Agent-Based Modelling in Population Studies

Concepts, Methods, and Applications

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Abstracts
Introduction: Agent-Based Modelling as a Tool to Advance Evolutionary Population Theory

Jan Van Bavel and André Grow

Abstract  Demography has a strong track record in the numerical monitoring of national population flows and structures. However, progress in theories that explicate the processes and mechanisms underlying these flows and structures remains limited. One reason why the development of population theory has been lagging behind may be that a specific concept of population has dominated our field. This conventional concept has greatly stimulated the development of national human bookkeeping, but this may have been at the expense of a more in-depth investigation of populations evolving through different kinds of interactions between individuals in very heterogeneous and partly overlapping subgroups and networks. As the chapters in this volume illustrate, agent-based modelling may help demographers to bridge the gap between the conventional and an alternative approach to population, combining the advantages and limitations of both. We argue that this may stimulate notably an evolutionary approach to population theory. In this way, demography may establish itself more firmly as a bridge between the social and biological sciences.
Model-Based Demography: Towards a Research Agenda

Daniel Courgeau, Jakub Bijak, Robert Franck, and Eric Silverman

Abstract  This chapter aims to contribute to the debate on the role of model-based approaches, such as agent-based modelling, in the future of demography. First we call attention to the developments of the discipline since the 17th century, and we describe its four successive paradigms related to the period, cohort, event-history and multilevel perspectives. We argue that these paradigms are complementary and that demography, since its beginnings, has subscribed to the classical scientific research programme launched by the promoters of modern science. Next, we examine how simulation modelling developing in population sciences recently, may help to respond to three main challenges: how to overcome complexity in social research; how to reduce its uncertainty; and how to reinforce its theoretical foundations. We sketch a model-based research programme for demography, looking specifically at interactions between various population systems. We then show how this approach might conform to the classical scientific research programme, in order to take advantage of its benefits.
The Role of Social Interactions in Demography: An Agent-Based Modelling Approach

Alexia Prskawetz

Abstract Individual demographic behaviour cannot be understood in isolation from the social network one is linked to. However, formal models of demographic behaviour lag behind the empirical evidence. In this chapter we demonstrate how agent based models can be applied to investigate the role of social interactions to explain macro-level demographic patterns like the age-at-marriage curve, age-specific fertility rates and the role of family policies for fertility. Based on these three examples we discuss the various steps that need to be followed when building up an agent-based model. These include the choice of the characteristics and rules of the agents together with the definition of how agents may interact and how macroeconomic behaviour may feed back on the micro level decisions processes.
Agent-based Computational Demography and Microsimulation using JAS-mine

Matteo Richiardi and Ross E. Richardson

Abstract  In this chapter we provide a hands-on guide on how to build a microsimulation using JAS-mine, a Java-based platform that provides unique simulation tools for discrete-event simulations, including both agent-based and microsimulation models. After presenting the rationale for the recent developments of the JAS-mine project and the main architectural choices made, we illustrate a step-by-step implementation of a rich dynamic microsimulation, which includes demographic processes (birth, death, household formation and dissolution) and other life course events (educational choices, labour market participation and employment outcomes).
Simulating Synthetic Life Courses of Individuals and Couples, and Mate Matching

Sabine Zinn

Abstract We present a novel microsimulation approach which is enriched by elements from agent-based modeling. Concretely, we have designed a simulation model and software which facilitate describing and simulating life courses of individuals and couples and conducting mate matching. To define individual and couple behavior we use a continuous-time multi-state model, that is, we use a continuous-time microsimulation model. For mate matching we apply agent-based modeling: first, to each individual who is seeking for a partner a random value is assigned that captures his or her aspiration level regarding the fit with a potential partner. Then, via an empirical likelihood equation we assess the probability that a given woman and a given man would mate. Thereafter, we simulate a decision making process whether two individuals form a couple applying individuals’ aspiration levels and their mating probability. Our description puts into perspective the differences between microsimulation and agent-based modeling, their relative strength, and limitations. We use the ml-DEVS formalism to specify the novel simulation approach and the modeling and simulation framework JAMES II to implement it. Projecting a hypothesized population based on the population of the Netherlands serves to illustrate its potential.
Using Survey Data for Agent-Based Modeling: Design and Challenges in a Model of Armed Conflict and Population Change

Nathalie E. Williams, Michelle L. O'Brien, and Xiaozheng Yao

Abstract Although agent-based models (ABMs) have become more commonly found in the demographic literature in the past decade, the use of survey data to populate and operationalize ABMs is still rare in demography. This technique, more commonly found in the geographic and land use literature, creates opportunities to study entirely new questions, but is time-consuming and cumbersome to use. In this article, we seek to contribute to the use of survey data based ABMs for demographic purposes. We do this by presenting details of the design, structure, and functioning of an agent-based model we created to examine the influence of armed conflict on population composition and change. In addition to presenting our model design, we also discuss several challenges and solutions to operationalizing survey data in the initialization and parameterization of survey-data based ABMs. Finally, we present illustrative examples from our ABM and compare the results with regression-based analyses. It is our aim that this presentation and discussion will expedite the design and testing of ABMs for future projects.
Regression Metamodels for Sensitivity Analysis in Agent-Based Computational Demography

André Grow

Abstract Agent-based computational simulation models can be complex and this can make it difficult to understand which processes are driving model behavior. Sensitivity analysis by means of metamodels can greatly facilitate the understanding of the behavior of complex simulation models. However, this method has so far largely been neglected in agent-based computational demography, with few exceptions. In this chapter, I illustrate how sensitivity analyses can be conducted by means of regression metamodels. I argue that this type of metamodel is particularly attractive for use in agent-based computational demography due to the fact that most demographers have at least a basic understanding of multiple regression. This makes this type of metamodel highly accessible and easy to communicate. After describing the basics of regression metamodels, I illustrate their use by conducting a sensitivity analysis of an agent-based model of educational assortative mating that is based on data on the structure of Belgian marriage markets between 1921 and 2012. I close the chapter with a discussion of the benefits and limitations of regression metamodels and point the reader to further readings on this topic.
Design and Analysis of Demographic Simulations

Jason Hilton and Jakub Bijak

Abstract  Agent-Based Models (ABMs) offer exciting possibilities for including explanatory mechanisms, such as behavioural rules governing the micro-level population dynamics, in the analysis of demographic phenomena. However, Agent-Based approaches are often difficult to analyse, and introduce additional sources of uncertainty to the modelling process, which need to be acknowledged. In this context, the aim of this chapter is to demonstrate how macro-level statistical analysis using emulators (meta-models) can be used to quantify and analyse the uncertainties inherent in ABMs.
How to Describe Agent-Based Models in Population Studies?

Jürgen Groeneveld, Anna Klabunde, Michelle O’Brien, and André Grow

Abstract   Agent-based models are increasingly used to describe, understand and predict human behaviour. The flexibility of agent-based models allows exploring mechanisms and feedbacks. However, this flexibility comes at a price, which is the problem of communicating and describing the model in a concise and transparent manner. There is no general agreement or culture yet on how agent-based models should be documented and described. Therefore, we want to contribute to the discussion on how agent-based models should be described in this position paper from a demography perspective. Firstly we present and discuss the plethora of different ways to describe published agent-based models in population studies and demography. Subsequently, we argue that the ODD+D (Overview, Design, Details + Decisions) protocol is apt to address the specific difficulties which arise in describing demographic ABMs. We describe the main elements of the ODD+D protocol and subsequently present the results of an experiment illustrating its usefulness to describe an agent-based model of circular migration. We conclude that protocols such as the ODD+D are not only useful to compile a model description, but also serve as tool for the model developer to check if she has provided all necessary information that allows the reader to fully understand and replicate the model.
The decision to emigrate: A simulation model based on the theory of planned behaviour

Frans Willekens

Abstract The theory of planned behaviour (TPB) is one of the most widely used theories of behaviour. It was developed by Ajzen as an extension of Fishbein’s theory of reasoned action (Fishbein and Ajzen 2010). The theory states that intentions predict behaviour and intentions are shaped by beliefs. In the paper, the theory of planned behaviour is extended to a process theory and that theory The model is used to specify a micro-simulation model of emigration decision-making. The validity of the model is assessed by determining how well the model predicts stylized facts about international migration.
Deciding to Disclose: A Decision Theoretic Agent Model of Pregnancy and Alcohol Misuse

Jonathan Gray, Jakub Bijak, and Seth Bullock

Abstract We draw together methodologies from game theory, agent based modelling, decision theory, and uncertainty analysis to explore the process of decision making in the context of pregnant women disclosing their drinking behaviour to their midwives. We employ a game theoretic framework to define a signalling game. The game represents a scenario where pregnant women decide the extent to which they disclose their drinking behaviours to their midwives, and midwives employ the information provided to decide whether to refer their patients for costly specialist treatment. This game is then recast as two games played against “nature”, to permit the use of a decision theoretic approach where both classes of agent use simple rules to decide their moves. Four decision rules are explored - a lexicographic heuristic which considers only the link between moves and payoffs, a Bayesian risk minimisation agent that uses the same information, a more complex Bayesian risk minimiser with full access to the structure of the decision problem, and a Cumulative Prospect Theory (CPT) rule. In simulation, we recreate two key qualitative trends described in the midwifery literature for all the decision models, and investigate the impact of introducing a simple form of social learning within agent groups. Finally a global sensitivity analysis using Gaussian Emulation Machines (GEMs) is conducted, to compare the response surfaces of the different decision rules in the game.
An Agent-Based Model of Sex Ratio at Birth Distortions

Ridhi Kashyap and Francisco Villavicencio

Abstract  Across a number of countries in Asia and the Caucasus, fertility decline in recent decades has been accompanied by an unprecedented and anomalous rise in the sex ratio at birth (SRB). Although the micro-level factors—persistent son preference within a context of fertility decline and growing access to pre-natal sex determination technology—are known, their specific levels, trends and interactions in explaining macro-level SRB trajectories are hard to discern with existing data and approaches. We present an agent-based model (ABM) that examines the contribution of each of these micro-level factors to the emergence of distorted SRBs at the macro-level. Calibrating our model to the South Korean and Indian scenarios, we show that even as son preference was declining in both settings SRB distortions emerged due to the diffusion of technology along with increases in probabilities to sex-selectively abort at lower parities as norms shifted towards smaller families. In South Korea, we find that SRBs peaked at 114 at relatively low levels of son preference of around ~30% wanting one son due to the joint effect of technology diffusion combined with steady increases in the readiness to abort, including small increases at parity 0 that is before the transition to first birth. In India, our model suggests that the SRB rise was less steep than South Korea’s as the readiness to abort was not as high as in South Korea, due to higher fertility levels when SRBs rose and slower technology diffusion.
Exploring the Role of Communication in Shaping Fertility Transition Patterns in Space and Time

Sebastian Klüsener, Francesco Scalone and Martin Dribe

Abstract  The fertility decline during the demographic transition is often viewed within the frameworks of innovation and adjustment. According to the innovation perspective, this process is mostly driven by the diffusion of new knowledge and attitudes; whereas in the adjustment framework fertility decline is seen primarily as an adjustment to changing circumstances. In this paper, we present models that allow us to simulate fertility declines that are solely driven by the diffusion of information structured by social and spatial variation in communication links. Using these models, we explore the question of whether observed social and spatiotemporal patterns of the fertility transition could be shaped by communication processes alone. The potential of these models is explored in a case study of Sweden. We run simulations on a full individual-level sample of the married female population aged 20-49 in 1880, which is around the time when the fertility transition started in Sweden. The population is divided into three social classes (elite, farmers, workers and others). As proxies for communication links, we use migration links. The simulation outcomes are contrasted with the observed fertility decline patterns in Sweden between 1880 and 1900. Our simulations demonstrate that communication structured by social and spatial variation in communication links could have shaped a substantial share of the observed social class and spatiotemporal characteristics of the fertility decline during the demographic transition.
Feedback Mechanisms in the Postponement of Fertility in Spain

Daniel Ciganda and Francisco Villavicencio

Abstract In this chapter we describe the process of fertility postponement initiated in Spain in the mid-1970s using a dynamic model that considers the interaction of four main factors. Rising economic uncertainty and the expansion of higher education provide the original impulse which is later amplified by the feedback generated via social interaction as young men and women start imitating the behavior of their peers and friends. As the pressure to conform to an early family formation standard is reduced, the postponement process gains momentum. This multiplier effect explains a substantial part of the observed trend, but its pace and extent also depend on the resistance exerted by social norms. Our model tries to capture the dynamic mechanism by which norms shape behaviors and behaviors shape norms, in a process of mutual dependence. This feedback loop between individual actions and aggregated outcomes allows us to bridge the micro and macro levels of analysis and it proves to be a key element in the explanation of the massive and ongoing transformation of fertility patterns in Spain in the last decades.
Linking Income, Transfers, and Social Support in an Agent-Based Family Exchange Model

Fanny A. Kluge and Tobias C. Vogt

Abstract  The positive relationship between income and old-age survival is well established. It is, however, less clear whether wealthier individuals live longer because they can afford certain goods and services not available to people with lower incomes, or because of indirect factors. This project investigates the role of intergenerational exchange in the relationship between income and mortality. In the previous literature on the link between income and longevity, this factor has seldom been analysed. We develop an agent-based model to examine the exchange relationship in a two-generational family. In the model, older parents use increases in their pension income as intergenerational transfers to younger family members, and receive emotional or functional support in return. Taking advantage of the natural experiment of German reunification, we estimate our model using realistic demographic, economic, and time use data. Our results imply that intra-familial resource exchange is beneficial for both the health of older parents and the living conditions of adult children in times of economic uncertainty. The findings therefore suggest that increases in pension income may affect old-age survival, both directly through the amenities elderly people can buy with the additional income, and indirectly through intergenerational transfers that incentivise adult children to provide support to their parents.
Agent-Based Modelling to Inform Health Intervention Strategies: The case of severe acute malnutrition in children in high-burden low-income countries

Hedwig Deconinck, Carine Van Malderen, Niko Speybroeck, Jean Macq, Jean-Christophe Chiem

Abstract Health interventions improve the management of severe acute malnutrition (SAM) in children under 5 in high-burden low-income countries. However, evaluation of their implementation faces a paucity of information and could benefit from a system perspective derived from the knowledge of implementers and experts. These challenges could be addressed using simulation modelling. We compared Markov and agent-based models of interventions for improving the management of SAM and assessed benefits and limitations in informing complex health intervention strategy designs. Based on a conceptual framework developed with existing evidence and expert advice, the agent-based model generated simulated data representing the complex evolution of the system. Multiple scenarios were investigated by varying parameters and mimicking rules of interventions. This study pointed out possible synergies between interventions enhancing early start of treatment and increasing recovery from SAM. When these interventions were adequately combined, outcomes of coverage, recovery and overall survival improved. Benefits of agent-based modelling were use of history, if-then rules to uncover mechanisms behind probabilities, and modifiable transition rates. Limitations related to model’s validation, choices of assumptions, and simplification. Agent-based modelling could be used to adapt intervention strategies to local contexts and support scale-up. As such, modelling could complement the methodological toolkit of health intervention strategy designs for improved policy decision.
Exploring Contingent Inequalities – Building the Theoretical Health Inequality Model

Michael Wolfson, Steve Gribble, and Reed Beall

Abstract There is considerable controversy whether a population’s extent of income inequality (not just individual income levels) affects a population’s health. Very provocative evidence is provided by a comparison of Canadian and US cities. There is a clear correlation in the US between city-level income inequality and working age mortality. But highly comparable data for Canada show no correlation. One hypothesis is that this major observed difference is due to greater income segregation (in turn highly correlated with racial segregation) in US cities compared to Canada. In this paper, we develop and present an agent-based model called the Theoretical Health Inequality Model (THIM). THIM embodies a theory of this correlation wherein it is contingent on a range of factors that are plausibly important, and that differ between Canada and the US in empirically verifiable ways. Drawing on both empirical evidence and various social science theoretical work, we posit a formal algorithmic structure for THIM, and then a set of parameters reflecting the “stylized facts” for Canada and the US. The focus of this chapter is on the development of THIM as an agent-based model, including its conceptualization, and the realization of these concepts as a virtual in silico laboratory for simulation experiments and hypothesis exploration.