Review of: "Towards a Model-Based Approach: Applications to Historical Demography and Palaeodemography"

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Potential competing interests: No potential competing interests to declare.

I liked Daniel's work. Like him, I also believe that the use of agent-based models for demography is becoming very relevant and in demand. Below I will discuss this topic.

The most cited organization that makes population projections is the Population Division of the United Nations Department of Economic and Social Affairs (hereinafter, UN). The latest forecast was published in July 2022 for 237 countries and territories, covering the world's population. The UN forecast is based on the assumption of a gradual decline in fertility in most countries under consideration and, in particular, is formalized as a function that is a combination of two logistic functions depending on the current level of the total fertility rate (TFR) for a particular country.

Each of the models parameters represents a range within which the rate of decline in fertility changes, the rate being calculated using a Bayesian hierarchical model, which considers not only the prevailing trends for a particular country but also the trends associated with it in other countries. Using Markov chains and the Monte Carlo method, about 100000 options of TFR changes are generated, among which the median is selected as the most probable scenario. The post-transitional phase of low fertility is modeled using autoregressive models, for which the TFR fluctuates around values that ensure population replacement (extended, simple, or narrowed).

Another frequently cited demographic forecast for 201 countries until 2100 was developed by the International Institute for Applied Systems Analysis (IIASA) and the Wittgenstein Center for Demography and Global Human Capital. For the corresponding calculations, methods of multivariate statistical analysis and expert assessments were used, which made it possible to determine trends in the birthrate by country, the education level, mortality, migration intensity, etc. As opposed to the UN forecast, to formulate assumptions about changes in the TFR for various countries, about 200 experts (economists, demographers, sociologists, etc.) were interviewed. In this case, it should be noted that, on the one hand, the opinions of competent specialists can be more accurate than computer calculations, while on the other hand, in some cases, expert assessments differed significantly. Thus, the estimated values of fertility rates for India varied from 1.5 to 2.5 by 2030 and from 1.1 to 2.5 by 2050.

Among the frequently cited forecasts are the results obtained during a large-scale study conducted by the Institute for Health Metrics and Evaluation (IHME), on the calculation of fertility, mortality, and population migration for 195 countries and territories from 2018 to 2100. Unlike the previous two forecasts, this study calculates and predicts not TFR but completed cohort fertility (CCF) at age 50—a coefficient representing the average number of children born to one woman from the age cohort under observation until she reaches the age of 50. This indicator is more stable since fertility in the

completed cohort practically does not increase and is less affected by various factors, such as delayed births.

At the same time, many demographers have criticized the IHME for a simplified approach to complex social phenomena such as migration, family planning, reproductive behavior, etc. Thus, the well-known demographer T. Sobotka from the Vienna Institute of Demography in co-authorship with Prof. S. Gietel-Basten from the Hong Kong University of Science and Technology published the study "Uncertain Population Futures: Critical Reflections on the IHME Scenarios of Future Fertility, Mortality, Migration, and Population Trends from 2017 to 2100," analyzing in detail the shortcomings of the proposed approach. The short summary of their work was signed by more than 170 demographers around the world and submitted to The Lancet, which had published an article with the IHME results. According to critics, a serious drawback of this study is its ignorance of the individual characteristics of people. In turn, the head of the IHME group, Prof. C. Murray, rejected criticism and said that the model used at the UN is based on a strange set of assumptions, and the demographic community is conservative and not inclined to accept new ideas.

Interestingly, both those and other research groups stress that for greater realism of reproducible processes, models should consider the heterogeneity of human society. Without detracting from the merits of the above-described approaches, we note that in our work we will use the agent-based approach, which, in addition to considering the heterogeneity of individuals, has several other advantages.

(1) Within the model of this class, an agent can be not only a unit of society, determining its dynamics by its social actions (marriage, having a child, moving to another region or country, etc.) but at the same time a participant in economic relations (working, paying taxes, shopping, etc.), as well as influence the ecological system (environmental pollution, etc.). Thus, it is possible to study simultaneously not only demographic processes but also many other interrelated components of socioecological and economic systems.

(2) Due to the complex stochastic behavior of agents, the simulated system is emergent and can generate bifurcations in the process of development. For this, the system does not have to be complex. Thus, even in very simple systems that reproduce the behavior of primitive entities, states can arise when the entire society dies out due to obscure causes (see Hennings work, 2008). In other words, the agent-based approach makes it possible to detect the onset of a transition state, which is difficult to identify by other methods (autoregressive models, etc.).

(3) Since agents are heterogeneous and differ from each other in a large set of characteristics, including spatial distance from each other, in the process of con[1]ducting computational experiments, it is possible to investigate the effects of differentiated impact only on a certain society located on a specific territory.

In (Makarov, Bakhtizin, Epstein "Agent-based modeling for a complex world", 2022), we gave many arguments in favor of using the agent-based approach for the analysis and forecasting of demographic systems. In our opinion, the growing complexity of the world and recent global upheavals (pandemic, disruption of production chains, trade wars, political upheavals, etc.), on the one hand, and the colossal performance of modern systems, on the other, contribute to the accelerated evolution of methods for computer simulation of social and economic processes, thanks to which it is possible to evaluate multiplier effects with direct and inverse links on the socioeconomic systems of most states.

That's why I think Daniel's work is so important and timely.