An Experimental AK Model of Growth*

Ferruccio Ponzano
University of Eastern Piedmont

Roberto Ricciuti**
University of Verona and CESifo

ABSTRACT

In this paper we test the AK model of growth with laboratory experiments. In each period, agents produce and trade output in a market, and allocate it to consumption and investment. The economy should experience a constant and positive rate of growth. We analyze two treatments differing from technology. We find evidence of positive and constant growth, and the treatment with a better technology exhibits higher growth. Remarkably, production, consumption and the capital stock grow at the same rate in the treatment with lower technology. We find that this growth process is fuelled by large inequalities between subjects.

Keywords: endogenous growth; capital accumulation; heterogeneity; experiments.

JEL Codes: O41, C91, C92

* We wish to thank Matteo Migheli, Guido Ortona and Stefania Ottone for useful comments and Marie-Edith Bissey for writing the software. We also thank the laboratory ALEX at the University of Eastern Piedmont for administrative and computing support. We thank the audiences at the University of Florence and the Second University of Naples for useful comments. We acknowledge financial support provided by the Italian Ministry of Education.

** Corresponding author: Roberto Ricciuti, Department of Economics, University of Verona, Vicolo Campofiore 2, 37129 Verona – Italy. Email: roberto.ricciuti@univr.it

1. Introduction

The economic growth literature has witnessed three main strands of research. The first in the ‘50s and ‘60s was primarily concerned with the accumulation of capital with diminishing returns, along Solovian lines (Solow, 1956). The second, in the ‘80s and ‘90s, was concerned with the policies that governments may implement in order to achieve sustained growth. These models embedded various forms of linearity in the production function, either explicitly – as in the AK model (Rebelo, 1991) or as a result of more complex dynamics involving externalities (Romer, 1986, 1990; Aghion and Howitt, 1992). More recently, the emphasis has moved on the effects of institutions on economic growth.

Recent surveys by Duffy (2008) and Ricciuti (2008) have identified and analyzed the breadth and the outcomes experimental macroeconomics to the empirical evaluation of macroeconomic models. The idea of these experiments is not to replicate any real economy, but to compare the numerical predictions of the models with the observed data. Laboratory economies are of course much simpler than the real economy, and the implicit message of this work is: if a simplified version of the economy rejects a model of macroeconomic behavior, this model cannot be applied to the more complex real world. Therefore, non-rejection provides first evidence of the plausibility of a model.

A small literature has analyzed the exogenous growth model first finding support to the model and then addressing the issue of the emergence of a “poverty trap” that makes some kind of policy intervention necessary in order to escape from it (we survey this literature later in this work). In this paper we provide the first test of a model of endogenous growth, by analyzing the simplest example in this literature, the AK model (Rebelo, 1991). We find evidence consistent with its main implications. Nonetheless, We highlight some heterogeneities between subjects that go beyond the traditional ‘representative agent’ upon which these and other macroeconomics models are built, pointing towards a *behavioral macroeconomics* (Akerlof, 2002, 2007).

Section 2 gives an outline of the AK growth model and surveys the small experimental literature on exogenous growth. Section 3 presents the experimental design, while the results are discussed in Section 4. Section 5 concludes.

2. The model and the experimental literature

We assume an economy with an infinitely-lived representative household. The preferences of the representative household at time $t = 0$ are given by:

$$U = \int_0^\infty e^{-\rho t}\left[\frac{c(t)^{1-\theta}-1}{1-\theta}\right]dt \qquad (1)$$

where ρ is the rate of time preference and $1/\theta$ is the elasticity of intertemporal substitution.[1]

The final good sector has the following aggregate production function:

$$Y(t) = AK(t) \qquad (2)$$

with $A > 0$. Dividing (2) by $L(t)$, we obtain the production function in per-capita terms:

$$y(t) = Ak(t) \qquad (3)$$

Each agent maximize equation (1) under the capital accumulation constraint:

$$\dot{k} = f(k) - \delta k - c \qquad (4)$$

where δ is the rate of capital depreciation. The consumption level that maximizes the intertemporal utility (1) under the constraint (4) under infinite horizon is given by the solution of the Hamiltonian:

$$H = e^{-\rho t}u(c(t)) + \nu(Ak - c) \qquad (5)$$

The first-order condition, the Euler equation, and the transversality condition are respectively:

[1] To obtain stable growth, the elasticity of intertemporal substitution must be constant: $-u''(c)c/u'(c) = \theta$, therefore, the utility function is isoelastic (CES).

$$e^{-\rho t}c^{-\theta} = v \quad (6)$$

$$\dot{v} = -vA \quad (7)$$

$$\lim_{t\to\infty} e^{-\rho t}vk = 0 \quad (8)$$

Under perfect competition, these conditions imply that the long-run rate of growth ($g = \dot{y}/y$) is equal to the rate of consumption growth ($\dot{c}/c$), and to the capital stock rate of growth ($\dot{k}/k$), and is given by:

$$g = \frac{A - \rho - \delta}{\theta} \quad (9)$$

There are a number of important features in this model. First, growth is unbounded, there is no steady-state. Second, the rate of growth of consumption is independent of the level of the capital stock per person. Third, there is no transitional dynamics: starting from any initial level of consumption per capital, it will immediately grow at a constant rate. Fourth, also the rates of growth of capital and output show no transitional dynamics. Fifth, the competitive equilibrium is Pareto optimal.

Lei and Noussair (2002) analyze the exogenous optimal growth model based on Cass (1965) and Koopmans (1965), in which the level of investment is endogenised in an economy where a representative agent makes optimal consumption and investment decisions over time for a given technology.[2] If production and utility functions are concave, there is a unique optimal steady-state level of consumption and capital stock. Two main different treatments are implemented. In the *social planner* treatment, each agent represents a single economy, which has to choose between consumption today and investment for future consumption. There is no trading between these individual economies. This treatment is closer to the literal formulation of the model. Two cases are considered: the low and high endowment, which is a

[2] An earlier experiment based on the same intertemporal decision problem can be found in Noussair and Matheny (2000), where an agent makes choices in isolation in several environments with different endowments, production technologies, and termination rules. Evidence of both over- and under-investment is found. The small experimental literature on Ricardian Equivalence also addresses problems of intertemporal optimization (Duffy, 2008; Ricciuti, 2008). See also Hey and Dardanoni (1988), Carbone and Hey (2004), and Ballinger *et al*. (2003) on consumption optimization over time.

situation where the endowment is lower or higher than the equilibrium level of capital. The model predicts that in the first case convergence occurs from below, whilst in the second it is achieved from above. In the *market treatment* each economy includes five heterogeneous agents that are allowed to trade their capital good through a double auction. This treatment has been added because of the properties of this market institution to achieve efficiency.

Each agent has his own production function and an individual utility function, which indicates the number of experimental currency units the agent can get when he consumes the good. The overall amount of experimental money is converted into dollars at a given exchange rate at the end of the experiment. The individual and aggregate production and the utility functions are concave. In each period a market for capital takes place: agents can make ask or bids for multiple units of capital at a named per-unit price. At any time buyers or sellers may accept offers made by another agent, or a part of an offer. To achieve aggregate efficiency capital must go from low- to high-productivity agents. To allow trading, each agent has an endowment of capital and another endowment of money that decreases as long as units of capital are bought, and increases when they are sold. The infinite horizon of the model is obtained imposing a 10% probability at the end of each period to stop playing, through a computerized random draw.

In both treatments consumption, capital stock, the price of capital and the realized levels of consumption converge to the optimal steady-state levels predicted by the theory, after a few initial periods. Convergence to the equilibrium is faster and stronger under the market treatment than in the social planner treatment, showing that the price mechanism helps agents at making intertemporal choices. There are no significant differences between the low- and high- endowment treatments both in the market and in the social planner experiments.

Lei and Noussair (2007) build an economy with two Pareto-rankable locally stable equilibria and find that without specific reasons the economy may end up in the lower equilibrium, which they interpret as a poverty trap. This occurs more likely under the low endowment treatment, and affects both the market and the central planner environments. Capra *et al*. (2009) show that the ability to make public announcements or to vote on competing and binding policies, increases output, welfare and capital stock, making it possible to escape the poverty trap.

3. Experimental design

The experiment is made up by a number of sequences, which in turn consist in a series of periods (see Figure 1 for a representation and Appendix 1 for the instructions). Each period includes three phases: a production phase in which the endowment of good X is multiplied by A equal to 2 or 4; a market phase in which good X can be traded in a double auction; and a consumption phase, in which units of X can be consumed. At the beginning of the first period each agent has an endowment of good X (x_t) equal to 10 that she can increase or decrease according to her buying/selling decision in the market phase (Δx_t).[3] Consumption (c_t) is obtained through selling units of X to the experimentalist, at the value given in the consumption schedule (Appendix 2).[4] In subsequent periods the amount of good X she owns depends on her market and consumption decisions taken in the previous period plus production, which is simply given by multiplying the units kept at the end of period by either 2 or 4, according to the treatment (the production phase described above).

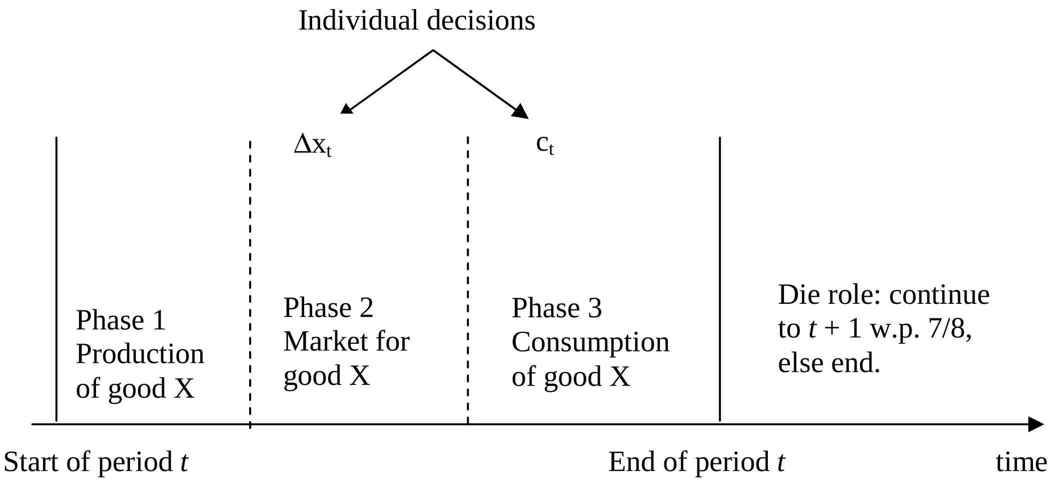

Figure 1 – Timing of the experiment

The theory assumes an infinite horizon that in the lab is obtained through drawing an 8-side dice:[5] the sequence will be over if number 8 is drawn, otherwise there is another

[3] They also have an additional endowment of ten experimental dollars.

[4] In order to simply the environment we imposed a single consumption schedule (utility function) for all subjects, deciding not to explore heterogeneity of preferences.

[5] We choose to let subjects to draw a dice in order to improve the credibility of the random termination rule: if the numbers were drawn by a computer, experimental subjects might believe that the selection is not actually

period. Therefore, the constant probability of termination is 12.5%. The resulting rate of time preference is 0.875. If number 8 is drawn before the experiment has reached one hour, another sequence will start. In any case, the experiment cannot last more than two hours. Figure 1 describes the timing of the experiment. At the end of the experimental dollars are exchanged at the rate 25 experimental dollars = 1 Euro. The remaining units of X are worthless.

In each period subjects face an intertemporal optimization problem: consuming more on period t gives higher utility, but this entails lower capital accumulation, therefore reducing consumption in the uncertain future.

We conducted 5 sessions for each treatment, in the first one 46 subject participated, while in the second we had 44 subjects. Subjects were drawn from the undergraduate population of the School of Economics at the University of Turin. Students sit on separated computer desks and read the instructions on the computer screen. They were given a sheet with the consumption schedule. At the end of the instructions they replied to a written questionnaire. The experimentalist then gave the correct answers. Afterwards, a three-period trial started in order to make subjects acquainted with the decision problem at hand. The experimental dollars accumulated during the trial were not added to the amount earned in the real experiment. The software was written in Z-Tree (Fischbacher, 2007). The average earning was 19.29 Euros. Table 1 describes each session of the two treatments.

Table 1 – Treatment and session details

	Session	Subjects	Periods	Sequences
Treatment 1 (A = 2)	1	7	16	2
	2	10	22	2
	3	10	21	2
	4	10	11	1
	5	9	11	3
Treatment 2 (A= 4)	1	10	18	2
	2	7	14	3
	3	9	13	3
	4	9	17	2
	5	9	17	1

random but somehow driven by the experimentalist, who may be interested in having a long series of observations, or saving money, or any other possible goal.

4. Results

In this section we analyze the results of our experiments first by deriving hypotheses from the model, and then looking at the behavior of the actual subjects.

4.1 Testing the theory

Hypothesis 1 – In both treatments we find evidence of a positive growth rate of production.

In the experiment, equation (9) becomes g = A – ρ - 1, since both δ and θ are equal to 1.[6] In treatment 1 the growth rate of production is equal to 0.096, whereas in treatment 2 it is equal to 0.852. These compares with the theoretical growth rates for the two treatments equal to 0.875 and 2.875, respectively. We find statistical evidence of positive growth for both experiments: by using a one-sample t-test, in Treatment 1 the null hypothesis $g = 0$ is rejected with p = 0.0123, in Treatment 2 we find that p = 0.000. The difference between the theoretical and the actual value is a well known phenomenon in experimental economics.

Hypothesis 2 – The growth rate is higher in the treatment with a better technology (A = 4) *than in the treatment a lower technology* (A= 2).

The two-sample Wilcoxon rank-sum on the equality of the mean growth rates between the two treatments rejects the null hypothesis with z = -5.779 and p = 0.000. Therefore, the growth rate in Treatment 2 is greater than in Treatment 1, as predicted by the comparative statics of the AK model.

Hypothesis 3 – The growth rate is constant over time.

In figures 2 and 3 we plot the growth rate of production for each period in Treatment 1 and 2, respectively. In both cases we cannot observe any significant upward or downward trend, which we interpret as evidence of stability over time of the growth rate. Running a regression on growth rates per period with a constant and a time trend gives for the latter a coefficient equal to -0.014 with standard error equal to 0.008 and p-value = 0.122. The same

[6] δ = 1 means that subjects can consume all good X.

regression of the previous footnote gives a coefficient equal to -0.017, a standard error equal to 0.011 (p-value = 0.166). However, we should note that in Treatment 1 there is a number of periods in which growth is negative, although in aggregate the rate is positive. This never happens in Treatment 2.

In Table 2 we report paired t-tests on the equality of means in each treatment, comparing the growth rate of a period with the growth rate of the following period. For Treatment 1 we find three out of ten cases in which there is a significant difference between the means, whereas in Treatment 2 this happens once in twelve tests. These results go into the same direction of Tables 1 and 2. We cannot expect that experimental subjects would jump on the constant growth rate and stay there until the completion of the experiment. We can expect, and indeed observe, subjects to have different growth rates from period to period, but in the large majority of the tests this difference is not significant. This is a good approximation of a constant rate of growth over time.

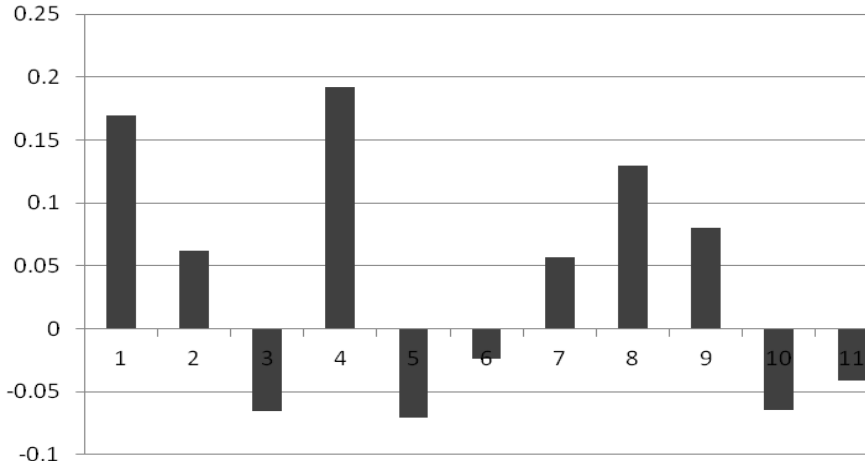

Figure 2 – Mean growth rates in Treatment 1 per period

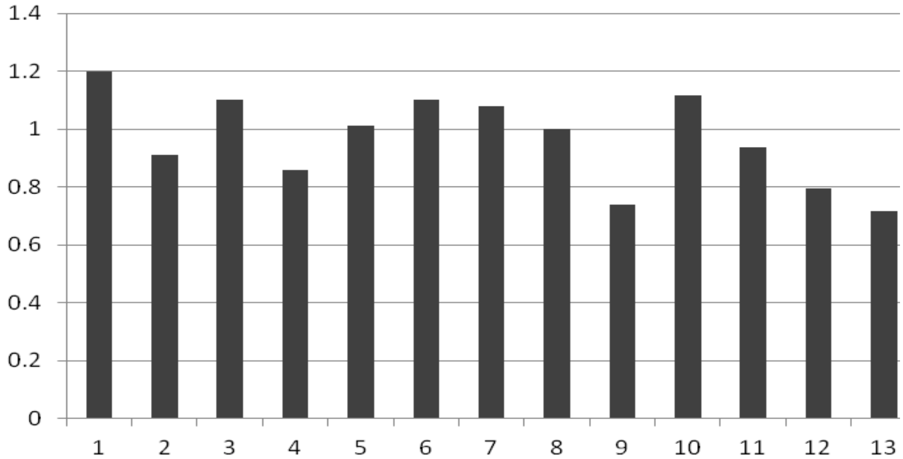

Figure 3 - Mean growth rates in Treatment 2 per period

Table 2 – Paired equality of means tests between periods for production growth

Periods	t-test stat.	p-value	Periods	t-test stat.	p-value
	Treatment 1(A = 2)			Treatment 2 (A = 4)	
1 – 2	2.8693	0.0062	1 – 2	1.3729	0.1769
2 – 3	0.9196	0.3627	2 – 3	1.1259	0.2664
3 – 4	-1.7614	0.0850	3 – 4	1.2330	0.2243
4 – 5	1.3547	0.1823	4 – 5	0.1711	0.8650
5 – 6	-0.7473	0.4588	5 – 6	-0.1525	0.8795
6 – 7	-0.1404	0.8890	6 – 7	1.3280	0.1912
7 – 8	-0.1319	0.1956	7 – 8	1.2574	0.2154
8 – 9	1.8781	0.0669	8 – 9	0.4376	0.6639
9 – 10	1.3239	0.1922	9 -10	-1.4469	0.1552
10 – 11	-0.3509	0.7273	10 – 11	3.4933	0.0011
			11 – 12	-1.3860	0.1729
			12 – 13	0.4225	0.6748

Hypothesis 4 – In each treatment production, consumption and the capital stock grow at the same rate

In Treatment 1 we find that g = 0.101, k = 0.074 and c = 0.071. In Table 3 We can never reject the null that these means are equal in pairwise t-tests. In Treatment 2 we find that g = 0.892, k = 0.482 and c = 0.703. In this case we cannot reject the null of equality of the means between production growth and consumption growth, and between production growth and capital stock growth, but we can reject it when we test capital stock growth against consumption growth.

Table 3 – p-values of pairwise equality of means tests between growth rates

Null Hypothesis	*t-test stat.*	*p-value*	*t-test stat.*	*p-value*
	Treatment 1		Treatment 2	
g = c	-0.2745	0.7850	-0.2170	0.8292
g = k	0.3740	0.7102	-2.5874	0.0131
k = c	-0.0294	0.9727	3.2162	0.0025

Taken together, the results of the four hypothesis bring considerable support to the AK model, since we observe positive growth, fulfillment of the implied comparative statics of the model, stability of the rate of growth over time, and equality between the growth rates of production, consumption and capital stock (in this case only in Treatment 1).

The main problem concerns the rates of growth, which are much smaller than the theoretical predictions. Given that capital accumulation is the source of growth in this stylized economy, there is a problem of insufficient capital stock growth. In Treatment 1 $k = 0.074$ and $g = 0.096$, whereas g should be equal to 0.875. In Treatment 2 $k = 0.482$ and $g = 0.892$, compared with a theoretical value of 2.875, which is worse than the former. Uncertainty about the continuation of the experiment (and therefore of the value of the units of X that are not consumed) is a suspect for this behavior. Moreover, in Treatment 2, for a given level of capital stock, subjects have higher yield, therefore they can save comparatively less in order to obtain a *satisfying* level of consumption. Because the exchange rate between experimental dollars and euros is the same in the two Treatments, we see that subjects in Treatment 2 earn more than subjects in Treatment 1 (€24.55 Vs. €14.27).

This behavior is not rational in a neoclassical way. If the aggregate properties of the AK model cannot be rejected, we can conclude that the model has some internal and external validity. However, we think that failures of the model call for a more detailed analysis of the behavior of single subjects in order to understand how and why they departed from full rationality. This is what we do in the following sub-section.

4.2 Individual behavior

We observe very distinct features in the saving behavior of the subjects: a minority of them saves a lot over time and ends up cumulating a sizable share of capital, whereas the large majority does not save. From Mankiw (2000) we call these subjects savers and spenders, respectively. Savers are the drivers to economic growth: since production is proportional to capital, we concentrate our analysis on the former. Savers on average experience a capital growth of about 50% over time. In a few periods they account for the majority of capital in the economy, and this tends to increase over time, reaching extremely unequal distributions of wealth. In Tables 4 and 5 we describe the behavior of our economies. We report the capital stock of each individual in each economy, in which we had sequences made of at least five periods (before drawing number 8) in order to have some history of each economy, and then averaging across each economy. The Gini index measures inequality in capital distribution:

we compute it for the first, the fifth and the last period of each economy to have an idea of its behavior over time. All subjects start with the same amount of capital at time 0 (10 units of good X), therefore the index is equal to 0.

We start analyzing Treatment 1 (Table 4). All but economy two show capital accumulation. In the first economy two individuals account for 77.25% and 22.48% of capital in the last period, therefore we have 2 savers and 5 spenders. The second economy, there is a decline in the capital stock, therefore all ten subjects are spenders. In fact, the total capital accumulation in the last period (56) is lower than the initial level (100). In the third economy one individual accumulates 99.99% of capital in the last period: we have one saver and 9 spenders. The situation is quite similar in the fourth economy, where one subjects gets 97.72% of the capital stock (one saver and nine spenders). A minor difference is observed in the fifth economy, in which one subjects ends up with 90.47% of capital (one saver and eight spenders). Overall, we find five savers and 41 spenders. The Gini index remarkably grows. Starting from 0 in period 0, it grows already after the first period, reaching a sizable level at period five and becoming quite close to one in the last period. The only exception is economy two, in which we observed no capital growth.

Table 4 - Capital cumulated in the last period, treatment 1.

Economy	1	2	3	4	5
Subject					
1	10	14	21	10	7
2	5184	30	3	6	1
3	4	3	10	16	13
4	10	2	4	5	0
5	1608	7	4	265	10
6	10	0	4	13	10
7	6	3	7	2	311
8		10	103884	4349	21
9		3	2	8	2
10		1	6	10	
Gini 1	0.1840	0.3628	0.4114	0.1675	0.3526
Gini 5	0.5653	0.6567	0.5822	0.6566	0.7870
Gini (end)	0.9219	0.7619	0.9999	0.9905	0.9345

As far as treatment 2 is concerned (Table 5), in all economies the capital stock grows over time. In economy one this is due to the behavior of three subjects that in the last period own a share of the capital stock equal to 66.34%, 17.12%, and 14.96%, respectively, leaving the other players with the residual (1.58%). Therefore, we have three savers and 7 spenders. In the second economy, however, growth is due to a single agent who ends up with a share of capital equal to 95.79%. Therefore, we find one saver and six spenders. In the third economy capital accumulation is driven by four subject, which end up with 52.09%, 20.62%, 12.12%, and 11.29%. Here we have four savers and 5 spenders. This is the economy showing the largest number of savers. This is possibly due to the circumstance that sequences last at most five periods, therefore preventing capital concentration over time. In the fourth economy the situation resembles the second economy, with even further concentration: an individual accounts for 99.98% of capital stock at the end of the period. In this economy there are also eight spenders. In the last economy capital accumulation is determined by two subjects that end up with 79.46%, and 19.32% of the stock. Therefore, we have two savers and seven spenders. Summing up, in this treatment out of forty-four subjects we have eleven savers and thirty-three spenders.

Table 5 - Capital cumulated in the last period, treatment 2.

Economy	1	2	3	4	5
Subject					
1	2887	100	5	6	10
2	100	367	189	5	8
3	11	6	1000	1	500
4	500000	0	16	3000000	900000
5	2216624	13002	10	76	313
6	49371	20	1701	96	56223
7	2	79	4297	20	2
8	200		100	40	30
9	32		931	500	3701696
10	572197				
Gini 1	0.1161	0.2181	0.2193	0.2919	0.3437
Gini 5	0.5931	0.9574	0.7588	0.9025	0.7395
Gini (end)	0.8846	0.9775		0.9998	0.9455

We can observe a larger number of savers in Treatment 2 than in Treatment 1 (11% vs. 25%; chi2 = 3.07, p = 0.80). This is probably due to the higher return of capital when A = 4, which gives more incentives to save and invest. The Gini index strongly increases, but since we have a higher number of savers, it does not reach the same levels we observed in Treatment 1.

In principle we should not expect any change in behavior when a sequence ends because number 8 is drawn and when a new sequence starts. After all, the problem at hand is the same. Actual subjects, instead, may see the value of their good X nullified and therefore may, for example, decide to save less because they have experienced a loss. We run paired t-test to check whether production changed before and after number 8 is drawn. In Treatment 1 we had 36 subjects that found themselves in this situation (in the sixth session there were 3 sequences but we do not consider the second restart because of non independence in the observations) and the null hypothesis of equality between growth rates cannot be rejected (paired t-test, $p = 0.4411$). In Treatment 2 35 subjects restarted once the sequence (in this case we excluded the second restart in sessions 2 and 3), the null cannot be rejected with $p = 0.6292$ (paired t-test). These results are confirmed if we consider the average between the last two period before the 8 and the first two after the 8 (paired t-test, $p = 0.7886$ in Treatment 1 and $p = 0.8984$ in Treatment 2).

5. Conclusions

In this paper we have tested the AK model of growth with laboratory experiments. We find evidence of positive and constant growth, and the treatment with a better technology exhibits higher growth. Finally, production, consumption and the capital stock grow at the same rate in the treatment with lower technology. These results show that the basic model of endogenous growth is able to explain the data very well. Besides these results, we find that the growth process is fuelled by large inequalities between subjects, since we identify two groups of individuals, a small number of savers (who save and invest, accumulating capital) and a much larger population of spenders, who do not save and invest, and play basically no role in capital accumulation and growth. We believe that this behavioral finding in interesting and captures an aspect that characterizes, at least temporarily, actual processes of growth.

We see this paper as a component of a larger research project on experimental endogenous growth. By combining aspects of experiments on patent race with the basic features of the economy of the present paper, we can provide an experimental evaluation of the Shumpeterian model of growth. Designing a way to address externalities in an experimental framework will enable us to test in the laboratory models of endogenous technical and increasing returns with more than one sector.

References

Aghion, P. and Howitt, P. (1992). A Model of Growth through Creative Destruction, *Econometrica*, 60, 323-351.

Akerlof, G.A. (2007). The Missing Motivation in Macroeconomics, *American Economic Review*, 97, 5-36.

Akerlof, G.A. (2002). Behavioral Macroeconomics and Macroeconomic Behavior, *American Economic Review*, 92, 411-433.

Ballinger, T.P., Palumbo, M.G. and Wilcox, N.T. (2003). Precautionary Savings and Social Learning Across Generations: An Experiment, *Economic Journal*, 113, 920-947.

Capra, M., Tanaka, T., Camerer, C.F., Feiler, L., Sovero, V. and Noussair, C. (2009). The Impact of Simple Institutions in Experimental Economies with Poverty Traps, *Economic Journal*, 119, 977-1009.

Carbone, E. and Hey, J.D. (2004). The Effect of Unemployment on Consumption: An Experimental Analysis, *Economic Journal*, 114, 660-683.

Cass, D. (1965). Optimum Growth in an Aggregative Model of Capital Accumulation. *Review of Economic Studies*, 32, 233-240.

Duffy, J. (2008). Macroeconomics: A Survey of Laboratory Research, mimeo.

Fischbacher, U. (2007). z-Tree: Zurich Toolbox for Ready-made Economic Experiments, *Experimental Economics*, 10, 171-178

Hey, J.D. and Dardanoni, V. (1988). Optimal Consumption under Uncertainty: An Experimental Investigation, *Economic Journal*, 98, 105-116.

Koopmans, T.C. (1965). On the Concept of Optimal Economic Growth. In: *The Econometric Approach to Development Planning*, Amsterdam: North Holland.

Lei, V. and Noussair, C. (2002). An Experimental Test of an Optimal Growth Model. *American Economic Review*, 92, 549-570.

Lei, V. and Noussair, C. (2007). Equilibrium Selection in an Experimental Macroeconomy, *Southern Economic Journal*, 74, 448-482.

Noussair, C.N. and Matheny, K. (2000). An Experimental Study of Decisions in Dynamic Optimization Problems, *Economic Theory*, 15, 389–419.

Rebelo, S. (1991). Long-Run Policy Analysis and Long-Run Growth, *Journal of Political Economy*, 99, 500-521.

Ricciuti, R. (2008). Bringing Macroeconomics into the Lab, *Journal of Macroeconomics*, 30, 216-237.

Romer, P.M. (1986). Increasing Returns and Long-Run Growth, *Journal of Political Economy*, 94, 1002-1037.

Romer, P.M. (1990). Endogenous Technological Change, *Journal of Political Economy*, 98, S71-S102.

Solow, R.M. (1956). A Contribution to the Theory of Economic Growth, *Quarterly Journal of Economics*, 70, 65-94.

Appendix 1 - Instructions (translation from Italian)

Welcome, we thank you for participating to our experiment. Your choices will be anonymous, and those who will analyze the data will be unable to identify who made each choice. We ask you to carefully follow the instructions on the screen, which are also available on paper next to you. Making the appropriate choices you can earn a considerable amount of money that will be given in cash at the end of the experiment in private. During the experiment you cannot communicate with each other, if you have a question please raise your hand and the experimenter will answer to you privately.

The experiment is made up by one or more sequences, which in turn consist in a series of periods. At the end of each period one of you will draw an 8-sided dice. If number 8 is drawn the sequence will stop, otherwise if a number between 1 and 7 is drawn it will continue. This means that there is a 12.5% (1/8) probability that the experiment terminates at any time. If the experiment lasted less than one hour we will start a new sequence. In any case, the experiment will not last more than two hours. The experimental dollars obtained in each sequence will be summed up to obtain the final payoff.

At the beginning of the experiment each of you will have an endowment of 10 units of a good denominated X and of 10 experimental dollars. Ownership of these units will allow to produce additional quantity of the same good. Experimental dollars will allow you to buy additional units of good X. In each period you have the opportunity to exchange on the market units of X and to consume them. Consumption consists in transferring some units of good X to the experimentalist. The number of units you have at the end of each period will determine your production level in the following period, in which you can again exchange and consume good X. The number of units of X will be transferred from period to period and will depend on your production, on the quantity you have exchanged in the market, and on your consumption. At the end of the experiment your experimental dollars will be exchanged into Euros at the following exchange rate: 25 experimental dollars = 1 Euro. The remaining units of X will not give you any payments.

Each period comprises three phases:
(1) a production phase of good X,
(2) a market phase in which X is traded,
(3) a consumption phase of good X.

The following instructions will explain how to produce, exchange, and consume.

Phase 1: Production of good X

At the beginning of each period the production level is automatically determined. The production level for a period is function of the number of units detained at the end of the previous period and is given by the following relationship:

*Production at period t + 1 = 2 * units of X at the end of period t*

In the first period your endowments of 10 units will allow you to produce 20. Production takes place automatically: the computer will multiply the units of X for each of you.

The quantity of X available at the end of each period depends on the number of units produced in phase 1, the number of units exchanged in phase 2 and the number of units consumed in phase 3, therefore:

Quantity of X available at the end of period t = quantity produced in phase 1 +/- units exchanged in the market in phase 2 *– units consumed in phase* 3*.*

Phase 2: exchange of good X on the market

In this phase you can exchange units of X. In this market you have three minutes to make asks for sells and bids to buy units of X. You have to name the price at which you are willing to sell/buy one unit of X. To accept an offer you have to click the relevant button. Given your endowment of X and of experimental dollars to allow trading, you can buy/sell any amount of X. Selling will increase your endowment of experimental dollars of a sum equal to the price; buying will decrease your experimental dollars by an amount equal to the price paid.

Your earnings at this stage are:

Gain/loss in phase 2 *= experimental dollars at the end of the phase – experimental dollars at the beginning of the phase.*

Experimental dollars are transferred from a period to the other during the experiment.

Phase 3: Consumption of good X

In this stage you can choose how many units of X to consume. Consumption is obtained by transferring units of X to the experimentalist. The amount of experimental dollars that you get is a function of the number of consumed units, as indicated in the consumption schedule.

Each additional unit causes an increase in the amount of experimental dollars received from the experimentalist lower than the previous unit. The quantity received in exchange of X will be carried over the next period. Each consumption phase lasts 1 minute.

Gain in phase 3 = experimental dollars obtained from transferring units of X to the experimentalist.

The earnings obtained at the end of each period is equal to the sum of gains in phases 2 and 3. At the end of the period the computer will show your earnings in that period and your cumulated earnings.

If you sell or consume too many units of X during the early periods of the experiment, you might end up with too few in the following periods, but you can buy them in the market.

At the end of each phase 3 one of you will draw a dice, if number 8 is drawn the sequence will end. If more than one hour has elapsed since the beginning of the experiment, it will be ended.

We now distribute a control questionnaire. After checking your answers we will start with a three-period trial. The earnings in this trial will not count for your final earnings.

Are there any questions?

Questionnaire

Question 1. Suppose that the sequence reached period number 4. Which is the probability that the experiment would end?___________ Your answer would be different if we reached period number 6? YES/NO
Question 2. Suppose that number 8 would be drawn and the experiment ends. You have *n* units of good X. How much are worth these n goods?________ Suppose that a number between 1 and 7 is drawn, how many units of good X you will have in the following period? _________ How many units you will have after the production phase? __________

Question 3. Suppose that you have 5 units of good X and 10 experimental dollars. How many units you can sell during the trading phase?_________ Suppose that you sell one unit for 4 experimental dollars. How many experimental dollars you will have afterwards?_________

Question 4. Suppose that you have 5 units of good X and 10 experimental dollars, and that you buy two additional units of good X for 6 and 4 experimental dollars, respectively. How many experimental dollars you have?________

Question 5. Suppose that you sell 3 units of good X to the experimentalist. How many experimental dollars you will receive?_________

Appendix 2 - Consumption schedule

Units of X transferred	Experimental dollars	Units of X transferred	Experimental dollars
1	10.00	51	0.20
2	5.00	52	0.19
3	3.33	53	0.19
4	2.50	54	0.19
5	2.00	55	0.18
6	1.67	56	0.18
7	1.43	57	0.18
8	1.25	58	0.17
9	1.11	59	0.17
10	1.00	60	0.17
11	0.91	61	0.16
12	0.83	62	0.16
13	0.77	63	0.16
14	0.71	64	0.16
15	0.67	65	0.15
16	0.63	66	0.15
17	0.59	67	0.15
18	0.56	68	0.15
19	0.53	69	0.14
20	0.50	70	0.14
21	0.48	71	0.14
22	0.45	72	0.14
23	0.43	73	0.14
24	0.42	74	0.14
25	0.40	75	0.13
26	0.38	76	0.13
27	0.37	77	0.13
28	0.36	78	0.13
29	0.34	79	0.13
30	0.33	80	0.13
31	0.32	81	0.12
32	0.31	82	0.12
33	0.30	83	0.12
34	0.29	84	0.12
35	0.29	85	0.12
36	0.28	86	0.12
37	0.27	87	0.11
38	0.26	88	0.11
39	0.26	89	0.11
40	0.25	90	0.11
41	0.24	91	0.11
42	0.24	92	0.11
43	0.23	93	0.11
44	0.23	94	0.11
45	0.22	95	0.11
46	0.22	96	0.10
47	0.21	97	0.10
48	0.21	98	0.10
49	0.20	99	0.10
50	0.20	100	0.10