Diffusion processes in demographic transitions: a prospect on using multi agent simulation to explore the role of cognitive strategies and social interactions

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SOM-theme B Innovation and Interaction

Abstract

Multi agent simulation (MAS) is a tool that can be used to explore the dynamics of different systems. Considering that many demographic phenomena have roots in individual choice behaviour and social interactions it is important that this behaviour is being translated in agent rules. Several behaviour theories are relevant in this context, and hence there is a necessity of using a meta-theory of behaviour as a framework for the development of agent rules. The consumat approach provides a basis for such a framework, as is demonstrated with a discussion of modelling the diffusion of contraceptives. These diffusion processes are strongly influenced by social processes and cognitive strategies. Different possible research lines are discussed which might be addressed with a multi-agent approach like the consumats.

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Introduction

Many phenomena involving human behaviour confront us with the limitations of empirical research. We are often puzzled when social processes, such as the diffusion of contraceptives, evolve at a different speed or even take another course compared with a previous about similar situation. Whereas the empirical data leave much room for interpretation, they usually do not allow for causal interpretation because the phenomena in question cannot be studied using an experimental design. Techniques involving computer modelling, especially the so-called multi agent simulation models (MAS), provide promising tools to explore the individual and social dynamics behind certain complex phenomena, and thus may contribute to our understanding of the behavioural dynamics behind complex phenomena.

The development of the computer allowed for the running of mathematical models, thereby creating a virtual laboratory with new possibilities. In the 1950's, when the first 'fast computing machines' were used by some social scientists, the expectations of using computer programmes to increase our understanding of human behaviour were very high. For example, Newell, Shaw and Simon (1958, p 166) concluded that '*the vaguenesses that have plagued the theory of higher mental processes and other parts of psychology disappear when the phenomena are described as programs*'. However, the use of the computer as virtual laboratory did not flourish due to problems with the precise conceptualisation of theories in program rules, the linking of simulation outcomes to real world processes and last but not least the complicated and time consuming programming at that time. It lasted until the 1980's until this use of the computer gained popularity amongst small groups of scientists. Especially in the last decade the use of computer simulations really took of, facilitated by the growth in computer processing speed. Overviews of this rapidly developing area can be found in Vallacher and Nowak (1994), Doran and Gilbert (1994), Gilbert and Conte (1995), Conte, Hegselmann and Terna (1997) and Gilbert and Troitzsch (1999).

Doran and Gilbert (1994) argue that the technique of computer simulation is an appropriate methodology to study social phenomena that are not directly accessible for research in the classical tradition. Such a lack of accessibility may be due to the complexity of a phenomenon, which does not allow for understanding it on the basis of observational data, or because the phenomenon in question does not exist anymore, as is the case with historical processes. Here, simulation may help us in finding regularities that facilitate the discovery and understanding of empirical phenomena.

The social sciences, studying the behaviour of individuals and groups of people, deal with many very complex issues. Much of this complexity can be attributed to the many interactions between individuals, which may cause changes in the group as a whole (e.g. norms), which in its turn affect the conditions for individual behaviour. Especially when phenomena do not allow for experimental study in a laboratory setting due to this complexity, it is often very difficult to derive clear conclusions from empirical data such as field surveys. Whereas some phenomena can be studied very well in laboratory settings, such as memory, perception and basic cognitive processes, other phenomena, such as social networks, are less amenable to be isolated from the real-world context in a laboratory setting. The more a phenomena is entangled with the daily lives of people, the more difficult it may be to study the phenomena in a laboratory setting. Especially demographic phenomena, such as fertility change in relation to industrialisation/development, are hard to isolate in a laboratory setting. Instead of laboratory experiments, the researchers may employ methods such as using statistics and surveys. These methods yield an abundance of data, relations between these data and insights in the underlying mechanisms, and as such contribute to the development of demographic theories. However, regarding the behavioural processes and social dynamics that underlay certain phenomena less is known. Statistics on e.g., fertility, age of childbirth, economic situation etc. do not reveal the behavioural processes underlying people’s reproductive behaviour. Survey research focussed on this behavioural process is often hampered by the fact that many people are not aware of how e.g. social forces affect their behaviour. Yet, social networks and (locally evolving) social norms may have a strong influence on peoples behaviour, as empirical research in the Collective Action Theory paradigm has demonstrated (e.g., Marwell & Oliver, 1993). For example, when the majority of people in a certain community gets married at a certain age, a powerful social norm may be instigated concerning the proper age to marry. Moreover, some kind of lock-in effect may occur, making it less attractive to marry at an older age because the pool of attractive candidates is likely to be smaller. Evolutionary psychology provides a biological basis for preferences in partner choice that is based on attributes of fertility and status. However, when asking people why they marry at this age they are more likely to come up with individual motives (fell in love, met a suitable partner) than with social constraints as explanation. Besides that, people may be biased towards answering in a social acceptable manner, or may be reluctant to answer such personal questions, thereby limiting the explanatory power of survey research. Yet between cultures the average age of marriage may differ substantially, and even within a culture serious changes may occur within a generation. This indicates that not only biological factors play a role, but that also economical and cultural (social) factors appear to affect the individual's behaviour. Moreover, it appears that cultural and economical factors cannot be separated to study e.g., the phenomenon of fertility change, which has serious consequences for the study of this phenomenon (Palloni, 1998). We suggest that a more thorough understanding of the underlying behavioural mechanisms and social dynamics are important as to (1) better understand the causality of phenomena, and (2) better understand how policy measures affect certain processes, such as the diffusion of contraceptives. Multi Agent Simulation (MAS) offers a technique in the toolbox of the social scientist that can be used to study behavioural dynamics in a controlled setting. Because MAS involves a relative dynamic perspective on phenomena rather than a static view, the communication with mainstream science is usually limited. This causes that a scientific community emerges around the method of MAS, whereas in our view scientists should gather around research questions, and study these using different methodologies simultaneously. Considering this, the workshop on Agent-Based Computational Demography appears to be good initiative, as it tries to explore how the MAS methodology can be applied to tackle demographic research questions. This implies that the demographic phenomena that occur in the real world should be studied using agents rules that resemble the basic characteristics of the decision making process of real people. This holds that the agent rules should be based on relevant theory on human decision making. Moreover, relevant data should be translated in agent characteristics, so as to representing the heterogeneity of real social systems. The central question is thus how to develop an agent rule architecture that captures the relevant behaviours behind the real world phenomena so as to improve our understanding of these phenomena.

Behavioural rules in MAS

On the basis of formal models it is possible to develop simulation models that to a certain extent behave like real-world systems. Whereas it is tempting to develop very complex agents to enhance the realism of simulation models, it is essential to keep the agent rules simple enough to keep the simulation outcomes transparent. When we intend to model human behaviour in the context of demographic phenomena, is seems obvious that we want to model those aspects of people that appear to be relevant for understanding (aspects of) the real-world phenomena. For demographic purposes we do not need an agent with a detailed vision system, as that is not the issue we are primarily interested in. However, when studying the marriage market, fertility and the decision to use contraceptives it seems important to capture decision making processes in the agent rules, as well as the basic factors underlying these processes.

Within the social sciences there is a growing tradition of MAS modelling, where agents have to make decisions in a situation where their outcomes are also affected by the decisions of other agents. Within game theory, many simulations of commons dilemmas have been developed. The computer tournament for the most viable strategy, being organised by Axelrod (1980a; 1980b; 1984), was an important stimulus for this kind of research. Many researchers developed strategies for automata, such as win-stay, loose change, or win-stay, loose-defect. These strategies were being applied in automata playing iterative games as to explore the dynamics of resource use (e.g., Liebrand and Messick, 1996). A very good strategy appeared to be the Tit-for Tat strategy, which prescribes cooperating unless the other automata defected in the previous round, which is being retaliated by defecting oneself. Later, more sophisticated rules were developed, e.g. by equipping the automata with a memory for the behaviour of other automata (Lindgren and Nordahl, 1995; Molander, 1985; Nowak and Sigmund, 1992), or by equipping the automata with evolutionary strategies (genetic algorithms), which allowed them to adapt their choice behaviour to the behaviour of the other agents (e.g., Axelrod, 1987; Macy, 1996). However, most game theoretical simulations were primarily focussed at developing optimal strategies instead of trying to develop strategies that reflect actual human decision-making. Recently, researchers are developing agent rules that are aimed at describing human behaviour more realistically. Epstein and Axtell (1996) for example created agents in a virtual world of Sugarscape that had different abilities, different needs, could be equipped with different cultural 'traits', could reproduce and ultimately would die. Despite the enormous appeal of Sugarscape, critique focussed on the lack of behaviour theoretical foundation of the agent rules, which caused the agents to have little in common with real people (see Durlauf, 1997).

Ernst (1998) on the contrary formalised attitude theory in simulated agents. His agents thus performed behaviour that went beyond the rational/optimal resource-management strategies that have been used in many other modelling approaches. Within the limited resource management task, this approach appeared to be useful to study how attitudes affect the (un)sustainable use of a common resource.

Whereas the use of behaviour theory to develop agent rules is gaining popularity, the fact remains that usually a single theoretical paradigm is being used for the modelling of the agent rules. Looking at the behaviour of people in the real world, we acknowledge that many behavioural theories are relevant to describe that behaviour, like theories about human needs and motivational processes, social comparison theory, social learning theory, the theory of reasoned action and others. According to some scholars there is a need for a meta-theory of human behaviour (Vallacher and Nowak, 1994). However, up to now no simulation model contains agent rules based on a meta-model of human behaviour that integrates various cognitive processes. The consumat approach as introduced by Jager, Janssen & Vlek (1999) is based on a comprehensive conceptual model of consumer behaviour, and as such tries to offer such a meta-theory. The consumat approach has been used for developing a set of agent rules that are based on various behavioural theories.

The consumat approach

The consumat approach as introduced by Jager *et al.* (1999, see also Jager, 2000) is based on a comprehensive conceptual model of choice and decision making behaviour (Figure 1). As such it tries to offer a more psychological based meta-theory of human decision making than the frequent used 'rational actor' approach.

Opportunity consumption is defined in a broad sense, including issues like material goods and services, but also issues like getting married and becoming parents can be considered as opportunities. The consumat approach considers basic human needs and uncertainty as the driving factors behind the human decision making process.

Based on this conceptual model, a multi-agent simulation model has been developed, in which the agents are called 'consumats'. The driving forces at the collective (macro-) and the individual (micro-) level determine the environmental setting for consumat behaviour. This may be represented by a collective resource. The individual level refers to the consumats, which are equipped with needs which may be more or less satisfied, are confronted with opportunities to consume, and that have various abilities to consume opportunities. Furthermore, consumats have a certain degree of uncertainty, depending on the difference between expected and actual outcomes of their behaviour.

The consumats may engage in different cognitive processes in deciding how to behave, depending on their level of need satisfaction and degree of uncertainty. Consumats having a low level of need satisfaction and a low degree of uncertainty are assumed to *deliberate*, that is: to determine the consequences of all possible decisions given a fixed time-horizon in order to maximise their level of need satisfaction. Consumats having a low level of need satisfaction and a high degree of uncertainty

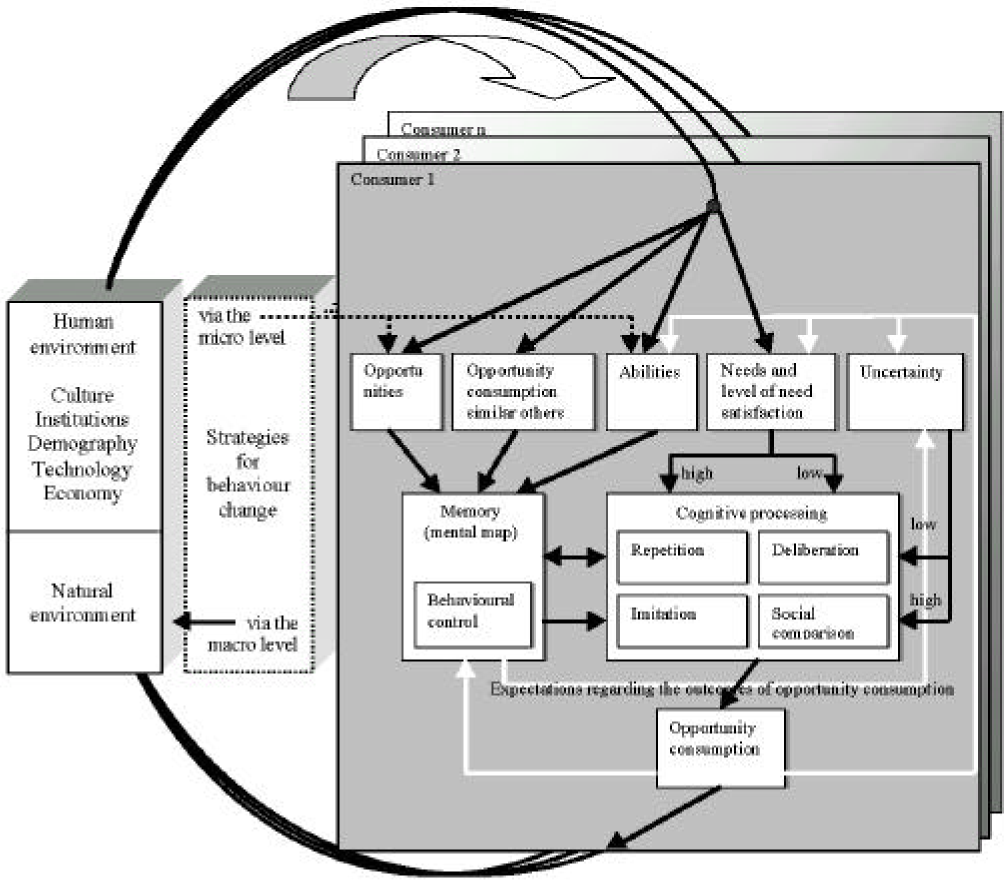

Figure 1: *The conceptual model of consumer behaviour*

are assumed to engage *in social comparison*. This implies comparison of its own previous behaviour with the previous behaviour of consumats having roughly similar abilities, and selecting that behaviour which yields a maximal level of need satisfaction. When consumats have a high level of need satisfaction, but also a high level of uncertainty, they will *imitate* the behaviour of other similar consumats. Finally, consumats having a high level of need satisfaction and a low level of uncertainty simply *repeat* their previous behaviour. When consumats engage in reasoned behaviour (deliberation and social comparison) they will update the information in their mental map, which serves as a memory to store information on abilities, opportunities, and characteristics of other agents.

After the consumption of opportunities, a new level of need satisfaction will be derived, and changes will occur regarding consumats' abilities, opportunities and uncertainty. Moreover, the resource will change, thereby affecting the consumption in subsequent time steps.

The consumat approach has been applied to several issues, mainly in the field of commons dilemmas and market dynamics (e.g. Jager, 2000, Jager et al, 2000, Janssen and Jager, accepted). In this last theme the role of diffusion processes is studied intensively (Janssen and Jager, submitted). These diffusion processes seem to be a suitable phenomena to use to explain observed behaviour in the demographic transition. The consumat approach can be considered to be a generic approach, that can be tailored to specific research questions. As such the consumat approach can be used as a toolbox that can be used to integrate behavioural dynamics in MAS models in a coherent manner.

A possible application of the consumat approach: the diffusion of contraceptives

A better understanding of diffusion processes can be important to provide a better explanation of the observed phenomena in demographic transitions. The diffusion of innovations is a widely studied phenomenon, and has also been applied to the issue of contraceptive adoption (e.g., Mason, 1997; Montgomery & Casterline, 1998). The innovation diffusion theory as introduced by Rogers (1962) is the most frequently cited publications in this field. Rogers states that the cumulative number of adopters typically follows an S-shaped curve. The S-curve starts to rise slowly when the first *innovators* adopt to the innovation. Following that, the cumulative number of adopters rises somewhat faster due to the *early adopters*. The curve is at its steepest when the *early majority* and *late majority* successively adopt to the innovation. The curve increases at a slower rate when the *laggards* adopt slowly to the innovation. Generally, early adopters appear to weigh their personal needs more, have a higher aspiration level (venturesome fore the innovator and respect for the early adopter; Rogers, 1995; pp. 263-264) and are more actively searching for information (Rogers, 1995; pp. 274), whereas late adopters appear to attach more weight to their social needs, have a lower aspiration level and search less for information. As it can be expected that both individual motives as social motives may play a role in the decision to adopt a certain type of contraceptives, the relative weight of these motives may affect at what time a person accepts (or not) the innovation. For the diffusion of contraceptives this holds that the first users will start using contraceptives after considering their personal needs. However, a large group of people find it important to comply to the behaviour of group members, and hence their decisions to adopt or not will rely more on social information (or social influence, see e.g. Montgomery & Casterline, 1998). Here, the observability of the innovation appears to be one of the crucial factors determining the speed and degree of diffusion. As the use of contraceptives is not public visible, social information concerns mainly indirect information, such as the economic success of small families and the negative effects of contraceptives. Especially when there are conflicting opinions regarding the use of contraceptives, the late adopters may find it difficult to make up their minds using social information. The early adopters will find it easier to come to a decision because they deal more actively with this uncertainty by searching for information, and they attach less value to the (conflicting) opinions of others. This preliminary analysis appears to be in line with the findings of Rogers, who reports that early adopters are better in coping with uncertainty than late adopters (Rogers, 1995; pp. 273). This uncertainty may have consequences for the type of decision process people employ, because people that have a lower tolerance level for uncertainty may engage more in social processing (social comparison, imitation, see also Jager, 2000, or social learning, e.g., Montgomery & Casterline, 1998). Rogers (1995) emphasises the importance of reaching a certain 'critical mass' of adopters beyond which the innovation will diffuse without much stimulation. For the diffusion of contraceptives it has been found that when about 20% of the target group has adopted contraceptives, the diffusion process continues without much effort to about 70% (Ross & Frankenberg, 1993). This can be assumed to reflect the importance of having sufficient role models that increase the chance that imitating and socially comparing people also adopt the innovation.

Since availability of information is important for the adoption process it might be worthwhile to have a closer look at the different channels of diffusion. Two types of channels can be categorised: social networks and mass communications (e.g., Bass, 1969). Social networks exist at various levels, varying from the personal to the international level. The social world of individuals is heavily influenced by new technologies such as a new road, the availability of telephone or the Internet. Mass communication such as radio, television or print media provides information and may influence social norms.

A MAS modelling approach could be fruitful in studying the behavioural dynamics behind the diffusion of contraceptives, because it connects the micro level to the macro level, thereby allowing to study phenomena from both the individual and aggregate level. The necessity of combining these different levels in an analysis has been asserted by e.g. Montgomery & Casterline (1993) and Tolnay (1995). Simulation experiments could focus on a sensitivity analysis for uncertainty levels, the availability and diversity of social information (culture), the structure of the social network, the economic benefits of using contraceptives and changes in social norms. These experiments would help identifying the behavioural dynamics behind the diffusion of contraceptives, and how these dynamics are affected by different variables, such as heterogeneity in social information. The results of such simulation experiments could be used for a comparative analysis of empirical data, and enhance our understanding of the diffusion of contraceptives from a micro-macro perspective, thereby drawing a perspective on how policy measures affect this diffusion process.

Prospects for applications of the consumat approach in demographic research questions

Whereas the consumat approach appears to be useful for a direct application on issues that deal with diffusion processes on the short run, important demographic phenomena, such as the demographic transition, involve processes that evolve over generations. In demographic research the concept of cohort refers to the replacement of generations. Social change has been related to cohort effects by Ryder (1965). Ryder observes that mostly young adults play a prominent role in war, revolution, immigration, urbanisation and technological change (Ryder, 1965, p. 843). Successive cohorts may differ in their behaviour because of changing education, changes in peer-group socialisation (sub-cultures) and differences in historic context (e.g., war). Cohort effects may play an important role in demographic transitions. For example, Ryder (1965, p. 854) explains that the cohort entering adulthood in the mid-sixties (baby-boom generation) was much larger than the previous cohort. Hence, the baby-boom generation has grown up in crowded houses, and educated in large classes. Because of the large size of this cohort, Ryder expects that this may have negative effects on the employability of many people, which could result in delayed marriage and smaller family sizes (Ryder, 1965, p. 854). More generally, the theory of demographic transition states that the transition is caused by socio-economic development and modernisation, and that a fertility decline follows a decline of mortality. However, empirical data often contradict with the theory. For example, in many countries socio-economic behaviour only loosely correlates with changes in reproductive behaviour (Reed, Briere & Casterline, 1999). Whereas demographic transitions are studied widely, the underlying dynamics are very complex and appear to be not fully understood (e.g., Landis MacKellar, Lutz, McMichael & Suhrke, 1998). Hence, the traditional research of demographic transition appears to reach its explanatory boundaries regarding the rate and time of demographic change. It can be hypothesised that socio-economic factors are related to demographic variables in a more complex and non-linear way. Here, MAS models offer a promising tool to explore possible complementary explanations concerning the behavioural dynamics behind demographic transitions. These explanations might be related to the way agents communicate (social networks) and make decisions (cognitive processes), processes that have been identified by De Bruijn (1999) as important in understanding demographic phenomena.

Because the cohort appears to an important factor in understanding demographic change, it appears to be necessary to include the metabolism of cohort replacement in a MAS model as a driving factor. This would allow for a more comprehensive approach of social networks and decision making in relation to the adoption of contraceptives, the age of marriage and the number of children. For example, it would be possible to experiment with assumptions regarding information transition between and within cohorts (social information processing). Moreover, it would be possible to explore how processes of transition are affected by differences between the cohorts regarding e.g. education, income, employability, participation of women on the labour market, experienced value of children (e.g., material and social needs, e.g. Fawcett, 1972).

To include the cohort effect in a MAS model, it is necessary to introduce age as a marker of life stages in the agent's formalisation. Biological, psychological and social abilities and needs change as a function of ones life stage (e.g., Arthur, Hall & Lawrence, 1989; De Bruijn, 1999). A life-cycle can be formalised in an agent as a fixed time-path along which certain abilities and needs of the agent may develop. Variables that seem to be important to incorporate in the formalisation of such a life-cycle are (1) biological factors, such as the age boundaries of fertility, a biological maximum age, (2), psychological factors, such as cognitive development, and (3) social factors, such as the degree of nurture that is needed during different stages in the life-cycle (relating to mortality). In simulation runs we propose to start with a network of several thousands of agents. The ages of these agents are distributed according to the demographic statistics of a particular condition to be explored (e.g. pre-industrial society). Also other micro-level data, such as number of children, abilities, income and the like can be tuned according to the precise situation. Simulation experiments may explore how the composition of social networks (size and within versus between cohorts) and economic development interact with the diffusion of e.g. contraceptives and norms concerning fertility. The role different factors play in the diffusion process can be studied by systematically varying model assumptions over many simulation runs. For example, different assumptions regarding the (heterogeneity) of the cognitive processing of the agents may have a large impact on the diffusion process. For example, an increased uncertainty may stimulate social processing (imitation and social comparison), which may either stimulate or inhibit the diffusion process, depending on how many others in the social network have adopted the innovation. The results of such experiments can be tested against existing empirical data. If existing empirical data appear to be incomplete, additional filed surveys may be performed to validate the effects as identified using the MAS experiments.

Up till now we did not discuss the issue of gender. However, gender specific behaviour, such as an increased female participation on the labour market or covert contraceptive use, may have large effects on fertility and the demographic transition. To study gender specific behaviour using a MAS approach a formalisation of gender in an agent is necessary. This can be done quite simply by allowing childbirth to only one gender. This would also allow for testing various (cultural) assumptions regarding the gender specificity of social networks. For example, to what extent is the diffusion of contraception being affected by the degree of separation of male and female networks?

A somewhat more sophisticated approach of gender would formalise different life-cycles (max. age, fertility boundaries) for male and female agents. This would allow for testing various assumptions regarding life-cycle and fertility, e.g. the effects of emancipation and female labour participation on the marrying age and family size. Moreover, because an inclusion of fertility boundaries allows for a more specific modelling of the age of becoming parents, this approach would also draw a perspective on the age difference between cohorts, which may have a counterpart in the resulting social network.

Another aspect that is important mentioning in discussing demographic transitions is the spatial context. Because social networks have a strong spatial component, it appears promising to test various assumptions regarding the spatial distribution of network. For example, it would be worthwhile to explore how an increased mobility and the Internet affects the spatial distribution of networks, and hence the diffusion of information demographic transitions. Essential in this use of MAS models is the focus on the better explanation of empirical data, thereby both contributing to the further development of demographic theory as well as to the projections of further developments in fertility.

Conclusions

Because many demographic phenomena cannot be studied in laboratory situations, and the behavioural dynamics of these phenomena cannot be (reliable) derived from surveys and statistical data, MAS offers a tool to get a better understanding of the dynamics and hence causality of these phenomena. Because behavioural processes and decision making play an important role in many demographic phenomena, it is important to derive agent rules from relevant behaviour theory. Because several behaviour theories are relevant in understanding demographic phenomena, it is required to develop agent rules from a meta-model of behaviour, that integrates relevant behaviour theory in a consistent framework. The consumat approach offers a toolbox to develop such agent rules. These behavioural rules can be used to study the demographic dynamics of typical population model, assuming exogenous developments in socio-economic developments. Whereas it is usually possible and often tempting to enhance the realism of the model by making many variables endogenous, we are convinced that it is essential to keep the MAS model relative simple to keep the simulation experiments transparent for interpretation. This transparency contributes to our understanding of the processes that affect the demographic transition, thereby possibly explaining observed discrepancies between data and theory. In this way MAS may provide a valuable tool that in combination with existing theory and empirical research may contribute to the further development of demographic theory.

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