. Toivonen, 2009), innovations in complex network models (e.g. stochastic pi-calculus, see Zinn, 2011, p. 169) and what they mean for ABM of international migration. The focus will be on networks that help shape migration intentions and migration flows.

References

Agunias, D.R. and K. Newland (2012) Developing a roadmap for engaging diasporas in development. A handbook for policymakers and practitioners in home and host countries. International Organization for Migration (IOM), Geneva, and Migration Policy Institute, Washington D.C.

Ajzen, I. (1991) The theory of planned behavior. *Organizational Behavior and Human Decision Processes*, 50:179-211.

Ajzen, I. (2012). The theory of planned behavior. In P. A. M. Lange, A. W. Kruglanski & E. T. Higgins (Eds.), *Handbook of theories of social psychology* (Vol. 1, pp. 438-459). London, UK: Sage.

Åkerman-Börje, E. (2012) Statement by Swedish ambassador to the United Nations Eva Åkerman-Börje at the GFMD Summit Meeting 2012, Port Louis, Mauritius, at the occasion of the Swedish Chair (January 2013 – June 2014). Available at www.gfmd.org/en/chair.

Bakewell, O., H. de Haas and A. Kabul (2011) Migration systems, pioneers and the role of agency. Working Paper 48, International Migration Institute, University of Oxford.

Beauchemin, C. and A. González-Ferrer (2011) Sampling international migrants with origin-based snowballing method: new evidence on biases and limitations. *Demographic Research*, 25(3):103-134.

Bijak, J. (2011) Forecasting international migration in Europe. A Bayesian view. Springer.

Bijwaard, G.E. (2010) Immigrant migration dynamics model for the Netherlands. *Journal of Population Economics*, 23(4):1213-1247.

- Bijwaard, G.E. and S. van Doeselaar (2012) The impact of divorce on return migration of family migrants. NORFACE Migration Discussion Paper no. 2012-34. www.norface-migration.org
- Bijwaard, G.E. and Qi Wang (2013) Return migration of foreign students. IZA Discussion Paper 7185, Bonn; Institute for the Study of Labor.
- Bijwaard, G.E., C. Schluter and J. Wahba (2013) The impact of labour market dynamics on the return-migration of immigrants. *Review of Economics & Statistics*, Forthcoming.
- Billari, F.C. and A. Prskawetz eds. (2003) Agent-based computational demography: using simulation to improve our understanding of demographic behaviour. Heidelberg: Physica-Verlag (Springer).
- Billari, F., T. Fent, A. Prskawetz and J. Scheffran eds. (2006) Agent-based computational modeling: applications in demography, social, economic and environmental sciences. Heidelberg: Physica-Verlag (Springer).
- Billari, F., A. Prskawetz, B.A. Diaz and T. Fent (2007) The "Wedding-Ring": an agent-based marriage model based on social interaction. *Demographic Research*, 17(3):59-82.
- Bonfiglio, A. (2012) New approaches for researching the determinants of migration processes: ESF strategic workshop on migration research, University of Oxford, 29-30 September 2011. Final report.
- Borchers, K (in cooperation with W. Breustedt) (2008) Die Datenanlage im Bereich der internationalen Migration. Working Paper 18, Nürnberg: Bundesamt für Migration und Flüchtlinge.
- Brierley, M.J., J.F. Forster, J.W. McDonald and P.W.F. Smith (2008) Bayesian estimation of migration flows. In: J. Raymer and F. Willekens eds. International migration in Europe. Data, models and estimates. Chichester: Wiley, pp. 149-174
- Cai, L., Hayward, M. D., Saito, Y., Lubitz, J., Hagedorn, A., and Crimmins, E. (2010). Estimation of multi-state life table functions and their variability from complex survey data using the SPACE Program. *Demographic Research*, 22, 129–158.
- Chi, G. (2009) Can knowledge improve population projections at subcounty levels. *Demography*, 46(2):405-427
- Congdon, P. (2008) Models for migraton age schedules: a Bayesian perspective with an application to flows between Scotland and England. In: J. Raymer and F. Willekens eds. International migration in Europe. Data, models and estimates. Chichester: Wiley, pp. 193-205
- Constant, A.F. and K.F. Zimmerman (2012) The dynamics of repeat migration: a Markov chain analysis. *International Migration Review*, 46(2):362-388.
- Courgeau, D. (2012a) Can one speak of causality in the population sciences? The counterfactual and mechanistic approaches. www.academia.edu
- Courgeau, D. (2012b) Probability and the social sciences. Methodological relationships between the two approaches. Springer.
- de Beer, J., J. Raymer, R. van der Erf, Rob and L. van Wissen (2010) Overcoming the problems of inconsistent international migration data: a new method applied to flows in Europe. *European Journal of Population*, 26, (4), 459-481.
- De Bruijn, B.J. (1999) Foundations of demographic theory: Choice, process, context. Amsterdam: Thela Thesis.

de Haas, H. (2009) Migration system formation and decline. A theoretical inquiry into the self-perpetuating and self-undermining dynamics of migration processes. Working Paper 19, International Migration Institute, University of Oxford.

de Haas, H. (2011) New approaches for researching the determinants of migration processes. Background paper, ESF Strategic Workshop on Migration Research, International Migration Institute, University of Oxford, September 2011.

DeWaard, J., K. Kim and J. Raymer (2012) Migration systems in Europe: Evidence from harmonized flow data. *Demography*, 49, (4), 1307-1333.

Elsenbroich, C. (2012) Explanation in agent-based modelling: functions, causality or mechanisms? *Journal of Artificial Societies and Social Simulation*, 15(3):1

Epstein, J.M. (2007) *Generative social science: studies in agent-based computational modelling*. Princeton University Press.

Esipova, N., J. Ray and A. Pugliese (2011) Gallup World Poll: The many faces of migration. Based on research in more than 150 countries. IOM Migration Research Series No. 43. International Organization for Migration (IOM), Geneva, in cooperation with GALLUP.

European Commission (2011a) A new impetus to the EU external migration policy: the Global Approach to Migration and Mobility. http://ec.europa.eu/dgs/home-affairs/what-is-new/news/news/2011/20111118_01_en.htm

European Commission (2011b) Migration and development. Accompanying the document The Global Approach to Migration and Mobility. SEC(2011) 1353 final. Brussels: European Commission. http://ec.europa.eu/home-affairs/news/intro/docs/2_EN_autre_document_travail_service_part1_v3.pdf

European Commission (2012) Communication from the Commission to the European Parliament and the Council. 3rd Annual report on immigration and asylum. COM(2012) 250 final, Brussels, 30th May 2012. Available at

http://ec.europa.eu/dgs/home-affairs/e-library/documents/policies/immigration/general/index_en.htm

Fishbein, M. and I. Ajzen (2010) *Predicting and changing behavior: the reasoned action approach*. New York: Psychology Press (Taylor and Francis).

Fouarge, D. and P. Ester (2007) *Factors determining international and regional migration in Europe*. European Foundation for the Improvement of Living and Working Conditions, Dublin.

Frattini, F. (2007) Enhanced mobility, vigorous integration strategy and zero tolerance on illegal employment: a dynamic approach to European immigration policies.

Speech delivered at the High-Level Conference on Migration, Lisbon, 13 September 2007. Available at <http://europa.eu/rapid/pressReleasesAction.do?reference=SPEECH/07/526&format=HTML&aged=0&language=EN&guiLanguage=en>

<http://europa.eu/rapid/pressReleasesAction.do?reference=SPEECH/07/526&format=HTML&aged=0&language=EN&guiLanguage=en>

Gampe, J., Zinn, S., Willekens, F., Gaag, N., van der, de Beer, J., Himmelspace, J., & Uhrmacher, A. (2009). The microsimulation tool of the MicMac-Project. In *Proceedings of the 2nd general conference of the international microsimulation association*, Ottawa, 8–10 June 2009.

Gubhaju, B. and G. de Jong (2009) Individual versus household migration decision rules: gender and marital status differences in intentions to migrate in South Africa. *International Migration*, 47(1):31-61

- Heppenstall, A.J., A.T. Crooks, L.M. See and M. Batty eds. (2012) Agent-based models of geographical systems. Dordrecht: Springer.
- IOM (International Organization for Migration) (2012) Facts and figures. <http://www.iom.int/cms/en/sites/iom/home/about-migration/facts-figures-1.html>
- Keyfitz N. (1982) Can knowledge improve forecasts? *Population and Development Review*. 8:729–51.
- Keyfitz, N. and H. Caswell (2005) Applied mathematical demography. Third edition. New York: Springer
- Liefbroer, A.C. (2011) On the usefulness of the Theory of Planned Behaviour for fertility research, *Vienna Yearbook of Population Research 2011*. Special Issue in Reproductive Decision-making. Vol. 9, pp. 55-62.
- Lubitz, J., L. Cai, E. Kramarow and H. Lentzner (2003) Health, life expectancy, and health care spending among the elderly. *New England Journal of Medicine*, 349(11):1048-1055.
- Massey, D.S., Arango, J., Hugo, G., Kouaouci, A., Pellegrino, A., and Taylor, J.E. (1993). Theories of international migration: a review and appraisal. *Population and Development Review* 19: 431-466.
- Massey, D.S. and Zenteno, R.M. (1999) The dynamics of mass migration. *Proceedings of the National Academy of Sciences*, 96:5328-5335.
- Mezger, C. (2011) Migration attempts: who tries, who succeeds, who fails? Paper presented at the Annual Meeting of the Population Association of America, Washington D.C.
- MOIA (Ministry of Overseas Indian Affairs) (2012) India and its diaspora. <http://moia.gov.in/accessories.aspx?aid=10>
- Nowok, B. (2010) Harmonization by simulation: a contribution to comparable international migration statistics in Europe. PhD dissertation, University of Groningen.
- Nowok, B. and F. Willekens (2011) A probabilistic framework for harmonisation of migration statistics. *Population, Space and Place*, 17(5): 521-533
- Penninx, R., M. Berger and K. Kraal eds. (2006) The dynamics of international migration and settlement in Europe. A state of the art. Amsterdam University Press, Amsterdam
- Penninx, R., D. Spencer and N. van Hear (2008) Migration and integration in Europe: the state of research. Report commissioned by the Economic and Social Research Council (ESRC) for NORFACE (Background paper of the NORFACE Research Programme on Migration (2009-)). ESRC Centre on Migration, Policy and Society (COMPAS), University of Oxford.
- Raymer, J., J. de Beer and R. van der Erf (2011) [Putting the pieces of the puzzle together: Age and sex-specific estimates of migration amongst countries in the EU/EFTA, 2002-2007](#). *European Journal of Population*, 27, (2), 185-215
- Rees, Ph. (2008) What happens when international migrants settle? Projections of ethnic groups in United Kingdom regions. In: J. Raymer and F. Willekens eds. International migration in Europe. Data, models and estimates. Chichester: Wiley, pp.329-358.
- Rees PH., P. Wohland, P. Norman and P. Boden (2012) [Ethnic population projections for the UK, 2001-2051](#)., *Journal of Population Research*, 29(1):45-89.

- Rogers, A., J. Little and J. Raymer (2010) The indirect estimation of migration. *Methods for dealing with irregular, inadequate and missing data*. Springer.
- Russo, F. (2009) *Causality and causal modeling in the social sciences*. Springer.
- Sanderson WC. (1998) Knowledge can improve forecasts: A review of selected socioeconomic population projection models. *Population and Development Review*. 24(Suppl.):88–117.
- Skaliotis, M. and D. Thorogood (2007) Migration statistics and globalization: challenges for the European Statistical System. Paper for the 93rd DGINS (Directeurs-généraux des Instituts Nationaux de la Statistique) Conference entitled „The ESS (European Statistical System) response to globalisation – are we doing enough?“ held in Budapest, 19-21 September 2007. Available at http://epp.eurostat.ec.europa.eu/portal/page/portal/conferences/documents/93rd_dgins_conference/SESSION%20II%20DOC%205.PDF
- Smith, C.D. (2012) Assessing the impact of climate change upon migration in Burkina Faso: an agent-based modeling approach. PhD dissertation, University of Sussex. Available online via Sussex Research Online <http://sro.sussex.ac.uk>
- Stark, O. and M. Jakubek (2012) Migration networks as a response to financial constraints: onset and endogenous dynamics. Discussion Paper on Development Policy no, 168, Center for Development Research, University of Bonn.
- Testa, M.R., T. Sobotka and S.P. Morgan (2011) Introduction: Reproductive decision-making: towards improved theoretical, methodological and empirical approaches. *Vienna Yearbook of Population Research 2011*. Special Issue in Reproductive Decision-making. Vol 9, pp. 1-9.
- Toivonen, R., L. Kovanen, M. Kivelä, J.-P. Onnela, J. Saramäki and K. Kaski (2009) A comparative study of social network models: network evolution models and nodal attribute models. *Social Networks*, 31:240-254.
- United Nations (2001) Replacement migration: Is it a solution to declining and ageing populations? ST/ESA/SER.A/206. New York: United Nations.
- United Nations (2002) Measuring international migration: many questions, few answers. UN/POP/MIG/2002/BP/1, Population Division, United Nations, New York.
- Van Dalen, H. and K. Henkens (2008) Emigration intentions: mere words or true plans? Explaining international migration intentions and behavior. Discussion Paper 2008-60, Center, Tilburg University.
- Van Dalen, H. and K. Henkens (2012) Explaining emigration intentions and behaviour in the Netherlands, 2005-10. *Population Studies*, 10.1080/00324728.2012.725135
- Van Imhoff, E. and W. Post (1998) Microsimulation methods for population projection. *Population: an English Selection*, special issue on New Methodological Approaches in the Social Sciences, pp. 97-138.
- Vertovec, S. (2012) Dataviz (Interactive data graphics). <http://media.mmg.mpg.de/>
- Willekens, F. (1994) Monitoring international migration in Europe. Towards a statistical data base combining data from different sources, *European Journal of Population*, 10(1): 1-42.
- Willekens, F. (2009a) International migration and migrants in Europe. An ESF Forward Look proposal (invited proposal). NIDI, The Hague.
- Willekens, F. (2009b) Continuous-time microsimulation in longitudinal analysis. In: A. Zaidi, A. Harding and P. Williamson eds. *New frontiers in microsimulation modelling*. Ashgate, Surrey, UK, pp. 413-436.

Willekens, F. (2011) Microsimulation in population projection. *Cahiers québécois de démographie*, 40(2):267-297 (in French). Special issue on Microsimulation in Demography, edited by L. Martel, E.C. Malenfant and A. Bélanger. Available at <http://www.erudit.org/revue/cqd/2011/v40/n2/index.htm>

Willekens, F. (2012) Biograph. Version 2.0.2. The Comprehensive R Archive Network (CRAN), <http://cran.r-project.org/web/packages/Biograph/index.html>

Willekens, F. (2013a) International migration. A perspective from complexity science. Submitted.

Willekens, F. (2013b) Biograph. Multistate analysis of life histories with R. Springer. Forthcoming.

Willekens, F. and J. Raymer (2008) Conclusion. In: J. Raymer and F. Willekens eds. International migration in Europe. Data, models and estimates. Chichester: Wiley, pp.359-369.

World Bank (2011) Migration and remittances factbook 2011. Washington D.C.: World Bank. 2nd Edition.

Wiś niowski, A. (2013) Bayesian modeling of international migration with Labour Force Survey data. Paper to be presented at the Annual Meeting of the Population Association of America, New Orleans, April 2013.

Wu, B.M. and M.H. Birkin (2012) Agent-based extensions to a spatial microsimulation model of demographic change. In: A.J. Heppenstall, A.T. Crooks, L.M. See and M. Batty eds. (2012) Agent-based models of geographical systems. Dordrecht: Springer, pp.347-360.

Wunsch, G. (1988) Causal theory and causal modelling. Leuven: Leuven University Press.

Zagheni, E. and I. Weber (2012) You are where you E-mail: using E-mail data to estimate international migration rates. *ACM Web Science*, June 22-24, pp. 1-10.

Zinn, S. (2011) A continuous-time microsimulation and first steps towards a multilevel approach in demography. PhD dissertation, University of Rostock.

Zinn, S. (2012) A mate-matching algorithm for continuous-time microsimulation models. *International Journal of Microsimulation*. 5(1):31-51.