

Fertility decisions – simulation in an agent-based model (IFSIM)

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2007-07-25

This paper is prepared for the 1st General conference of the International Microsimulation Association in Vienna, 20-22 August 2007

Abstract.

This paper explores the method of using agent based modeling to intergenerational transfers in general and to the fertility decision in particular. We set up thumb rules for the fertility decision that are not based on the individual's age, except for the biological fertility ability, and try to match the empirical fertility distribution by age. By using economic and social aspects in the decision rule we manage to obtain a reasonable fit. Based on this, we then continue to explore agent based modeling as a tool for policy evaluation. In this case we focus on how changes to the parental leave benefit may affect the fertility choice. We find no noticeable change in the fertility rates when the minimum level of parental leave benefit is raised. However there is no noticeable cost associated with the reform either.

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1. Introduction

There is a striking difference between the population debate some decades ago and the one that is currently taking place. The worries about over population and large birth cohorts have been replaced by anxiety about low fertility and population aging in general. This is natural considering that many Western countries are now entering a transition in the labor market with the retirement of the large baby-boom cohorts at the same time as the fertility rates are low.

Demographic changes affect the relative size between the active population, mainly individuals of working age, and the inactive, mainly children and retired individuals. The inactive part of the population is mainly supported by the active population through private and public intergenerational transfer. These transfers are very large and constitute the lion share of the overall public spending. In Sweden, for instance, it is estimated that 80 percent of an individual's tax contributions are returned to the individual in form of benefits over the life-cycle (SOU 2003:110). That demographic changes affect these transfers has received plenty of attention but these transfers might also affect demographic outcomes. Most apparently they have the ability to affect fertility.

There are many different policy proposals to stimulate births, such as: direct lump sum payment at birth, increasing child benefits, child care provision, parental leave benefits, and etc. Irrespective of the form these transfers are intergenerational transfers and as such they interact with other public and private transfers. For this reason it is important to account for the interaction between different transfer systems when assessing the consequences of a new policy. Moreover if the policy is able to alter the demographic outcome there will be other economic effects also, for instance on factor prices.

Many of the policy proposals that are discussed in countries with low fertility rates are already implemented in for instance Sweden. Most notably is that Sweden has a generous parental leave system and that child care is heavily subsidized. Compared with low fertility rates countries that have TFR below 1.5 Sweden has somewhat higher TFR about 1.8, but up to now Sweden has had somewhat stable completed cohort fertility rates around 2. What has increased in Sweden, as well as in other countries, is the age at first child birth. Today the average age for first child is 29. There is thus a concern that if the trend in postponement of first child continues that it will be difficult for these generations to catch up and reach completed cohort fertility around 2. One explanation that has been put forward for this delay in first child birth is the university expansion. Students do simply not get as many children as non-students. It is an open question why this is the case but one hypothesis that we will elaborate on in this paper is that the construction of many social insurance systems, including the parental leave system, to a large extent excludes students, at least in Sweden.

In Sweden, the basic levels of support (if not qualified) given in the unemployment insurance, sickness insurance, parental leave, and study allowance systems are very low. In order to qualify for reasonable levels in these systems, a history of employment is required. However, most students have not qualified because they are still in collage or university. It is therefore financially difficult to support family formation or starting a housing carrier before graduation and establishing in the labor market. One hypotheses is therefore that this explains the problems described above. Labor market evidence from Sweden suggests that young have serious

problems getting established in the first job thus not qualifying for the social insurance systems. For a young individual it makes perfect sense to remain in university (or collage) for one more year instead of trying to enter the labor market under such hard conditions (only to become unemployed). Evidence also suggests that very few decide to give birth while enrolled in university (SOU, 2003). There are however also evidence which tells us that a substantial fraction of the students have kids (28 percent of women and 13 percent of men, see SOU, 2003). A possible explanation for these observations could naturally be that students with children are older than the average student. Perhaps a supposition might be that educational activities in combination with having small kids actually work fine for a great number of families in terms of having more flexible hours etc. The data, however, does not indicate whether such parents are qualified for the higher benefit in the parental leave system.

The purpose of this paper is to investigate the agent based approach to fertility by simulating an increase to the minimum parental leave benefit. One aspect that we are interested in is how it might affect fertility timing and fertility rates. Our hypothesis is that prolonged education per se must not be an obstacle for family formation. It could instead be so that the existing parental leave system affects fertility timing by discouraging students to have children, through the qualification requirements. It is, however, not certain that timing in itself is enough to affect fertility rates in the long run. Certainly, if the delay in first birth is so large that it occurs just before the ending of the reproductive period then fertility rates must decrease. But if the delay is not as drastic, and there is still enough time to reach the amount of desired children then the long run fertility rates could be unaffected by the delay in first birth.

If the policy change has the possibility of affecting either timing or the fertility rates then we are interested to see the economic consequences of this. An increase in minimum benefit constitutes a cost. This is however not the only effect. If it is a pure timing effect then the increased cost today has to be compared to the future decrease in parental leave payments. For those individuals that already today receive the minimum benefit it will be a pure cost, since this benefit increases. Even if the cost of the parental leave benefits in total increases it is not certain that the overall cost is as high due to external effects.

There are external effects both from a timing change and from changes to the fertility rates. If fertility rates change we know that the age structure of the population will change and that this will affect other intergenerational transfer systems, such as the education system and the pension system. If the economy is not a perfectly open one we also know that changes to the age structure will affect factor prices. The external effects from a pure timing change are somewhat harder to evaluate but there could be effects both for the human capital acquisition of the children as well as the human capital depreciation of the parents. That the age of the parents might affect the child's human capital accumulation is very likely, however it is very hard to evaluate the magnitude. When the parents take time off to raise children it will most likely constitute a depreciation of their human capital. That this depreciation varies during the different stages of human capital accumulation (accumulation either through education or through work experience) is also likely, but here it is also hard to determine the magnitudes.

To evaluate a simple policy change thus becomes cumbersome if one tries to account for the above mentioned possibilities. For this reason we use an agent based micro simulation model, the IFSIM model. In particular, IFSIM models the micro-macro linkages between fertility, education choices, labor market choices, and growth. It simulates social and economic interactions to drive model outcomes rather than micro estimation. The set-up includes heterogeneous agents with bounded rationality and imperfect information. Agents act according to

”rules of thumb” rather than utility maximization derived behavior. Macro outcomes might not be equilibrium. Rather the focus is on system dynamics more than steady state. Agents also interact simultaneously with each other in networks and adapt to changes in their environment (macro-feedback), e.g., investment in higher education is linked to observed average wage. Within households there are intergenerational links for e.g. inheritance of personal characteristics. These networks generate interaction and information sharing. There is also social and economic pressure affecting e.g. fertility choices.

It must be noted though that at this point there remain many calibration issues of the model to empirical results. The main advantage of the simulation model is that the whole effect of many social insurance systems may be accounted for, including the macro feedback on the individual level of other agents’ choices. It would not be analytically feasible to try to account for this in a general equilibrium setting.

The findings at this stage is that the policy of raising the minimum benefit has negligible impact on fertility rates, but this is also true regarding the cost of the system.

The rest of the paper is organized as follows. Next we give some stylized facts concerning the development of fertility. In section 3 we discuss the whys and the whats of agent based modeling. Section 4 gives a model overview. In section 5 results from our simulations are presented, and Section 6 concludes the paper.

2. Descriptive evidence on low fertility

The case we want to make here is that there has been declining fertility or at least a postponement of the first child, and that this might have something to do with a turbulent labor market and an expansion of the educational system in Sweden. Since very few get children while they are students, delayed and prolonged education will result in fewer babies.

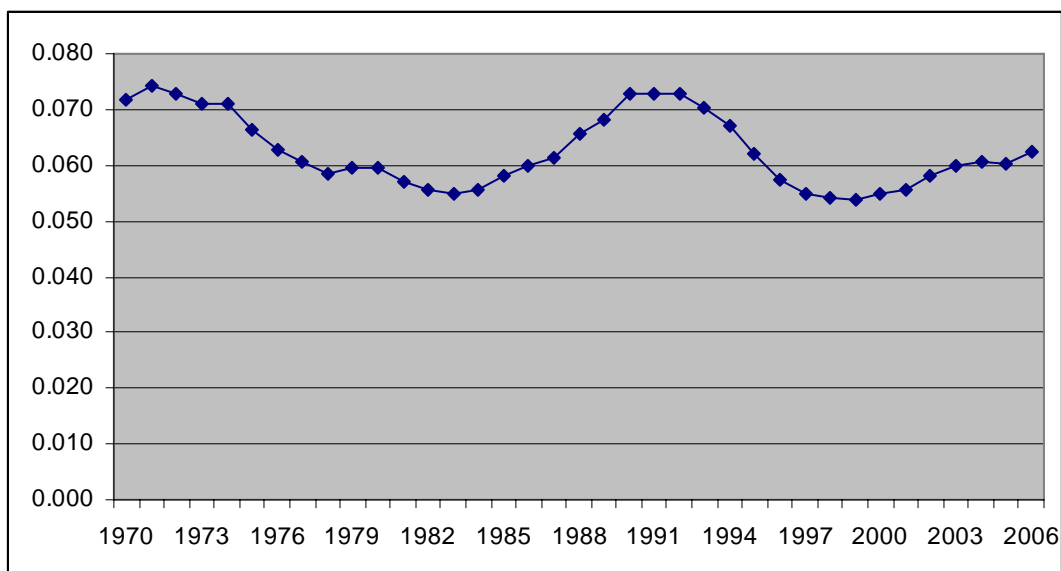


Figure 1 The number of births divided by the number of women aged 16-44 (source: Statistics Sweden)

In Sweden the period fertility pattern has been characterized by much variation.

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Figure 2 shows the fertility rates in some other western countries for the years 1980, 1990 and 2000. The general impression is that there has been a decline in fertility.

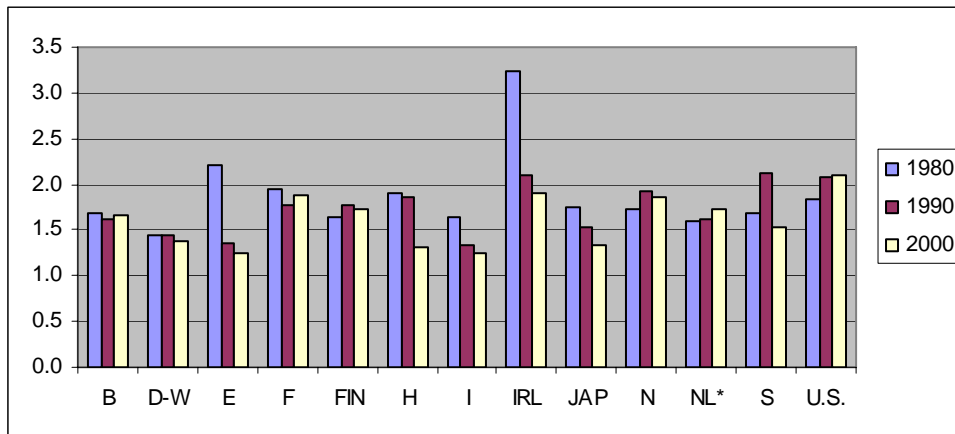


Figure 2 Total fertility rate in selected countries (*Source: Eurobarometer*)

Individuals were also questioned about the preferred family size, see Figure 3. Interestingly, this number lies well over the actual outcome in just about every country. Between the survey years (1981 and 1990) it has also gone down in most countries. In the Nordic countries one can note that the preferred family size did not change much between the surveys.

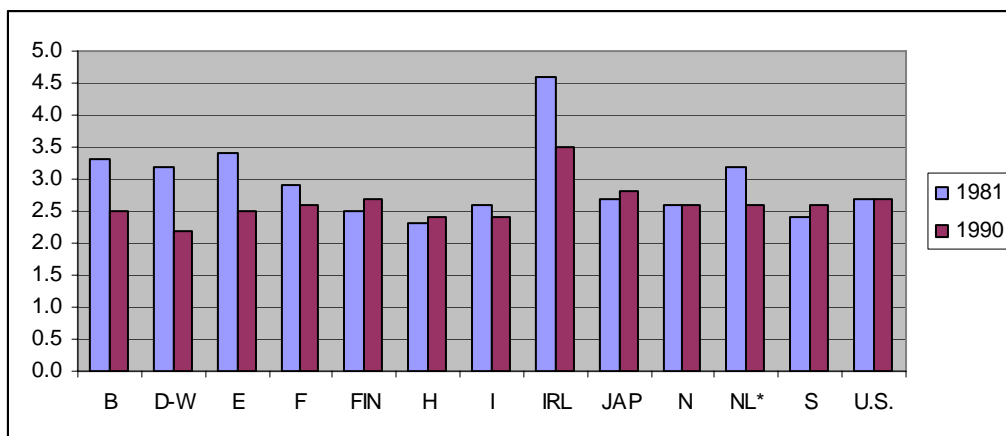


Figure 3 Mean number of children considered as the ideal size of a family (*Source: Eurobarometer*)

Another empirical fact seems to be that the age of first child has gone up, see Figure 4.

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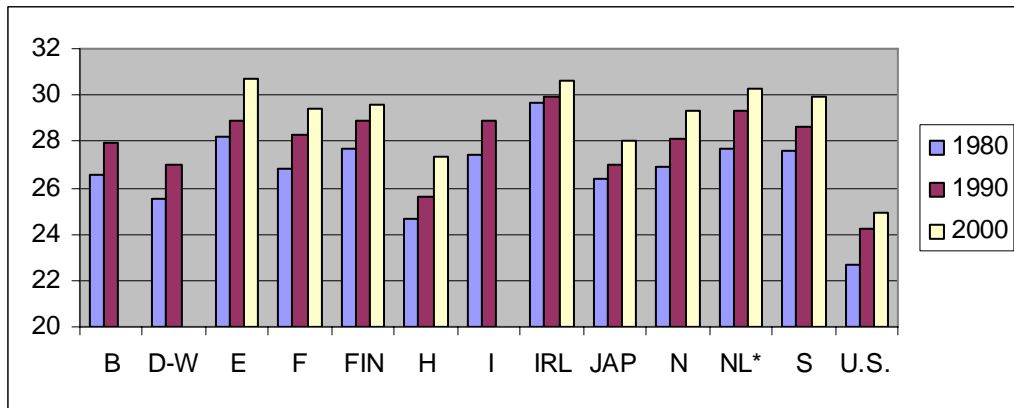


Figure 4 Arithmetic mean of age at birth of first child (*Source: Eurobarometer*)

The economic turbulence in terms of unemployment rates, depicted in Figure 5, shows that unemployment is very age-specific. Young experience higher unemployment rates than older (age groups 55-64 also have high unemployment rates however).

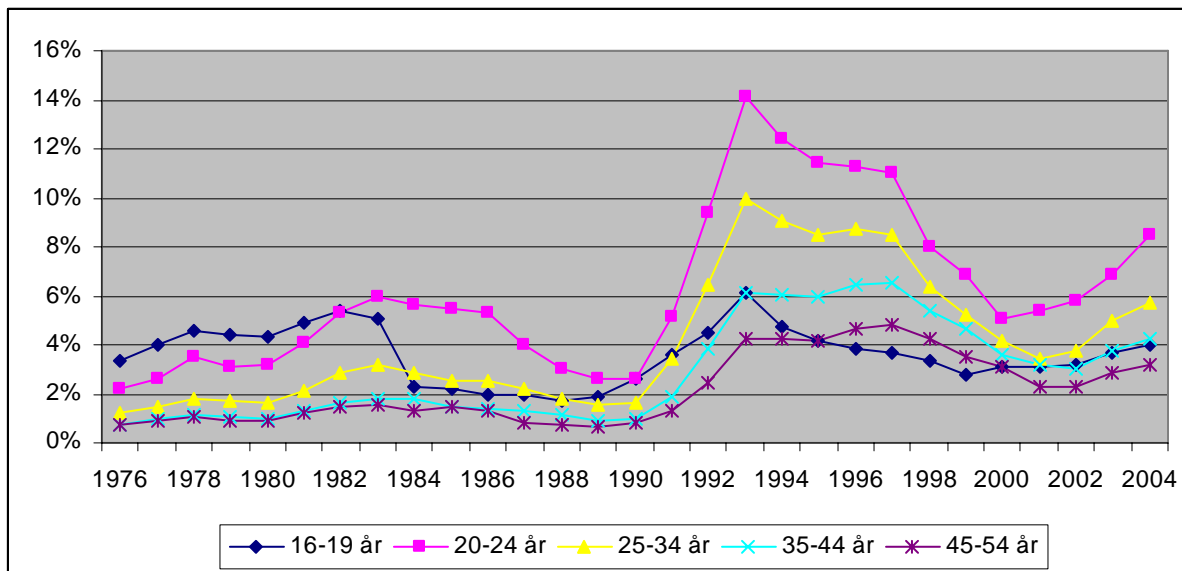


Figure 5 Unemployment rates by age group

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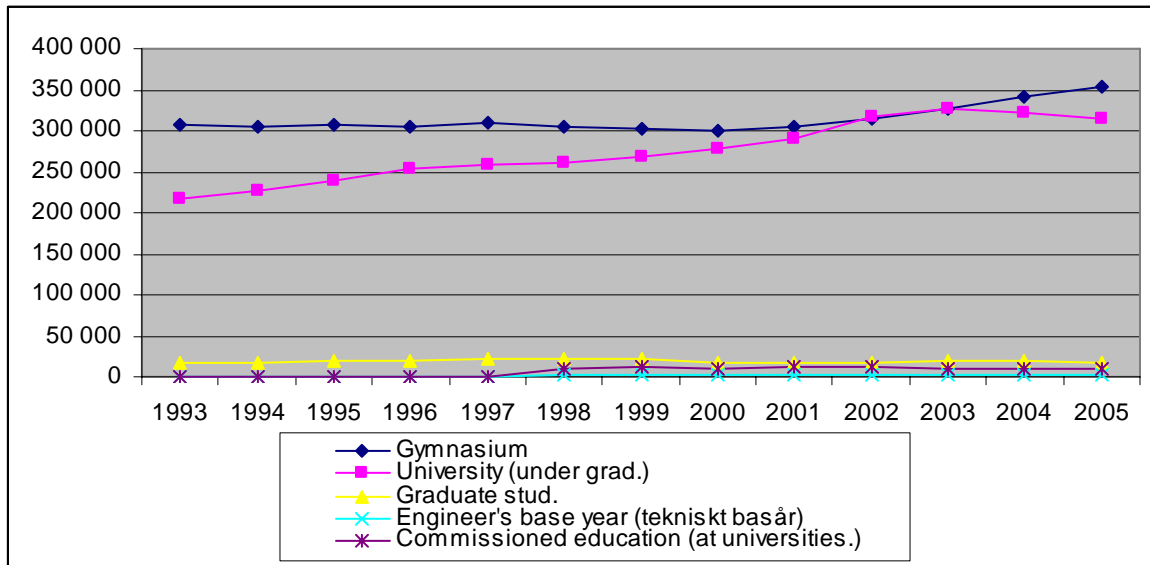


Figure 6 Education Enrolment

The expansion of the educational system during the 1990s was quite astonishing (depicted in Figure 6). The expansion was predominant at university level. From 1993 to 2005 the numbers enrolled in university increased from just over 200 thousand to just over 300 thousand, an increase of almost 50 percent! As share's of the population the undergraduate students are overrepresented in the age group 20-24 but also a growing share of 25-34 year olds are enrolled, see Figure 7.

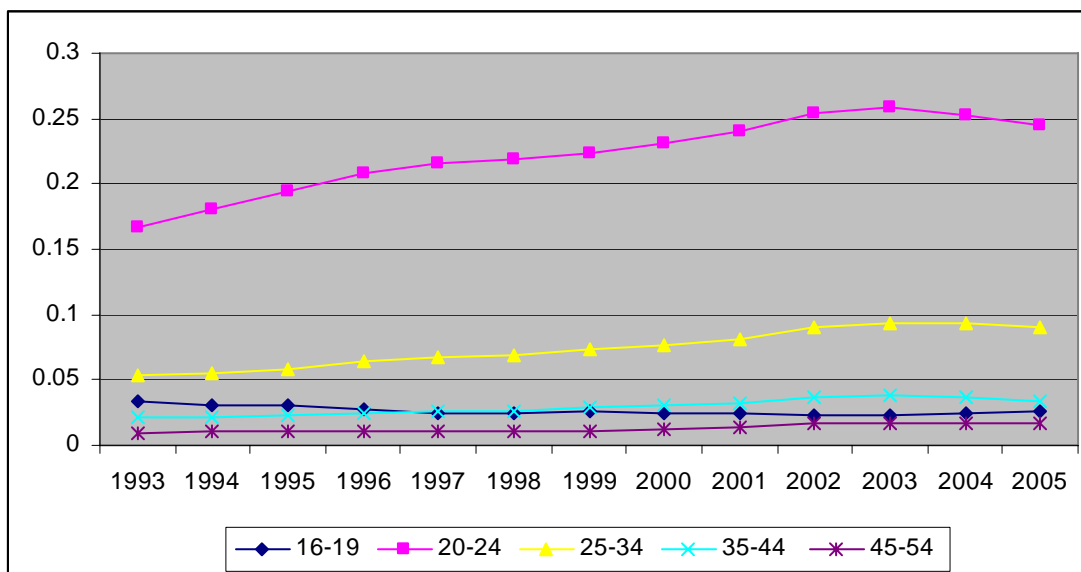


Figure 7 Educational enrollment, as a share of population, by age-group

There has also been a substantial increase in the number of individuals getting university diplomas over time, see Figure 8. ¹ This number is, as expected, highest among the older age group as it takes a couple of years to finish university. There is also, over time, a shift towards students being older when they get their diploma. One can note that there is a notable decline in young people aged 21 or younger getting a university diploma, and in later years an increase in 35+ getting their first university diploma. Now, some of the enormous increase in

¹ If a person has more than one diploma, only the first diploma is included in this figure

the enrolment rate depicted above naturally account for the overall increase in diplomas, but we might expect that the shifting towards older is a result of delayed entrance into university and prolonged periods in university.

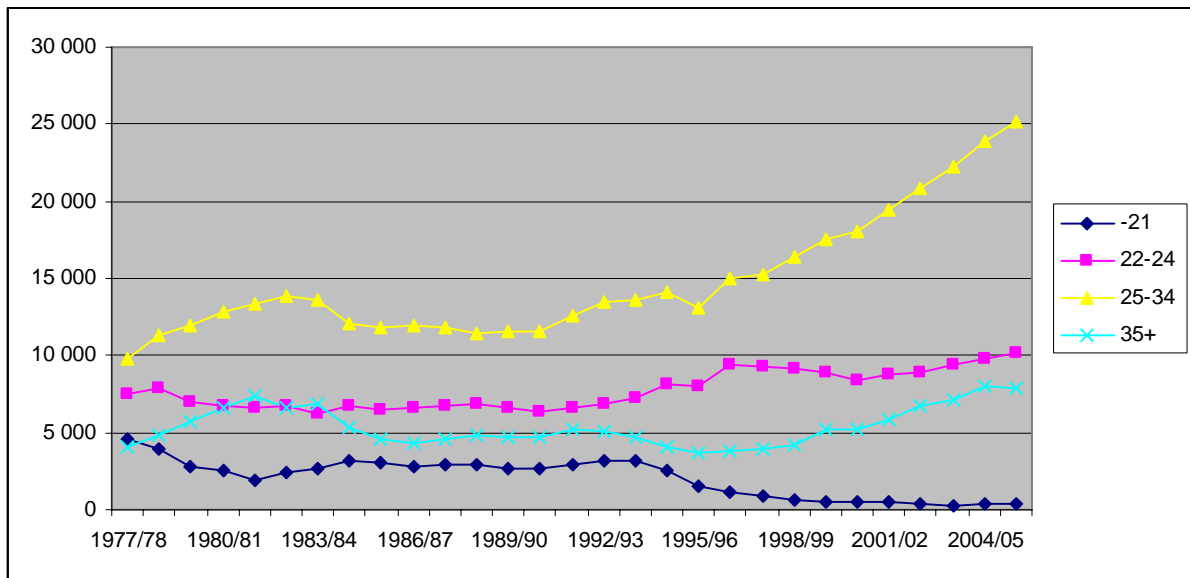


Figure 8 The number of university diplomas by year and age (*source: Statistics Sweden*)

Figure 9 shows the fraction of female students by age in 2003 calculated from micro data on income registers.² The student status definition results in quite reliable fractions by age that are labeled as students. Almost 100 percent are defined as students at age 17 (when most enter gymnasium). Thereafter it drops and stabilizes at around 40 percent in the ages 20 to 22. The students then become fewer by age. At 30, about 8 percent are students in the examined year.

The probability to give birth (or adopt) differ substantially between students and non-students.³ Figure 9 shows that while a 30 year old female non-student have a 14 percent risk of getting a new child, the risk for the student counterpart is around 5-6 percent (there are more uncertainty because of fewer observations). The probability is also more stretched out over a wider age interval among students. Judging from the rather thick right tail, postponement of births is more pronounced among students than others.

² Student status is identified by having study allowance during a calendar year, including student's loan and study benefits for adults ("studiepenning"), and wage earnings below 2 basic amounts (approx. 8500 Euro). This definition might underestimate the number of students since it is possible to enroll without claiming study allowance.

³ Only biological and adopted children to the mother are included. A woman is assumed to be at least 16 to be the mother, and coded as a living as married, cohabiting, or single. One potential source of bias is that as children move out of the parental home they are no longer counted, why the number of kids might be underestimated for older mothers.

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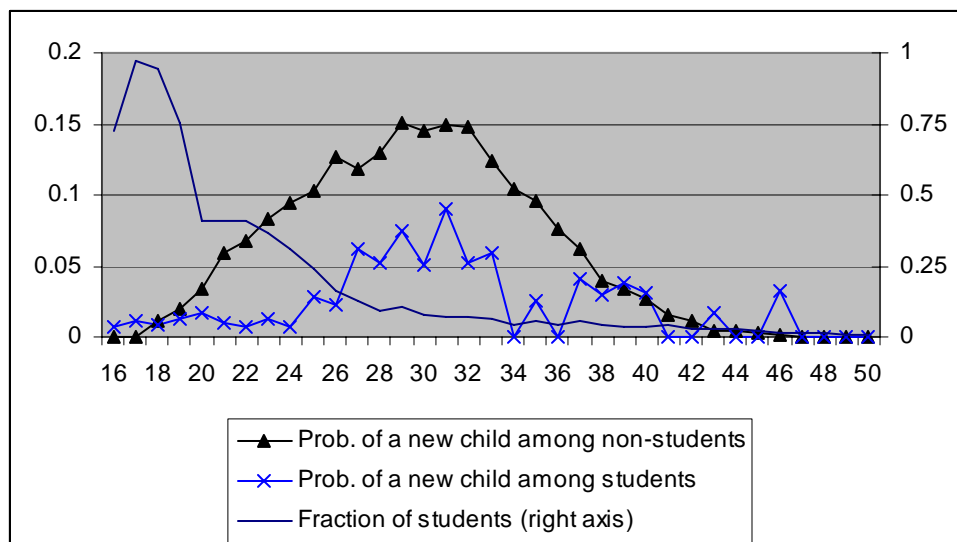


Figure 9 The probability to give birth (or adopt) by student status, and the fraction of students, by age, 2003 (source: LINDA)

Also the family size (the number of children) differs between students and others. In Figure the distribution of the number of children is shown for the age group 20-35. We see that students have fewer children. The biggest difference in the distribution is that a greater share among the students has no children, about 75 percent, compared to non-students, around 50 percent. However, this means that 25 percent of the female students 20-35 actually have at least one child, which is quite remarkable (and corresponds to SOU, 2003). The childless fraction decreases with age. Limiting to age group 20-25 increases the childless fraction to 83 percent for students and to 75 percent for non-students, while looking at 30-35 year old females reduces these fractions to 37 percent for students and to 32 percent for non-students. To sum, the impression is that a substantial share of female students has children, but very few get them as students.

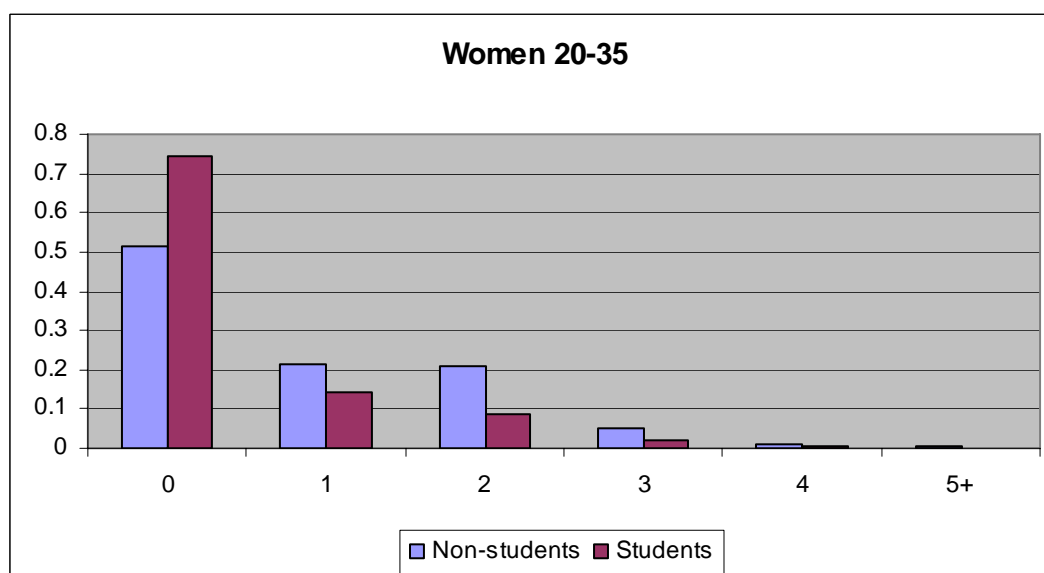


Figure 10 The distribution of the number of children for women aged 20-35, by student status, 2003 (source: LINDA)

3. Agent Based Modeling (ABM)

3.1 Why AMB?

A main goal of Agent Based Modeling (ABM), in particular of a sub-branch of it known as Agent Based Computational Economics (ACE), is to reproduce the real "complexity" of the economic world, i.e. moving beyond traditional approaches which instead rely on a number of simplifying assumptions.

ACE starts from the premise that the "real world" is hardly the work of a central planner, making it conform to rational rules. Rather, the "real world" is characterized by decentralized, simultaneous interactions between a very large number of different agents, whose decision making is often the expression of limited rationality, imperfect information, past personal experiences, and where the local relational context also contributes to those agents' strategies and behaviors. For tractability reasons, traditional economics model tend to overlook such complexity, but this is bound to generate model predictions with limited use. If instead rationality becomes "bounded" by e.g. social or other contextual contingencies, modeling agents' decision-making will require somehow modeling also such contingencies: it is these very contingencies which will make otherwise identical agents adopt different decisions, thus generating diverse (and possibly unexpected) societal outcomes.

Indeed, it has become rather common among economists to want to model "micro-macro linkages" between individual and aggregate level variables. However, existing modeling tools often fall short of quantifying interactions and feedbacks in any way close to their actual complexity. Most recent attempts have consisted of combining economy-wide Computable General Equilibrium Models (CGE), with micro-based microsimulation models (see Davies, 2004, for a review). On the one hand, the former (CGE) model the behavior of key economic agents (households, firms, government) to provide the micro foundations of overall production, consumption, price and trade levels, and to simulate the consequences of economic shocks. They rely on the classical assumptions (e.g. rationality, perfect foresight, competitive markets, perfect information, market clearing etc.), in order to find an optimal solution or "equilibrium" for aggregate level variables such as total output. In other words, by relying on the principles of optimization, CGE impose a functional structure on the way the economy is meant to behave as a whole, i.e. they provide a "top-down" approach governing agents' behaviors. It follows that, for model solubility, CGE often cannot account for many functional differences among agents of the same class, e.g. for heterogeneity between various household types, preferences or technologies; they just limit themselves to specify few types of representative agents and assign to all of them the same production or utility functions. This is clearly a simplification which overlooks important variations at the micro level, and more generally makes distributional analysis unfeasible (i.e. how total output and consumption are actually distributed between different agents, and what drives these differences).

Microsimulation models on the other hand, are mostly used to study distributional effects e.g. of tax and benefit systems, at the micro level, including (in the case of dynamic microsimulation models) projections over the individual agent's entire life cycle (including behavioral responses e.g. labor supply, fertility choice, education etc). Usually built on household survey data (or other micro-level data), they allow access to detailed information e.g. about individuals' income sources, areas of residence, past employment history etc., but they cannot deal with modeling the monetary side of the economy or with the inclusion of structural macro features, which therefore have to be assumed as exogenous. Traditionally they often (although not always) tend to be non-structural i.e. agents' choices are based on reduced form estima-

tions that do not reveal the underlying preference structure or the rational "rule" guiding them (i.e. predicted behaviors are not necessarily derived from optimization). Therefore they can be interpreted to be more ad hoc or less "generalizable" than CGEs. Fortunately, over the past decade the distinction between these types of models is increasingly breaking down, for instance through layered or integrated CGE, and Microsimulation models, which essentially can combine the study of endogenous price changes with distributional changes at the household level (e.g. Cogneau and Robilliard, 2000). For example, household level micro-data are used to estimate heterogeneous households' preference functions parameters to derive an income distribution (i.e. choice of labor market status and income generated at given wages); a standard CGE model, which includes all the key sectors of the economy (i.e. both its supply and demand structure), is then used to produce equilibrium prices and wages, which are then fed into the micro model to derive behavioral responses. Overall, these integrated models allow to capture effects of external shocks (e.g. trade liberalization) not only on aggregate level variables such as total output and prices, but also on labor statuses, inequality and on the income distribution (as the access to real micro data allows to predict household specific responses). Convergence between micro and macro results can sometime be a problem in these models; iterative loops between the two models can be generated until convergence is reached.

In practice, integrated macro-micro models suffer from difficult implementation, mostly due to a trade off between adding model complexity and finding solutions which can be handled by standard computational tools. Given such difficulties, ABMs represent a further step in the development of dynamic macro-microsimulation modeling, as they avail themselves of modern computing developments (e.g. object-oriented programming languages) to simulate complex interactions simultaneously, and how these interactions evolve in time through the accumulation of new information, with no need to have two separate converging models (e.g. one micro and one macro), nor to have convergence to an equilibrium solution at all.

3.2 What is ABM?

Agent-based Models (ABM) are computer generated micro-simulation models suited to study not only how individuals behave, but also how the micro interaction of many individuals together can lead to large-scale societal outcomes. So, as they aim to explain micro - macro linkages, ABMs are becoming increasingly popular among the social sciences, not least economics.

Quoting L. Tesfatsion, one of the most prominent scholars in the field of ABM: "ABM [...] is a method for studying systems exhibiting the following two properties: (1) the system is composed of interacting agents; and (2) the system exhibits emergent properties, that is, properties arising from the interactions of the agents that cannot be deduced simply by aggregating the properties of the agents. When the interaction of the agents is contingent on past experience, and especially when the agents continually adapt to that experience, mathematical analysis is typically very limited in its ability to derive the dynamic consequences. In this case, ABM might be the only practical method of analysis".

In summary, the principle behind ABMs is that of multiple interacting agents who are goal directed (e.g. preserving a certain consumption level in old age), and who try to control their environment, in a decentralized (i.e. non-coordinated, non-centrally planned) system. ABMs, unlike other models, do not assume rationality nor contemplate the existence of a pre-defined equilibrium outcome. Agents might behave in sub-optimal ways, but they can gradually learn from their experiences and adjust their behavior to the neighboring environment.

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The first attempt to apply ABM to the social sciences is considered to be T. Shelling's "Models of segregation" (1969). It is however only in the last decade that computer advances have seen the real development of ABMs. Often using JAVA or similar "object-oriented" programming languages, ABM agents are usually implemented in software as "objects" i.e. computational entities who have initial states (e.g. sex, age), are able to perform some pre-specified action or method, can communicate or share information with others, pass on or even inherit characteristics or behavioral rules.

Running an ABM simply means instantiating an agent population, and let it run forward in time - executing it, rather than solving it. The outcomes of agents' interactions can be "observed" at any given time by the modeler who only needs to specify some initial behavioral algorithms (the equivalent of classical "preferences") and initial conditions for his agents and their environment. These agents can represent people (say consumers, sellers, or voters), but they can also represent social groupings such as families, firms, communities, government agencies and nations.

There are several advantages to ABM. For a start, ABM help towards gaining empirical understanding of certain observed large scale regularities (e.g. the intergenerational persistence of inequality) which emerge and persist from micro-processes without an apparent "top-down" control system or in any case with limited rationality. Given assumptions about autonomous heterogenous agents, ABMs simply rely on powerful computer simulation platforms (e.g. JAS) to generate "histories" that can reveal the long term macro consequences of these assumptions.

ABM can also fulfill a second aim of normative understanding, i.e. they can be used as simulation laboratories where alternative socio-economic structures can be studied and tested, for instance with regard to their effects on family welfare, and the best-performing policies e.g. in terms of equity or efficiency can be picked on the basis of alternative model outcomes. Axtell (2000) identifies three key motives for using ABMs against more traditional approaches to modeling macro regularities (such as dynamic general equilibrium models in economics etc.). The first motive is when fully soluble stochastic equations can be formulated to describe a social process. In this case, as the solution corresponds to a distribution of possible outcomes (e.g. requiring a Monte Carlo experiment), ABMs can be used to provide numerical simulations. The second motive is when a mathematical model of social processes can be written down but cannot be completely solved analytically, and so its properties become hard to assess. In these cases ABM can shed light on the dynamical properties of the model (e.g. non-equilibria phenomena), and on its parameter dependence, without actually having to solve it. Finally, ABMs are most useful when it becomes impossible to devise a full mathematical model of equations and solutions, with a closed form solution, as it is the case in so called intractable models. Often in these cases numerical solutions are attempted, but often these are not very useful (e.g. in cases where governing equations are highly non linear). In all these cases, ABM can become a useful alternative. Following assumptions already developed e.g. by experimental or evolutionary economics, ABMs thus relax the dependency on the rational agent and on equation-based models involving optimizing behaviors (as it is the case in the classical economic approach). ABMs instead introduce a less able but more realistic agent which has "bounded rationality" i.e. whose behavior is not dictated by forward looking optimization abilities but rather by adopting a set of decision rules, given an initial states, current information, and surrounding opportunities. This effectively simplifies the computational work compared to optimization-driven models.

The advantages of ABMs over more traditional mathematical models are exactly to limit the agent rationality, as well as to introduce more agents' heterogeneity (in initial states, preferences etc.) in such a way that classical models could not handle, by discarding the idea of a "representative" agent. By developing an initial heterogenous population (i.e. initialized so that each agent has a different "state"), and a set of heterogenous rules / algorithms guiding the behavior of this population, the researcher can observe the evolution of the macro system without worrying about its equilibrium properties, but rather focusing on the system's entire behavior at any point in time. By varying initial conditions, and randomizing the order of agent activation, the researcher can then check the robustness of the emerging results, e.g. how sensitive social outcomes are to changes to the underlying system parameters, again at any point in time (rather than at the "equilibrium" point). There is therefore no fixed "solution" to an ABM; rather there are many possible evolutions or "histories" which can be simulated by changing some initial parameters.

The disadvantages of ABM models vis-a-vis mathematical modeling can be mostly explained in terms of their alleged methodological weaknesses, in particular their inability to produce robust "theory" about emerging regularities from just a simple model "run". Indeed, in ABMs, final outcomes depend entirely on the initial distribution of the "state variables" pertaining to the artificial agents, but in the absence of a general "law" from which their evolution can be derived a priori, it becomes difficult to defend their scientific validity. Richiardi (2005) however provides an interesting methodological defense of ABMs, arguing that outputs from ABM runs can ultimately be used to infer a functional representation of the systemic behavior i.e. a general law linking the macro outcome, Y , to all the agents' exogenous initial states.

A meta-model can thus be estimated, i.e. a fitted function approximating the general function, obtained by estimating the functional parameters on the simulated data. The "fitness" of this meta-model can be furthermore validated against real data.

3.3 Agent-Based Computational Economics (ACE)

Agent-based computational economics (ACE) is "the computational study of economies modeled as evolving systems of autonomous interacting agents. ACE is thus a specialization to economics of the basic complex adaptive systems paradigm" (Holland, 1992).

ACE models are a subclass of ABMs models specifically applied to the study of economics problems. This type of application has gathered impetus over the 1990s, although it still encompasses a very small area of economic research, often confined to specialized journals and ignored by the so called mainstream. ACE research areas in economics have included the evolution of behavioral norms e.g. mutual cooperation between self interested agents; the formation of trade networks (see various papers by Tesfatsion, e.g. 1997); empirical features of financial markets, especially the Santa Fe' artificial stock market model; the emergence of labor markets stylized facts (Fagiolo Dosi Gabriele, 2004).

The ACE view of economies as self-organizing, evolving systems giving rise to global regularities such as employment and growth rates, is not new. Evolutionary theories were applied to economic institutions already by Shumpeter (1942), and also later on by economists such as Nelson and Winter (1982).

In addition to the advantages that ACE models share with the general ABMs models mentioned earlier, ACE models usually suspend classical assumptions of perfect competition / perfect information or Walrasian equilibria. The existence of a Walrasian equilibrium in fact presupposes the existence of an Auctioneer imposing a market clearing mechanism, which

completely removes the possibility of strategic, autonomous interactions between economic agents. An ACE economy instead focuses on the mechanisms through which, e.g. production or price levels are set; how buyers are matched with sellers; how goods are actually distributed etc. For an example of an ABM trading model see Tesfatsion (2005).

3.4 Why agent based approach to fertility

There are different approaches to why people get kids. The standard economic approach is to view kids as a consumption good, whereby children enter the utility function and the budget constraint. Somewhat more elaborated economic view is to treat children as an investment good as well. One reason for why this standard economic approach of optimizing the utility function under the budget constraint is not used here is that it does not account for social interaction between individuals. There are demographers that view this social interaction mechanism as an important factor in the fertility decision, e.g. Lutz et al (2006). Another reason why it is not used is simply because it does not allow for much heterogeneity between individuals (see above regarding general benefits of agent based modeling).

4 Model overview

In this section we present a brief overview of the simulation model in its current form. In the model, there are a few distinct, but interrelated, modules handling various events on the micro and macro level. These are discussed below.

4.1 Model agents

The model incorporates at present four key agents: individuals, households, networks and the State. By agents here we mean java objects belonging to a specific agent class to which certain actions and characteristics are ascribed. Individuals are of course the main agent type being simulated; they are uniquely identified, they can be born, die, procreate, leave home, study, work or retire. Individuals are grouped into households which are separate agents in that they have characteristics of their own: a separate ID, a given size, number of children, household income, a history and special “links” between household members such as inheritability of certain personal features (e.g. initial skills are inherited as the average of both parents). Networks are less tangible agents but still they exist as separate entities with a specific location and group composition. At the moment networks are lists of individuals grouped by age rather than household (i.e. an individual’s network does not include his or her household). Networks are programmed so as to be able to perform certain actions for instance retrieve network characteristics such as mean participation or education rates which can be used by the agents to make forward looking decisions. Finally the State is the only single agent in the model i.e. the single class being instantiated only once. The State performs the tax and redistribution functions, including setting a local tax rate to keep the budget in balance, calculating and collecting income tax rate, paying teachers’ salaries, student allowances, parental leaves and pensions, as well as setting some policy targets through which it can affect micro behaviors and macro outcomes.

4.2 Demographic module

Consider a household denoted by H consisting of n members I_1, \dots, I_n . Each member is an individual with distinct characteristics. Each individual has an individual ID, and a link to its "biological" mother and father and to its children. These links allow us to analyze intra-household and inter-generational transfers. Individuals can be born either outside or inside the model. Individuals born outside the model are those who come directly from the initial data set (discussed in appendix). At time zero, they will have an age greater than zero and a history that we import from the original data. On the contrary, individuals born inside the models are produced from the model's fertility modules, and start their life at age zero within the model; they are thus "artificial" agents.

Ageing and mortality

The most basic life process simulated in the model is the process of aging: at any period, the age of individuals (whether born outside or inside the model) is increased by one year. The maximum age an individual can reach is 110. If the individual has not died before, the model will automatically "kill" him at age 110. In any given year, the individual has a certain probability of "dying" which at present is totally exogenous. We in fact take age specific mortality rates from SCB (Statistics Sweden) data for 2006 and align each individual to the relevant age-specific probability through a random draw. In other words, for each individual we simply draw a random number and compare it to her age-specific external mortality rate. If the number falls below this probability, we kill this individual. In so doing, we are able to reproduce a mortality distribution by age which closely resembles the real Swedish distribution for 2006.

Social Networks

A distinguishing feature of ABMs is their ability to capture agents social interactions as these are supposed to influence individual decision making. The role of these social interactions is mostly to provide individuals with incomplete (as opposed to perfect) information which individuals in turn use to make decisions. This exchange is a process often described as social "learning", or even as social or peer "pressure" (Billary, Prskawetz, Diaz and Fent, 2006). For instance, the share of people married among one's friends might contribute positively to that individual's desire to get married herself, representing a conditioning or pressure to conform. The crucial idea behind modeling social interactions more generally is that this might indeed work together with economic incentives in explaining human behaviors, possibly affecting the size or even the direction that economic incentives might have otherwise. Our assumption therefore is that missing out social interaction from an analytical framework might bias the final results. In the subsequent chapters we will use the education decision as an example of how to integrate social pressure into the more standard forward looking economic calculation of individuals when they decide whether to continue investing in their education or rather going into the labor market.

Every individual in our model is, from birth, member of a "social network" containing all those individuals to whom he or she is "close". We follow Billary, Prskawetz, Diaz and Fent (2006) in defining social "closeness" as a spatial area representing the individual's scope of interaction, by age group. Most specifically, agents are arranged along the surface of an imaginary cylinder, whose vertical length is broken into as many segments as there are age groups in the model (at present they are 8, from age 0 to 90). Each age group therefore is allocated to an imaginary sub-cylinder whose height is the age interval for that group, and whose

circumference is in turn sliced into a different number of networks (i.e. different age groups have different numbers of networks belonging to them). Each network is constructed as a segment on the circumference delimited by a corresponding angle. The model develops a procedure to then allocate each individual to a given network group within his or her own network space, by age group, and also to update his or her network in time, as the individual ages and moves between age groups and networks. A graphical representation of the network group organization is presented in Figure 1 below.

This means that the individuals will migrate between network groups as the age, and two individuals that belongs to the same network group at one age, may belong to different groups at later ages. Furthermore, this implementation will allow for “spatial” migration as well as individuals could be allowed to change their “spatial” location, here measured as the angle on the circumference, over time.

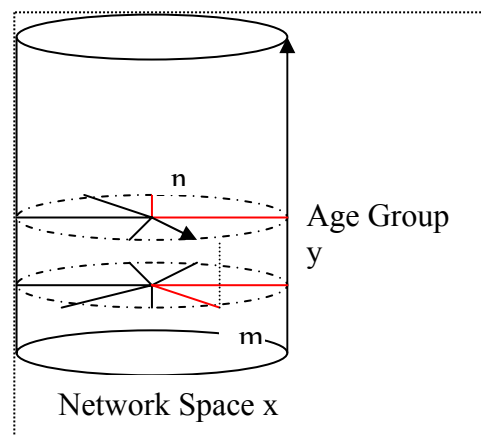


Figure 11. Graphical representation of the network groups

Any newborn inherits a "network angle" which is the average of her parents' plus a random term. A network angle is a technical construct which allows the individual to be placed, given his age, on a specific segment of the circumference throughout her life. At any point in time, his or her individual angle is compared against the angle determining where each network begins and end (by age group), and placed within the network segment corresponding to his or her angle. In the same network the individual will therefore meet a sub-sample of other people in the same age group who happen to have a similar angle (both randomly and due to parents' characteristics). In time, as the individual grows older and jumps between age groups, the composition of his or her network will change since different age groups are characterized by different network angles, hence individuals are shifted not only vertically but also "horizontally", so to say, depending on their own angle relative to the new age-group network configuration.

To sum it up, the individual's location within the cylinder space is determined by 2 coordinates: (i) their age group. This defines the location within the vertical Y space, or in other words the sub-cylinder to which the individual belongs (ii) the angle of the circumference within which the individual's network falls (corresponding to the interval on the circumference occupied by that network). This defines the horizontal x-coordinate.

By looping over all age groups and angle group, networks are thus populated. The size of networks will vary in time while the characteristics will remain relatively stable at least in terms of age composition. Each network group is modeled as a Java object capable to iterate

over its members and extract a number of summary statistics such as averages by group (i.e. proportions).

Fertility

Individuals that are married in the model and whose age is comprised between 20 and 40 can, under some conditions, generate a new individual, which in the model is referred to as "giving birth"⁴. Only fertile mothers can give birth to a new individual. Each new individual will have a mother and a father "inside" the model and will inherit some of its parent's characteristics.

Overall, the fertility decision is based on biological, economic and social factors. In a standard economic setup there would be a utility associated with number of children. In this agent based approach we do not model a specific utility of having children but we instead assume that a couple for some reason desires a certain number of children. To keep the decision rules as basic as possible, we simply assume that desired number of children is the average between the couples siblings (in home of origin), plus a random number. The couple thus wants to reach this preferred number but if they succeed or not depends on biological, economic and social factors.

By the biological factor we aim to capture the fact that all women are not capable of giving birth and that this ability varies with age. Female between the age 20 and 40 are able to give birth. How able they are depends on the biological factor which we model according to the following function:

$$(1) \Pr(Fertility_{BIO}) = \frac{\alpha - e^{\ln(\alpha) * (age - \eta) / (MaxFertAge - \eta)}}{\alpha - 1}.$$

Where α and η are set to 50 and 15 respectively. By doing so we obtain a biological fertility ability that is not that different from estimates by Manken et al (1986). Infertility for the age groups 20-24 would in this case amount to 7 percent, while it would be 11, 15, 22, 32 percent for the age groups 25-29, 30-34, 35-39, and 40-44.

The biological ability presents a window of opportunity. If a female is infertile she will not be able to have children and this probability increases with age. From the age of 20 and until MaxFertAge each women that is fertile receives a uniform draw which is compared to the $Fertility_{BIO}$. If the uniform draw exceeds this probability she will be classified as infertile and will not be able to have a child.

For those who instead are fertile, the actual probability of giving birth in a given year is determined by two additional "pressures", a so called economic and a social pressure which together will determine if they will give birth or not.

The economic pressure is meant to account for the couple's economic circumstances when deciding whether to have a child. An important part of this pressure (see the *relativeNPV* term in equation 2 below) is given by the expected life-time financial constraints (or incentives)

⁴ In the model we have not allowed females that are younger than 20 to have children, although there is no corresponding biological restriction in the real life.

that different women (depending on their labor market status, skill and wage growth potential) face if they were to have a child or not in that given year. Individuals are in fact considered to be forward looking and capable to compare life time changes to their budget constraint way into the future depending on what choice they make today. A household's expected disposable income will in fact be affected whether the couple has a child or not, due to (i) child's fixed costs, which are a set amount for all (ii) varying costs stemming from the temporary exit from the labor market, if in work, or from studying, from the consequent depreciation of human capital, as well as varying incentives, stemming from the level of parental benefits relative to earnings. At the moment, we do not base the expected income difference between having a child or not on household income, but rather on the mother's only. We do so since it is often the female career that is affected by childbirth.

The *relativeNPV* term in (2) below is a function of the expected relative difference in an individual's future discounted disposable incomes under the two states (having a child or not); it is an expected difference estimated over a certain number of years ahead, which at present is set to be 6 (but can be easily changed). Clearly, different labor market situations (i.e. whether one is skilled or unskilled, or whether one is still in University) will affect the expected projected income and the relative difference when considering to have a child. We allow the economic pressure to take into account variations in earnings growth rate applied over the considered timeframe for projection (depending on one's degree, different skill levels are awarded different average earnings growth rates in the market), and also in terms of the parental leave amount if having a child (people with working history are given a benefit equivalent to the 80 percent of last earnings, while people not in work such as students, are just given a minimum fixed amount). As we will see later, parental leave subsidy is made payable only for up to three years.

Students considering having a child will assume also different expected earnings over the next six years depending on which academic year they currently are at, and how many years they would need after parental leave in order to finish their degree. Students who are in the final year would be more likely to consider having a child from the economic point of view as they would assume to start working straight after the three years, at an earning rate similar to average earnings for current first year workers with a university degree. Other students would need to resume studying hence after parental leave they would go back to student allowance as their main income source, before joining the labor market, which might represent a possible disincentive (if the student allowance is sufficiently low).

We also add another forward looking parameter in the economic pressure, namely the household's expected change in income over the next five years if it was not to have a child now (see the *Inc / IncFuture* term in equation 2). Compared to the previous term, this one is meant to capture the different growth path in incomes that different individuals might expect in the immediate future, given e.g. their skill level, regardless of their parental choice. An individual with a high expected growth in income might have a stronger incentive to postpone giving birth by a few years compared to one with a low expected growth (due to higher opportunity costs).

Beside objectively different expected financial constraints and costs that individuals might face when deciding on having a child, our economic pressure also aims to account for differences in "subjective" preferences, which have to do with the different ways in which individuals perceive the adequacy of their living standards for supporting a family. This is done by introducing another parameter which we call the "Easterlin Income" pressure, and which is meant to roughly capture Easterlin's idea that the fertility decision is also affected by the way

Fertility decisions among students – simulation in an agent-based model

the individual perceives his or her own income prospects relative to those of the family of origin. The Easterlin Income parameter measures the relative size of the family income when growing up (between the age of 10 and 16) relative to the expected future household income when one's own child will be that same age: the lower this ratio (indicating lower projected standard of living for one's child relative to one's own), the lower the overall economic pressure, hence the probability of having a child in a given year).

Putting all these elements together, equation (2) shows the final form of the economic pressure:

$$(2) \text{ eco Pres} = \left(0.5 + \left(\frac{e^{\text{relativeNPV}}}{1 + e^{\text{relativeNPV}}} \right) \right) * \left(\frac{e^{\text{Inc}}}{1 + e^{\text{IncFuture}}} \right) \left(\frac{e^{\text{Easterlin}}}{1 + e^{\text{Easterline}}} \right)$$

The social pressure is meant to capture the effects that the social environment as well as the perceived biological “pressure” have on the individual's decision to reproduce. The social environment is meant to capture pure peer pressure. This is calculated as the proportion of peers within one's network who already have children (*shareWithKids* in (3) below).

The perceived biological pressure comes from the individual's own knowledge about how her fertility window will decrease between now and the next five years, given her current age (*bio/bioFuture* term in (3) below). The *bio* term is simply the biological rate for the women's age while *bioFuture* is the rate she will have five years in the future. Biological rate is not that different for at the age 20 compared to 25 this ratio will be close to one in this case, and will thus not have a strong impact on the fertility decision. However, after the age 30 the biological rate decreases more rapidly and the term *bio/bioFuture* will be higher than 1. As the woman realizes that her fertility window is closing more rapidly this will give incentives to get a child. Thus older women will have a stronger overall social pressure than younger ones due to their smaller window of opportunity, relative also to their respective total preferred number of children.

$$(3) \text{ soc Pres} = \left(0.8 + 0.4 \left(\frac{e^x}{1 + e^x} \right) \right) * \frac{\text{bio}}{\text{bioFuture}}$$

Where $x = \text{avg.siblings} - \text{current children}$

Having calculated the individual economic and social pressures, fertile women are then assigned their final probability of having a child in that given year as per the following Cobb Douglas function:

$$(4) \text{ ProbChild} = A * \text{Prob}(\text{Fertility})_{\text{BIO}} * \text{eco Pres}^{\gamma_S} * \text{soc Pres}^{\gamma_E} *$$

Where A is a parameter currently set to 1. γ_S and γ_E , are scaling parameters used to control the relative weight that the social and economic pressures should have on the final fertility rate. These are chosen as to get as close fit as possible to the Swedish fertility rates.

We compare the individual outcome against a random draw to assign an actual birth. We then calibrate this function to 2006 Swedish fertility data, by age (from register SCB data). Results

of our calibration are shown in the figure below. The line with squares refers to the actual Swedish data, while the line with triangles refers to the average fertility rate achieved by our model.

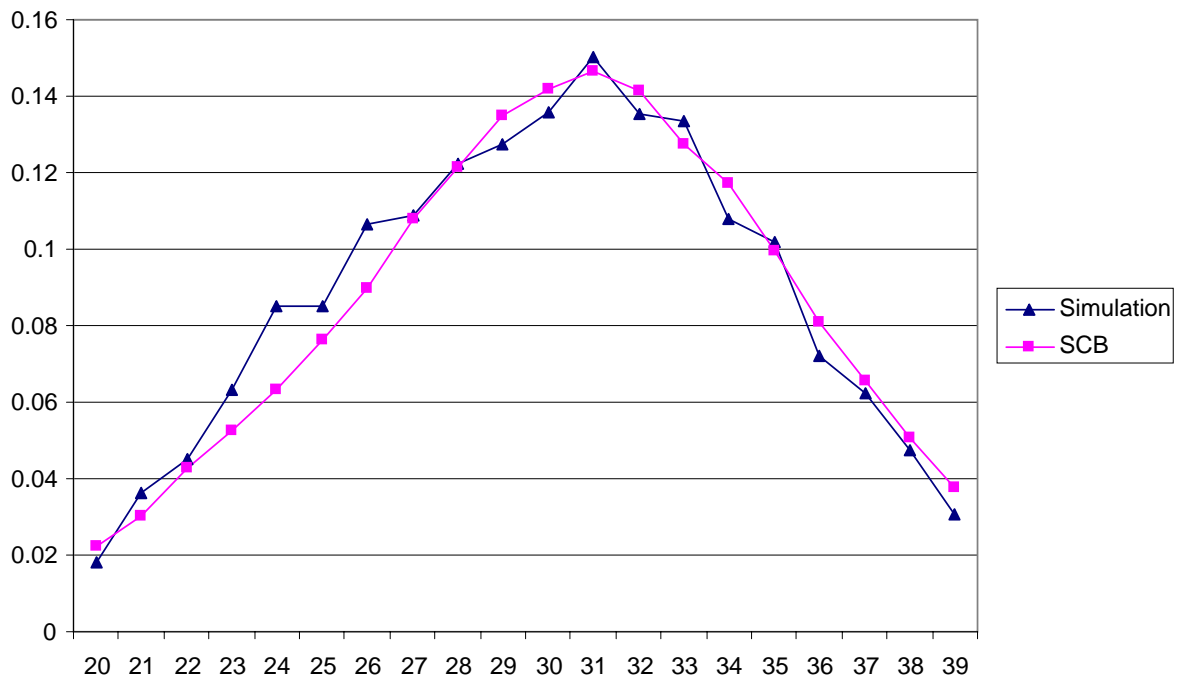


Figure 12. Simulated and actual fertility rates by age. The actual rates are for Sweden 2006 according to Statistics Sweden.

The simulated births, by age, are the result of the joint effect of the biological fertility rate, the social and economic pressure, and a random draw. We obtain plausible age-profile for giving birth. There is a slight overestimation for women between ages 23 to 26. Considering that we have not put in any age specific rates, except those coming from biological studies concerning female fertility variation by age, the model fit fits the data quite well. The combination between economic and social pressure combined with the agents rules of thumbs is able to fit the data surprisingly well.

Adolescents leaving home

Starting from age 18, individuals living with their parents may start to leave the parental household and set up a household of their own. The decision to leave home is modeled as an exponential probability function depending positively on age, and adjusted on the basis of social pressure effects (i.e. how many people of similar age in that individual network have left home). Those whose final probability is high enough (against a random draw), are made to leave and their new household is given the status of single household. The baseline probability of leaving home (i.e. without social interaction effects) is given by the following expression:

$$(5) \quad \Pr(\text{leave home}|\text{age}) = \frac{e^{(\text{age}-20)/2}}{1 + e^{(\text{age}-20)/2}}$$

This probability is then corrected by an adjustment factor k reflecting the proportion of individuals aged 15-20 and 20-30 not living with their parents (specifically, with their mothers) across the individual's network. We calculate the proportion of individuals not living in their parents' household within each network group and compute the relative difference between this share and the leaving home rate. This relative difference is then transformed into a variable that varies between 0.8 and 1.2 using an exponential transformation. The final variable is multiplied by the baseline probability of leaving home producing the final probability of leaving home. Hence if the proportion of individuals not living with their parents is higher, the probability that this individual will leave home increases, and vice versa. The final probability is this

$$(6) \quad \Pr(\text{leaving home}) = p * \left(0.8 + 0.4 \frac{\exp\left(\frac{(\text{mean}_g - p)}{p}\right)}{1 + \exp\left(\frac{(\text{mean}_g - p)}{p}\right)} \right)$$

where p is the baseline probability and mean denotes the network group specific proportion of (young) individuals not living in their parents' household.

Those individuals who are selected to move out are placed in a new household of their own, assigned both adult and single marital status, and are removed from the member list of their original household. Individuals who leave school at 16 and enter the labor force then are still regarded to live in the parental household. Their earnings add to the household's income.

Matching

The matching process consists of making single people meet in order to create a new married household. First, the model looks for all single households of age 18 or above (students as well as non-students). Hence, individuals still living with their parents are not allowed to match. Eligible single households are divided between male and female households, and individuals of opposite sex are picked randomly from these singles lists. In the current version, the matching probability depends linearly on the age difference between the potential partners only, rather than on more complex criteria (e.g. education, income etc.) with a maximum of a three year difference between the male and female age. A candidate couple's matching rate is determined by how far their age difference is relative to the optimal age difference, and this rate is then compared to a randomly drawn number in order to determine the actual matching outcome for that couple. When a couple is formed, the man moves into the female's household.

$$(7) \quad \Pr(\text{Matching}) = \frac{\text{MaxMatchRate}(\text{AgeDiff} - \text{AgeDiffMin})}{\text{AgeDiffOpt} - \text{AgeDiffMin}}$$

Where MaxMatchRate is a calibration parameter set to 0.03, AgeDiff is the age difference between the matching partners, AgeDiffMin and AgeDiffOpt are two parameters referring to the minimum and optimal age difference set in the model to -5 and 0 respectively (i.e. the minimum age difference is set to the woman being 5 years older than the man, while the maximum is the man being 15 years older than the woman).

Although this matching procedure appears primitive, it does allow for assortative matching as university degree individual match later in life and are thus more likely to match another unmarried university degree individual of the same age.

The social network approach is implemented in the matching process only in so far as that a man and a woman belonging to the same network will have their matching rate “boosted” up by a uniform random number.

4.3 Education

When reaching the age of 7, all individuals are universally put into basic schooling up until the age of 16, hence everybody is awarded with a basic degree, corresponding to 9 years of compulsory education. 12 After completing the elementary schooling at 16, an individual can continue education onto college or enter the labor market.

College Education

The choice of college education follows the idea of calculating both a social and an economic "pressure" which balance the baseline (in this case exogenous) probability of going to college. The final individually adjusted probability is then compared to a random number for determining the actual stock of college students in any given year.

If entering secondary school, the individual will stay in school until graduation in a predetermined number of years (3 years in the standard version). The individual can however postpone entry into secondary school until she reaches 18. The baseline probability to enter secondary school is exogenous and age dependent with probabilities currently set at 0.8 at age 16, 0.2 at age 17, and 0.2 at age 18.

The economic incentive is calculated by the individual as his or her expected economic return from going to college rather than going to work. We assume that each individual is forward looking and able to predict the difference in wages over the next ten years stemming from each choice, based on the wages of those whom have gone to college versus those who have not (we will give more technical detail about these calculations in the next section). The individual's probability of going to college should therefore incorporate the rational preference of going to college if the predicted future income is higher under this choice than otherwise. In particular, if the wage difference college-versus-basic, ΔY is positive, then the probability to enter college increases otherwise it decreases:

$$(8) \quad EP = 0.8 + 0.4 \frac{\exp(\Delta Y)}{1 + \exp(\Delta Y)}$$

The social incentive is calculated similarly. The average participation rate (i.e. proportion of youngsters in college) is first calculated at the individual's network level. Subsequently, the model calculates the relative deviation of the network's specific participation rate from the baseline probability p . This deviation is then fed into the same exponential function, returning a value between 0.8 (if the pressure is negative) and 1.2 (if the pressure is positive):

$$(9) \quad SP = 0.8 + 0.4 \frac{\exp\left(\left(\text{mean}_g - p\right) / p\right)}{1 + \exp\left(\left(\text{mean}_g - p\right) / p\right)}$$

At this point, this baseline probability is multiplied by a factor obtained in turn by multiplying the economic and social pressure factors together, thus introducing individual heterogeneity. The final participation stock is determined by random selection.

Those who are selected to go into college will have their student status changed accordingly for the next three year, after which they are made to graduate. After graduation from secondary school, the individual face the option to continue to tertiary school.

Higher education

The individual's decision to go to higher education, i.e. university (or tertiary) level, is governed by three parts. First we have a base line probability that is assumed to capture the over all probability that any eligible individual enters the university. Next, we have a probability that increase with the perceived economic pay off of higher education, here denoted as the economic pressure. Finally, there is a probability that relates to the average participation rate at university within each given network group, denoted as the social pressure. The path into university is made up by an “application step” and an “acceptance step”.

First we construct a set of university applicants based on expected life time incomes, based on contemporary cross-section projections of disposable income on age. This is assumed to correspond to individuals construction of a rough expectation about future pay-offs associated with the educational decision. The mean projections are based on the full sample whereas a specific individual's position in the distribution of disposable incomes will depend on her position in the network group's distribution of human capital. This aims to reflect that individuals with high accumulated human capital should expect to be positioned higher in the distribution of incomes. In other words, individuals with college degree will have higher probability to apply to University if their expect costs (i.e. 3 years of foregone labor income) will outweigh the future benefits (i.e. higher human capital, higher earnings and higher pensions). Applicants will be able to compare the NPV stream of expected future incomes if they were to go to work immediately or rather go to University, hence they will choose the option the yield the highest expected income. The applicants are then ordered with respect to their accumulated human capital such that the ones with the highest human capital are actually accepted by the University. The number of individuals finally accepted is determined by a policy parameter, currently set to a maximum of 30 percent of people of each age within the 19-30 age group.

In order to create expectations of future disposable incomes with respect to various educational decisions, the individual is made to regress disposable income on age and age squared for current workers in the population. The individual's prediction about her future age profile will further reflect the individual's position in the distribution of human capital within her network group. Formally,

$$(10) \quad \mathbb{E}DI_{ia}^{school} = \mathbf{x}_{ia}' \beta^{school} + d_i \sigma_{DI}^{school}$$

where $school = \{college, univ\}$, $d_i = (HC_i - \overline{HC}_g) / \sigma_{HC,g}$ and σ_{DI} and σ_{HC} refer to the standard deviation in the distribution of disposable income and human capital, respectively. The subscript g indicates that the measure relates to a network group. The vector of independent variables includes a constant, age, and age squared.

Thanks to this regression, the individual can compile for every age and degree an expected life income profile, i.e. the lifetime expected value of income for each educational outcome (i.e. college or university).

The economic pressure is then calculated as follows:

$$(11) \text{ EcoPr es} = 0.5 * \frac{\exp(x)}{1 + \exp(x)}$$

Where $x = (npdUniversity - npvCollege)/npvCollege$, or simply the relative difference in net present value terms of expected life income if going to University versus just having a College degree (i.e. cumulated over the whole life).

In figure 11 we illustrate an example of projected disposable incomes for a randomly selected individual that is in the position to decide whether to apply for university or not. The discount rate eventually is individual specific, which may cause otherwise identical individuals to make different decision regarding education.

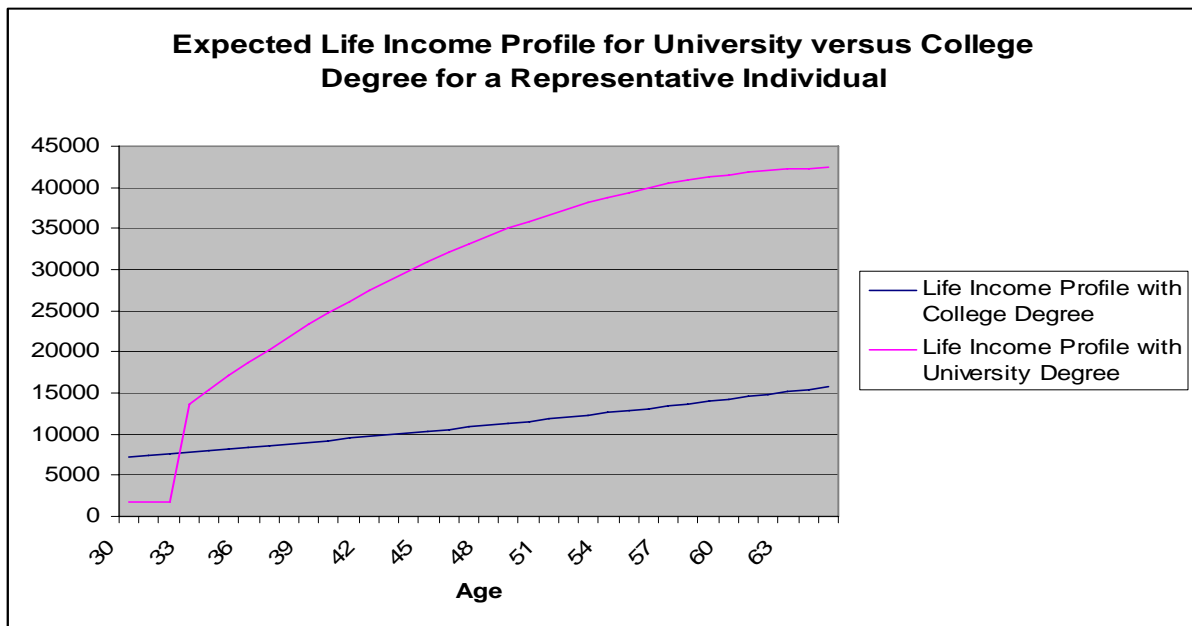


Figure 13 Projected disposable incomes at the university decision for a representative individual

In sum, for every transition, the outcome is recorded and the individual is assigned an educational status, on the basis of which he or she is also added into a student list, grouping together all the students currently attending each one of the three educational levels (basic, college, university) in any given year.

4.4 Production of human capital

In the current version of our model, we postulate a production technology only dependent on human capital i.e. there is no savings into other types of productive assets.

Human capital pertains to the quality of labor embodied in each worker, for a given amount of schooling, training, work experience, as well as innate abilities. As such, the individual human capital level can be accumulated and measured as the output from a human capital production function which should capture, e.g. the quality of educational institutions and the ability of the system to transfer knowledge between individuals, as well as parental attitudes and native endowments.

The difference between human and physical capital, first postulated by Shultz and then Becker, can be explained by the presence of social externalities embodied in the private accumulation of human capital. When someone is increasing their human capital, e.g. through an additional year of schooling or on-the-job training, their action has two distinct effects: (i) he or she is increasing their marginal productivity, hence, according to the basic principle of competitive markets, they will increase their returns or wages. This is empirically supported (people with higher education tend to have higher wages) (ii) he or she is contributing to raising the quality of the total human capital stock, which also enters the "human capital production" functions of current students, determining the rate at which another individual will in turn be able to accumulate their own human capital, hence increase their own productivity and wages. This spill over effect is essentially the key "externality" distinguishing human from physical capital. It is this very feature which provides an interesting macro-micro linkage. We want to incorporate this linkage into our model.

There are four main inputs into the production of human capital: (i) individual early ability, whether innate or acquired (ii) ability acquired from parental influence and parental own human capital levels (iii) ability acquired through formal education (iv) skills and expertise acquired through training on the job. After the native human capital has been set "by nature" (i.e. through an inheritance mechanism and a random number), the model aims to separate these three phases of human capital accumulation through the definition of three distinct production functions (i.e. depending on age and labor market status, the individual is run through each function in subsequent steps), in order to derive a human capital value for each individual which is so to speak "dynamic", i.e. is not fixed but responds to periods of unemployment and skills depreciation.

At first, upon birth, an individual is immediately assigned a native human capital level which captures the average native human capital levels of the parents (i.e. a purely genetically inherited feature) plus a random number. Subsequently, from the first year of life, this initial human capital level is "expanded" in line with the relevant human capital production function (depending on the age).

Generally speaking, individual i 's accumulated human capital stock in period t , denoted by h_{it} , depends on years in school and the productivity of the human capital production during years spent in education. In each period, the individual's stock of human capital is updated using a human capital production function that determines the evolution of the stock as a function of e.g. the individual's current stock, parents human capital stock, the quality of education in school (i.e. the teachers aggregated human capital per student), and the employment status when in the labor market. For example, for a given amount of schooling years, higher parental human capital implies a larger production (growth) of the individual's human capital. Reflecting the impact of better educational facilities, the number and the sum of teachers' human capital also increase the growth rate of human capital when in school. Further, when in the labor market, a year of employment increases human capital (potentially with a decreasing rate) whereas a year of unemployment or parental leave deteriorates the stock.

Next we present the evolution of the human capital stock when an individual is aging from birth to death.

Natal endowment and pre-school human capital production

To fix ideas, consider an individual with natal human capital h_{i0} . This natal human capital is derived from the natal human capitals of both parents (cf. genetic and inheritable ability), and a random factor.

The discrete time evolution of the natal human capital in the pre-school periods is modeled as

$$(12) \quad \Delta h_{it+1} = A h_{it}^{\alpha_{own}} \left(h_{i_m t} + h_{i_f t} \right)^{\alpha_{parents}}$$

where Δ indicates first differences and h_{i_m}, h_{i_f} denote the human capital of individual i 's mother and father (in that given year). Hence, the human capital production function is a Cobb-Douglas type with the sum of parents' human capital and the child's own capital as input factors, and their respective elasticities α_{own} and $\alpha_{parents}$ are specific to the pre-school period and set exogenously. The importance of natal human capital becomes evident as the initial value of human capital stock will determine the subsequent growth through the lagged stock.

School and human capital production

During schooling periods, not only the parents' human capital enters the individual's human capital production function. During these periods, also the human capital of the "teachers" enters the function.⁵ The argument is that training by highly educated teachers should imply a steeper learning curve for the current students. This creates an additional link between current aggregate human capital and the production of "new" human capital through schooling.

We assume that the *aggregate level* of human capital among the teachers, scaled by the number of students, enters the human capital production function along with the parents' human capital. The rationale behind this assumption is that the policy makers should be able to influence the output of the educational sector by allocating more teachers. If teachers are assumed to be randomly drawn from the population of the labor force, then using the average would not enable policy decision in this respect as the "quality" of education would be more or less independent of the number of teachers. However, using the (scaled) sum of human capital enables such policies.

To formalize, the human capital production during school periods is defined as

$$(13) \quad \Delta h_{it+1} = A_t^s \left(h_{i_m t} + h_{i_f t} \right)^{\alpha_p^s} \left(H_t^{teach} / \#students \right)^{\alpha_t^s} h_{it}^{\alpha_{own}^s}$$

where the superscript s indicates that the parameter values depends on the level of education (primary, secondary, and tertiary). For example teacher human capital has level specific impact on human capital production. The time index on the productivity factor A indicates that the over all productivity of human capital production can be time dependent.⁶ Here, the human capital production function can be influenced directly by the policy makers by allocating more resources to the educational sector (employing more teachers) or indirectly by lagged effects when the average human capital in the labor force increases.

⁵The meaning of a "teacher" will be discussed below.

⁶This could be used to formalize a Becker-Murphy-Tamura approach with convexities in the human capital production function.

It is important to add that, for those university students who are temporarily on parental leave, the accumulation of human capital is temporarily stopped.

Teachers

The total number of teachers T_t in the educational sector is determined by a policy parameter which gives the target share of teachers per student. Currently, the ratio of teachers per student is set to 0.1. Hence, the policy maker can influence the human capital growth by increasing the number of teachers per students implying a higher aggregated teacher human capital per student.

At-work human capital production

In standard wage equations, labor market experience approximates human capital production at work. In our set up, we can use a pure "at-work" human capital production function similar to the in-school production function in (13). The human capital while in work will increase for every year in work proportionately less the older the individual gets, up until the age of 55. We extend the production function to incorporate a deterioration of human capital in unemployment spells or periods of parental leave. Formally, the human capital production at work is a percentage increase, decreasing in age, which turns negative after age 55 such that

$$(14) \quad \Delta h_{it+1} = \frac{55 - age_{it}}{10} * 0.02 * h_{it}$$

During periods out of the labor market, notably on parental leave, the human capital is set to depreciate at a yearly rate of 0.015. However, this is not assumed to be the case for students on parental leave (i.e. we assume that they will not depreciate their skills while looking after a child, only workers will).

4.5 Labor market

Individuals that are not in school, above 16 years of age, enter the labor market. The labor market module aims at determining, at any period, the individual's labor market status - whether employed, unemployed, on parental leave, or retired, as well as the total output levels and earnings. The hours of work are not estimated for the moment. If someone is in work, we assume that they are in full time work. If someone is neither a student nor unemployed (currently we do not model unemployment), we employ them automatically i.e. they receive an in-work status and one year is added to their work experience. Again, we assume full time employment all year round.

Among those who are in work, we also randomly assign the work status of teachers, following a policy set parameter which fixes the desired number of teachers per student. Those people who are designated to become teachers, do not participate to the production of consumption goods but rather to that of human capital. The number of teachers fluctuates with the number of students (so that the ratio is constant). However, at any given time, the total human capital of teachers will depend on the human capital of those randomly selected to become teachers; in turn, the total human capital level of teachers is an input into the total human capital production of the population, hence it will influence the future total output level which will be produced.

Retirement

In the current version, retirement is deterministic. At age 65, individuals are automatically removed from the labor force and included into the list of "retirees". From this point onward, individuals are entitled to a retirement pension.

Output production

There is a single sector in this economy producing a single consumption good. The amount of consumption good produced depends entirely on the total human capital level of the labor force (excluding teachers). The production function follows a Cobb-Douglas shape with a time-dependent productivity factor. Modeling the output production function this way is meant to capture the idea that returns to human capital investment are increasing, in line with endogenous growth theory, but after a certain level the situation might be actually reversed, if, e.g. there is an excess supply of skills in the economy. There are two input factors in the model; the total human capital of the non-university degree (primary or secondary degree) individuals, and the total human capital of the university (tertiary) degree individuals. The output function looks as follows

$$Q_t = A_t H_{1+2}^{\alpha_{1+2}} H_{t3}^{\alpha_3}$$

where $\alpha_{1+2} + \alpha_3 = 1$, and $H_{t,1+2}$ and H_{t3} is the aggregated human capital in the non-university and university degree groups, respectively. In this version, the productivity factor is set equal to 1.⁷

4.6 Earnings

There are no monetary values in the model at present so earnings for now are represented by the share of total output produced going to each worker. The allocation of the produced good to workers is separated into two steps. First, the total produced goods are allocated to the two production factors (non-university and university degree individuals) proportional to each group's marginal product. Then, within each group, the consumption good units are allocated proportionally to the human capital of the individual. This implies for example that, if the supply of university degree individuals is reduced, their marginal product will increase and thereby increase their share of the produced goods.⁸ This will be observed by young individuals who will be more prone to choose university and thus increase the future supply of university degree individuals.

For individuals not born inside the model, we also need to impute past consumption good earnings, in order to track their earnings history (comparably with other individuals born inside the model), and thus establish their eligibility e.g. for certain income related benefits such as pensions.

⁷ In another version of the model, the productivity factor is determined as $A_t = 0.5 + \frac{\exp\left(\frac{H_t - \bar{H}}{k\bar{H}}\right)}{1 + \exp\left(\frac{H_t - \bar{H}}{k\bar{H}}\right)}$ where

$H_t = H_{1+2,t} + H_{3t}$ and $\bar{H} = 1.5H_0$. This cause the production function to be convex initially and then concave (if $\alpha_{1+2} + \alpha_3 < 1$).

⁸ The net effect could be either positive or negative as the total amount of consumption good produced will decrease.

4.7 State, tax and benefits system

Beside individual agents, the model includes an institutional agent which represents "the State" and has the main function of collecting and redistributing resources. The State can also react on its environment and implement policy changes according to certain methods and rules.

The function of collecting taxes from individuals is managed through the State, an agent capable of (i) identifying people who are eligible to pay tax, social insurance contributions, and collect them into a tax payer list (ii) calculate an income tax function and a capital tax function for each individual (once savings will be introduced), and summing the total revenues. (iii) Manages public expenditures including students allowance, teachers' salaries, parental allowances and pensions.

First, the State calculates the total expenditure bill, by aggregating the costs of the education, teachers' salaries, parental leave subsidies and pensions (including both income and guaranteed pension). The education bill comprises the total costs of paying university student allowances (set to a fixed proportion of average consumption good earnings, e.g. 20 percent. The pension bill consists of aggregating the total value of all guaranteed and income pensions paid to retirees, although only the guaranteed pension will affect the revenue side as it will be paid out of taxation, while the income pension will be paid out of a separate "fund" made up of individuals' contributions.

Once total expenditures are calculated, the State will adapt the tax system so as to raise sufficient revenues to balance the budget (no debt is allowed in the current version of the model). The tax system comprises a State and a Local tax. The State tax is a progressive tax payable on all income greater than an endogenous earnings threshold (currently set to include only earnings in the top 20 percent of the income distribution at each time period); the tax rate is set by a changeable policy parameter (e.g. 20 percent rate on all income above the threshold). The local tax is derived also endogenously to cover any revenues' shortfall from the State tax, given total expenditures, and given the current tax base. The individual income tax will therefore be a combination of both the State tax (if eligible) and the Local tax (payable by everybody with positive earnings). The individual disposable income therefore is calculated as the sum of any earnings, pensions, student or parental allowances, minus the income tax.

The Parental Leave Benefit

The parental leave benefit is modeled according to the Swedish system (2007), with some simplifications related to the rules e.g. on number of eligible days for each parent etc. In our model we assume that only the woman gets the benefit within the couple, hence the amount of the benefit is calculated on her eligible income.

The benefit comprises a guaranteed amount, for those who have no previous income history (such as students) and an insurance-related amount, for those who have earnings up to a certain thresholds (i.e. up to 10 times the so called Basic Amount equivalent, which in our model is calculated to reproduce a level comparable with the Basic Amount for 2007 in Sweden, around 40000 SEK per month).

Upon the birth of a child, people with no work history or students would receive therefore a minimum benefit corresponding (in daily terms) to around 0.45 percent of the Basic Amount

equivalent. For a parent that is on a full time parental leave this would correspond to a monthly benefit of 13.5 percent of the Basic Amount. Most students that receive a child during their studying period would receive this amount. In our alternative scenario we elaborate to see what happens when this minimum level is raised.

People in work instead first need to have their base income calculated (for the purpose of receiving an income related benefit). This requires the application of a coefficient to their gross earnings which reduces them slightly for the purpose of benefit calculation. The parental leave benefit amount is set to 80 percent of the individual's base income.

The benefit is paid for three years after the birth of the child, after which the individual returns to their previous labor market status. This length of the leave is higher than what is actually possible to take obtain. However, we do not include the right to benefits when taking care of a sick child nor do we include the effect of part time work when raising children. We thus believe that adding a longer initial leave compensates for this.

Being on parental leave does not exclude per se the possibility to have another child, since the model allows women with a child older than one year of age to have another one. In these cases, during the overlapping period when the mother is looking after two children, the parental leave benefit amount is frozen (i.e. it is not doubled).

The Pension System

The pension system is modeled according to the Swedish system (2003), with some simplifications related e.g. to the fact that the model does not yet have capital markets (hence, we currently do not include the funded part, or premium pension). At present we assign to every retiree a state pension which is comprised of two elements: an income pension and a guarantee pension. The income pension is related to the amount of notional contributions paid by each individual during their working life into their personal account. The guarantee pension is instead a minimum universal pension for all.

During working life, each individual pays an amount of contributions C equivalent to 16 percent of her earnings into a personal fund PF which accumulates over time and grows at the rate of earnings. Every year, we assume that the fund grows at a rate R . At the time of retirement (age 65), the individual will have therefore accumulated a certain lump sum which will then be converted into a yearly pension income, IP . The general algorithm for the total value of the individual pension fund is given by:

$$PF_{t+1} = (PF_t + (C_t - IP_t)) * R_t$$

An issue which is inherent to simulating a pension model is to back simulate historical earnings and contributions for those people who either have already retired or are in the middle of their working life in the first year of model simulation (in our case, e.g., 1996). For those who have already retired then, we simply assume that their pension will be entirely based on the old system, i.e. they would not be eligible for an income pension hence would not have a pension fund, but only the maximum amount of guaranteed pension. For each individual who is already in work at this time, we need to make some assumptions about the pension fund that they will have probably accumulated up to the point when we start simulating. Since we lack historical data for these individuals, we currently opt for making the simplifying assumption that, for each year of declared work experience, they would have contributed 16 percent of

their current discounted earnings. We assume that the discount rate would offset the fund's growth rate R .

Once the individual retires within the model, her income pension is calculated by dividing the pension balance of the individual pension fund by a so called annuitization divisor. This divisor is the average life expectancy at age 65 (17.6 for males and 20.7 for females in 2006). Each year in retirement the benefit is furthermore increased by the rate of R . The pension benefit is eventually adjusted also so as to keep the (PAYG) in balance. The system's overall balance at any given time period is given by the amount of total social insurance contributions CW (paid into each individual account by the current generation of workers, W) and the amount of total income pension benefits IPN (paid out to eligible current retirees, N):

$$\sum_t CW = b \sum_t IPN$$

Where $b = \Sigma (CL) / \Sigma (IPN)$ is the balancing index required to keep the income pension bill financially sustainable. As we are modeling the Swedish Notional Defined Contribution system here, we develop b into a simplified equivalent of the real Swedish automatic balancing mechanism, which entails a proportional reduction in the amount of pension IP any time the ratio CL/IPN (i.e. when the income pension liability exceeds or falls short of the assets of the system). Finally, the income pension benefit at time t becomes:

$$IP_t = \frac{PF_t - IP_{t-1}}{L_{65}} * b_t * R$$

Where the subscript t is any time after retirement, L is the life expectancy for the individual at 65 (by gender), R is the growth rate of the fund and b is the balancing index.

Once the income pension is calculated, the individual will be checked to see whether additionally she will be eligible for a guaranteed pension. A guarantee pension will be awarded to all individuals, regardless of their social insurance contributions, who have an income pension amounting between 0 and 38% of GDP per worker (this threshold has been set on the basis of the 2003 system).

Given 2003 values for Sweden, those who have an income pension equal to zero (i.e. no income pension at all), will be entitled to the maximum amount of guarantee pension, currently fixed at 27% of GDP per worker. This amount has been calculated on the real maximum guarantee pension in 2003, which then was set to 2.13 basic amounts for singles and 1.90 basic amounts for couples⁹. For those with an income pension above zero, yet below the 38% of GDP per worker threshold, more precisely up to 16% of GDP per worker, the income pension amount is withdrawn from the maximum guarantee pension amount by 100% (so in practice the total pension income of these people will be equal to the maximum guarantee pension, albeit the composition will be split between income and guarantee pension). For those with an income pension above 16% of GDP per worker, the maximum amount of guarantee pension will be tapered away at a rate of 48% for every additional unit of income pension. In other words the guarantee pension benefit is calculated as follows:

$$GP = MaxGP - \alpha(IP) \quad > 0$$

⁹ In 2003, one Basic Amount corresponded to SEK 38,600.

Where α is set equal to 1 for IP < 16% of GDP per worker, and to 0.48 above that.

5. Results

The aim of this simulation is to investigate the overall effects of raising the minimum benefit in the parental leave system. The base scenario represents the model of the current Swedish system, while the alternative scenario is a simulation when the minimum level in the parental leave system is raised.

We have chosen to look at the following variables: completed cohort fertility, share of students with children, government spending on parental leave and total government spending on intergenerational transfers. All results that are presented are such that we let the model first run for 100 years to level off, then we look at the average for the following 50 years when we analyze the variables of interest. The calculated averages are based on five runs for the base scenario and five runs for the alternative scenario. The difference between the different runs, under the same scenario, is however negligible.

In the table below we see the results for the base scenario when the minimum benefit level is according to the Swedish current system, and for the alternative when the minimum benefit is based on the average wage. The alternative policy has more or less no impact on the aggregate results. We see that there are slightly more students that get children during their studying period under the alternative scenario. The difference is however negligible and when it comes to the aggregated results over the life cycle we see no impact.

	Base scenario	Alternativ
Completed coh. fert.	1.8	1.8
Share stud that give birth	5.8 %	6.0 %
Government spend on parental leave	1.4 % of GDP	1.4 % of GDP
Total gov cost	58 % of GDP	58 % of GDP

Table 1. Summary for different variables under the base scenario and the alternative scenario.

How can it be that the government cost for the parental leave does not increase when the minimum benefit is raised? First of all it is a small group that is affected by the policy change. Second, those individuals who get children during their study period instead of afterwards, receive a smaller benefit since their benefit would be based on a higher income than the average income.

6. Concluding remarks

There are many policy proposals to raise the low fertility rates. To investigate if these different proposals will have any effect or not is not an easy task. We have in this paper illustrated how agent based modeling could be used as an approach for policy evaluation. To illustrate our approach we have considered a change to the Swedish parental leave benefit. The consid-

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ered change has been to increase the minimum level of benefit that is received when no prior earnings are available. The results of the policy simulation are that there are no noticeable aggregate effects from the change. Sweden would have nothing to gain or lose by implementing such a policy. The negligible difference in numbers of births by students comes from the fact that the economic decision aspect for this group is not that large. However for those students that gets children there is a difference in what they actually receive.

One of the major challenges in the agent based approach is to find the thumb rules and calibrating these. When it comes to the fertility rules we choose to calibrate these to the Swedish fertility rates by age in 2006. We deliberately did not choose the standard route to apply the empirical age specific fertility rates to our individuals. Instead we tried to find thumb rules that where not age specific except for the pure biological impact. By doing so hopefully we avoid some of the standard critique that otherwise applies when it comes to policy changes of this sort. We actually manage to some extend to fit the empirical fertility rates by using economic and social aspects in the decision rules combined with the biological fertility ability.

Many other issues can be investigated with this agent based approach. The key lies in the ability to validate the model by finding appropriate thumb rules. In this paper we have mainly focused on the fertility decision but many other thumb rules that we use would need to be validated more extensively.

The benefit of using an agent based approach in this case is that the thumb rules are more likely to be unaffected by the policy change then what most relationships in a standard micro simulation approach would be.

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Appendix: The development environment

The simulation model is developed in a java-environment using the pre-compiled package JAS 1.2. JAS is a JAVA-based object-oriented simulation toolkit, specifically designed for agent based simulation modeling. JAS is developed and distributed (as freeware) by Michele Sonnessa, Dept. of Computer Science, University of Turin, Italy¹⁰.

JAS does not define a domain-specific language: it provides the JAVA programmer a collection of ready to use libraries, widgets and a set of methods to build such kind of simulations. A JAS model is an instantiation of a particular Java class (*jas.engine.SimModel*), creating a collection of agents and a schedule of discrete events performed over those agents. Our model is itself an instantiation of the JAS class *SimModel*. Therefore, it can interact with JAS library commands and features.

JAS is a flexible tool which can be easily embedded in the user's own JAVA model. In our case, the JAS library is included in the Eclipse development environment. The JAS User Interface is launched from within the development environment, allowing the programmer to run the simulation, as well as easily follow and analyze its outputs. In other words, the JAS User interface is an application through which the user can execute simulation experiments, loading JAS compatible models and controlling their execution. The main panel of JAS, once PABM has been uploaded but before running it, is shown in Figure 1.

¹⁰ For more information, you can visit: <http://jaslibrary.sourceforge.net/>

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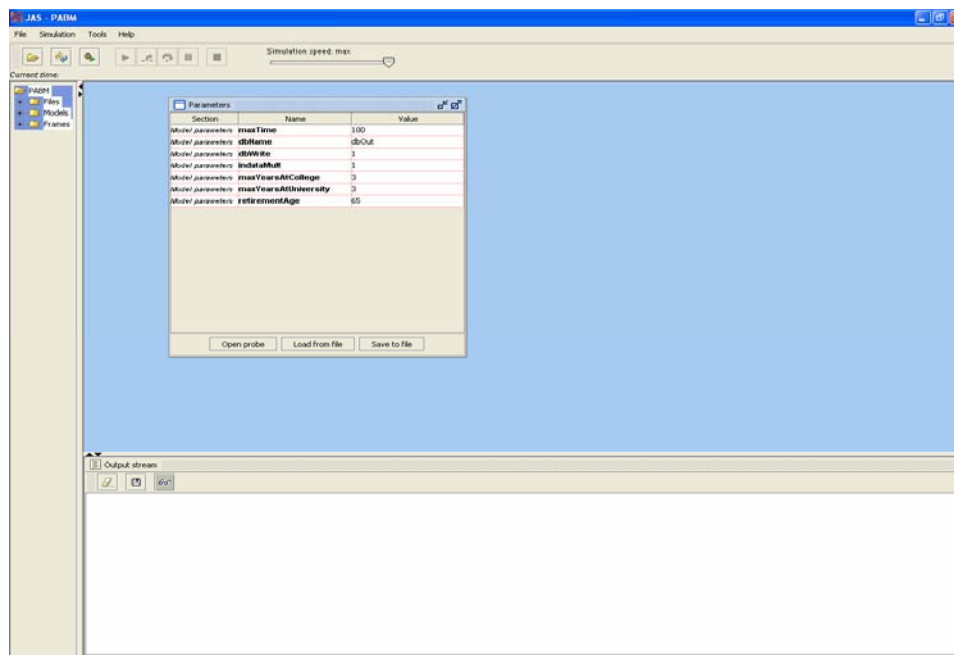


Figure 14 Screen dump of JAS user interface

The Parameters window allows the user to change any model parameters of his or her choice, for instance the simulation times, or some policy related parameters, such as retirement age or schooling years, provided they are previously coded in the relevant “JAS parameter bag”. The Parameters window also allows to save the simulation output in an SQL¹¹ database which can be subsequently accessed and analyzed, provided a name (e.g. dbOut) is specified before running the model. Finally, the Parameters bag allows access to an on-line probe (“Open probe” button on the bottom-left side), which the user can access to follow the history of every agent in the model as it develops.

The running of the model in JAS actually consists of two separate steps: first, the model needs to be initiated. This essentially means that the input dataset (external) needs to be read into JAS and transformed into an output database (the one where new information is stored as the model runs). Only then, the model is actually run. On the top left corner, the user can observe the model current time and stop the simulation at any point. Otherwise the model will continue running until the number of time periods specified in the Parameters window is elapsed.

From the JAS interface, the user can also view graphical outputs of various variables’ time paths (e.g. total GDP, population growth, average human capital levels etc.). Figure 2 shows

¹¹ Structured Query Language database

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an example of the graphical outputs which can be produced after running PABM for 100 years.

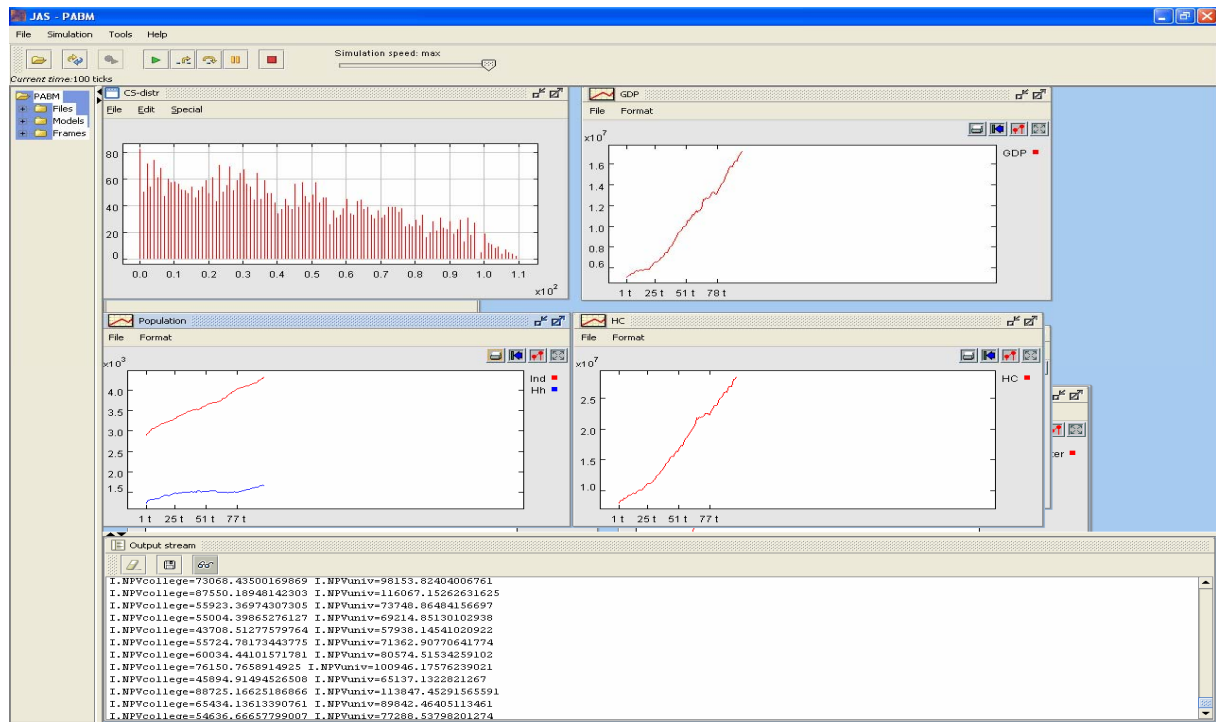


Figure 15 Screen dump of the simulation model running

From the Output Stream window, the user can check any errors occurring in the run as well as print statements specified in the code.