An agent-based model that relates investment in education to economic prosperity

Yuqing Tang
Department of Computer Science
Graduate Center
City University of New York
365, 5th Avenue
New York, NY 10016, USA
ytang@gc.cuny.edu

Simon Parsons and Elizabeth Sklar
Department of Computer & Information Science
Brooklyn College
City University of New York
2900 Bedford Avenue
Brooklyn, NY 11210, USA
{parsons,sklar}@sci.brooklyn.cuny.edu

ABSTRACT

We describe work on an agent-based model that captures the relationship between the investment that a society makes in education and the outcome in terms of the health of the society's economy. In this work we created an agent-based version of an equation-based model from the economics literature, and explored various settings for parameters that control the behaviors of the agents and their environment.

Categories and Subject Descriptors

I.6.6 [**Simulation and Modeling**]: Model Validation and Analysis

General Terms

Experimentation, Verification

Keywords

Agent-based modeling, simulation, education

1. INTRODUCTION

We are building tools that can be used in determining the effects of particular choices in education policy [4]. Our long-term aim is to be able to use such tools to inform the debate about initiatives like the US "No Child Left Behind" Act [3], and illuminate the controversies that such initiatives have created. To this end we have been extracting predictive models from sets of data related to human education, and equation-based models from the economics literature [5], and using them to implement predictive models. This paper describes the adaptation of one such model.

2. THE MODEL

The model that we have implemented is taken from [2]. The setting for the model is a simple economy that has two sectors. Each of these sectors produces one good: units of education that are used to train individuals in the population; and units of a numeraire good. "Numeraire" is defined as "a basic standard by which values are measured, as gold in the monetary system" [1]. In [2] it is a good that is produced (see below) and then traded for things that individuals consume.

The individuals who inhabit this economy live for three time periods, periods in which they are students, adults and pensioners. Consider an individual who is a student during period $t-1$. She spends this period living with her parent and studying. Parents provide the numeraire good that supports the child during this period, but the child selects her own units of schooling, borrowing the money to finance this. In the period t, the now adult individual forms her own household, rears a child (paying for the child's consumption but not the child's schooling), and chooses how much of the numeraire good, c_t^l, that she earns during this period the household will consume during the same period. In the period $t+1$, the individual is a pensioner, and chooses her consumption for that last period, c_{t+1}^2, from the numeraire good that she has saved. An individual's utility, u, is:

$$u = (1-\alpha)\ln(c_t^l) + \alpha \ln(c_{t+1}^2) \quad (1)$$

where $\alpha \in (0,1)$, and all individuals have the same α.

While working, period t in our example, our individual earns w_t per unit of human capital she possesses. Her human capital depends on her ability and the amount of schooling she chose as a child. An individual with ability a who purchased e_{t-1} units of education will have human capital:

$$h = a\left(\frac{(e_{t-1})^\gamma}{\gamma}\right) \quad (2)$$

where $\gamma \in (0,1)$ and all individuals have the same γ. The relationship between e and a allows education to raise human capital, but in a way that is subject to the law of diminishing returns. Ability is randomly assigned from a stationary distribution given in [2].

The model does not include inheritance and bequests, so every individual has to pay for her consumption and education out of what she earns during the period t during which she works. If r_t is the interest rate on savings made during period $t-1$ and held until period t, every individual is constrained by

$$c_t^1 + \left(\frac{c_{t+1}^2}{r_{t+1}}\right) + p_{t-1} r_t e_{t-1} \leq w_t a \left(\frac{(e_{t-1})^\gamma}{\gamma}\right) \quad (3)$$

AAMAS'07 May 14–18 2007, Honolulu, Hawai'i, USA.

where p_{t-1} is the cost of a unit of education in period $t-1$. In other words, the total amount that an individual consumes, including their education, suitably discounted over time, must be less than their earnings.

In every period, m individuals are born, and so there are $3m$ individuals in total in every period in time — m of these are being educated, m are working, and m are retired.

Considering the sector of the economy that produces the numeraire good, the model assumes constant returns to scale, so that the output per individual in a given generation is:

$$n = (K_t^n)^{\beta^n} (\lambda_t^n H_t^n)^{1-\beta^n} \tag{4}$$

where $\beta^n \in (0, 1)$, K_t^n is the physical capital the sector has per working individual at time t, and H_t^n is the average human capital per individual in the generation that is currently working. $\lambda^n > 1$ models the tendency of technological change to increase the effect of human capital in the sector of the economy that generates the numeraire good. The other sector of the economy produces education. Here we have:

$$e = (K_t^e)^{\beta^e} (\lambda_t^e H_t^e)^{1-\beta^e} \tag{5}$$

and the model allows for λ^e and β^e to be different from, or the same as, λ^n and β^n, their counterparts in the numeraire sector of the economy. For both the numeraire and education sectors, the assumption is that all physical capital is consumed in a single period, so the numeraire good produced in period t has to equal all consumption plus the physical capital used at time $t + 1$.

As described in [6], we converted this into an agent-based model, and examined the behavior of that model under a range of parameter settings.

3. RESULTS

Some of the results of two experiments, run over 30 generations, are given in Figure 1. These show: the average utility of individuals; the total earnings of all individuals in the economy, along with their savings for retirement, and the unpaid debt for their education; the education that is produced, per individual in the economy, along with the average demand for education; the number of numeraire goods that are produced, per individual in the economy, along with the average demand (measured by the amount of goods consumed); the wage rates, broken down across sectors; and the number of individuals who cannot generate enough wages during their lifetime to pay for their education and their consumption as a worker or as a retiree, broken down across sectors.

By all these measures, the economy in Figure 1(a)–(f) is healthy. The overall utility of individuals grows over time, as do wages (which reflect production). Education production flucuates over time, but fits well with demand — note that when demand exceeds supply, then individuals only receive a proportion of the education they want, and the surplus demand is spread across the population. Numeraire production grows over time. Wages in the numeraire sector grow steadily over time, as do those in the education sector, but these latter are also affected by spikes in demand. Finally, no individuals go bankrupt.

In contrast, the economy in Figure 1 (g)–(l) is dramatically unhealthy. Once we get past the start-up effects, which are responsible, for example, for the same modest jump in average utility in both experiments (note that Figure 1 (a) and Figure 1 (g) are on rather different scales), utility enters a long slump, total earnings are static while debt mounts, demand for education consistently outstrips supply by a factor of around 3, average wages have a downward trend, and after about six generations (20 timesteps) become insufficient to support the whole population — indeed after around 15 generations (40–50 timesteps) the entire population cannot meet its needs. The only apparent bright spot is that numeraire production exceeds demand, but this is because individuals do not have enough money to consume any of the goods — at the end, production is 40 times less than that in the healthy economy.

4. DISCUSSION

The results in the previous section are taken from only two examples of many we have run, but they are typical — [6] gives examples of successful and failing economies. The question, of course, is "why do the failing economies fail?", and it seems to us that all the economies that fail have a consistently unmet demand for education. Over time, if economies lack the ability to educate the workforce, productivity falls, there is no basis for capital investment, and so demand for education remains unmet.

Of course, this feedback effect is written into the equation-based model, so it is no great surprise that it surfaces in the agent-based model. Indeed, we would be worried if it did not. However, note that in all the economies, even the successful ones, the demand for education initially outstrips supply. It is those economies responding to this mismatch by pumping resources into education and thus growing education production, that manage to bootstrap themselves out of the initial surplus demand for education.

Acknowledgments

This work was partially supported by NSF #ITR-02-19347 and by PSC-CUNY #68525-00-37.

5. REFERENCES

[1] S. B. Flexner, editor. *The Random House Dictionary of the English Language*. Random House, 1987.

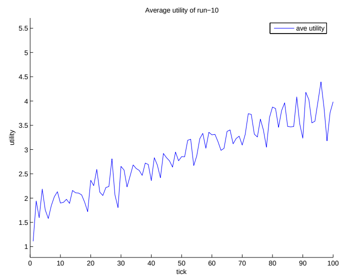
[2] J. Laitner. Earnings within education groups and overall productivity growth. *The Journal of Political Economy*, 108(4):807–832, Aug. 2000.

[3] No Child Left Behind. `http://www.whitehouse.gov/news/reports/no-child-left-behind.html`, July 2001.

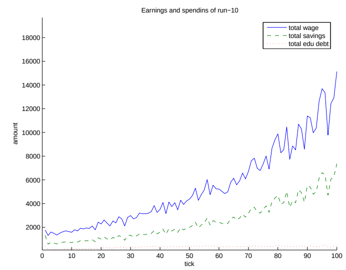
[4] E. Sklar, M. Davies, and M. S. T. Co. SimEd: Simulating Education as a MultiAgent System. In *Proceedings of the 3rd International Conference on Autonomous Agents and MultiAgent Systems*, pages 998–1005, 2004.

[5] Y. Tang, S. Parsons, and E. Sklar. Agent-based modeling of human education data. In *Proceedings of the 5th International Conference on Autonomous Agents and MultiAgent Systems*, 2006.

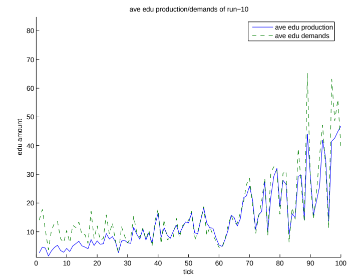
[6] Y. Tang, S. Parsons, and E. Sklar. An agent-based model that relates investment in education to economic prosperity. Technical report, Department of Computer and Information Science, Brooklyn College, 2007.



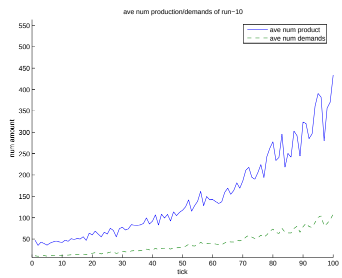
(a) Average utility of individuals



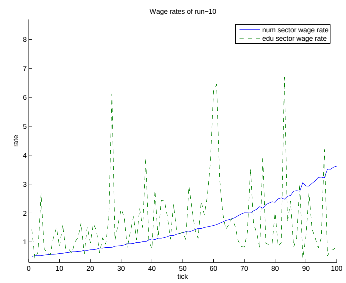
(b) Earnings and savings. The solid line shows total earnings. The dashed line shows total savings. The dotted line shows debt.



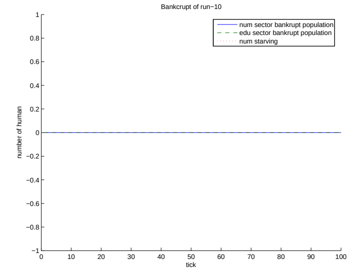
(c) Education production per individual. The solid line shows actual production. The dashed line shows demand



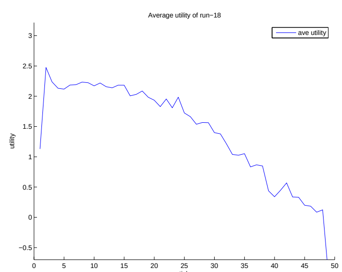
(d) Numeraire production per individual. The solid line shows actual production. The dashed line shows demand



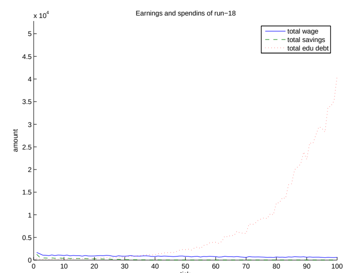
(e) Wage rates. The dashed line shows wages in the education sector. The solid line shows wages in the numeraire sector



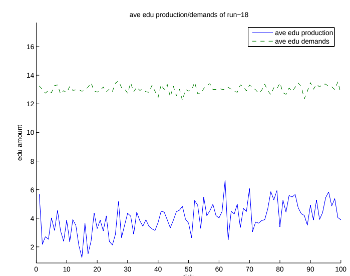
(f) Bankruptcy. The solid line shows the number of workers in the numeraire sector who are bankrupt.



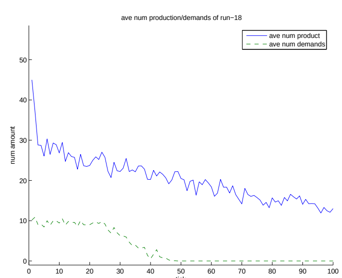
(g) Average utility of individuals



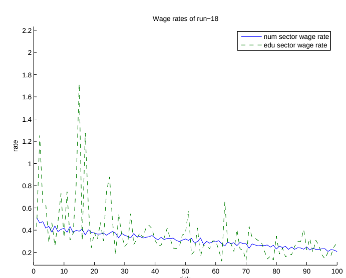
(h) Earnings and savings. The solid line shows total earnings. The dashed line shows total savings. The dotted line shows debt.



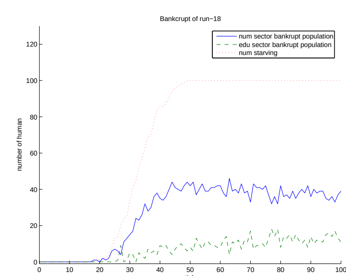
(i) Education production per individual. The solid line shows actual production. The dashed line shows demand



(j) Numeraire production per individual. The solid line shows actual production. The dashed line shows demand



(k) Wages. The dashed line shows wages in the education sector. The dotted line shows wages in the numeraire sector



(l) Bankruptcy. The solid line shows the number of workers in the numeraire sector who are bankrupt. The dashed line shows the corresponding number for the education sector. The dotted line shows the number of individuals who cannot afford to consume.

Figure 1: Examples of a healthy (a)–(f) and an unhealthy (g)–(l) economy.