International migration
A perspective from complexity science

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Abstract

The governance of international migration is particularly difficult because many actors are involved and their actions and local and global interactions may have cascading effects throughout the migration system and major consequences in sending and receiving countries. Unforeseen events contribute to the complexity. Successful governance of international migration depends on the ability to identify, understand and predict the actors and their interactions, and to anticipate the consequences for migration and society. International migration has many features of a complex system. Complexity science offers a comprehensive conceptual and analytical framework for the study and management of complex system. The aim of the paper is to demonstrate the implementation of principles and methods of complexity science in international migration research and governance.

Many people in the world longing for a better life consider emigration. Few do emigrate. The main features of the multi-stage decision process are captured in a model that operationalizes Ajzen's theory of planned behaviour and reproduces characteristic migration patterns at the population level. Migration policies help shape the geography of opportunities and barriers. An agent-based model is used to translate decision processes, including responses to policies, into individual migration histories. Aggregation of individual histories reveals characteristic patterns of migration and population change.

1. Introduction

International migration is an active field of research but it is fragmented. That hinders the contribution migration research could make to the governance of international migration. More specifically scholars are challenged to develop comprehensive conceptual, analytical and empirical frameworks of migration that explain why people migrate, how migration systems emerge and evolve, and how migration relates to an increasing global connectivity (Penninx, 2006, p. 306; Castles, 2010). The frameworks should offer handles for the management of migration. They should include agency in addition to structural factors (Bakewell et al., 2011). Individuals, groups, institutions and organizations respond to the geography of opportunities. Their actions and interactions produce migration systems. In their response they exercise a certain degree of agency and choice.

Migration research is in need of a perspective that is realistic, strategic (able to guide research across the social sciences) and responsive to the mindsets of scientists, policy makers and the general public. In this paper a perspective is proposed that emphasizes actors rather than variables. The *what* question ("What are persistent patterns in migration?", "What factors influence migration and shape migration flows?") is replaced by the *who* question ("Who are the actors influencing migration and shaping migration flows?"). Actors have traits or attributes (the variables) and they interact with other actors, near and distant. They are part of a context (environment) with which they interact. During the interaction, they exchange information and maybe goods and services. As a result they adapt, i.e. they adjust their mindset, intentions and behaviour. The interaction also changes the collective behaviour and the social structures (e.g. social networks). The collective behaviour is experienced as 'a system'. A familiar example (OECD, 2009) is a flock of birds swarming across a countryside. No single bird is in charge, yet the flock's behaviour is organized and exhibits a kind of group intelligence. As they fly together, each member of the flock adjusts its location and speed based on the location and speed of others nearby. The collective produces beautifully non-uniform swarming motions that protect the members by frustrating predators that try to aim at individual birds. A common approach in science is to describe and model the system, using variables that characterize the system. A complexity science perspective describes and models the emergence and evolution of the system in terms of actions and interactions at the lower level. Agency and interaction (interconnectedness) are key features of the proposed perspective. Complexity science is the study of complex systems, i.e. systems of interacting actors or agents. Agents are individuals and institutions (organizations). The interaction gives rise to collective behaviour with characteristic patterns and processes. Agents react to the patterns they create (Arthur, 1999). Interactions usually follow simple rules. The challenge is to identify the agents and the rules of interaction. Feedback mechanisms are important drivers of systems behaviour. Negative feedback is necessary to maintain the characteristics and stability of the system. Positive feedback leads to change but may also lead to system disintegration and collapse.

To comprehend the complex systems, computer simulation is used. The simulation model describes a virtual world of individuals and institutions that follow relatively simple decision heuristics and rules. The validity test is the agreement between model outcomes and real-world observations. The model should reproduce known phenomena. Since observations at the level of agents (micro-level) are often missing, not reliable or not representative, observations at the population level (macro-level) are used. Models that describe the behaviour of the system as an outcome of actions and interactions of agents are known as agent-based models (ABM). The models simulate decision processes using established theories of behaviour. The value-expectancy theory (Fishbein and Ajzen,1980) and the theory of planned behaviour (Ajzen, 1991; 2002) are widely used theories of behaviour, also in the study of migration. These theories distinguish stages in the decision process. In the literature, a few ABMs of migration exist that apply these and related theories (Kniveton et al., 2012; Espındola, 2006; Wu, 2008; Heiland, 2003; Benenson et al.,, 2003).

The aim of this paper is to show that complexity science can enhance innovation in the study of migration by enabling integration of scattered evidence and knowledge into a coherent and comprehensive conceptual and analytical framework. The paper consists of five sections. In section 2 concepts that are often used in migration studies are integrated in a complexity science perspective on migration and the major ingredients of the new perspective are discussed. In section 3, agency is operationalized using the value-expectancy theory and a life-course perspective. A microsimulation model of international migration is developed. The model determines who migrates, at what age and how the decision is influenced. It produces individual migration histories, allowing for repeat migration. International migration systems and population changes in countries of origin and destination emerge from the individual migration histories. The model is presented in Section 4. The model captures stylized facts. The aim is to illustrate the operationalization of the complexity science perspective. Section 5 is the conclusion.

2. The complex migration system

In this section I focus on international migration and view migration as a movement in response to opportunities and challenges. I combine the established conceptual framework of migration research and the viewpoint of complexity science. First I present a few general remarks on international migration.

To most people international migration is a life-course strategy. The usual types of migration such as employment migration, marriage migration, family reunion, residential mobility and retirement migration are manifestations of the dependence of migration on events and stages in life. The life course perspective on migration also points to the repetitive nature of migration. A migration is often followed by another migration (e.g. return or onward migration) or even a sequence of migrations (e.g. circular migration).

The geography of opportunities and the mobility it generates result in spatial networks (nodes and corridors) and other spatial structures that influence future mobility. One structure is the mobility (migration) system, a group of communities or countries linked by migration (e.g. Euro-Mediterranean migration system). They encompass countries and communities of origin, destination and transit. The flow of migrants in a mobility system triggers flows of money (e.g. remittances), goods, services, information, ideas, etc.. Transnational diaspora networks and other migrant networks are manifestations of social networks and migration systems. They influence not only future migration but also trade and investment flows. They may cause ideational changes and even produce new, transnational identities. Some countries, such as

China and India, use social networks and transnational identities to promote economic growth. The geography of opportunity structures and the schemes that determine access (including mobility schemes) underlie geographical mobility. The geography of opportunities, the desire to move to where the opportunities are and the accessibility of these opportunities drive migration.

A generic and interdisciplinary framework involving the concepts of life course and social interaction may successfully be formulated in the language of *complexity science*. Complexity science does not focus on simple cause–effect relationships as traditional science does. It posits that complexity in the world arises from simple heuristics. The rules determine how agents behave in a changing environments and what feedback mechanisms underlie adaptation to new realities. From the behaviour of agents and the interaction between agents, structures and processes emerge that resemble real-world phenomena such as age and spatial patterns of migration, migration networks, migration systems and diaspora.

Various types of agents may be distinguished operating at different levels of organization or aggregation: the individual migrant, the family, community organizations, and public, semi-public and private agencies that facilitate or inhibit migration, etc. For example, recruitment agencies may try to facilitate migration whereas government agencies may deter migration. Agents have attributes, aspirations and intentions. To an individual and household, migration may be a survival strategy or a search for a better life. An employer or labour broker may be in search for cheap labor and/or skilled labour. A community organization may advocate the human rights of immigrants. Border management agencies, such a Frontex in Europe, have a narrow but clear mandate to reduce illegal border crossing. Intergovernmental organizations such as the International Organization for Migration (IOM) advocate human rights and good governance. They may also support migrants and migrant organizations. Many actors are directly or indirectly involved in international migration. They give rise to what Castles and Miller (2003) refer to as a migration industry.

Agents have the capacity to make choices and act accordingly (agency). They learn from experiences and from others, in particular significant others and members of the peer group. As a result they evolve (develop) within particular environments that may change too. Agents interact and exchange information, money, goods and/or services. They may also exchange values they cherish. As a result of the interactions and transactions, networks and other social structures may arise. Structures are not designed and imposed but they evolve endogenously from the decisions agents make. Most networks are local but as networks evolve, nodes emerge that may be reached from every other by a small number of steps. These *hubs* are highly connected. Most networks have these characteristics; they are known as small-world networks. Recently Klabunde (2011), using data from the Mexican Migration Project, found that after three decades the network structure resembles a small-world network where 26 percent of workers have 80 percent of links. The study shows the prospects of the complex networks theory (see e.g. Cohen and Havlin, 2010) for the study of international migration.

3. The migration process

3.1 Introduction

The purpose of this section is to illustrate how a complexity science perspective may be implemented. An agent-based, behavioural model is developed of international migration between four countries. The countries are hypothetical but the migration flows between the countries are realistic and capture patterns observed in the real world. The model incorporates insights from migration theory and empirical studies. The parameters of the model are not directly estimated from empirical data however, because *representative* data on migration do not yet exist. In this paper I make extensive use of the recent Gallup report "*The many faces of global migration*" (Esipova et al., 2011), which offers a look at the experiences of people who desire to migrate. The report is based on interviews with more than 750,000 adults worldwide since 2005. The report provides information on the decision process and the effects others have on the outcome.

International migration has several characteristics of a complex system. The 10 main characteristics of a complex system are (see also e.g. OECD, 2009):

1. Agents drive the system. Agents are individuals and institutions at different t levels of organization (e.g. household, community, country, international). Complexity science aims at identifying the micro-level mechanisms that generate observed collective phenomena.
2. Process. Complex systems change continuously due to internal forces and external influences. As a result, structures evolve. Processes are staging processes with each stage building on the previous one. An outcome is cumulative causation and path dependence.
3. Interaction. Agents interact and, as part of the interaction, exchange information, values, goods and services. Relatively stable networks and other patterns may emerge. Clustering may emerge too because agents are more likely to interact with similar agents (assortative mixing, also known as homophily). Game theory is often used to describe the interaction mechanisms.
4. Stochastic. In complex systems, events are stochastic. Their occurrence cannot be predicted with certainty, even when their distribution in time is known. The rate or probability of event occurrence depends on type of event, attributes of agents and contextual factors such as living conditions and the presence of institutions that facilitate or restrict migration.
5. Networks. Complex systems are best represented by networks with particular structural features and following specific dynamic laws.
6. Adaptability. Agents adjust their behaviour in response to the actions by other agents and changes in the environment.
7. Emergence. Patterns at the system level are consequences of the behaviour of units within the system.
8. Self-organization. No global entity designs or directly controls the system. The *invisible hand*, mechanisms of competition, cooperation and coordination, generates order. Self-organizing systems adapt to changing conditions, including changes in policies.
9. Attractors. An attractor is a state or a set of states to which a complex system is attracted spontaneously and consistently. It is a dynamic equilibrium (steady

state) pulling the system to some type of order. Attractors are persistent patterns and regularities in a chaotic system. They are not permanent, but temporary states to which a system evolves. Persistent collective values, norms, customs, religion, collective belief systems and social networks have been identified as attractors in social systems. Attractors are important for understanding self-organized order.

10. Predictability. The stochastic nature of a complex system, the feedback mechanisms and the dependence on external factors make prediction of the state of the system at a future date a major challenge.

Consider a system of countries linked by migration. Individuals engage in a migration decision process, with migration one of the possible outcomes. Empirical and theoretical migration research produced considerable knowledge about the process. The propensity to migrate depends on individual factors (personal attributes and experiences, stage of life) and contextual factors. The latter include push factors, pull factors and intervening factors. Measures in destination countries that enhance or discourage migration act as pull factors and intervening factors. Government policies, recruitment agencies and migrant organizations are intervening factors affecting the outcome of the decision process. The decision process has a number of stages. Passage through the stages takes time and not everyone reaches the next stage. Many persons who intend to migrate do not move. The pay-off may not be sufficiently high or the risk and uncertainty too large.

Fishbein and Ajzen (1980) developed the value-expectancy theory, also known as the theory of reasoned action, to explain the discrepancy between attitude, intention and behaviour. Intervening factors increase the intention to migrate if they increase the potential migrant's perceptions of his/her ability to migrate. The significance of that perceived behavioural control led to the theory of planned behaviour (for a discussion see Ajzen, 2002). The value-expectancy theory has been applied extensively to explain migration (e.g. De Jong et al., 1983, Kley, 2011). Most applications refer to the seminal work by De Jong and Fawcett (1981) who listed the most important motives for migration and assigned them to general values or goals in life. The simulation model proposed in this paper incorporates the main features of the migration decision process. The distinction between attitude, intention and behaviour is captured by distinguishing stages in the decision process. Each stage takes time and a potential migrant may decide not to continue the process. A positive attitude towards emigration, including the subjective belief that significant others approve the migration, does not necessarily result in an intention to migrate and an intention to migrate may not lead to an actual migration. In this paper, the decision process is embedded in the context of the life course and age is used as the time scale. For each individual in the population, the model generates sequences of migration (migration histories). Individual migration histories represent key features of the model. They describe migration as a stochastic process influenced by different factors.

For the agent-based model to be valid, the individual migration histories generated by the model should produce at the population level a migration pattern that is observed empirically. At the population level the individual migration histories result in an age profile of migration. Rogers and others have studied age profiles of migration extensively (see e.g. Rogers and Castro, 1981). They found that the age patterns of migration can adequately be described by a double exponential distribution. The individual migration histories should produce characteristic age patterns of migration at the population level. The individual migration histories should also produce plausible spatial patterns. Spatial patterns have also been studied extensively. They are generally described by spatial interaction models, which incorporate push factors, pull factors and intervening factors. In summary, a complexity science perspective describes migration decision processes and individual migration histories in a way that reproduce empirically observed (or plausible) age and spatial patterns of migration[1].

Consider four countries and a cohort of young adults, aged 15. The countries are denoted by A, B, C and D. Cohort members differ by personal attribute. In this paper, a single attribute is considered: skill level. I assume that 80 percent of the 15-year old have moderate skills and 20 percent are highly skilled. Skill is defined as the ability to do well. The model generates migration histories for cohort members until they reach age 50. I assume that mortality, emigration to third countries, and immigration from third countries are absent. Without loss of generality, I assume that at age 15 the cohort resides entirely in country A. Later in this paper, that assumption is relaxed. The model distinguishes between emigration and the choice of destination. In the literature, these two components are known as the generation and the distribution components. I refer to the two aspects of the migration decision process as the emigration process and the destination choice process. The desire to emigrate depends on country of residence, age and skill level. The destination choice depends on the attractiveness of the possible destination countries. To keep it simple, I assume that the attractiveness of a country for potential migrants is determined by a governmental migration policy. That makes the government an actor in the migration system. Several policies may be considered, e.g. residence permit, green/blue card, tax reductions, educational programs. In this paper, policies are considered aimed at attracting migrants with desired skill levels. In the absence of a migration policy, all destination countries are equally attractive.

The behavioural model is validated by (a) comparing the age pattern of emigration emerging from the micro-level model with the double exponential distribution, which is generally used to describe empirical migration age profiles and (b) assessing the spatial pattern of migration and the way the patterns shift as a result of changes in conditions and policies in sending and receiving countries.

3.2 The emigration process

A 15-year old may consider emigration some time in the future to start a new life somewhere else. The thought signifies a positive attitude towards emigration. The development of that attitude may trigger an intention to emigrate, which may be followed by planning for emigration, making the necessary preparations and actually leaving the country. The value-expectancy theory distinguishes between attitude, intention and behaviour as the three stages in the process of planned behaviour. Several studies, including the Gallup World Poll, found empirical evidence for the staging process. The Gallup World Poll found that 14 percent of the world's adults (15+) population (630 million) say they would like to emigrate if they could. Only 8 percent of them are planning to do so within 12 months and less than half (39 percent) of those planning to move say they have already started making preparations (Esipova, 2011). Most individuals stay in what the report calls the *dream stage* and do not continue to the planning stage and preparation stage. The poll also found that adults with at least some secondary education tend to be more likely to want to go than those with less education. Employment status and job prospects also matter. Most adults desiring to migrate do not progress to the planning and preparation stages because of personal circumstances (finance, family situation) or discouragement resulting from policies that create roadblocks to leaving or entering a country. While age and education strongly relate to people's *desire* to migrate, they do not matter as much in whether potential migrants are *planning* to move in the next 12 months. However, education and employment status are important factors in the transition from planning to *preparation*. The most educated are twice as likely to start preparation than those in other education groups. Employed persons planning to migrate are much more likely to start preparation than those not employed. The majority (54 percent) of professionals planning to migrate are actually preparing to leave. It may be related to the importance of employer-generated international migration in the United States and some other countries.

In the simulation model I assume individual differences in susceptibility to develop a positive attitude towards emigration. I assume that 80 percent of highly skilled persons in country A consider emigration, i.e. they develop a positive attitude towards emigration. The age at which they develop an attitude towards emigration and de facto start an emigration decision process is 18 on average. Some start earlier and some later. I assume that the age at onset of the migration decision process follows a normal distribution with mean 18 and a standard deviation of two years. Among persons with moderate skills, thirty percent ever consider emigration and the age at which they start reflecting on it is 18 with a standard deviation of four years. Forty percent of the moderately skilled cohort members with an attitude towards emigration and sixty percent of the highly skilled will progress to an intention or plan to emigrate. Some progress soon after they considered emigration while most take more time. I assume a constant progression rate of 0.2. It means that it takes an average of 5 years to develop an intention, provided a person moves from attitude to intention. The next stage of the process is to start preparing and to actually emigrate. I assume that a person with an intention to emigrate starts preparing when an opportunity comes along. Emigration is much easier for high-skilled persons than for persons with moderate skills. I assume that among the highly skilled one out of two persons get an opportunity within a year of developing an intention to emigrate and three out of four within two years. It implies an arrival rate of opportunities of 0.7[2]. The arrival rate of opportunities for moderately skilled persons planning to emigrate is assumed to be 0.3. I assume that a person who plans to emigrate is not selective and starts preparing when given a chance to leave the country. One my easily introduce the restriction that only opportunities that meet certain criteria are accepted, similar to the approach in search theory and search models in labour economics, where the reservation wage determines the acceptance of an offer.

The individual-level processes generate emigration patterns at the cohort (population) level that are consistent with observations in the real world. The empirical age pattern of migration between ages 15 and 50 closely resembles a double exponential distribution (Rogers and Castro, 1981; Raymer and Rogers, 2008). The behavioural model produces a similar shape at the population level. That is not unexpected since the double exponential emerges from a convolution of a normal distribution and a number of exponential distributions. As early as 1972, Coale and McNeil viewed a demographic event (first marriage) as the outcome of a multistage process and proposed convolution models to formalize that view of the process (for a recent discussion, see Kaneko, 2010). Their behavioural interpretation is that first marriage is stochastically determined by a transition through a sequence of latent states in young adulthood (see also Billari and Prskawetz, 2003; Todd et al., 2005; among others). The analogous approach to migration provides a behavioural interpretation of model migration schedules and produce a pattern described by a double exponential distribution.

The behavioural model is implemented using microsimulation. Consider a virtual cohort of 10,000 persons aged 15. The skill level is moderate for 80 percent of the cohort and high for 20 percent. Thirty percent of those with a moderate skill level and 80 percent of those with a high skill level ever develop a positive attitude towards emigration. Persons developing an attitude towards migration are selected at random from cohort members of a given skill level. To determine whether a person with moderate skill level is selected, a random number is drawn from a uniform distribution. If the number is less than 0.3, the person is selected. The same procedure is applied to the subcohort of highly skilled persons, but the threshold is 0.8. Only a proportion of these people will develop an intention and even fewer will ever start preparation. The age at migration of persons who complete the entire decision process is stochastically determined by the convolution of a normal distribution describing the age at the development of an attitude towards emigration and two lags, one to develop an intention or plan (dream stage), and another to start preparation (planning stage) and actually emigrate (preparation stage). During each stage the process may be abandoned. In that case, termination of the process for reasons other than the event of interest (transition to the next stage, emigration) leads to attrition or censoring. The attrition can be modeled using the theory of competing risks. In this paper, I assume that individuals who develop a positive attitude towards emigration may terminate the decision process before developing an intention or reaching the planning stage. I assume that, once an individual starts planning for emigration, any opportunity to emigrate leads to an emigration. The dream stage ends when the person enters the planning stage, when he/she chooses to abandon the desire to emigrate and stops the decision process, or at the end of the observation period, i.e. at age 50. I assume that during the dream stage, individuals abandon the desire to emigrate at a rate of 0.10 and continue to the planning stage at a rate of 0.25, both irrespective of the skill level. The exit rate from the dream stage is therefore 0.35. Twenty nine percent continue to the planning stage (0.10/0.35) and 79 percent abandon the desire to emigrate (0.25/0.35).

The planning stage ends when the preparation of emigration starts. During the planning stage, no one abandons the desire to emigrate. Continuation to the preparation stage is determined by the rate at which opportunities for emigration arrive. I assume a rate of 0.3 for moderately skilled persons and 0.7 for highly skilled. I assume that everyone who receives an opportunity to emigrate leaves the country. It means that the preparation stage is part of the planning stage. Since no one abandons the planning stage, entry into the planning stage implies emigration or censoring. Random numbers are drawn from a number of distributions. First, a number is drawn from normal distributions with mean 18 for both the moderately skilled and highly skilled persons and a standard deviation of 4 for the moderately skilled and 2 for the highly skilled. The random number determines the age at which an individual develops an attitude towards emigration. Second a number is drawn from an exponential distribution with a rate of 0.35 (0.1 + 0.25) for both skill levels. The random draw determines the waiting time to entry into the planning stage. In addition, a random number is drawn from a uniform distribution to determine whether a person in the dream stage abandons the desire to migrate or continues to the planning stage. If the random number is less than 0.1/0.35, the person continues to the planning stage, otherwise the desire to emigrate is abandoned. The number of individuals who transfer from the dream stage to the planning stage, i.e. who develop an intention to emigrate, is an outcome of the stochastic mechanism. In one set of random draws, 31 percent of the moderately skilled and 28 percent of the highly skilled abandon the decision process; the other continue to the planning stage. Finally, a number is drawn from two other exponential distributions, one with a rate of 0.3 for those with a moderate skill level and 0.7 for those with a high skill level. That rate determines the duration of the planning (and preparation) stage. The differences in standard deviation of the normal distributions implies that the range of ages at which moderately skilled persons emigrate is larger and their mean age of emigration is expected to be larger than that of highly skilled.

The simulation produces for each member of the cohort a status variable indicating the migrant status (emigrant = 1, stayer = 0) and an age at emigration or censoring. Censoring occurs at attrition, i.e. when the person decides to abandon the decision process, or at end of observation (age 50). Figure 1 shows the numbers of emigrations by age and skill level. The erratic pattern is due to random variation implied by the relatively small sample (1000). The smooth curves are double exponential distributions estimated form the individual ages at emigration in the virtual cohort[3 4]. Although persons with a moderate skill level are less likely to get a chance to emigrate, more depart because they constitute a large part of the population. The age pattern of migration of persons with high skills is narrower than that of other persons.

3.3 The destination choice process

The emigration rates derived in the previous section apply to country A, in which the initial population is concentrated. A person moving from A to C may stay in C until the end of the observation period or may move on to another country during the observation period. I assume that the rate of leaving C at a given age is the same as the rate of leaving A at that age. The same applies to countries B and D. That assumption implies that in the four countries residents go through the same migration decision process with the same parameters. The assumption is simplistic but it serves our purpose to illustrate that simple rules of behaviour may generate relatively complex patterns at the population level. I assume that the attractiveness of a country to a potential immigrant does not vary with age and skill level. If countries are equally attractive a very simple destination choice model applies: the probability that an emigrant from A chooses country C is the same as the probability of choosing B or D. It is equal to 1/(nr-1) where nr is the number of countries considered in the study. I do not assume that countries are equally attractive. I assume that country B has an immigration policy to attract moderately skilled migrants and country D has a policy to attract highly skilled migrants. In the model, policies (and other pull factors) may be introduced in two ways. The first is to adjust the destination choice probability without affecting the emigration rates. In other words, policies affect the distribution component of international migration but not the generation component. That approach directs moderately skilled emigrants to B and highly skilled emigrants to D, but it does not affect the level of emigration of sending countries. Countries B and C attract migrants that without the policy would go to other countries. The number of migrants that are expected to go to another country but do go to B or D is an indicator of the effectiveness of the policy. A similar idea is used by van Wissen and Jennissen (2008) in an effort to predict the number of asylum seekers in countries of Europe. They refer to the redirection as *pairwise substitution* (p. 238). The second method is to change the evaluation of opportunities by persons intending to migrate. Country B increases the probability that moderately skilled persons in a sending country get an opportunity to emigrate, while country D increases the probability for highly skilled persons with an intention to migrate. The change in opportunity structure affects both the distribution and the generation components. It is likely to generate additional migrants, to redirect migrants but also to shorten the time it takes for persons with the intention to emigrate to leave the origin country. A similar phenomenon exists in labour markets when persons substitute jobs in response to changes in earning differential. In fact, when a nurse in the Philippines or Bangladesh decides not to accept a local job offer but to migrate to Europe instead, she evaluates opportunities and expected values, and acts accordingly.

The first approach is followed in this paper. Countries A and B have no policies to attract migrants. The attractiveness measure is zero. Country B has a policy to attract moderately skilled persons and country D to attract the highly skilled. They have an attractiveness measure of two:

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             Skill
Destination  M  H
          A  0  0
          B  2  0
          C  0  0
          D  0  2
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The countries are indifferent about the origin of the migrants. The attractiveness of a country is a pull factor. The pull factor of a given country is a predictor of the probability that an emigrant chooses that country as the destination. The multinomial logit model is used to convert the attractiveness factor to a destination probability. The logit model assures that the destination probabilities add up to one. The probability that country B is selected as a destination is $p_2 = \frac{\exp(a_2)}{\sum_{k \neq 2} \exp(a_k)}$. The destination probabilities, by country of origin are shown in Table 1.

The age- and destination-specific migration rates are obtained by multiplying the emigration rates by the destination probabilities. These migration rates are used in the microsimulation. The rates differ by age, origin, destination and skill level. For the moment, they are assumed not to vary in time.

4. Simulation of migration histories

International migration is described by a continuous-time Markov process. A Markov process pictures the transitions between states of existence. A country of residence is such a state. It is the most common approach to the modeling of migration by origin and destination (for a review of migration models, see Willekens, 2008). The parameters of the model are migration rates that vary by age, origin, destination and may also depend on covariates. In this paper I consider a single covariate: skill level. The variation with age is a step function: the migration rates are piecewise constant. They vary between ages and remain constant within age groups of a single year. The age pattern of migration rates follows the double exponential distribution, with the continuous distribution replaced by a step function. The use of age-specific rates rather than rates that vary continuously with age is a common practice in demography. The migration rates that are used in the microsimulation are not estimated from data (the common approach) but are outcomes of a postulated decision process, as described in Section 3. A change in parameters of the decision process will change the migration rates and consequently the migration histories generated by the microsimulation.

Migration histories are generated in continuous time. In demography and other social sciences, microsimulation in continuous time is relatively recent although some authors (e.g. Wolf, 1986) proposed the technique long time ago. For a review of the method and discussion, see Willekens (2009), Zinn et al. (2010) and Zinn (2011). In longitudinal studies and life history analysis continuous time has three advantages over discrete time. First, dates of events are determined more precisely. Exact event times are generated rather than time intervals. That feature is of particular interest when durations between events (durations of stay) are required. Second, the sequence of events that occur in a same period is not determined pragmatically, as in discrete-time simulation, but follows from the theory of competing risks and the continuous-time stochastic process model that underlies the simulated life histories. Third, parametric waiting-time distributions, developed as part of the statistical theory of event-history modeling, can be used in simulation. It is an advantage to be able to draw random numbers from established theoretical distributions with known and desirable properties. The simulated trajectories they produce are usually very similar to the empirical trajectories described by the same probability models.

The core of the microsimulation is to *randomly determine individual migration histories from the migration rates produced by the behavioural model*. Consider the cohort of 15-year olds in country A. The migration rates by age and skill level were discussed in the previous section. To produce migration histories, we need to determine when an emigrant leaves A and what the country of destination is. For the simulation, I do not consider all 10,000 cohort members, but a 10 percent random sample[5]. The simulation of migration histories is a two-step procedure. The first step is to determine the age at departure. The second step is to determine the destination. At age 15, the rate of leaving A is very low (0.00365 for moderately skilled persons and 0.01646 for highly skilled persons), but the rate increases with age. To determine the age at departure, the rates of departure from A at all ages beyond the current age are considered. In statistical terms, it is the cumulative hazard that is used in the simulation. In this paper I assume that the age at leaving A is described by an exponential waiting time distribution with piecewise constant rates. A random number drawn from a cumulative exponential distribution with piecewise constant rates returns a waiting time. The age at departure is the current age plus the waiting time. We may also convert ages to calendar dates, provided the date of birth is given. To determine whether an individual in the sample develops a positive attitude towards emigration, a random number is drawn from a uniform distribution. If he develops a positive attitude, the age at which that occurs is determined by drawing a random number from a normal distribution with mean 18 years and a standard deviation of 4 years if the person is moderately skilled and 2 years if he/she is highly skilled. Another random draw from a uniform distribution determines whether the person moves from the *dream stage* to the planning (intention) stage. The age at transition is determined by drawing a random waiting time. The number is the length of the interval between the development of a positive attitude and entry into the planning stage. I assume that everyone in the planning stage starts preparing to emigrate if given a chance. The waiting time between entry into the planning stage and the onset of preparation is determined by a random draw from a waiting time distribution with parameter the rate at which the person is given opportunities to leave the country (which vary by age and skill level). The duration of preparation is determined by a random draw from another waiting time distribution. The age at emigration is the sum of all these random numbers drawn from the normal distribution and the piecewise-constant exponential waiting time distributions. The distribution of the age at emigration is the convolution of a normal and three piecewise exponential distributions.

The country of destination is determined by drawing a random number from a multinomial distribution with parameters the destination probabilities that apply **at the age of emigration**. After the emigration the process is repeated but with parameters pertaining to the receiving country. The random draws from the different probability distributions produce a migration history for one cohort member in the virtual sample. Consider an fictitious individual with moderate skills. He leaves A for D at age 22.56, leaves D for C at age 26.73, and stays in C till the age of 50 when the observation ends. Suppose that person is born on February 16, 1997. The dates of emigration are then September 8, 2019 and November 8, 2023. Calendar dates are useful to study the demographic consequences of the migration histories of individuals and cohorts. They are required when the simulation of migration histories are integrated in population projections.

The simulated migration histories need to be processed. To that end, they are stored in a data file, one record per person. A record contains the identification number (ID), the date of birth, the dates when observation starts and ends, the covariates (in this case, skill level), the countries of residence and the dates of migration. The data format is that of the *Biograph* package (Willekens, 2012) designed for the exploratory and statistical analysis of life history data. *Biograph* is programmed in R and is publicly available at the Comprehensive R Archive Network (CRAN) (http://cran.r-project.org/package=Biograph). The package includes utilities to prepare input data in the right format for other packages.

The individual migration histories produce a pattern at the cohort (population) level that may be compared with patterns in the real world. Normally the patterns are compared with observations in the population that served as the empirical base for the estimation of the parameters of the behavioural model and/or the migration rates. In this paper that is not the case since the parameters are educated guesses and are not derived from a particular data set. The pattern is therefore compared to established regularities in migration flows. The age profile of emigration derived from the multistage decision process is a double exponential distribution, as expected (Figure

1). Substantial random variation exists around the theoretical distribution due to the 20 percent sample (1000 cohort members). The sample has 787 persons with moderate skills and 212 persons with high skills. In the population 80 percent has moderate skills. A total of 220 persons migrate from A to B, most with moderate skills. The migration from A to D (164) consists predominantly of highly skilled. The difference is the effect of the different migration policies in B and D. Country C, which has no migration policy, attracts considerably less migrants than the other countries. Table 2 shows the migration flows. Note that the figures show the total number of migrations between the countries. A person initially in A may migrate more than once. Table 3 shows the most frequent migration histories between ages 15 and 50. The migration trajectory is shown in column five (case). The number of persons experiencing that trajectory is shown in the second column (ncase). The third and fourth columns show the share of that trajectory in the population and the cumulative proportion, respectively. The columns tr1 and tr2 show the mean ages at transition and the destination country for those who experience the given trajectory. Of the moderately skilled persons in A 77 percent remain in A during the entire period of observation (from age 15 to 50). That is not surprising because in the specification of the behavioural model it was assumed that 70 percent of the moderately skilled persons do not develop an attitude towards migration and some who develop a positive attitude abandon the desire to emigrate during the dream stage. Among the highly skilled, 33 percent never leave A. The figure is higher than the 20 percent that was assumed to never develop an attitude towards migration because some abandon the idea to emigrate.

Individual migration histories shape migration flows and the size and composition of the population in the different countries. Initially, the entire cohort is in A. Most of the moderately skilled persons remain in A but those who leave are likely to move to B. As a result B has a high concentration of moderately skilled persons. Most of the highly skilled leave A and they are likely to move to D. Although highly skilled persons are much more likely to emigrate than moderately skilled persons, country B is growing more in population size than country D because the sending country (A) has many more persons with moderate skills than with high skills. The individual migration histories can produce complex and realistic population dynamics.

How would the migration pattern and the population distribution look like if countries B and D do not have a migration policy? In a rerun of the microsimulation without differential attractiveness, the subsample has 777 persons with moderate skills and 223 persons with high skills. Because countries B and D lost their attractiveness, migrants are indifferent with respect to the destination. Of the persons with moderate skills, 598 remain in A, 49 move to B to stay (without moving to C or D before moving to B and without moving out of B), 49 move to C and 64 to D. Of the highly skilled, 78 remain in A, 26 move to B, 35 to C and 24 to D. Migrations are about equally distributed among the possible destinations. At the end of the observation period (when persons reach age 50) the receiving countries B, C and D have populations with a similar distribution of skill levels. The picture differs considerably from that in the presence of policies targeted at migrants with desired skill levels.

In the previous analysis, it was assumed that all 15-years olds are concentrated in country A. Suppose now that the cohort of 10,000 is distributed equally between the countries. Each country has 2,500 15-year olds. In each country 2000 persons have moderate skills and 500 have high skills. In the presence of migration policies in B and D, most persons remain in their country of residence but those who leave are likely to move to B if they are moderately skilled and to D if they are highly skilled. As a result B has a growing concentration of moderately skilled persons and D of highly skilled. The migration policy is the source of differential population growth and skill composition.

5. Conclusion

A complexity approach to the study of migration is one that emphasizes actors rather than variables. Actors are individuals, institutions and public and private organizations. Migration patterns and migration systems emerge as a result of actions of actors and interactions between them.

Because of the focus on actors, behavioural migration theories can be integrated in migration modeling relatively easily. Actors have attributes and a life course. Emigration rates vary with age, indicating an effect of stage of life. In this paper a behavioural model of emigration is proposed that captures important stages of the decision-making process but that maintains the characteristic age profile of migration rates between ages 15 and 50. That profile is often described by a double exponential distribution. The behavioural model is based on Fishbein and Ajzen's theory of reasoned action and extensions of that theory. The link between the behavoural model and the characteristic age profile is a convolution of a normal distribution and a number of exponential distributions. Each of these random variables represents a behavioural mechanism. The normal random variable is the age at developing a positive attitude towards emigration for those who ever develop such an attitude. The distribution of that random variable, which is the normal distribution, describes the age at which that event occurs. Exponential distributions describe the time needed to develop an emigration intention and start planning to emigrate, and the time it takes to start preparation to leave the country. The behavioural model accurately reproduces the typical migration age profile documented extensively in the literature. In the behavioural model of destination choice, emigrants respond to immigration policies in receiving countries. In this paper I divide migrants by skill level and postulate migration policies targeted at migrants with a desired skill level. That interplay is captured in a microsimulation model that operationalizes the behavioural mechanism and generates individual histories of international migration. Different migration histories lead to different migration flows and patterns of population change.

The paper intends to demonstrate how to incorporate behavioural theories in models of international migration and population change. Only a few aspects of behavioural theories of migration have been used in this paper but the framework paves the way for extensions leading to increased realism. A more realistic model includes feedback effects, diffusion mechanisms and elements of game theory. Feedback mechanisms can be introduced by varying the emigration rates and destination choice probabilities in response to conditions produced by migration. For instance, migrants are more likely to move to countries with communities of people with similar origin, background and characteristics. It means that the decision to emigrate and the destination choice depend on the decisions made by past migrants. An agent-based model such as the one used in this paper can be used to model the assortative mixing mechanism. That mechanism underlies clustering of immigrants. Diffusion mechanisms describe how information travels in a social network; it is used to model the rise of collective values, norms and beliefs. Game theory is used to explain and model competition and cooperation. Cooperation is a condition for integration of individuals in higher levels of organization. The combination of behavioural theories and microsimulation models is a significant strength of a complexity science perspective on international migration.

The implementation of a complexity science perspective in models of migration and population dynamics raises new theoretical, methodological and data processing challenges. The strategy adopted in this paper is to generate individual life histories. The life histories are stored and subsequently aggregated and analysed. The life histories generated by the microsimulation are treated as outcomes of sampling, following the recommendation by Wolf (2001). The simulated life histories are samples from theoretical distributions; they can be analysed in the same way as samples from real populations. The life histories are processed using techniques of event history analysis, although simulation addresses a different research question than data analysis. In microsimulation the research question is not whether persons with different attributes have significantly different migration rates (the dominant research question in the analysis of event history data), but whether different behavioural mechanisms can explain the empirically observed differences in migration rates and the migration patters that result. In my view, the ultimate aim of complexity science in migration research is to better integrate theory and models. Pursuing that integration seems to be the best remedy to end the fragmentation that characterizes migration research today.

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Table 1. Destination probabilities by skill level

Skill level M

Destination \ Origin	A	B	C	D
A	0.000000	0.3333333	0.106507	0.106507
B	0.786986	0.0000000	0.786986	0.786986
C	0.106507	0.3333333	0.000000	0.106507
D	0.106507	0.3333333	0.106507	0.000000

Skill level H

Destination \ Origin	A	B	C	D
A	0.000000	0.106507	0.106507	0.3333333
B	0.106507	0.000000	0.106507	0.3333333
C	0.106507	0.106507	0.000000	0.3333333
D	0.786986	0.786986	0.786986	0.0000000

Table 2 Migration flows by skill level and total, derived from the individual migration histories.

A. Total

Origin	Destination A	B	C	D	Total	Censored
A	0	140	32	163	335	692
B	5	0	10	19	34	144
C	3	7	0	19	29	42
D	19	31	29	0	79	122
Total	27	178	71	201	477	1000

B. Individuals with moderate skills

Origin	Destination A	B	C	D	Total	Censored
A	0	132	18	26	176	605
B	4	0	8	6	18	122
C	0	5	0	1	6	20
D	0	3	0	0	3	30
Total	4	140	26	33	203	777

C. Individuals with high skills

Origin	Destination A	B	C	D	Total	Censored
A	0	8	14	137	159	87
B	1	0	2	13	16	22
C	3	2	0	18	23	22
D	19	28	29	0	76	92
Total	23	38	45	168	274	223

Table 3 Most frequent migration histories, total and by skill level

A. Total population

	ncase	%	cum%	case	tr1	tr2
1	674	67.4	67.4	A		
2	118	11.8	79.2	AB	25.02>B	
3	87	8.7	87.9	AD	23.83>D	
4	18	1.8	89.7	ADB	22.74>D	25.68>B
5	15	1.5	91.2	AC	25.34>C	

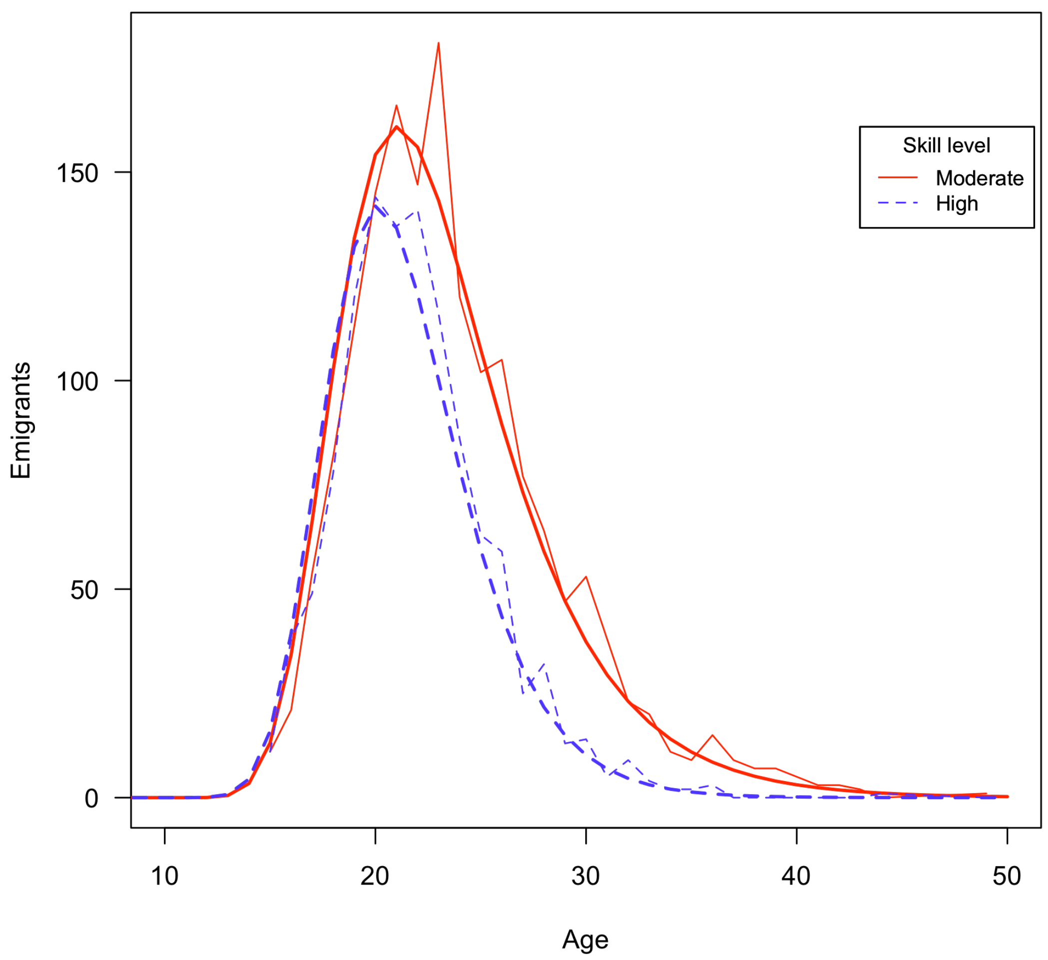
B. Individuals with moderate skills

	ncase	%	cum%	case	tr1	tr2
1	601	77.35	77.35	A		
2	114	14.67	92.02	AB	25.03>B	
3	23	2.96	94.98	AD	23.5>D	
4	13	1.67	96.65	AC	25.34>C	
5	7	0.90	97.55	ABC	22.59>B	29.32>C

C. Individuals with high skills

	ncase	%	cum%	case	tr1	tr2	tr3
1	73	32.74	32.74	A			
2	64	28.70	61.43	AD	23.84>D		
3	15	6.73	68.16	ADB	22.43>D	25.89>B	
4	14	6.28	74.44	ADC	21.51>D	25.69>C	
5	9	4.04	78.48	ADCD	22.22>D	23.67>C	27.81>D

Figure 1 Number of emigrants by age and skill level



[1] From a perspective of migration estimation, the method may be viewed as an extension of the approach developed by Rogers et al. (2003) to estimate migration using information from different sources. In the 2003 approach, processes at the individual level are not considered explicitly. In this paper, they are our main interest.

[2] The probability of an emigration opportunity during the first year is 1-exp(-0.7). The probability of an opportunity during the second year is exp(-0.7) * (1 – exp(-0.7)).

[3] Using the maxLik function of the *maxLik* package in CRAN. I thank Govert Bijwaard for programming the likelihood function.

[4] For the moderately skilled, the parameters are: alpha = 0.2129, lambda=0.2148 and mu = 23.48. For the highly skilled, the parameters are: alpha = 0.2104, lambda = 0.2967 and mu = 20.55.

[5] Note that the double exponential is estimated on 10,000 virtual observations, which reduces the random fluctuations (Monte Carlo variation) substantially.