Essays on Growth and Intergenerational Links

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Contents

Introduction

0.1 Motivations

If we think about the history of human society as we know it, we can state that it began around 10000 years ago, when the first populations settled in the fertile lands of the middle east. Under a macroeconomic and demographic point of view, the more impressive and sizeable changes took place only in the last 2% of this period: until the beginning of 18th century, per capita income were constant and around 1400$, then, growing at around 1.3-1.4% per year, the per capita income reached today, in industrialized countries, 20000$ (Maddison, 2003). At the same time, population multiplied by more than six: in 1800 people were less than a billion. Again during the last 200 years, life expectancy, that for millennia swinged between 20 and 35 years, soared up to almost 80 years in most industrialized countries. Average formal education, despite the invention of writing took place 5000 years ago, were still negligible 200 years ago, while nowadays people spend up to 20 years in acquiring education, from parental nurture to tertiary education (Lee 2001). One hundred years ago a worker could enjoy less than three years of retirement (usually associated to bad health conditions), now people retire for almost one quarter of their life and their pension benefits are often paid by people of younger generations.

The aim of this dissertation is to jointly study, by means of microfounded growth models, the abovementioned macroeconomic and demographic aspects and some intergenerational, microeconomic issues that are described below. The kind of microeconomic issues that we analyze share the common feature of describing links *among* generations, in a social and interpersonal fashion. Our idea, based on the evidence shown above, is that, for millennia, the intergenerational behavior of different generations kept replicating itself, since the macroeconomic and demographic environment were stable and immobile. Conversely, from the beginning of the Industrial Revolution onward, people face very significant changes in the macroeconomic and demographic variables within their own life span and, in some ways, their behaviors contributes to the changes in the "macro" environment itself. The links among generations are therefore mutable because they are embedded in an economic environment that is all-changing in its fundamental features.

This introduction is organized as follows: section 2 broadly describes the two microeconomic effects on which we focus our analysis, section 3 resumes the first paper of the thesis, that addresses the presence of habit in education among generations. Section 4 reviews the literatures on aging, technology adoption and growth. Section 5 presents the second paper, where a taxonomy based on demographic and economic features of economies is formulated. Section 6 resumes the third paper, where a politico-economic model of aging, technology adoption and growth is implemented.

0.2 Intergenerational links: "micro" aspects in a mutable "macro" world

In this work we focus our attention on two intergenerational aspects that in the last two centuries experienced big transformations in their nature, due to the impressive changes in the macroeconomic and demographic environment stressed above: the inertia we find in the transmission of education from one generation to the next one and the effects (and causes) of the increase in longevity on individual and collective choices in terms of education and innovation technology.

Education at individual level shows a low degree of vertical mobility all over the world: the inertia in the intrafamiliar transmission of education from one generation to the next one seems to be, for a sizeable share, unexplainable by standard economic theory (Checchi, Ichino and Rustichini, 1999). The evidence collides with the fact that in many counties different form of roughly egalitarian schools were introduced decades ago. The first chapter of the thesis is devoted to the issues of inertia in educational choices and macroeconomic effects.

The lengthening of life expectancy that humanity is experiencing in the last two centuries comes together with an impressive shift of production systems toward knowledge and human capital intensive productions. In terms of intergenerational links, two are the possible implications of these events: first, specific institutions are needed in order to maintain, hand down, process and improve knowledge, such as schools, libraries, databases, etc. (Mokyr, 2002). Second, having knowledge (and, in some ways, human capital) characteristics of both an investment and a public good, the need for coordination mechanisms in producing it is stronger than in the case of other types of factors of production (i.e. physical capital). The aim of the second and third chapters is to introduce this kind of analysis in a theoretical framework where the lengthening of life expectancy is a cause, and in part a consequence, of people's behavior, looking at these people as at "generations of societies".

0.3 Chapter 1: "Intergenerational Links and Growth: a Preferences Approach"

The paper in the first chapter initially reviews the theoretical literatures on habit formation (de la Croix, 1996 and 2001 and Banerjee, 2004 among others), multidimensional bequeathing (Viaene and Zilcha, 2001, Zilcha, 2003, Mookherjee and Ray, 2005) and "reference group" theory (Piketty, 2000 and Ray, 2003). Empirical evidence about intra-family inertia in educational choices is reported (Brunello and Checchi, 2003 and Checchi, Ichino and Rustichini, 1999). Ermisch and Francesconi (2001) stress that an important step that needs to be done is to disentangle the production process of human capital from the preferences of individuals upon education.

In order to address this issue, we build an overlapping generations model able to capture the inertia in individuals' educational choices, that are driven by individual and aggregate variables. Agents are characterized by a utility function where, together with the usual consumption, there are two altruistic ("warm glow" specification) components: the financial bequest that their children will get once adult and the investment in their children's education. The innovation we introduce in the design of preferences is the presence of the habit term in education expenditure, rather than in consumption. Moreover, the habit term is constructed in order to take into account both familiar and social past history: the idea is that a parent more educated than the average of her generation will invest a higher fraction of her income in her children's education, and vice versa. This mechanism, joint with the usual general equilibrium adjustment of factors' prices (human and physical capital's rental rates), leads to different steady states that are driven, in their nature, by the intensity of the habit. A small habit concern leads the economy to a separate equilibrium: highly educated people will grow at a rate that is higher relative to the rate of growth that characterized less educated people. Conversely, a big habit concern boosts the counterbalancing effect of general equilibrium adjustment and the economy, after some oscillatory periods, converges to a unique steady state growth rate. However, people separate completely in the investment they do: less educated people end getting no education (and they only pass physical capital to their children) while more educated people only end educating their children.

0.4 Aging, technology adoption and growth

The second and third chapters of this thesis jointly tackle some issues that characterize nowadays economies, in particular the lengthening of life expectancy, the increase in years spent both in education and in retirement (at the expenses of working years), the shift toward knowledge and human capital intensive productions, the big differences in technological policies among quite similar countries. The idea is to joint together, into a unique theoretical framework, two strands of literature: the one that studies the interactions among demographic variables (in particular life expectancy) and economic growth and the other that explores the politico-economic mechanisms that drives an economy toward different innovation policies.

0.4.1 Life expectancy and growth literature

One idea in this literature is that a causal link running from wealth indicators, such as income or human capital, to life expectancy is in place and it is positive. Historians, Biologists and economists support this view: Mokyr (1998) stresses how both centralized innovations (R&D in chemistry, cures against cancer developed in hospitals and research centers, etc.) and knowledge-driven individual behaviors (water sanitation, food storage, personal hygiene, etc.) led to the dramatic rise of life expectancy in the last two centuries. Galor (2005) reports that at the beginning of Industrial Revolution life expectancy was around 40 years. Lee (2001), for the US, finds that together with the increase in life expectancy, more than proportional increases in education and retirement periods took places, making the share of lifetime devoted to work to shrink.

From a theoretical point, an increase in life expectancy has always been associated with more time spent in education, more human capital and therefore higher level (or rates) of economic performance (Kuznets, 1973, Ram and Shultz, 1979, Kalemli-Ozcan et al., 2000). Only in the last decade some contributions that call into question this conclusion appeared: de la Croix and Licandro (1999) and Boucekkine et al. (2002), through the introduction of vintage human capital, show that a growth-diminishing effect arise because the more the population ages, the more the human capital used in production depreciates, possibly leading to smaller growth rates. Blackburn and Cipriani (2002), Blackburn and Issa (2002) and Castellò-Climent and Doménech (2005), introducing the hypothesis of endogenous life expectancy in the level of human capital, show that multiple equilibria can exist: people living in economies in which life expectancy is too short do not find optimal to invest in human capital. In turns they will get a low level of human capital, avoiding the next generation to experience increases in life expectancy. This kind of poverty trap is avoided in the case initial life expectancy is high enough to permit agents to invest in human capital: this leads, generation by generation, to reach a higher steady state level (or growth rate) in income.

0.4.2 Technology adoption literature

Among the vast strands of literature on technology, we focus on the one that studies *implementation*, rather than the one on the *invention,* of new technologies. The latter literature is based on the Shumpeterian view of creative destruction that takes place among competitive firms, or the processes of learning by doing and research and development that take place within the firms. In the former literature, that we review in deep in chapter two, attention is on the process that makes an already disposable technology[1] to be put in place and exploited in the productive process. The analysis is about the costs and benefits of

[1] The term "technology" has to be thought in a broad sense: it can include, apart from the usual economic meaning, laws, norms, standardization systems, productive organization, etc. that are not productivity-enhancing by themselves, but make the production of new technology easier.

the single actors of the economy and on the conflict of interests that arise among them: being economic units heterogeneous in different dimensions (consumers vs producers, old vs adults, riches vs poors, etc.), rarely they will be together in favour or against the introduction of a new technology. The decision to adopt or not a superior technology is not the simple profit maximization problem of producers, but comes out from a more complex political and economic mechanism in which different groups (lobbies, governments, productive systems, etc.) act together, driven by their own interests. The crucial point is, therefore, how to find the optimal "social" choice as the reflection of the behaviors of the single actors. Fundamental contributions in this literature come from the works of Olson (1982), Bauer (1995) and Mokyr (2002).

0.5 Chapter 2: "Aging, Technology Adoption and Growth: a Taxonomy"

The paper in chapter 2, by means of a simple OLG general equilibrium model, puts together the links between the endogenous lengthening of life expectancy, the technology adoption process and economic growth. Allowing life expectancy to be endogenous, we introduce both the direct positive effect on savings (driven by the concern of agents in old age consumption) and the feedback effect, running from the *aggregate* choices in terms of innovation and the life expectancy itself. The main aim of this paper is to classify into three categories the way economies develop, in terms of innovation choices and growth rates. The key variables that characterize the economies come out to be the initial life expectancy, the cost-benefit scheme of the innovation and the political weight of different age classes. Two different effects, coming from the population aging, are isolated. One is called *economic* effect and positively relates the incentive of adults to innovate with life expectancy: the longer is agents' life, the more they find profitable to pay the fix cost of adopting a new technology, since they need to finance a longer stream of consumption when old. The other is called *political* effect and negatively relates the aggregate incentive to innovate to life expectancy: the bigger is the share of old people in the population, the heavier is their political power. Since old are, by construction, against innovation (they should pay today a cost that will give benefits tomorrow, once they are dead), in a simple majoritarian voting mechanism they will be pivotal once they get the absolute majority.

Therefore, according to the initial and the upper bound[2] of life expectancy, the individual political weight[3] and the parameters of utility function, production function and technologic structure, an economy ends in one of the three following states. A "stagnant economy" occurs whenever initial life expectancy is very short or very long: in the former case is the economic effect that binds, in

[2] The biological limit, say hundred and twenty years.

[3] Galasso and Profeta (2004) show that the turnout rate in political elections is increasing with age.

the latter is the political one. A "stopping economy" is the case of a favorable cost-benefit of innovation but old people political weight is heavy. Finally, a "growing economy" turns out to be the outcome when innovation is cheap and old people have a light weight in the political mechanism.

0.6 Chapter 3: "A Politico-Economic Model of Aging, Technology Adoption and Growth"

The last paper (joint with Francesco Lancia) presents a model built upon the same scheme of the one in chapter 2, introducing some simplifications but expanding in several dimensions the analysis. The main simplification is to eliminate physical capital: in this way we can introduce a PAYGO pension system and focus on the only other kind of investment, human capital. In fact we introduce a third period in the agents' life: youth. They choose how to split their youth time between education and unskilled work: as it happened in chapter 2, an increase in life expectancy makes people to invest more in the investment good. This time it is human capital, and in fact the model replicates the empirical evidence of increasing in education with life expectancy. Moreover, adding one more age class makes the mechanism of preferences aggregation more interesting: it can be the case that with a long enough life expectancy, an innovation-oriented policy has to be supported by a coalition of age classes (young and adults in our case).

The space of analysis is therefore over two dimensions: the private one and the public one. The former refers to the incentives that young face when deciding how long they will stay in school, given a certain life expectancy. It can be the case that a poverty trap arises, because of a unfavorable private incentive scheme. The latter must keep into account the way the individual incentives are aggregated in one public choice: it can be the case that the same policy intervention impacts differently on different age classes. Given these two dimensions and the fact that the economic and demographic environments evolve in time, the timing of policy intervention is crucial when the aim of such policies is to enhance growth.

Concluding, the lengthening of life expectancy, in the presence of technologies that allow to accumulate human capital, is a necessary, but not sufficient, condition for sustained economic growth. Adverse conditions both on the private side (high costs of investments in human capital, small productivity of education system) and the public side (high social costs of entering in a new technological paradigm, heavy weight of more conservative age classes) can mine the reaching of a stage of economic evolution characterized by sustained growth.

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Chapter 1

Intergenerational Links and Growth: a Preferences Approach

1.1 Introduction

Links between intergenerational transfers and economic growth have been studied extensively in many different ways and in several contexts. What we find in the growth and human capital accumulation literature is that the emphasis is often put on the production process of human capital and the choice of how agents behave is functionally taken to be coherent with the assumed production functions. We notice that the effort macroeconomists put on micro-founding the production side of growth models (human capital production, different competitive environments, multi-sectoral production, etc.) does not find a counterpart in the "human" side, i.e. the agents' behaviour. In this paper our aim is to shift the emphasis from the production process of human capital to the decisional process that heterogeneous agents (differentiated both in the level of their financial wealth *and* in their level of human capital) face when they have to allocate their wealth between their own consumption and resources left to the next generations. Two specific questions encouraged us to face this approach. First, how does parents' education (of heterogeneous agents) at individual and aggregate level influence consumption, bequest and education decisions taken by their children? Second, how do these decisions influence aggregate economic growth and individual wealth? The latter question has been quite deeply explored under different viewpoints. Galor and Zeira (1993) introduce credit market imperfections and fixed costs in human capital investment allowing for multiple steady states: their second assumption, in contrast with Loury (1986), makes an equilibrium with persistent inequality to possibly exist. Galor and Tsiddon (1997) allow for two different types of externalities in the production side of the economy: one is *local* and refers to the intra-generational bequeathing of human capital, the other is *global* and refers to the TFP-augmenting effect of the average human capital in the economy. The main result is that poor but equal economies face a trade-off between two alternative growth-oriented policies: an inequality-augmenting redistribution that brings to a high long run growth rate with long run equality or an equality-preserving policy that, instead, brings to a lower long run growth rate. Galor and Moav (2004), inspired by Moav (2002)'s work, build a general equilibrium model that uses the Classical approach of increasing saving rates and a fully private human capital production function to show how economic growth can be coherent with a time-varying relation between inequality and growth. The growth engine of the economy is, in the early stage of industrial development, physical capital accumulation, while in more recent development it is human capital accumulation that makes the economy to grow. Viaene and Zilcha (2001) focus on the production-side of the human capital accumulation process, introducing both public and in-house education in a general equilibrium model of endogenous growth. The policy implications that they draw are that high growth and inequality reduction can be achieved if the resources left by parents to children are redistributed through a proportional tax-public school scheme. If private effort in educating children is dominant on public education (or subsidized by government) the growth level could be the same, but associated with a higher inequality level. What encouraged us to focus both on human and physical capital investments comes from Mookherjee and Ray (2005): they introduce a two-side bequeathing behavior of adults and this assumption helps to expand the set of possible equilibria (and their types) in which an economy ends up. In their paper adults care about the consequences of bequests that they leave to their children: financial bequest is a sort of "aid" to the son because parent could not afford the fixed costs of education. In the case of a wide range of training costs for the different kinds of education and a weak bequest motive inequality is persistent in the long run.

Regarding the first question motivating our analysis, Zilcha (2003) analyzes different motivations of altruism of parents towards their children. He calls these motives "education-inclined" and "bequest-inclined" types of altruism related to parents' investments in education of their offspring and to financial bequests, respectively. He finds that economies face a trade-off between growth and inequality, and the more an economy is "education-inclined", the more equal, but slower, it will grow. Banerjee (2004) reviews very different ways to model decision-making by families about human capital investments. He finds, in a case that allows for joy-of-giving bequeathing of human capital, that the parameters describing the preferences of the adults about different kinds of bequests drive the long run accumulation of human capital, conversely to the case of pure altruism in which the long run behavior of the economy is only driven by technological parameters and exogenous policy variables. Checchi, Ichino and Rustichini (1999) try to solve what they call the "Italian puzzle": a country where a roughly egalitarian education is associated with a strong social immobility in terms of work and educational attainments. The authors explain this anomaly considering the self confidence that every agent puts on her talent, built through the observation of the past history of her own family. This mechanism, combined with the distortion that public school introduces in the incentives to spend in educating the descendents, gives rise to the observed inertia in the mobility within each family.

Evidence regarding significant differences in investments in education and in school attainment between countries has been documented in recent years (among the OECD countries see, for example, Education at a Glance: OECD Indicators (2002), for other countries see: World Development Indicators (2000)). Looking at the causality running from parental educational investment to school attainment of children we find that educational level and its dynamic show a wide variety of scenarios. The determinants of children's school attainment has been widely empirically studied and we are particularly interested in analyzing wealth and past educational determinants (i.e. the wealth of the parents and their educational level). For example, Brunello and Checchi (2003) as well as Ermisch and Francesconi (2001) found a positive correlation between parental education and descendents' education attainment. This correlation has been found to be more significant than the one with parents' income. Glewwe and Jacoby (2004) found that children enrolment is not significantly driven by expected return on education, supporting our hypothesis that education is not primarily an investment good but essentially, using Banerjee's terminology, a symbolic consumption good.

What characterizes our model is what de la Croix (1996, 2001) and Artige, Camacho and de la Croix (2004) formalize in the agents' choices: an intergenerational handing down of "behaviors", called habit[1]. The authors, analyzing historical patterns of countries and cities' cyclical rise and fall, find how the inherited consumption level of the economies can be taken into account to explain these waves. As it will become clear in a while, we prefer to investigate the case of a habit attached to education. In our view it is crucial that when agents make their choices, especially for what concerns the education of their descendents, they take into account their personal history but also what happens around them. Indeed, they are influenced by the level of education of the whole society or neighborhood to which they belong, in a fashion that will be explained in the next section. Another reason is an empirical one: data on education are easily and straightforward to find, relatively to data on households' consumption, and the use of mincerian functions can allow us to derive testable equations about the intergenerational persistence of human capital (i.e. social immobility), whose explanation is far from clear. In facts, Ermisch and Francesconi (2001), at the beginning of their paper, stress that *"[...] in the last two decades there has been an extensive body of empirical work concerned with the links between parental investment in children and children's outcomes, particularly educational attainment. Most of these studies are implicitly embedded in the household production model [...] but only a few of them attempt to disentangle the household's tastes from its technology in "producing" young*

[1] We could have used other words instead of habit, for example reference point, aspirations, etc. but, due to the strong similarity between our work and de la Croix's articles, we preferred habit.

people's human capital". This statement, joint with Ray (2003)'s[2] and Piketty (2000)'s views of how people set their goals (and together with additional micro literature), encourage us to explore this field of research.[3] To resume the ideas presented above, our work can be described by three main characteristics: the analysis is carried on for a simple dynamic economy populated by heterogeneous agents, the focus is on what happens *before* the production of human capital (at individual and aggregate level) and the social and familiar environments in which agents live enter as driving forces of the economic behavior of the agents themselves.

The model setting is an economy in which bi-dimensional heterogeneous agents (in both human and financial capital endowments) interact in both production of final good and in passing on financial wealth and education to their descendents. There is another type of interaction, a *social* one, due to the comparison of every agent's educational level with that of the whole community to which they belong. This comparison is instrumental to the decision of educational investment of each agent[4]. The particular behavior that arises leads the economy to be characterized by two different types of steady states: one that shows high-educated agents growing faster than the others and another, in which habit matters are stronger, where all agents grow at the same rate but fully divide, in terms of kind of supplied factors of production.

Anticipating a feature of the model, we find that there is a sort of "hierarchy" in educational choice, in the sense of bequeathing decisions: a parent will decide to educate her descendent only if she is educated enough, given a fixed amount of wealth. Another feature of the model is that the benchmark that individuals refer to in choosing whether to spend (and how much) or not in education is not a function of their human capital alone (used as a proxy of their education), but it is combined with the average human capital in the population. Accordingly, above-average educated adults, conditionally on their wealth, will invest in their descendents' education a larger share of their wealth, relatively to below-average educated adults. We will come back deeply to this point in the next section. To conclude this introduction, we add that our view of education as a symbolic consumption good (and not as an investment good) comes from the evidence of a "myopic view" about return rates of education. One simple but representative example in Italy is the strong reduction in enrolment rate in technical-scientific university in the last ten year (for Italy: ISTAT (2005)) and, at the same time,

[2] In a sense, in our model we put in practice the "aspirations window" to which Ray refers to: we construct this window with the parents' and the average level of education. The gap between this two measures is the goal that peope take as a benchmark level.

[3] *"The reference group theory [...] has been particularly influential. The basic idea of the theory is that individuals tend to compare their social achievements to the reference group from which they come from. [...] Assuming that dynastic heterogeneity in tastes does explain a significant fraction of the intergenerational persistence of inequality, the policy implications are far from clear, however. The key question is where the heterogeneity of tastes comes from and whether it can be altered",* Piketty (2000).

[4] Gramsci (1975) stresses how familiar and social environments act, separately, in the formation of "educational production attitude" of young children. What we introduce is the interaction between the two environments (by means of the comparison between the familiar and *social* human capital), focusing in particular on the choices of individuals.

vast enrolment rates (up to thirty times the effective demand, as Checchi and Jappelli (2004) stress) in degrees like law or literature.

The paper is organized as follows. In section 2 we present the main features of the model, in section 3 we show the optimal behavior of agents and firms and the different equilibria that the habit component can lead to, in section 4 we analyze in deep the dynamics driven by the habit weight, in section 5 some simulations are shown and in section 6 we conclude.

1.2 The Model

The framework we adopt derives from the models by Zilcha (2003) and Artige, Camacho and de la Croix (2004). The former allows for two type of bequests (educational investment and financial bequest) and heterogeneous agents, while the latter, even if it is specified in a representative-agent environment, uses the habit formation mechanism in a way that is easy to be modified for our purposes.

Agents live for two periods. The growth rate of the population is zero and the size of population is normalized to one. When young, agents only acquire human capital through educational expenditure of their parents, during adulthood they receive a financial bequest from their parents and sell their human capital inelastically on the labour market. Thus, their wealth derives from the wage and the interest rate combined with the amounts of human capital and financial bequest, respectively, that they are endowed with. Adults split their wealth among consumption, a financial bequest for their descendents and an educational expenditure. In every period firms produce, in a perfectly competitive environment, a single good that can be consumed, accumulated as physical capital or spent by adults in children's education.

1.2.1 Endowments

The economy starts in $t_0 = 0$ with an adult generation (named "0") and a young generation: the name of a generation comes from the time in which it becomes adult. At time t all the capital stock is owned by the adults and the endowment of agent i is $b_{it-1} = x_{it}$, the financial bequest given by adult i of the foregoing generation. Each adult is endowed with h_{it} units of human capital.

The wealth of agent i is given by

$$y_{it} = w_t h_{it} + R_t x_{it} \tag{1.1}$$

where w_t is the competitive market wage and R_t is the return rate on financial investments. This wealth will be used by the agent to finance consumption, c_{it}, leave a financial bequest b_{it} and spend on education for her descendent, e_{it}:

$$c_{it} + b_{it} + e_{it} \leq y_{it} \tag{1.2}$$

1.2.2 Preferences

Every agent has the same utility function, given by:

$$U_{it} = \log c_{it} + \alpha \log b_{it} + \beta \log(e_{it} - \gamma a_{it}) \tag{1.3}$$

where b_{it} is the financial bequest given by the adult and e_{it} is the contribution of educational expenditure to the utility function. We have joy-of-giving motivation in both the kinds of bequest. The term a_{it} is the stock of educational habit. We assume that while evaluating the utility gain given by educational expenditure, the adult faces a certain habit: the higher her habit, the more she will spend to educate her descendent, in order to gain a given utility level. The constant γ weights this habit, that is defined in the following way:

$$a_{it} = h_{it} - \bar{h}_t$$

where $\bar{h}_t$ is the average human capital of the adult generation in the economy (assuming population dimension constant and equal to one). In this specification the more an adult is above the average (in terms of human capital, i.e. "broad education"), the more she will spend in her descendant's education. An important aspect is that a_{it} can take also negative values, and this happens for adults with below-average human capital. Our choice for the habit term comes from two considerations.

The first is that human capital is quite different from a consumption or investment good: usually, in works allowing for habit formation in consumption, there is an habit term given by a fraction of the consumption of the previous period's generation. Sometimes the reference level is set to be the average consumption in the population: this is the catching-up-with-the-Johneses literature. In this work our aim is to give to human capital a more *social*, rather than a strictly atomistic, economic interpretation: what we want to build up is a *"...benchmark [...] level determining a goal to reach for the new generation"* (de la Croix (2001)) introducing a measure for this "human capital benchmark" that embodies both intra-family and inter-family comparison. The idea is that a reasonable benchmark level would be the educational level of the person who decides for the education of her descendent, *relatively* to the educational level that prevails in the community where she lives. What we have in mind is that with low level of average education it is easier for the high-skilled professions to be passed vertically from one generation to the next one. Or, in other words, less inequality in education tends to minimize the inertia of this habit to be bequeathed through successive generations. We again stress that here we are modeling the *preferences* of individuals, included education: issues concerning the *production* of human capital will be faced in the next subsection.

The second consideration is a technical one. We could have used a parameter to weight the term $\bar{h}_t$, but with the specification we use we can ideally separate the general equilibrium effect (GEE) from the habit effect (HE). The GEE refers to the inverse relation between the relative abundance of a factor of production and its relative market price: in a dynamic economy this effect describes the "natural" tendency of the rates of return of the factors of production to stabilize around a steady state level. As in a Solow model with human and physical capital (Mankiw, Romer and Weil (1992)), at the steady state the return rates of both factors are constant (or both growing at a given rate, for example, equal to an exogenous TFP growth rate) and their relative rate is constant. The HE refers to the dynamic handing down of the bias in agents' investing behavior. As we will show clearly in subsection 3.3, the distance-from-average specification makes the disentanglement of the two discussed effects easier.

1.2.3 Technologies

The production technology of the single good in the economy can be described by a constant return to scale Cobb-Douglas function that uses human capital and physical capital as inputs. At time t production is:

$$Y_t = AK_t^{\lambda} H_t^{1-\lambda} \qquad 0 < \lambda < 1 \tag{1.4}$$

where A is a constant TFP, K_t is the aggregate physical capital (that fully depreciates in one period) and H_t is the aggregate human capital. These aggregates are given by the total amount of financial bequests left by adults of generation $t-1$ and by the total amount of human capital of the adults of generation t, respectively.

Adult i's human capital, h_{it}, is privately produced, as in Artige, Camacho and de la Croix (2004), with a linear technology that transforms one to one educational expenditure of the parents in human capital of their descendents (1.5). This simple production function is used in order to focus the analysis on the choice-side of the economy, leaving computations lighter .

$$h_{it} = e_{it-1} \tag{1.5}$$

1.3 The Equilibrium

In this section we describes the optimization problems of the two sides: consumers maximize their utility, firms maximize their profits.

1.3.1 Consumers

The member i of generation t maximizes her utility function (2.1), choosing e_{it} and b_{it}, under the budget constrain, (1.1) and (1.2), and the two other constrains (1.6) and (1.7):

$$\max\{0; \gamma a_{it}\} \leq e_{it} \leq y_{it} \tag{1.6}$$

$$b_{it} \geq 0 \tag{1.7}$$

The double inequality in (1.6) indicates that the habit could have a wide range of influence on educational decisions. In what follows, we will see formally how this can be the case.

As in Zilcha (2003) and Cardak (2004), adults do not care about earning capacity of their descendents, and they do not have nested utility functions *à la Barro*, either. They are only interested in the educational expenditure that they do and in the amount of financial bequest leaved to their descendants. This allows us to separate the motivations that drive intergenerational bequeathing in this model: the former of "status" motivation, as in Glomm and Ravikumar (1992), and the latter for the "economic" motivation. Within this specification, adults only form expectations about next period's rate of return for what concerns the financial bequest. FOCs, (1.5) and the simplifying identity $x_{it+1} = b_{it}$ bring, for agent i, the optimal choice of e_{it} and b_{it}:

$$e_{it}^{*} = \frac{\beta}{1+\alpha+\beta}\left(w_t h_{it} + R_t x_{it}\right) + \frac{\gamma(1+\alpha)}{1+\alpha+\beta}(h_{it} - \bar{h}_t) \tag{1.8}$$

$$b_{it}^{*} = \frac{\alpha}{1+\alpha+\beta}\left(w_t h_{it} + R_t x_{it}\right) - \frac{\gamma\alpha}{1+\alpha+\beta}(h_{it} - \bar{h}_t) \tag{1.9}$$

where h_{it+1} and x_{it+1} are the human and physical capital owned by agent i's descendent. These equations hold until the habit term is not too high or too low relatively to the agent's wealth. With a too high habit term, we would not have a well-defined utility function and we assume that the habit weight γ can not be "too large". Later on we will define the exact magnitude of γ_{UB}, the Upper Bound value that the habit weight can not exceed and how to calculate it. Conversely, a very low habit (for example when the agent is so poorly educated to be much below the average) makes the marginal utility of the educational investment always lower than its marginal cost: the agent will split her wealth only between consumption and financial bequest. In this case the agent will maximize her utility function in the corner solution defined by $e_{it} = 0$. The financial bequest will be:

$$b_{it}^{*} = \frac{\alpha}{1+\alpha}\left(w_t h_{it} + R_t x_{it}\right)$$

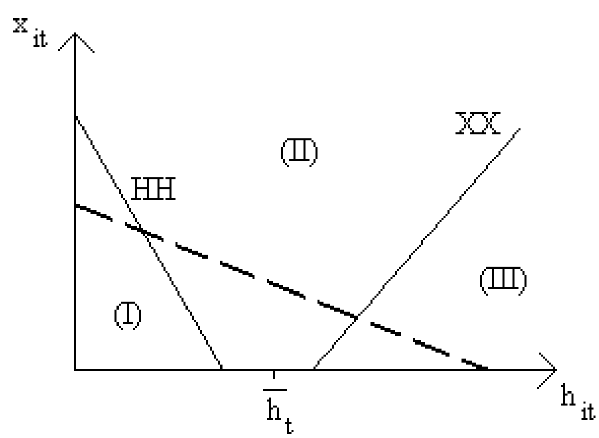
Referring to 1.8 and 1.9 and taking into account the example above, it is clear that the shares of wealth that agents invest in education and financial bequests are not the same for everybody. On the contrary, for each agent they depend both on the private and average human capital. This shows how important are, in determining the individual and aggregate investments in human and physical capital that flow from one generation to the other, both the *magnitude* and the *composition* of individual wealth: in fact, for example, agents endowed with the same wealth can split it in very different ways, depending on *where* their wealth comes from. This is a point that we want to underline: also variables other than the "pure" wealth can (and, actually, do) drive the choices of individuals and we are proposing a way to do it. At this stage of the analysis, it is very useful to show our results by means of a graph. Figure 1 shows how agents choose how to split their wealth as a function of their human and physical capital endowments. The loci (HH) and (XX) divide the first quadrant in three regions: region (I), corresponding to relatively low educated agents, region (II) where agents have an educational level around the average of the distribution in the economy ($\bar{h}_t$) and region (III) where agents are high educated. People in region (I) choose to invest only in financial bequests, people in region (II) invest in both educational and financial bequest and people in region (III) pass on only education. The dashed isowealth line represents the idea stressed above: it could be the case of agents endowed with the same wealth that choose differently how to split it. The loci (HH) and (XX) are characterized by the equations

$$x_{it} = \frac{\bar{h}_t \gamma (1+\alpha)}{\beta R_t} - \left(\frac{\gamma(1+\alpha) + \beta w_t}{\beta R_t} \right) h_{it} \tag{HH}$$

$$x_{it} = -\frac{\gamma}{R_t} \bar{h}_t + \frac{\gamma - w_t}{R_t} h_{it} \tag{XX}$$

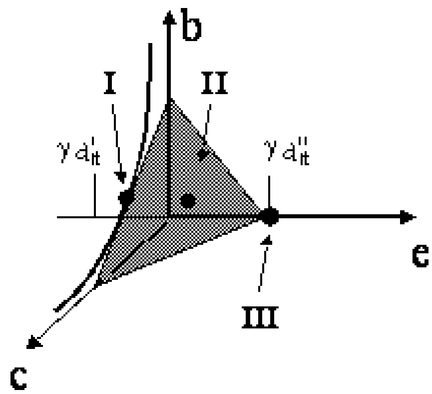
that are obtained, for given values of w_t and R_t, equating (1.8) and (1.9) to zero and solving for x_{it}. It is easy to verify that if γ equals zero the two loci disappear because the "bequests biases" due to the habit are zero.

Figure 1. Agents behave conditionally on their endowments of human and physical capital. The dashed isowealth line shows that agents with the same wealth can behave in three different ways.



The intuition behind the behavior described above is that an agent with a little amount of human capital (relatively to the average human capital in the economy) would not feel educating her descendent crucial, and if her financial endowment is not so high, she would prefer to consume and to leave only financial bequest. Differently to the case of other works (for example Galor and Zeira (1993)) in which there are indivisibilities in human capital accumulation, this time it is the particular utility function that allows for non-convexities in both human and financial capital production at individual level. In figure 2 we show, now looking at a single agent with a given wealth and with different habits, the different choices that she can make.

Figure 2. How different habits lead agents
to split the same total wealth.



The grey simplex represents the budget constrain of the agent in the space of consumption, financial investment and educational investment. The maximization of utility under the budget constrain can give rise to the three different behavior described above. The choice is of type (I) if the habit term is strongly negative (imagine a standard convex isoutility surface that is shifted to the left by the negative term $\gamma a'_{it}$): educational expenditure will be zero due to its high marginal cost, higher than its marginal utility. Choice of type (II), therefore an interior solution, is the result of a low habit concern: in the limiting case of $\gamma = 0$ the wealth's shares that goes in consumption, educational investment and financial bequest are $\frac{1}{1+\alpha+\beta}$, $\frac{\alpha}{1+\alpha+\beta}$ and $\frac{\beta}{1+\alpha+\beta}$, respectively. The more the habit term increases, the more the choice is biased toward investment in education. Once the habit term reaches $\gamma a''_{it}$, all agent's wealth goes in educational investment, represented by type (III).

1.3.2 Firms

Firms produce in a perfectly competitive environment. The producers' inverse demand for factors of production is: $R_t = \lambda A k_t^{\lambda-1}$ and $w_t = (1-\lambda) A k_t^{\lambda}$, where $k_t = \frac{K_t}{H_t}$. In turns, $K_t = \sum\limits_i x_{it}$ and $H_t = \sum\limits_i h_{it}$.The share of production that goes to human capital is therefore $(1-\lambda)$, while the one going to physical capital is λ.

1.3.3 Intertemporal Equilibrium

A competitive equilibrium, given historical distributions of human and physical capital in the population in $t = 0$, is a sequence of $x_{it}, h_{it}, w_t, R_t, H_t, K_t$ and $\bar{h}_t$, $t = 1, 2, \ldots$ such that:

a) each adult i selects the amounts of the two type of bequest optimally, given her endowments, market prices and habit;

b) this decisions aggregate to H_{t+1} and K_{t+1}, according to (1.5) and the identity $x_{it+1} = b_{it}$;

c) w_t and R_t equal the marginal productivity of human capital and physical capital, respectively.

The first step is to show the individual accumulation functions (of human and physical capital). Agent i behaves accordingly to her endowments of human and physical capital, that enter both in the determination of her wealth and habit. Moreover, the average level of human capital enters in the agent's decisions, too. Therefore the accumulation functions for agent i takes different forms when she is in different situation: if the agent is in region (I), that means that she is endowed with relatively low wealth and a low level of education, she will pass to her descendent only physical capital, *independently* on the magnitude of the habit weight:

$$h_{it+1} = 0 \tag{8 I}$$

$$x_{it+1} = \frac{\alpha}{1+\alpha}\left(w_t h_{it} + R_t x_{it}\right) \tag{9 I}$$

An agent in region (II), that is to say *not too far from* the average wealth and education, will pass both physical and human capital accordingly to the two following equations:

$$h_{it+1} = \frac{\beta}{1+\alpha+\beta}\left(w_t h_{it} + R_t x_{it}\right) + \frac{\gamma(1+\alpha)}{1+\alpha+\beta}(h_{it} - \bar{h}_t) \tag{8 II}$$

$$x_{it+1} = \frac{\alpha}{1+\alpha+\beta}\left(w_t h_{it} + R_t x_{it}\right) - \frac{\gamma\alpha}{1+\alpha+\beta}(h_{it} - \bar{h}_t) \tag{9 II}$$

An agent in region (III), very (relatively) highly educated and not too much wealthy, will spend everything she got in educating her descendent, independently from the habit weight:

$$h_{it+1} = w_t h_{it} + R_t x_{it} \tag{8 III}$$

$$x_{it+1} = 0 \tag{9 III}$$

We focus on individuals because of the intractability of aggregate dynamic behavior of the economy. The impossibility to give an analytical characterization of the dynamics originates from the technical way in which human and physical capital aggregates: in the previous subsection we have derived the expressions of the wage and the rate of return and they are both dependent on k_t , that in turns depends on the aggregate value of human and physical capital. The heterogeneity of agents (complicated by the two types of heterogeneity: in human and financial capital) makes impossible to write the expressions of w_{t+1} and R_{t+1}. Notice that the same *behavior* could have been obtained with other more complex human capital production functions, due to the double joy-of-giving specification in the utility function. The use of a linear specification allow us to derive some analytical properties of the equilibria in the steady state analysis.

Now we want to investigate what types of equilibria and dynamics our model allows for: the two-dimensional heterogeneity of individuals is a source of very different initial configurations that can describe a broad types of economies. For example it is easy to show that an "equal" economy, in terms of personal wealth, can be populated by individuals with very different endowments of physical and human capital. Indeed, this could bring agents of each type to behave in different ways with respect to educational investment, consumption and financial bequest. Moreover, what we will find is that the habit weight change radically the kind of steady state reached, while, due to the strong linearity of the model, initial conditions impact only on the transitiondynamics and not on the steady states features.

Our strategy is to split the population in two groups *1* and *2*, weight them μ and $(1-\mu)$ and check which are the determinants of the steady state reached and how it is reached. We assume, from now on, that, at time $t=0$, agents belonging to group *2* are relatively more abundant in human capital than the ones in group *1*, i.e. $h_{20}-h_{10}>0$. Notice that the expression of the intensive capital is given by $k_t=\left(\frac{\mu x_{1t}+(1-\mu)x_{2t}}{\mu h_{1t}+(1-\mu)h_{2t}}\right)$.

The benchmark case: representative agent or $\gamma=\gamma_{LB}=0$

In this subsection, we begin with what we call the benchmark case, that can be both the case of representative agent or the case of habit weight equal to zero (we refer to this zero-weight, the Lower Bound value of γ, with γ_{LB}): using (2.3), (1.8), (1.9) and noting that the habit term equals zero, we get the growth rate (common for wealth, human capital and physical capital):

$$g_{LB}=\frac{A\alpha^{\lambda}\beta^{1-\lambda}}{1+\alpha+\beta}-1 \tag{1.10}$$

Regions (I) and (III) disappear due to $\gamma=0$, the representative agent (or the agents) evolves always in region (II). Both physical and human capital grow at the same steady state growth rate g_{LB} and the intensive capital k_t is constant: $k^*_{LB}=\frac{\alpha}{\beta}$. This is, trivially, the rate between the share of wealth passed by in financial bequest and the share of wealth spent in education of the adult's (or the adults') descendent(s). The dynamics are driven by equations (8II) and (9II), without the second additive terms that describes the habit formation mechanism (with or without the suffix i, that disappear in the case of the representative agent). In the representative agent case, due to the homotheticity of the utility function and the linear production function of human capital, the wealth shares that each agent spends in education and in financial bequeathing are the same, so the growth rate is the same for both the groups, as we showed before. The only effect that acts in this case is the GEE that sets, instantaneously, the relative return rate between the two factors of production constant.

The "extreme case": $\gamma = \gamma_{UB}$

Before describing how to find γ_{UB} and what it represents we have to make one assumption about the parameters of utility and production functions, in order to have a coherent behavior of agents. We impose, from now on[5]:

$$\frac{1-\lambda}{\lambda} > \frac{\beta}{1+\alpha} \tag{1.11}$$

This assumption, that concerns the "net-of-habit" link between productivity of factors of production and bequeathing behavior of agents, states that the rate between the share of production going to human capital $(1-\lambda)$ and the share of production going to physical capital (λ) is bigger than the rate between the share of wealth devoted to education (β) and the share of wealth devoted to other causes $(1+\alpha)$, i.e. consumption and financial bequest. In dynamic terms, this means that there is a *natural primacy* in earning power of education: the assumption above avoids that the advantage that agents get being educated is not harmed by the preferences for education (β), in the sense that the investment in human capital does not make the return rate on education to be so small (due to the relative accumulation of human capital itself with respect to physical capital) to make more educated agents worst. Our assumption plausibly hold because, from the literature, we find for λ a value around 0.25, and we assume that the main argument in the utility function is consumption: α and β are hypothesized to be smaller than one.

We define the "extreme case" a steady state in which the economy evolves with the two groups completely separated: one passes only human capital, the other only financial capital. In the following of this subsection we study the properties of the steady state and the conditions on the parameters that make it happen. Analytically, we impose that group *1* evolves according to equations (8 I) and (9 I) and group *2* evolves according to equations (8 III) and (9 III), that is group *1* passes only financial capital while group *2* invests only in educating their descendents. Expliciting the expression of w_t, R_t and then k_t, we get:

$$h_{2t+1} = w_t h_{2t} = h_{2t}(1-\lambda)A\left(\frac{\mu x_{1t}}{(1-\mu)h_{2t}}\right)^{\lambda} \tag{8 III'}$$

$$x_{1t+1} = \frac{\alpha}{1+\alpha}R_t x_{1t} = \frac{\alpha}{1+\alpha}x_{1t}\lambda A\left(\frac{\mu x_{1t}}{(1-\mu)h_{2t}}\right)^{\lambda-1} \tag{9 I'}$$

Notice that, since we have *assumed* that the two groups evolve in region (I) and (III), respectively, these equations are *independent* from γ. Due to expressions (8 III') and (9 I') we have endogenous growth, so the equilibrium will be a constant and equal growth rate of human and physical capital and,

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[5] We make this assumption at this stage to leave the description above as general as we can. If this condition would not hold, the implied dynamics of the economy would give birth to equilibria, with persistent or diverging oscillating dynamics of the economy's stock variables. Although these cases are very interesting to study, we are mainly interested in more tractable cases, that are the ones described in this section.

as a consequence, a constant k. We can write the expression of steady state intensive capital, k_{UB}, looking at the steady state ratio between (9 I') and (8 III'):

$$k_{UB} = \frac{\mu x_1}{(1-\mu)h_2} = \frac{\alpha}{1+\alpha}\frac{\lambda}{1-\lambda} \tag{1.12}$$

For this to be the case, agents in group *1* have to pass only physical capital and agents in group *2* have po pass only education. Since the two loci (XX) and (HH) are dynamic and their evolution depend on the investments in physical and human capital done by the agents, we have to impose that two dynamic conditions have to hold simultaneously:

$$x_{1t+1}(x_{1t}; h_{2t}) < \hat{x}_{1t+1}(x_{1t}; h_{2t}) \cap h_{1t+1}(x_{1t}; h_{2t}) > \hat{h}_{1t+1}(x_{1t}; h_{2t})$$

where $\hat{x}_{1t+1}$ and $\hat{h}_{1t+1}$ are the intercept of (HH) with the x_{it} axis and the intercept of (XX) with the h_{it} axis in figure 1, respectively. In other words, in steady state the evolution of the two bounds does not have to make the agents to change their behaviors. Simple calculations using (8 III'), (9 I'), (XX), (HH) and (1.12), combined with assumption (1.11), lead to:

$$\gamma > \gamma_{UB} = \frac{(1-\lambda)^{(1-\lambda)}\lambda^{\lambda}A}{\mu}\left(\frac{\alpha}{1+\alpha}\right)^{\lambda} \tag{1.13}$$

In (1.13) we have a condition on the parameters that ensures that the two groups evolve exactly in the way we have described above. The steady state growth rate of the economy is, in this case,

$$g_{UB} = \frac{x_{1t+1} - x_{1t}}{x_{1t}} = \frac{h_{2t+1} - h_{2t}}{h_{2t}} = \mu\gamma_{UB} - 1 = (1-\lambda)^{(1-\lambda)}\lambda^{\lambda}A\left(\frac{\alpha}{1+\alpha}\right)^{\lambda} - 1 \tag{1.14}$$

As expression (1.14) shows, the growth rate is common for both the groups and independent on γ: the idea is that, having a very high concern about past behavior (γ equal to γ_{UB}), each group "choose" a single type of capital in which invest, that means that the two groups completely specialize. In this extreme case the growth rate does not depend on β because agents in group *1* split their wealth only between consumption and financial bequest, while agents in group *2* spend everything in educating their descendents. The two groups are therefore "forced" to stay on the two opposite corner solutions (in figure 2, the choices (I) and (III)) at the hand of their own high habits: this implicitly impedes them to benefit from the further "degree of freedom" of investing in the other kind of capital. In this case the strong HE separates completely the two groups and the GEE can work only in the domain of x_1 and h_2: this restriction makes the only possible equilibrium the one in which the growth rate is the same for both groups. In the next section it will become clear how the possibility to invest in both types of capital gives, to one of the two groups, the possibility to exploit one additional degrees of freedom with respect to the other group.

1.4 Dynamics in the intermediate habit case

In this section we study the dynamics in the case of $\gamma_{LB} < \gamma < \gamma_{UB}$. We hypothesize, in this section, that the two groups are endowed with similar amounts of human capital and financial capital and that their total wealth is the same. These assumptions do not change our qualitative results but help us to better describe the dynamic behaviors of the agents. In this section it is important to keep in mind how the economy behaves in correspondence of the two extreme bounds of γ and which are the effects that enter the game: only the GEE in the case of $\gamma = \gamma_{LB} = 0$ and the HE and a "restricted" GEE in the case of $\gamma = \gamma_{UB}$.

Now we analyze the temporary equilibrium in the case of *small* values of γ. This means that adults face a mild habit (a sort of positive or negative externality) in doing their educational expenditure.

1.4.1 The short run

Using (8 II) and (9 II) and the expressions of wage and return rate, we get, at least for some periods, again the same stationary results for aggregate human and physical capital than in the previous sub-case. The intensive capital is constant because of the habit terms' forms we choose in (8 II) and (9 II): adding up h_{1t+1} (x_{1t+1}) and h_{2t+1} (x_{2t+1}) to get the stock of human (physical) capital, the distance-from-average specification makes the habit terms to cancel[6]. As a consequence we claim that when both groups belong to region (II) wage and return rate are constants. In other words, in this model's specification aggregate human and physical capital are *independent* from the distribution of the human capital itself across the population. What changes is the relative wealth and the dynamics of human and physical capital *at group level*, due to the externality given by the inherited habit, that drives up or down the opportunity cost of the different investments that each adult can do. Accordingly to the foregoing definitions, the force that drives the dynamics of the economy comes from the HE, rather than from the GEE. Given the hypotheses of "similar agents" endowed with the same wealth, referring to figure 1 there are two groups that belong to a generic isowealth line, in the segment between (XX) and (HH). In other words, both the two groups choose an internal point of the simplex in figure 2. Two pairs of equations describe the dynamics, one set of (8 II) and (9 II) for each group. It is possible to show that the growth rates of the two groups diverge from one period to the other combining (8 II), (9 II) and (1.1), remembering that the wealth of the two groups at time t are assumed to be equal and $(h_{2t} - h_{1t}) > 0$ by assumption:

$$g_{y1t} = \frac{y_{1t+1} - y_t}{y_t} = g_{LB} + \gamma G_1 \left(\frac{h_{2t} - h_{1t}}{y_t} \right) \tag{1.15}$$

[6]As we stressed in subsection 2.3 and (not reported) simulations show, an alternative specification of the habit term could have been something like: $a_{it} = h_{it} - \theta \bar{h}_t$. The further weight θ that people attach to the *social* measure of human capital would only complicate the mathematics but would not add significant new issues to tackle.

$$g_{y2t} = \frac{y_{2t+1} - y_t}{y_t} = g_{LB} + \gamma G_2 \left(\frac{h_{2t} - h_{1t}}{y_t} \right) \tag{1.16}$$

where the constants G_1 and G_2 are negative and positive, respectively, holding (1.11). Both G_1 and G_2 are constants, functions of A, α, β, λ and μ.[7] The expressions above show clearly how the two effects described above work: the GEE contributes with a growth rate equal to g_{LB}, while the HE, proportionally to γ, boosts in opposite directions the second addictive terms of the growth rates. We summarize that (11) makes the habit to have a positive (negative) *level* effect on the educational investment of the more (less) educated group (look at expression (1.8)) and a positive (negative) *growth rate* effect on the wealth of the more (less) educated group. We claim that if two groups at time t are characterized by the same wealth level and similar endowments of human and physical capital, the one more educated will show, at least for some periods, a higher and increasing growth rate. In fact, the assumption of similar endowments makes agents to be in region (II) and to choose a composition of human and physical capital that leads them again to region (II). With the same wealth the expression $h_{2t+1} - h_{1t+1} > 0$ holds from (8 II) and, under assumption (1.11), $y_{2t+1} - y_{1t+1} > 0$ holds, too. It is so straightforward that, for some periods, $g_{y2t} > g_{y1t}$.

1.4.2 The long run

We have described how the economy behaves *in the first periods*: in fact, after some periods the less educated group will end to be "trapped" in region (I) and therefore will stop to invest in education. This is because the differential term $(h_{2t} - h_{1t})$ is always increasing, lowering the *growth rate* and, at the same time, the *level* of human capital of group *1*. This causes the habit of this group to decrease the marginal utility of education so much that its opportunity cost would not justify the investment in the education itself. The dynamic that arise from now on is one in which group *1* passes only education, while group *2* continues to pass both financial and human capital. When group *1* stops to invest in human capital, the relative rate of return between the two factors of productions adjusts through the GEE: the *intertemporal* equilibrium is reached once the production factors' rates of growth and the intensive capital are constant. The main message is, therefore, that after some period the less educated group *loses its educational lever* while the other group can adjust between both educational and financial bequeathing to reach the maximum utility level.

As we have explained above, the case of group *1* evolving in region (I) and group *2* in region (II) could be the dynamic that arises at the end of a *transitory* time span during which the two groups invest in both education and financial capital. It could be the case, however, of an economy that begins already in this situation (that can arise from higher values of γ): a part of its population

[7] Precisely, $G_1 = \frac{\gamma(1-\mu)A(\frac{\alpha}{\beta})^{\lambda}(\lambda\beta-(1+\alpha)(1-\lambda))}{1+\alpha+\beta}$ and $G_2 = G_1(\frac{-\mu}{1-\mu})$. The signs come straightforwardly from (1.11).

is more educated and, apart from passing some financial capital, educates their descendents. The other part of the population only passes financial capital. We let (1.11) to hold, so we can also analyze the evolution of the economy described above: an economy in which two groups start with similar endowments of human and physical capital but, because of habit in educational investment, one of the two groups ends stopping to invest in education, once its opportunity cost is too high relatively to its marginal utility.

Formally we describe these cases (both the one with higher γ and the second time span of the case of lower γ, when group *1* have already stop to invest in human capital) with three accumulation equations. The first describe the evolution of financial bequests in group *1*: note that the bequest is a constant fraction of the wealth characterizing each agent belonging to the group. The second and third equations describe the evolution of physical and human capital of agents in group *2*, respectively:

$$x_{1t+1} = \frac{\alpha}{1+\alpha}\left(\lambda A k_t^{\lambda-1} x_{1t}\right)$$

$$x_{2t+1} = \frac{\alpha}{1+\alpha+\beta}\left((1-\lambda)Ak_t^{\lambda}h_{2t} + \lambda A k_t^{\lambda-1}x_{2t}\right) - \frac{\gamma\alpha\mu}{1+\alpha+\beta}h_{2t}$$

$$h_{2t+1} = \frac{\beta}{1+\alpha+\beta}\left((1-\lambda)Ak_t^{\lambda}h_{2t} + \lambda A k_t^{\lambda-1}x_{2t}\right) + \frac{\gamma(1+\alpha)\mu}{1+\alpha+\beta}h_{2t}$$

The analyses of the steady state and the dynamic will be carry on through simulations because, as it will become clearer in a while, a simple analytical solution for the steady state is not available: the strategy is to look at the behavior of the economy, conditional on the value of the habit weight, γ. First of all, notice that $k_t = \frac{\mu x_{1t}+(1-\mu)x_{2t}}{(1-\mu)h_{2t}}$. Remember that, maybe after a transitory as described in the previous subsection, $h_{1t+1} = h_{1t} = 0$: this means that agents in group 1 have no human capital and choose not to invest in human capital for their descendents. The growth rate of intensive capital is constant if and only if:

$$\frac{g_{x1t}}{1+\left(\frac{1-\mu}{\mu}\right)\frac{x_{2t}}{x_{1t}}} + \frac{g_{x2t}}{1+\left(\frac{\mu}{1-\mu}\right)\frac{x_{1t}}{x_{2t}}} = g_{h2t}.$$

This relation between growth rates and levels of endowments of human and physical capital directly arises taking the difference of the expression of k_t above and equating it to zero. The key issue is that, in equilibrium, two only possible cases can arise: (i) $g^*_{x1} = g^*_{x2} = g^*_{h2}$ or (ii) $g^*_{x1} < g^*_{x2} = g^*_{h2}$, where the inequality sign comes from (1.11). The equality between g^*_{x2} and g^*_{h2} holds because, during the transition toward the steady state, under the hypothesis $g_{x1t} < g_{x2t}$[8] eventually $\frac{x_{2t}}{x_{1t}}$ goes toward infinity and in this case the contribution of g_{x1t} in

[8] This, in turn, is implied by the short run analysis above through the hypothesis that $(h_{20} - h_{10}) > 0$.

determining g_{h2t} weights zero and, in an analogous way, the denominator of the second fraction equals one. The first main conclusion here is that two are the possible types of steady state: the former implies a wealth's growth rate equal for the two groups, the latter an higher growth rate for the group that invests in human capital.

The kind of equilibrium reached and the dynamics that lead the economy to the specific equilibrium depend on the weight of the forces that interplay in the economy: remember that in subsection 3.3.1, in which $\gamma = 0$, only the GEE is in action while in subsection 3.3.2, where the habit is very strong, the HE forces the economy to experience a corner solution. We stress that in this intermediate case it is not possible to disentangle the GEE from the HE (due to the impossibility to properly characterize the dynamics and the steady state of the three-equations system above), but what we can say is that these effects work together and we can describe the adjusting mechanism as a two-blocks control system: the GEE works *until* k_t is constant, no matter if, in the end, x_{1t} vanishes with respect to x_{2t} or it grows at the same rate. The GEE does not depend on γ, it is an intrinsic characteristic of this kind of models. The HE works independently from the GEE: what it does is to bias (toward or against educational expenditure, according to the sign of the expression $(h_{it} - \bar{h}_t)$) the choices of how to split the wealth of each adult. The higher is γ, the stronger is the HE. Our aim is to find the threshold value of the habit weight, γ_L, below which the economy ends up with different growth rates for the two groups and above which the two groups grow at the same rate.

1.5 Simulations

In the simulations that we run we set the parameters' values following the considerations mentioned in subsection 3.3.2. From the literature we set $\lambda = 0.25$. Since we have assumed that the main subject in the utility function is consumption, the weights of the financial and educational bequests are less than unity ($\alpha = 0.3$ and $\beta = 0.5$). Thinking about generations that born every thirty years, we chose the TFP, A, to be equal to 10, in order to have a *standard* annual growth rate of about 3%[9]. This parameters' values make (1.11) to strongly hold, so we rule out the case of a different inequality sign that would make possible different dynamics, as explained in the notes. Without loss of generality, the economy is splitted in two groups of the same size, so $\mu = 0.5$. We let γ to vary and we observe how the economy behaves, in terms of both dynamics and steady states.

With low values of γ (in our simulations positive values smaller than $\gamma_L =$

[9] From expression (1.10) the ratio between production in generation $t+1$ and production in generation t equals $\frac{A\alpha^{\lambda}\beta^{1-\lambda}}{1+\alpha+\beta}$. If a new generation borns every 30 years, we have to solve $g_{ann} = \left[\frac{A\alpha^{\lambda}\beta^{1-\lambda}}{1+\alpha+\beta}\right]^{\frac{1}{30}} - 1$ to obtain the annual growth rate of the economy. We call g_{ann} the *standard* growth rate because we look at the growth rate that would prevail without the habit mechanism.

6.8867) the steady state that is reached by the economy is one that involves different growth rate for the two groups: this is case (ii). What we can say is that if habit is weak (once that we have assumed to be in the case of group *1* in region (I) and group *2* in region (II), the only habit *intensity* to take into account is the one of group *2*) the positive (negative) contribution in the accumulation of human (physical) capital for group *2* is not enough to raise the return rate on physical capital so much to make group *1*'s wealth to grow faster than group *2*'s wealth. In other words, the GEE "does its job" *before* the HE have given to group *1*'s agents the possibility to exploit the high return rates on physical capital given by the GEE itself. The result is that the two groups grow at different rates: group *1*'s agents' wealth grows at the same rate than their financial capital's growth rate, g_{x1}^*, while group *2*'s agents' wealth grows at the rate $g_{x2}^* = g_{h2}^*$, higher than g_{x1}^*. Moreover, this case of low values of γ is the only case compatible with a past history characterized by all the agents in region (II) investing in both types of capital, described in the previous subsection.

Higher values of γ (with $\gamma_L < \gamma < \gamma_{UB} = 7.8996$) imply a stronger HE and this leads to a strongly unbalanced habit-driven accumulation biased toward human capital (for group *2*, while there is a strong preference toward financial investment for group *1*). The effects are again shown by the three dynamic equations above: for given y_{2t} and h_{2t} a high value of γ leads group *2* to strongly accumulate human capital and weakly accumulate physical capital (anyway, we stress that the constraints (1.6) and (1.7) have to hold). As before the GEE raises the return rate on physical capital and lowers the wage rate, but this time habit-induced variations are so big (especially looking at R_t) that in later periods group *1*'s agents, whose wealth comes only from physical capital, experience a high growth. This in turn contributes one to one to the high level of g_{x1t} so, at some point in time, the growth rate of the aggregate physical capital will be higher that the growth rate of human capital: the GEE now reverses and an opposite situation occurs. So, conversely to the case of small habit, the GEE works only asymptotically because the HE is so strong to make the economy's characteristic variables (growth rates, intensive capital and return rates) to fluctuate around a steady state level. In other words, the HE acts as a feedback that stabilize the growth rate of the three accumulating variables around the same steady state growth rate. Being all equal the growth rates, ratios between different stock variables are constants, in particular $\frac{y_{2t}}{y_{1t}}$ is constant and its steady state value decreases as γ increases: this means that if the habit is high, educated people invest a lot in their children's education and these massive investments in education make the wage rate to fall and, as a consequence, to lose the earning advantage that, in the case of the GEE completely exhausted, education would give.

When γ reaches γ_{UB}, the economy perfectly separates: one group will invest only in human capital and the other only in physical capital. This is the case that we have studied in subsection 3.3.2.

In the following simulations, group *1* is always represented by a continuous line, group *2* by a dashed line. In this first simulation (figure 3a) the two group begin with the *same* wealth level, but group *2*, as we have assumed in section

3.3, is more educated (i.e. has more human capital). We set $\gamma = 1.4$: both the two groups pass, for 12 periods, both financial and educational bequests. Wage and return rate are temporarily constant. Since (1.11) holds, referring to (1.16) is clear that agents of group *2* experience a growth rate always higher than agents of group *1*. After this time span educational investment is no more preferred to agents belonging to group *1*, due to the decreasing marginal utility driven by the habit term, and from now on the economy evolves with the two groups proceeding at two paces. This is the case in which, using the terminology of the previous section, there is a *mild* habit, where the GEE fully works before the HE had time to change "too much" the relative return rate of the factors of production. The higher is the habit weight γ, the shorter is the time span during which all agents invest in both types of capital.

When we look at the differential between the two groups' steady state growth rates, we do not find a clear relationship with the habit weight, because it depend in a non-trivial way also on parameters other than γ: in figures 3b and 3c we graph the steady state wealth's growth rates as functions of γ both in our standard case and in a case in which we change parameter β from 0.5 to 0.1 (that is, to give less weight to descendents' education in adults' utility function). Note that, holding (1.11), γ_{UB} does not depend on β: what happen is that the region in which non-complete-separation and same growth rate coexist narrows.

figure 3a: dynamics of growth rates with low habit (γ=1.4)

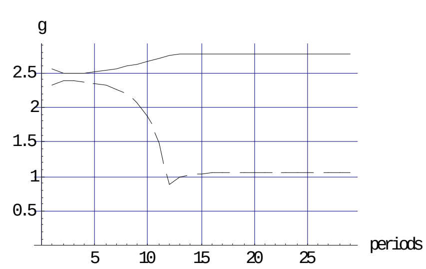


figure 3b: steady state growth rates as a function of γ (β=0.5)

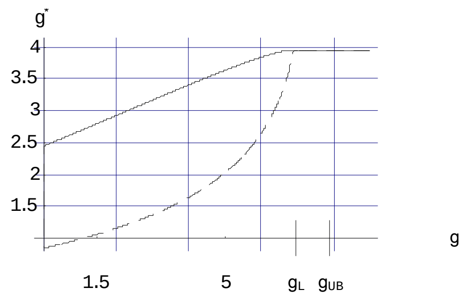
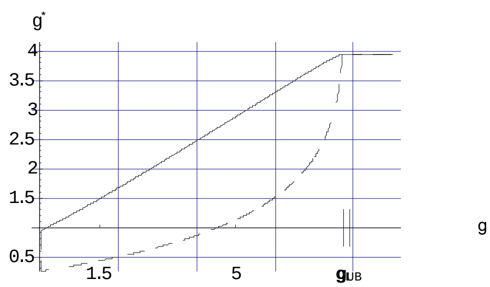


figure 3c: steady state growth rates as a function of γ (β=0.1)



For higher values of the habit's weight (but, in any case, $\gamma < \gamma_{UB}$) we have that the contribution of the GEE and the HE act together and, after some fluctuations, the growth rate is constant and common for the two groups, although group *1* passes, as in the previous case, only financial capital. In figure 4a we set $\gamma = 7.1$, while in figure 4b $\gamma = 7.5$. In figure 4b the high growth rate peak experienced by group *1* is very clear: after some periods in which group *2* invests strongly in human capital, the increased return rate on physical capital boosts group *1*'s growth.

figure 4a: dynamics of growth rates with high habit (γ=7.1)

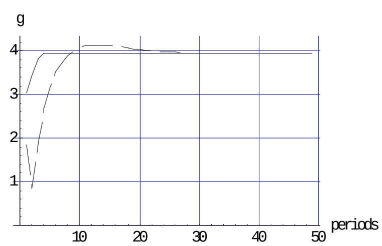
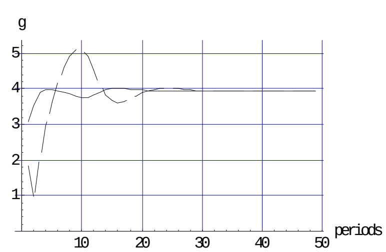


figure 4b: dynamics of growth rates with high habit (γ=7.5)



In figure 5a and 5b we show how the relative wealth of the two groups evolves: after some fluctuation, as expected from the previous figure, $\frac{y_2}{y_1}$ reach a constant value. The higher is γ, the lower is the steady state value of $\frac{y_2}{y_1}$. Again, in the two figures below we have $\gamma = 7.1$ in figure 5a and $\gamma = 7.5$ in figure 5b.

figure 5a: relative wealth (γ=7.1)

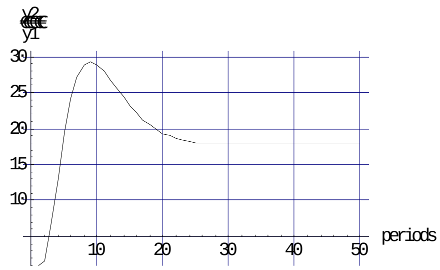
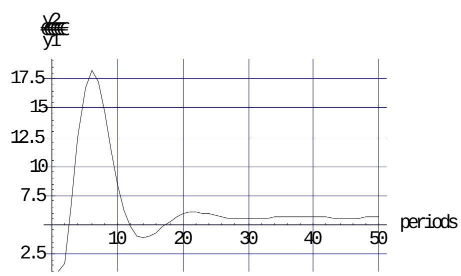


figure 5b: relative wealth (γ=7.5)



For further higher values of γ the economy experience complete specialization, as described in subsection 2.3. Once γ reaches γ_{UB} the steady state growth rate and $\frac{y_2}{y_1}$ are constants, equal to $(1-\lambda)^{(1-\lambda)}\lambda^{\lambda}A\left(\frac{\alpha}{1+\alpha}\right)^{\lambda}$ and $\frac{1-\lambda}{\lambda}\frac{\mu}{1-\mu}$, respectively.

1.6 Conclusions

In this paper we have built a simple general equilibrium model that tries to shed some light on the effects of a habit-driven intergenerational transmission of wealth, in the form of human and physical capital, passed through education or by means of financial bequeathing, respectively. Our focus has been put on the *choice* determinants, rather than on the *production* features, of the mechanisms that transfer resources from one generation to the next. The key features included in the model are:

1) Educational choice of adult people for their descendents are primarily driven by status motivation and not by a perfect forward looking behavior concerning the human capital's return rate.

2) The "educational story" of each person is an important determinant of her *attitude* toward education, that results in her decision about her descendent's education.

3) The "educational story" involves both *personal* and *social* aspects of a person's past (as stressed by Ray (2003)): the family's educational background, as well as the "educational environment" to which the family belongs, contribute to form the habit that a person faces in her educational choices.

4) People are heterogeneous both in educational and wealth endowment: these different types of heterogeneity could, *in principle*, drive the economy through different paths.

The straightforward translation of these ideas into the hypothesis of a model are summarized in the utility function (2.1) where the independence of the educational investment from the return rate of next period's human capital and the presence of a habit term that includes both personal and average human capital can be noted, and the composition of the total wealth of a person is defined by expression (1.1).

The benchmark case that we refer to is an economy without habit[10]: in this case each agent split her wealth in constant proportions between consumption, financial bequest and educational investment. No matter what are the initial distributions of human capital and physical capital in the economy, all the accumulating variables grow at the constant rate g_{LB} and, as a consequence, the ratio between the wealth of the two groups does not change from its initial value. In this case the general equilibrium effect (GEE, explained in section 2.2) acts immediately and the steady state is instantaneously reached.

The extreme case is characterized by a very high habit concern by the side of adults: the strong habit effect (HE, explained in section 2.2), forces the better educated group to pass only human capital through education and the less educated group to pass only physical capital through financial bequest. The resulting equilibrium is one in which the GEE sets a common growth rate for both the groups due to the lack of degrees of freedom for the two groups: both are fully specialized in supplying only one of the two production factors and there is only one value of intensive capital that guarantees a constant growth rate. The steady state ratio between the wealth of the two groups is, in this case, independent from initial endowments.

The case of intermediate habit weight induces different behavior of the economy, depending on the value of γ, the habit weight parameter. We claim that for positive but low values of γ that bring to a steady state in which one group grow faster than the other, initial values of human and physical capital matter: letting (1.11) to hold and assuming people in group *2* to be more educated, this group will grow faster than group *1*. In other words the group relatively more educated will end up growing faster than the other group. In the case of the two groups that begin one close to the other (in the sense of human and physical capital endowments and, consequently, in wealth) the dynamics are initially

[10] Or, from another point of view, an economy characterized by a representative agent, where the hypothesized habit term loses its sense.

characterized by some periods in which both groups invest in both physical and human capital. Once the habit of people less endowed in human capital became too negative, these people will stop to educate their descendents and will pass only financial capital. The direct consequence is that people in group *2* will grow at a rate higher than those in group *1*.

The case of quite higher values of the habit weight leads again to the same groups' *bequeathing behavior* described in the previous paragraph, but this time the HE is so strong that the GEE cannot set, alone, the economy's growth rates. In this case the quite strong HE forces group *1* to pass only physical capital and, due to its intensity, to *temporarily* make the return rate on financial investment very high, through the overaccumulation of human capital by group *2*. This high return rate on financial investments makes group *1* to grow faster and this impedes the GEE to set the intensive capital in the economy. Conversely, the growth rate of group *1* soars until the circumstances reverse: the overaccumulation of physical capital by group *1* leads now to a decrease in its return rate. At the steady state the growth rates (of wealths, physical capital of agents of group *1* and human and physical capital of agents of group *2*) are all equal to g_{UB}, reached after some smoothing fluctuations. Also the ratio between the wealth of the two groups, at the steady state, is a finite constant, and the final value is reached, like the steady state growth rate, after some smoothing fluctuations. The more the habit weight increases, the more the above-mentioned ratio decrease and its limit is reached once that γ approaches γ_{UB}.

The framework that arise is one in which the *intensity* of the habit motive in educational investment drives the *type* of steady state and dynamics that an economy experiences. We have shown that with little habit the economy will grow with different growth rate and only one group will invest in education. If the habit is quite stronger the bias induced (by the habit itself) in educational investment makes the GEE intervention relatively stronger and in this case the "earning advantage" of educated people is eroded by the declining wage: the economy ends with the same growth rate for each agent, whether or not she's educated[11].

A lesson that we want to retain is that in an economy in which agents are endowed with a multiplicity of production factors (in this case two), these factors are "mixed" in order to achieve the maximum utility, under the given constraints. If constraints are too reinforced by externalities (or new constraints arise along the evolution of the economy) it can be the case that some degrees of freedom are no more available to agents and the behavior of the whole economy *changes in type*. In our case a mild habit externality restricts the choices of less educated agents, leading them to grow slower than the other group because of the constraint to not invest in education for their sons. With a little bit stronger habit weight the behavior is the *same*, but in this case the low relative intensity of the GEE prevents the better educated group to exploit its "education

[11] This conclusion is in a way consistent with the empirical evidence found by Checchi, Ichino and Rustichini (1999) that indicates for Italy (where we suppose habit forces are higher than in the US) a lower inequality (that in our model must be translated in a lower or null growth rates gap between groups).

advantage" and the two groups grow at the same rate of growth. A stronger habit weight leads to *another* behavior, forcing each group to choose only one factor of production to invest in: again the two groups grow at the same rate, but because of very different reasons compared with the previous cases.

To conclude, we again stress that our analysis focuses on the choice-side of the economy, so simulations' results have to be carefully interpreted: we believe that human capital production function can not be so "flat" as we built it, but this is the easier way to show our idea. Using our framework a high habit weight nullifies the growth advantage of educated people and, as a consequence, policies addressed to make the *slower group* (in principle, the less educated) to catch up (for example proportional taxation and lump-sum transfers) would be useless. Of course we have to keep in mind that the conclusions we have reached involves a linear human capital production function and no government intervention at all. For example, the higher is the habit's weight, the higher are the growth rates of the two groups (and, eventually, they reach the same *plateau*): although we know that a high rate of growth is a good goal for an economy, we find that, in the extreme case of high γ, it comes from a *completely polarized* economy in which agents' optimal choices are on corner solutions. It is straightforward to claim that, with a human capital production function involving human capital externalities and/or public education financed through taxation, things would be somehow different.

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Chapter 2

Aging, Technology Adoption and Growth: a Taxonomy

2.1 Introduction

In the economic and political debate, especially in Europe, both technologic advancing and population aging are gaining increasing importance. The political outcome of these debates is part of the Lisbon Agenda of 2000. Specifically, on the one hand, particular effort needs to be spent in transforming the European Union in "the world's most dynamic and competitive economy", by means of widespread knowledge-based technology. Reading between the lines allows us to think about this process of moving from a technological paradigm to a new one as the will of policymakers to *actively drive* this shift: economic history (and the related theoretical literature) is full of examples in which the best available technology is not implemented, due to intrinsic conflicts of interests between different actors of the economy. On the other hand, the fact that member countries are experiencing a rapid aging of the population (a combination of low fertility rates and a rise in life expectancy) led the European Commission to put increasing weight on it in judging member countries' policies, especially in the field of debt management and sustainability of pension systems. Within this context of aging population, Cremer and Pastieu (2000) are right in saying that pension systems' management is mainly a political, rather than economic, issue. Galasso and Profeta argue that the projected political power of older generations[1] can explain the high support that electors put on generous pension systems, despite their expected decreasing return rates in the future. Our concern is that also

[1] They calculate for the UK the age of the median voter to be 45 and 53 in 1997 and 2050, respectively. Patterns are similar for median voter's age in other european countries such as Italy, Spain and France.

long run economic growth could be (if not mainly, at least partially) a political issue if we allow the process of technology improvement to be the outcome of a centralized choice characterized by a conflict of interests among different age classes, as in Krusell and Rios-Rull (1996). The relation linking aging and technological improvement is, however, not at all clear. Focusing on the age composition of population could be misleading when we analyze the political and economic interplays among different types of *economic actors*, namely people studying, working, or retired. To this end, one of the focal points that we want to underline is how, in the last two centuries, the roles of students and retireds became very important in terms of size, economic needs and, moreover, political representativity. Our contribution is, in particular, to identify and analyze the two-sided link between aging and technologic innovation: one is *economic* and makes innovation preferred by adults once they have enough time to enjoy their savings in old age. The other is *political* and refers to the power that the old people have, once they have reached a certain size, to veto a costly technologic innovation whose gains can not be enjoyed by the old themselves.

The paper proceeds as follows. In section 2 we review historical data on education, retirement age and life expectancy. Section 3 reviews the literature on aging, technology adoption and growth. Section 4 proposes our unified view. Section 5 presents the model, some policy implication and further research lines. Section 6 concludes.

2.2 Overview on historical trends

In this section we review, under an historical point of view, the age structure of developed countries, in terms of the *role* of different age class in the economic life. Our aim is to stress how impressive are these changes in the composition of the population, in the light of the political and economic implication we suggest in our theoretical model. At the beginning of 19th century people entered the labor market when very young (almost no public school where in place at that time), they worked for almost their entire lifetime and used to retire at the very end of their life. Around 1850 things did not changed very much: people aged 5-14 enrolled in primary school were less than 10% in United Kingdom (Galor, 2005) and the expected length of retirement at age 20 was, in the US, below three years (Lee, 2001). At the same time, life expectancy at birth was around 40 (Galor, 2005). In 1930 average years of education was less than 8 years and life expectancy rose to 59.7 years, with an expected retirement period length of 5 years. When focusing just on retirement and life expectancy[2] we note substantial changes occurred in the last century, both in magnitudes and trends of the series. In figure 1 we show, for US males aged 20, that the steady

[2] Though the dynamics of education are very impressing, in terms of growth and diffusion, in this paper we only address aging matters in term of increasing relative weight of old people with respect to adult, without analyzing students. We think that a natural extension of this study is to include the formation of human capital, allowing for a different class of agent with specific economic and political interests.

increase of life expectancy at birth is positively correlated with retirement age between late ninetieth century 1950, while it reversed once the welfare state developed**.** At the same time the percentage of life spent as a retiree changed from 2.7% in 1880 to 17.4% in 1990, respectively.

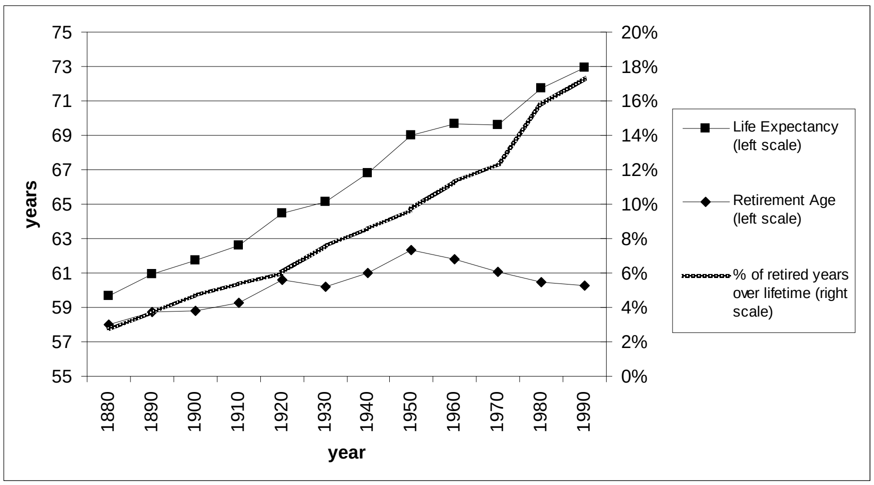

Fig.1. Life expectancy, Expected length of retirement period and percentage of life spent as a retiree for US males. Souce: Lee (2001), our calculations.

For european economies these kinds of trends are similar but magnified in several senses. First of all life expectancy is increasing more in Europe than what is happening in the US. In 2004 it was 76.3 for EU-12 males and 75.2 for US males, while it is projected to be 82.1 and 79.5 in 2050, respectively (`www.cdc.gov/nchs/` and Carone and Costello, 2006). European welfare systems are more developed than US welfare state, so european workers retire, on average, before their homologues in the US (in 2000 US male workers retired at age 62.6, while in Western Europe the average was 60). Finally, the lower fertility rates that european countries are experiencing nowadays[3] shrink from below the demographic distribution, shifting upward mean and median age. The increasing weight of retired population, combined with their historically higher turnout rate at elections[4], makes their presence always more sizeable and important in political choices involving changes that applies to agents with different roles.

[3] Total fertility rate in 1997 was 2.06 in the US while it was 1.40 in EU-12. In 1980 they were similar around 1.82, then started to diverge. (`www.europa.eu.int/comm/eurostat/`).

[4] Galasso and Profeta (2004) report that the turnout rate among people aged 60-69 relative to people 18-29 is double in the US and 50% higer in France.

2.3 Aging and technology adoption literatures

The literature linking aging and economic growth mainly focuses on empirical, country-specific studies about the sustainability of the pension system. A common feature of these studies is to simulate the projected social expenditure (and other significant economic variables such as the amount of savings, the government balance, etc.) under different scenarios of growth rates and demographic dynamics. Due to this approach, in this kind of framework the interaction between demography and growth are not explicited. One exception is Lindh and Malmberg (1999), where they test how the demographic structure affects the growth rate of OECD economies. They find, but do not justify theoretically, a negative correlation between output growth and the share of people over 65 and a positive one with the share of people aged 50-64. Thus the (relative) aging that OECD countries are experiencing in the last years should lead to a decrease of the growth rate of per capita income. Conversely, in developing countries Barro and Sala-i-Martin (1995) find significant positive effect of life expectancy on the growth rate of per capita income. In this paper we suggest an explanation to this non-monotonic relation between aging and economic growth, highlighting the different determinants of the abovementioned relation.

In the theoretical field, most of the work concentrates on the study of the demographic transition occurred during the industrial revolution. In particular Galor and Weil (2000), Kalemli-Ozcan (2002) and Doepke (2004) studied the interrelation between the switch to quality of children (rather than quantity) and the beginning of a regime of sustained economic growth. A key feature of any demographic transition is the lengthening of life expectancy of people. Again in the context of the industrial revolution (and, in general, in the transition from agriculture to industrial production) work have been concentrated on the decreasing opportunity cost of acquiring human capital with the lengthening of life expectancy, in the usual framework used, between others, by Cervellati and Sunde (2005) and Boucekkine et al. (2002). Both built on a monotonic increase of human capital investment with life expectancy, but the former shows a monotonic relation between life expectancy and growth rates, while the latter allows for a decrease in growth rate after some values of life expectancy, determined by the use of a vintage capital formulation for the production of human capital. Without contrasting this view, supported by the empirics of Barro and Sala-i-Martin, we focus on another issue, namely the lengthening of people's retirement period. The reason is simple: the cited works essentially study the demographic transition occurred before and during the industrial revolution, while the dynamics we observe in the last decades (mainly in developed countries) show a somehow different picture. Beside the evidence we presented in Section 2, Lee (2001) shows that for 20-year-old american people, between the end of nineteenth century and 1990, the retirement period's length has increased four-fold and its ratio to life expectancy has increased three-fold. These data suggest how the retirement period is becoming a significant share of human life and how fast this share is growing in magnitude, relatively to the whole lifetime and the working life.

The literature on technology adoption is very wide, ranging from Schumpeterian growth model to agent-based model of knowledge diffusion. We restrict our attention to OLG models of vested interests: the reason is because in our model we need to aggregate choices *between* agents of different generations and to characterize the property of different ages *within* each generation. The mechanism behind every model of vested interests in technology adoption is the asymmetric gain that agents experiencing a new technology get, due to their heterogeneity: heterogeneity can be either within the same generation (for example skilled/unskilled workers) or between generations (youngs and adults, having different time-horizon). The two formulations have been jointly studied by Krusell and Rios-Rull (1996) in a model where three generations are alive at the same time and the generations themselves are internally heterogeneous in terms of skills. Their main conclusion is a methodological one: it is relatively simple to find a policy that leads to sustained growth, but the very hard task is to find the determinants of this policy, once it is endogeneized in the model. In fact their results are specific to the distribution of skilled (managers) and unskilled agents, but regularities are hard to find in determining links between these distributions and the kind of equilibrium achieved (growth, stagnation, cycles). Bellettini and Ottaviano (2005) built a model of innovation through a regulator that reacts to lobbing activity of the different generations alive in each period. Cycles of innovation-stagnation can arise in equilibrium and they are characterized by dynamic inefficiency: the introduction of a infinitely lived social planner would lead the economy to a sustained growth path, with always increasing technologic level, per capita income and utility. The possibility of cycles is determined by the short time horizon of old workers: since they would lost from the introduction of a new technology because of their human capital that is specific to the previous technology, they lobby for a policy of "no innovation" using their resources. If their resources are high enough to beat youngs' contributions to the regulator, a "no innovation" policy is implemented by the regulator.

2.4 A unified view

Until nowadays, technologic adoption and population aging have been studied separately in two different strands of literature. One paper that attempts to unify the analysis is Canton et al. (2002) where authors describe a three-period OLG model in which agents choose to adopt a new technology by means of majority voting mechanism. Their comparative static results are that an increase of life expectancy or a reduction in the productivity gap between contiguous technologies can harm the adoption of a new technology. Our purpose is to adopt the mechanism of voting on a new technology but to allow for an endogenous increase in life expectancy (the retirement period length of old people) and a clear separation of the role of different age classes in the economy. In our view the mean by which people get their income in different stages of their life is crucial in determining their political choices due to the different interests involved (i.e. labor/capital income). Two mechanism are in place in our view: one runs from technology adoption toward aging and is described in the next paragraph, the other runs in the opposite direction and incorporates both *economic* and *political* matters. The former refers to cost-benefit analysis based on the returns from capital investment, labor income, productivity increase and life expectancy itself. The latter counts for the shift of political power toward old agents, which are against technology adoption as in the standard literature. The interplay of these forces makes economies to evolve in different fashions, driven by initial conditions and production and utility parameters.

In our model we endogeneize the probability of surviving in old age linking it positively to the technology level reached by the economy, namely the TFP. Another way to study this issue could have been to introduce in the model directly the length of life, rather than the probability of surviving, but this would have needed more assumptions and a slightly more cumbersome modelling of the time structure[5]. One facet that we want to stress is the nature of the determinant of expected probability of surviving in the old age: as Mokyr (1998) underlines, in the last century people's length of life is a matter of *widespread* health/knowledge conditions, such as vaccines and health infrastructures, rather than *individual* knowledge (such as water sanitation, food-cooking habit, etc.) that characterized earlier periods. Following him, we decided to relate life expectancy to an economy-wide measure, such as the TFP, rather than to an individual-specific measure like human capital[6].

2.5 The model

We set up a model whose aim is to incorporate the demographic and politico-economic features of nowadays economies, in order to point out the links between aging and technology adoption. To this end, we design a clear separation between the stages of agents' life, in terms of economic roles, incentives, political power and interests. Our economy is populated by agents living at most for two periods, with a probability p_t of surviving from adult to old age[7]. In every period of their life agents vote in favor or against the adoption of a new technology, that will be available in the next period. The adoption is decided by means of a majority voting rule and the political weight of an adult and an old agent are 1 and $\eta > 0$, respectively[8]. The political power of old people increases with the number of people alive in old age and this probability is assumed to be

[5] In what follows, we will use the terms life expectancy and probability of surviving in old age as if they had the same meaning.

[6] In this paper things would not change because we have identical agents and, introducing human capital, there are no differences between individual and economy-wide measures. In fact, both human capital and technologic level are non-decreasing in time in all standard model of growth. Thus the difference here is just conceptual, but it would change some conclusion intruducing heterogeneity of agents.

[7] Though we model the probability p_t to depend on the past technologic level A_{t-1}, in the rest of the paper we avoid the use of the notation $p(A_{t-1})$, where unnecessary, and we simply write p_t.

[8] Detailes are in subsection 5.4.

positively related with the technological level achieved by the economy. For a new technology to be implemented after the vote, every agent (adults and old) has to pay a fixed proportion of their income. Adults work and split their *net* labor income between consumption and saving for their retirement. Moreover, once people become old (but before any other events including, in case, dying), each of them give birth to one adult[9]. Old people consume the *net* return from their investment and then die. If, at any point in time, a new technology is not implemented, the net income of each agent coincides with her gross income.

Production uses labor and capital to produce a single output, that can be either consumed or saved.

2.5.1 Agents

At time t agents of generation t born already adults. They are homogeneous of measure one and they get utility from adult and old age consumption. The weight they attach to old age consumption increases with their probability (whose realization is unknown when adult) of reaching old age $p_t \in [\underline{p}; \bar{p}]$, where $\underline{p}$ is the probability of surviving in old age at time t_0 and $\bar{p}$ is the the biological upper bound of the probability of surviving. Their ranges are summarized as $0 < \underline{p} \leq \bar{p} \leq 1$. Later we will show how p_t evolves. The utility of the representative agent adult at time t is:

$$u_t = \log c_t + \beta p_t \log c_{t+1} \tag{2.1}$$

Every adult supply inelastically one unit of labor and get the gross labor income w_t, where w_t is the wage, taken as given. If a new technology is decided to be adopted at time t, every adult has to pay a fraction $i_t = i$ of her income. Otherwise, in the case of a no-innovation policy, $i_t = 0$. The net income is divided between consumption c_t and savings s_t. In the old age, she consumes the return from her investment, net of a fraction $i_{t+1} = i$, if a new technology is adopted at time $(t + 1)$. The budget constraint is represented by

$$\begin{cases} s_t + c_t \leq w_t(1 - i_t) \\ c_{t+1} = s_t \frac{R_{t+1}}{p_t}(1 - i_{t+1}) \end{cases} \tag{2.2}$$

The variables i_t and i_{t+1} are discrete and they can either take the values $i_\tau = 0$ or $i_\tau = i$, with $\tau \in \{t; t + 1\}$ and $0 < i < 1$. We think about i as the *frictional cost* of innovation, rather than a tax used to finance some kind of investment. As in Blackburn and Issa (2002) we allow for a fair annuity market that redistribute the savings of deceased to people that remain alive: this is explicited dividing R_{t+1} by p_t.

[9] We could restate the model in terms of a three-period OLG, where, during youth, people are totally passive and once they became adult they behave as described in the text.

2.5.2 Production

The production technology of the single good in the economy is described by a constant return to scale Cobb-Douglas function that uses labor and capital as inputs. At time t production is:

$$Y_t = A_t K_t^{\alpha} L_t^{1-\alpha} \qquad 0 < \alpha < 1 \tag{2.3}$$

where A_t is the level of technology available at time t, K_t is the aggregate capital (that fully depreciates in one period) and $L_t = L = 1$ is the aggregate labor. In the production process, a new technology brings about a better way of producing the final good through an higher TFP: $A_t = A_{t-1}(1+\delta)$, with $\delta > 0$, if a new innovation is chosen at time $(t-1)$, $A_t = A_{t-1}$ otherwise. A technology improvement is undertaken if the political majority of the population votes in favor of it (i.e. the weighted median voter). The new technology is financed by the frictional cost that we have defined above: the share i of both adults' wages and old people's savings.

2.5.3 Probability of surviving

In the introduction we have already outlined what drives our choice of the determinants of the probability of surviving in old age: we assume that p_t follows a bounded, monotonic increase from $\underline{p}$, the initial expected probability of surviving, to $\bar{p}$ as a function of the level of technology in the economy, the TFP parameter A_t. We model this as an externality, out of the control of agents. More precisely, we assume that p_t, the probability of living in old age of people adult at time t, is a function of A_{t-1}, that is the technology implemented in the economy during the period before people of generation t are born. The function is described by (2.4). This means that innovations experienced by people during their own adulthood and old age do not affect their probability of surviving.

$$\begin{cases} p_t = \underline{p}; & A_{t-1} < \underline{A} \\ p_t = p(A_{t-1}); & \underline{A} \leq A_{t-1} \leq \bar{A} \\ p_t = \bar{p}; & A_{t-1} > \bar{A} \end{cases} \tag{2.4}$$

where $\lim\limits_{A_{t-1} \to \underline{A}^+} p_t = \underline{p}$; $\lim\limits_{A_{t-1} \to \bar{A}^-} p_t = \bar{p}$ and $p' > 0$. With this kind of specification, we want to emphasize the way in which technology impacts on the life expectancy of people. In figure 1 we show one of the possible form of the function $p(A)$.

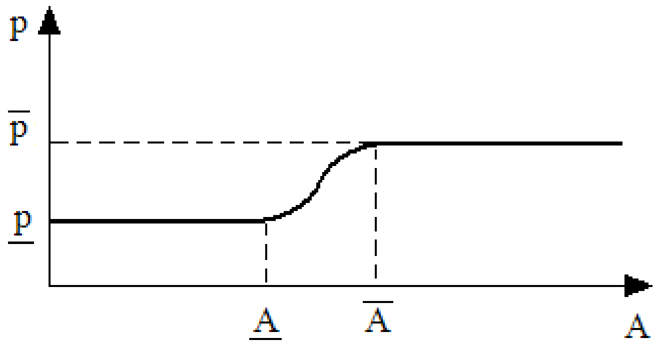

Fig.2. Probability of surviving as a function of TFP

Below the threshold $\underline{A}$ the determinants of probability of surviving could be explicited (for example the human capital level of agents) but, since this is not the aim of our research, we take p_t as given and constant, equal to $\underline{p}$. Above the threshold $\bar{A}$, probability of surviving reaches its biological limit, and no technological improvements can further prolong it. Between $\underline{A}$ and $\bar{A}$ life expectancy increases every time a new technology is implemented: again, we think about *extensive* innovations, like cures against cancer, better nutritional guidelines or widespread vaccines that depends on the existing technological environment in the economy, rather than the human capital that agents are endowed with.

2.5.4 Political mechanism

The decision to implement or not a new technology is undertaken by means of a weighted majority voting rule at every period t. The two groups involved in the voting are adults and old of generation t and $t-1$, respectively. The standard result is that the bigger of the two groups is the one to decide upon the social choice involved. In this case adults weight one and are numerically of measure one, while old weight $p_t\eta$ (where p_t is their size, obviously less than one, and η is their individual political power). In the case of $p_t < \frac{1}{\eta} = \tilde{p}$ the adults decide, while, with an opposite inequality sign, the old set the agenda[10]. We call $\tilde{p}$ the *political* threshold.

[10] Of course we need η to be higher than one in order to have the political power in the hands of old agents: what Galasso and Profeta (2004) report about turnout rates (note 4) helps us in allowing for this case.

2.5.5 Timing

The timing of the agent's relevant choices is described below. Steps from 1 to 4 represent agent's adulthood and steps 5 to 9 span the old age:

1) Agent is born
2) Votes over technology innovation (effective in the next period, step 5)
3) Works getting $w_t(1-i_t)$
4) Consumes and saves
5) Originates one descendant
6) With probability p_t she stays alive
7) Votes over technology innovation (effective in the next period, when the agent is passed away)
8) Gets the net returns from savings $s_t\frac{R_{t+1}}{p_t}(1-i_{t+1})$
9) Consumes and dies

2.5.6 Optimizations

We now solve the optimization problems of both firms and agents, and for the agents we will solve the problem for both adults and old.

Firms

Since firms produce in a perfectly competitive environment, the producers' inverse demand for factors of production, from (2.3), is:

$$\begin{cases} R_t = \alpha A_t k_t^{\alpha-1} \\ w_t = (1-\alpha)A_t k_t^{\alpha} \end{cases} \tag{2.5}$$

where $k_t = \frac{K_t}{L_t} = K_t$, w_t is the wage per unit of labor and, given a complete capital depreciation, $R_t = r_t$ is the return rate on investment in this factor of production. Since $K_t = s_{t-1}N_{t-1}$ and $L_t = 1$, we can write $k_t = s_{t-1}$, where s_{t-1} are the savings of the representative adult of generation $(t-1)$.

Agents

Agents have three choice variables: in every period of their life they vote in favor or against a technologic innovation policy, and during their adulthood they choose how much to save of their net labor income. Saving is the only choice completely under agent's control, while votes of different agents are summed up by means of a weighted median voter mechanism. In every stage of her life, an agent take as given past outcomes of the voting mechanism, perfectly foresee next period values of the economic variables (i.e. future rates of return on capital) and maximize her utility. She can not commit herself to a specific vote from one period to the next. Due to the log specification of the utility function, its maximization with respect to s_t involves, after replacing c_t and

c_{t+1}, only predetermined variables such as w_t and p_t and the variable i_t, chosen by majority rule at time t.

$$\frac{\partial u_t}{\partial s_t} = 0 \Leftrightarrow s_t^* = \left(\frac{\beta p_t}{1+\beta p_t}\right) w_t(1-i_t) \tag{2.6}$$

The optimal saving s_t^* is, therefore, a share of net labor income, whose magnitude increases with old-age life expectancy p_t. Plugging the optimal saving into (2.1) we get the indirect utility function as a function of the two dichotomic choices of innovation/not innovation in the different periods of her life.

$$u_t^{IND} = \log\left[\left(\frac{1}{1+\beta p_t}\right) w_t(1-i_t)\right] + \beta p_t \log\left[\left(\frac{\beta p_t}{1+\beta p_t}\right) w_t(1-i_t)\frac{r_{t+1}}{p_t}(1-i_{t+1})\right] \tag{2.7}$$

In the next grid we summarize the costs and the direct effects in the case of the adoption of a new technology in the two stages of agent's life.

	ADULTHOOD	OLD AGE
Cost of Innovation	$w_t i$	$s_t r_{t+1} i$
Direct Effects	$A_{t+1} \uparrow \Rightarrow r_{t+1} \uparrow$	None

When adult, the cost associated to innovation is a share i of her labor income and the advantage she gets is a better productivity parameter: this, in turns, makes r_{t+1} to rise. When old, she has to pay for a new technology to be implemented, but she does not experience any direct effect: it is straightforward to note that elderly people, since they are modeled to be not altruistic towards their progenies, are always against innovation.

Political-economic outcomes

In this subsection we describe the specific problem the agent (of generation t) faces at the two different stages of her life when the pivotal voter belongs, in every period, to the same age group.

Old age. When old, the agent faces the decision to vote in favor or against innovation, taking as given everything else. Looking at (2.7) it is clear that the best choice is to vote against innovation: with no gains from innovation, she has to minimize her costs setting $i_{t+1} = 0$.

Adulthood. When adult, she takes as given the variables w_t and p_t, forms correct expectations about i_{t+1} (taking them as given and out of control) and votes over i_t. Since the utility function is additively separable, expectations about next period's adults' choice on i_{t+1} do not change the agent's problem, therefore she will vote in favor of innovation if and only if the differential utility between innovate and not innovate is positive:

$$\Delta u_t^A = (1+\beta p_t)\log(1-i) + \beta p_t \log\left[\frac{r_{t+1}^I}{r_{t+1}^N}\right] > 0 \tag{2.8}$$

where Δu_t^A stands for the differential utility innovate/not innovate from the viewpoint of an adult, the superscript I stands for innovate and N for not innovate. Note that there is no time subscript attached to the i in the first log because that is the ex-post cost of innovation, once the decision to innovate is undertaken. From (2.5) and the effects of technologic innovations on A_{t+1} we simplify the expression above:

$$p_t > \frac{-1}{\beta\left((1+\alpha) + \frac{\log(1+\delta)}{\log(1-i)}\right)} = \hat{p} \tag{2.9}$$

We call $\hat{p}$ the *economic* threshold. It is positive if and only if the denominator is negative, so we study the cases in which $(1+\alpha) + \frac{\log(1+\delta)}{\log(1-i)} < 0$. Given this restriction we can state that an adult will be more likely *in favor* of innovation the *smaller* is the frictional cost i. Her propensity to vote for innovation will also be increased by *high values* of δ, the direct effect of technology adoption on TFP, and β: this because the adult is willing to pay the frictional cost i only if she would enjoy a *large* increase of utility deriving from old age consumption. Moreover, the *higher* is the share of production going to capital, α, the lower is the propensity to innovate: this because high values of α, through $(1-i)^{\alpha-1}$ in the expression of r^I_{t+1}, drain a lot of *net* saved resources and make innovation less attractive.

2.5.7 Intertemporal equilibrium

We can now derive how an economy evolves, starting from its characteristic parameters of production and utility functions, the shape of the function linking p_t to A_{t-1} and the political weight of old people, η. At time $t = 0$ there are p_{-1} old and (a measure of) one adults alive, the generation named 0. Old are endowed with capital k_0. With the hypothesis that at time $t-1$ no innovation had occurred, we can write $p_0 = p_{-1}$. Obviously, A_0 has to be consistent with the relation $p(A)$ described in section 5.3 above. To obtain the intertemporal equilibrium we need that the savings at time t form the capital used at time $(t+1)$: $k_{t+1} = \left(\frac{\beta p_t}{1+\beta p_t}\right)(1-\alpha)A_t k_t^\alpha (1-i_t)$. The other dynamic equation is the one that rules how the technologic parameter A evolves: we have $A_{t+1} = A_t$ in the case of no innovation and $A_{t+1} = (1+\delta)A_t$ in the case of innovation, and the decision to innovate or not is undertaken by the weighted majoritarian group.

Formally, a competitive equilibrium, given the initial stock of per capita capital k_0, the initial level of life expectancy p_0 and a (coherent) initial TFP level A_0, is a sequence of k_t, w_t, R_t, A_t and p_t, $t = 1, 2, \ldots$ such that:

a) innovation is decided by means of a weighted majority voting. This affects A_{t+1} and p_{t+1};

b) each adult selects the amounts of savings optimally, given her endowment and the correctly anticipated innovation policy, market prices and life expectancy p_t;

c) savings aggregate in k_{t+1};

d) w_t and R_t equal the marginal productivity of labor and capital, respectively.

There are three different cases in which an economy can end up: we call these cases stagnant, stopping and growing economy, respectively.

Stagnant economy

A stagnant economy is characterized by a constant steady state per capita capital $k^* = \left[\left(\frac{\beta \underline{p}}{1+\beta \underline{p}}\right)(1-\alpha)A_0\right]^{\frac{1}{1-\alpha}}$ and no innovations at any point in time: $A_{t+1} = A_t = A_0$. This equilibrium can be reached under two different configurations on the initial value p_0: either (i) the innovation process is not attractive due to a too low probability of surviving, i.e. $p_0 < \hat{p}$, and in this case is the economic threshold that binds, or (ii) the political power of old people is high enough to avoid innovation from the beginning, i.e. $p_0 > \tilde{p}$. This is the case in which the political threshold binds. Moreover, independently on the initial value A_0 (and p_0), we observe a stagnant economy whenever $\eta > -\beta\left((1+\alpha) + \frac{\log(1+\delta)}{\log(1-i)}\right)$, that explicits the condition $\hat{p} > \tilde{p}$. The main point to note is that a stagnant economy can be the outcome of two very different economic processes: in the former is the decision to not innovate, decided by adults, that avoid the economy to innovate and, as a consequence, harms the old not permitting them to increase their life expectancy. In the latter is the old generation, due to its great political power, that makes its choice to be implemented: no expenditure in innovation in order to sustain old-age consumption. Under a descriptive point of view, we could view the former case the one of sub-saharan african countries, while the latter case the one of so-called Old Europe.

"Stopping" economy

A stopping economy is characterized by some initial periods of growth of both per capita capital and technology and then a sudden stop, once the old get the majority in the voting mechanism. In order to get this case, we need the chain of inequalities $\hat{p} < p_0 < \tilde{p} < \bar{p}$ to hold. The first inequality states that, at least initially, innovation is attractive. For some periods two equations drive the economy: $k_{t+1} = \left(\frac{\beta p_t}{1+\beta p_t}\right)(1-\alpha)A_t k_t^{\alpha}(1-i)$ and $A_{t+1} = (1+\delta)A_t$. At some point in time, let's say $t = s$, p_t reaches the political threshold $\tilde{p}$ that makes old generation to be the political majority. This is ensured by the third inequality: old's majority is reached before the probability of surviving reaches its biological maximum $\bar{p}$. From $t = s$ onward the economy evolves as in the case of stagnant economy described above, but with the steady state per capita capital $k^{*s} = \left[\left(\frac{\beta \tilde{p}}{1+\beta \tilde{p}}\right)(1-\alpha)\tilde{A}\right]^{\frac{1}{1-\alpha}}$, where $\tilde{A} = A^{-1}(\tilde{p})$, that is uniquely defined since $p(A)$ is increasing between $\underline{A}$ and $\bar{A}$ (look at Section 5.3 for details). Without forcing too much the predictive power of the model, we can think about India: high fertility rates are slowly decreasing, preparing the field for a relative aging of population once the demographic dividend[11] vanishes: this could bring in the

[11] The demographic dividend refers to the time window in which there is an increase of workforce relative to non-workers, such as retired and youngs (de la Croix et al., 2006).

next future a stop in technologic innovation once the large share of today's young people will age.

Growing economy

The economy grows forever, governed by the equations $k_{t+1} = \left(\frac{\beta p_t}{1+\beta p_t}\right)(1-\alpha)A_t k_t^{\alpha}(1-i_t)$ and $A_{t+1} = (1+\delta)A_t$, in the case of $\hat{p} < p_0 < \bar{p} < \tilde{p}$. This because, apart from the initial propensity to innovate ensured by the first inequality, old do never get the majority: the third inequality states this condition. In the same fashion as before, we can think, in this example, to China. In this case very low fertility rates are beginning to grow, leading the economy to a fall in relative aging: this is one of the factors that could sustain China in its, at least for now, steady growth.

2.6 Policy implications

We now discuss some policies and their effectiveness in moving an economy from a steady state characterized by constant per capita capital to a steady growth state. First of all, referring to figure 3, in order to have a non-empty set characterizing the growth region, we need that $\hat{p} < \tilde{p}$. Remember that this means that, at the some point in time, old people are not too influent in the innovation choice and the net adults' benefit from innovation are not negligible. Referring again to figure 3 we find that for a poor country, characterized by a low TFP level (below $\hat{A}$) and, as a consequence, short life expectancy, the more effective policy is to rise exogenously the life expectation by means of an improvement in health (widespread vaccines against lethal illness, investment in hospital, water sanitation, etc.). This policy is represented by the upward shift of the left branch of the function $p(A)$: once a higher p_0 is implemented, for the given A_0, the economy will experience innovation up to $\tilde{A} = A^{-1}(\tilde{p})$.

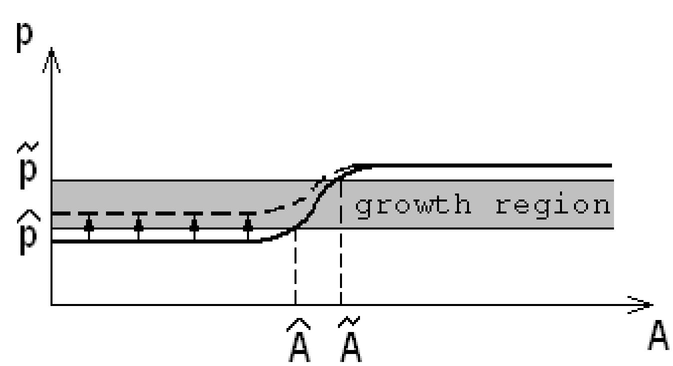

Fig.3. Effect of widespread vaccine in least developed countries.

Other policies can be designed in order to shift downward the abovementioned economic threshold $\hat{p}$, as the mechanism in subsection 5.6.2 describes. In figure 4 we show that once a lower economic threshold $\hat{p}'$ is implemented, every economy starting before $\tilde{A}$ grows until $\tilde{A}$ itself. More important, policies only oriented toward the narrowing of political power of old (every policies that lowers η) are completely ineffective for economies below $\hat{A}$, since the political threshold $\tilde{p}$ does not bind.

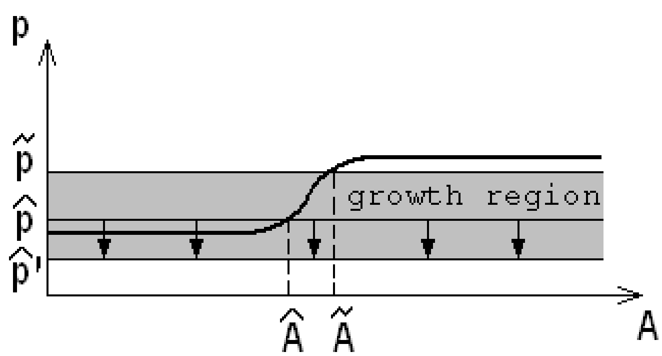

Fig.4. Effect of policies that enhance innovations' net returns

The other way round is true for developed economies: in this case is the political threshold $\tilde{p}$ that binds, so the only policy that are effective are policies that increase the relative political weight of adults with respect to old people.

2.7 Conclusions

We have presented a simple framework designed to address the links between aging, technology adoption and growth. We have identified two channels through which people act in the economy. One is *economic* and refers to the choice an agent makes in terms of evaluating the cost and benefit associated to the adoption of a new technology. With this respect, an increase in life expectancy always leads adults to adopt a new technology more likely, in line with standard literature. The other channel, the *political* one, makes old people to be pivotal in the process of voting upon a new technology once the life expectancy is long enough. Being the old always against innovation, at some point they will stop the process of innovation. Our main finding is that technology adoption can be prevented in the case of both very short or very long life expectancy. The former case corresponds to the one in which adults are not willing to innovate because the frictional cost of innovation does not "pay back" in the old age, that is too short. The latter case refers to the case of a *gerontocracy*, where old impose, by means of majority voting, their opposition to technologic improvements, whose gains are not internalized by them in future periods. Though the empirical evidence of this mechanism can be very difficult to isolate, we think that the implication of aging on economic growth *via* the adoption of new technologies needs to be taken into account in the process of designing sound policies in the future. The political feedback running from aging to technology adoption should be deeply studied in future research as well as all the other political channels already addressed such as the problem of pension systems sustainability and debt management.

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Chapter 3

A Politico-Economic Model of Aging, Technology Adoption and Growth (with Francesco Lancia)

3.1 Introduction

Over the recent past–no more than two hundred years–the Western World has experienced an extraordinary change in the economic environment and in all aspects of human life. We can observe that, in this period, all OECD countries have experienced a dramatic increase both in the longevity of their citizens and in the aggregate and per capita income. Simultaneously, the traditional social environment changed profoundly: the proportions of the population that were educated, and that were retired, increased significantly, causing the proportion of working people to shrink.

Looking at the details, we can stress some qualitative and quantitative facts behind these features of the economies. Life expectancy in the last century and a half increased tremendously: in 1850 it was below 60 years in US (Lee, 2001) and around 40 in England (Galor, 2005), while today it almost reaches 80 years (Fogel, 1994). At the same time, both the shares of lifetime that people devoted to education and retirement increased. In 1850 the percentage of people enrolled in primary education was less than 10%, so, on average, the time devoted to schooling was negligible. Now people, adding up informal (child caring carried out by parents) and formal schooling, study for around 20 years, one quarter of their expected lifetime. The participation of people in retirement shows similar trends: in 1850 less than three years were devoted to retirement, while today, especially in Europe, thanks in particular to the introduction of social security systems after World War II, people retire for almost 20 years:[1] again, one quarter of their lifetime (Latulippe, 1996).[2] In figure 1 we show how life expectancy and its components, in terms of economic roles of people, evolved in the last century and a half, for the USA. In Europe some trends presented here are even more evident: in particular, life expectancy increased more rapidly (from a lower level to a higher level than in the US) and retirement length increased more.

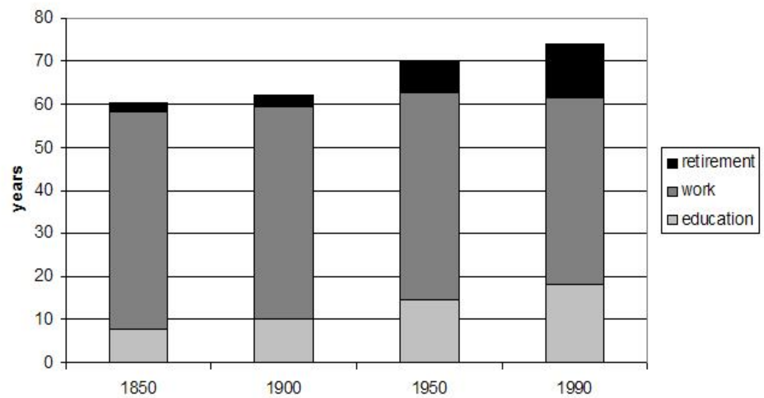


Fig.1. Life expectancy and economic roles in the US. Source: Lee (2001), www.bls.gov, and our calculations.

One of the most important implications of these trends is that developed countries are changing their political structures, moving from a form of *"workers' dictatorship"* to a more diluted political representation: the voices of both young and retired people in the political debate continually increase, and intuitively their interests should not coincide with the interests of adult workers. This almost certainly impacts on the composition of the aggregate demand. Consider, for example, the increasing demand for expenditure in health care for elderly people, residential structures for retired people, old age entertainment, etc. Here we are, however, interested in the production side of the economy, specifically in the mechanisms that run from individual and aggregate preferences to the production process and which could be affected by demographic, and therefore political, changes. A conflict of interests among age classes, in terms of production choices, will probably arise between workers and students, if these are innovation-prone, and retired people, who are not interested in technologic innovation, since their real income is not tied to their own labour income, which is linked to the *past* innovation choices. Moreover, a conflict of interests can also arise between young people and adults: for the former innovation has long lasting effects, since it affects both their productivity in the labour market once they will be adult and their children's capacity to acquire human capital. For the latter, a new technology impacts on the ability of their children to pay them a pension. These different incentive schemes would hardly be identical.

[1]All data come from www.census.org and our calculations.
[2]For European data see Galasso and Profeta (2004).

Since our theory rests on the idea that human capital and technology are the two engines that boost economic growth,[3] we analyze how a longer life expectancy affects the dynamics of these two variables. In this framework we analyze, by means of a three-periods overlapping generation model in which life expectancy endogenously changes, the interactions among education, technological change, aging and growth.[4] What we have in mind are the potential conflicts of interests that arise among different generations. Due to different time horizons and economic incentives, individual and aggregate choices can endogenously change because of the demographic evolution of population.

The purpose of this work is to provide an illustration of how an economy might evolve when life expectancy mainly affects both private and public choices concerning the production side of the economy and, therefore, the growth process. The paper is organized as follows. In section 2 we specify what we consider "systemic innovation". Section 3 presents the model. Section 4 contains a simple dynamic example. Section 5 concludes.

3.2 Systemic Innovation

Innovation is a discontinuity in knowledge and, therefore, in production techniques, whose outcome is an appreciable increase in productivity. With the same resources the system is capable of producing more goods, or it is capable of producing the same quantity of goods with less resources. We refer to a systemic innovation[5] as to a type of innovation that, in order to be implemented, has to pass through the endorsement of a political mechanism, where, in general, the interests of different groups of agents (consumers, producers, the government, high/low skill groups, etc.),[6] do not coincide. The public nature of systemic innovation, in contrast with the Schumpeterian view of innovations developed by firms running for the best cost-saving technology, comes from the historical point of view where the implementation of a new technology is rarely the outcome of pure profit-maximizing by firms.

The public nature of systemic innovation requires a different innovation model in comparison with linear ones based on R&D and, consequently, on innovation and technological transfer. Accordingly to Mansell and When (1998),

[3]It has been increasingly recognized that both human capital formation and technological changes play important roles in economic growth (Lucas, 1988; Romer 1986). That is, the improvement of knowledge and skills embodied in labour, as well as changes in technology, mostly embodied in physical capital, determine the potential for moving the production frontier outward.

[4]Recent studies have shown, at least theoretically, that economic growth is helped by an increase in life expectancy (Galor and Weil, 1998; Blackburn and Cipriani, 2002; Cervellati and Sunde, 2005).

[5]We take it that there is no uncertainty in the outcome of a new technology of this kind: once the decision to shift to the new technology is undertaken, with probability one a productivity enhancement takes place. It follows that we are not dealing with risky process of producing new ideas, but with the process of implementing existing ideas in new ways that are more efficient, although not for everybody in the same way.

[6]In our framework the contrast evolves among different age groups.

the systemic innovation model can be defined as a *"chain model"*, characterized by interdependence between both the development of knowledge and its application to the production processes and negotiation of interests among different agents. Innovation used to be a linear trajectory from new knowledge to new product, now it becomes neither singular nor linear, but systemic. It arises from complex interactions between many individuals, organizations, and their operating environment.

Following the historical point of view delineated by economists like Mokyr (1998a, 2002) and Olson (1982), in this study we focus our attention on systemic innovation as a growth-enhancing technology. Bauer (1995) points out that a decentralized market outcome seems to be a poor description of many technology breakthroughs. Economic convenience is certainly not irrelevant, but, as Mokyr (1998a) suggests: *"there usually is, at some level, a non-market institution that has to approve, license or provide some other imprimatur without which firms cannot change their production methods. The market test by itself is not always enough. In the past, it almost never was."* (p. 219) Thus, as reported by Olson, the decision whether to adopt a new technology is likely to be resisted by those who lose by it through some kind of activism aimed at influencing the decision by the above-mentioned institutions.

Consequently, we construct a model in which, for endogenous reasons, technology adoption is delegated to a regulatory institution, the democratic vote. We formalize the idea that an innovation, before being introduced in large-scale production, has to be approved by some non-market institution. Its adoption is *ex-post* disposable for all individuals in the economy, but *ex-ante* the choice to adopt it or not can be affected by the interests of different age groups. According to Bellettini and Ottaviano (2005), the central authority can be seen as a licensing system that has some agency to approve new technologies before they are brought to the market. Again in Mokyr (1998a)'s words: *"almost everywhere some kind of non-marketing control and licensing system has been introduced"*. A recent example is the creation of standard-setting agencies such as the International Organization of Standardization (ISO) or, about property rights, the European Patent Office (EPO).

To capture the evolving clash between resistive and innovative interests, we consider an economy that, at any point in time, is populated by three different overlapping groups of agents differing in terms of their life horizons and incentives schemes. In fact, besides the increasing human capital accumulation, productivity improvements come from the innovation process. A systemic innovation is implemented if and only if there is a political consensus for it: because its net benefits are not equal among the different age classes, in a heterogeneous setting there is always room for suboptimal provision of the innovation itself. Among different political mechanisms (majority vote, lobby intervention and so on) for implementing a new innovation, according to Krusell and Rios-Rull (1996) as well as Aghion and Howitt (1998), we assume that the public choice is carried out by means of a democratic majority voting where the interests of the absolute majority of the population prevail.

3.3 The model

Time is discrete and indexed by $t \in \mathbb{N}^+$. The economy is populated by homogeneous agents of measure one living up to three periods: they survive with probability one from youth to adulthood and with probability p_t to old age. When people of generation t are young they split their unit time endowment between schooling (e_t) and working as unskilled ($1 - e_t$), using the average human capital that their parents bequeathed them (in the form of an externality). Their income is linear in human capital and is, in case, taxed for a new productive technology to be implemented in the next period.[7] From now on, we call this operation of taxation simply innovation tax. It is a fix share of income and takes the values i , $0 < i < 1$, or zero in case innovation is decided or not, respectively. As adults, each of them has a single child. Adults' human capital is a function of past human capital and the effort they made when young. They combine their human capital with a TFP parameter that increases if a new technology is endorsed the period before. Their income is divided between consumption, a constant share s that goes, in a PAYGO fashion, in paying their parents' pensions[8] and, in case, the innovation tax i_{t+1}. When old, they consume the pension that their children pass to them, net of the innovation tax i_{t+2}. The complete scheme of the timing for an agent born at time t is represented in figure 2.

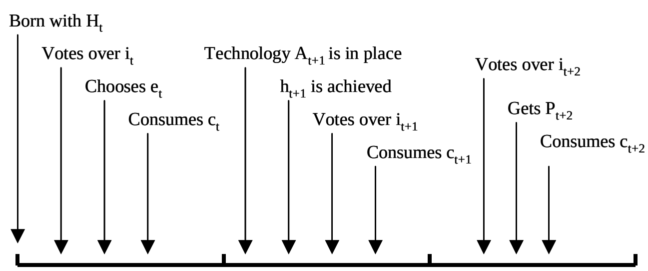


Fig.2. Timing for an agent born at time t.

Agents' political lever is characterized by their ability to vote, every period of their life, for a systemic innovation to be implemented in the next period. In order to take into account the increasing and, in some cases, crucial power of old retired, we assume that young people show a lower turnout rate with respect to adults and old.[9] Thus, their weight in the political process is represented by an exogenous parameter $\eta \in (0, 1]$. All adults and old can vote, so their measure is 1 and p_t, respectively, where p_t is the share of old alive.

[7] Using a school/leisure choice it would have been difficult to introduce the tax on innovation.

[8] We do not discuss the way in which the pension system is implemented and if it can be politically self-sustaining, as Bellettini and Berti Ceroni (1999) do. We assume instead that a commitment between generations is in place and no one can default on it.

[9] Galasso and Profeta (2004) report that the turnout rate among people aged 60-69 relative to people 18-29 is double in the US and 50% higher in France.

Production output is undertaken by firms: competitive firms employ the human capital supplied by agents as the only input, using a technology A_t, taken as given and out of their control.

3.3.1 Utility, budget constraints and production functions.

The expected lifetime utility for an agent born at time t (3.1) is non altruistic and its arguments are the consumption levels in the three periods. $\alpha \in (0,1)$ is the usual discount parameter, while p_t is the probability to survive in old age. In this subsection, despite the time suffix, we consider pt as a constant. Thus, we could just write p, but below we will endogenize it and it will be important for the analysis to let this variable change over time.

$$u_t = \log c_t + \alpha \log c_{t+1} + p_t \log c_{t+2} \tag{3.1}$$

The budget constraints in the three periods are as follows. Note that in every period the incomes are taxed in case a new technology is decided to be implemented in the next period.

$$c_t = H_t(1 - e_t)(1 - i_t) \tag{3.2}$$

$$c_{t+1} = y_{t+1}(1 - s - i_{t+1}) \tag{3.3}$$

$$c_{t+2} = P_{t+2}(1 - i_{t+2}) \tag{3.4}$$

Production of final good in the skilled sector (i.e. by adult) takes the form of a decreasing return function of human capital (3.6). The TFP parameter A_t is equal to A_{t-1} in case a new technology is not implemented ($i_{t-1} = 0$), while $A_t = (1+\theta)A_{t-1}, \theta > 0$ in case a new technology is implemented ($i_{t-1} = i$). At time $t = 0$, $A_t = A_0 = A$. A compact formulation for A_t is:

$$A_t = (1 + \theta \frac{i_{t-1}}{i})A_{t-1} \tag{3.5}$$

where θ denotes the growth rate of the technology and is a strictly positive scalar. The straightforward expression for skilled production at time t is as follows, with $0 < \gamma < 1$:

$$y_t = A_t h_t^\gamma = A_{t-1}(1 + \theta \frac{i_{t-1}}{i})h_t^\gamma \tag{3.6}$$

Human capital of an adult born at time t (3.7) increases with the human capital with which she is born (H_t) and the effort she exerted in schooling when young (e_t). The human capital depreciates by a factor $(1 - \delta)$ in case an innovation is decided at time t. The assumption is that when new technologies are implemented, human capital produced in schools based upon previous types of technology is less useful (Boucekkine et al., 2002, 2005). Ranges for the parameters are $\lambda > 0$, $0 \leq \delta < 1$ and $0 < \epsilon < 1$.

$$h_{t+1} = \lambda \left((1 - \delta \frac{i_t}{i}) e_t H_t^{\epsilon} \right) \tag{3.7}$$

At the same time, an old of generation $(t-2)$ receives (3.8) that is the share s of income that an adult of generation $(t-1)$ disbursed in the PAYGO system, multiplied by the coefficient p_t^{-1} that takes into account the share of people surviving to old age.

$$P_t = \frac{s y_t}{p_t} = \frac{s A_t h_t^{\gamma}}{p_t} \tag{3.8}$$

3.3.2 Individual optimization with given innovation policy

In every period of her life an agent takes as given the innovation policy. We will add the case of majority voting on the innovation policy later. Agents choose the schooling time when young. From the first order condition $\frac{\partial u_t}{\partial e_t} = 0$ we obtain the optimal schooling time:

$$e_t^* = \frac{\gamma[\alpha + \epsilon p_t]}{1 + \gamma[\alpha + \epsilon p_t]} \tag{3.9}$$

It is easy to find a positive relationship between p_t and the equilibrium value of e_t: the longer is the life expectancy of people, the higher is the time investment needed to finance their prolonged consumption, consistently with existing literature. Substituting (3.9) in (3.7) and writing h_t instead of H_t (due to straightforward equilibrium considerations) we get the accumulation function of human capital as a function of past human capital, the innovation policy chosen the period before and the fraction of time youth spend in education. At time t we obtain:

$$h_{t+1} = \lambda \left(1 - \delta \frac{i_t}{i} \right) \frac{\gamma[\alpha + \epsilon p_t]}{1 + \gamma[\alpha + \epsilon p_t]} h_t^{\epsilon} \tag{3.10}$$

The human capital accumulation function shows the usual concave shape (given that $0 < \epsilon < 1$) and the role of human capital depreciation in the case of innovation, $\left(1 - \delta \frac{i_t}{i}\right)$, is clear. Moreover, the human capital augmenting effect of life expectancy can be evaluated by looking at the expression of e_t^*.

3.3.3 Endogenous life expectancy

In this subsection we allow for the level of life expectancy to increase with the aggregate human capital level as in, among others, Blackburn and Cipriani (2002) as well as Cervellati and Sunde (2005).[10] The probability to reach old age

[10] Empirically, both private and aggregate endowment of human capital are conductive to a longer life, although we focus on the aggregate view: on the one hand, demographic and

is, therefore, $p_t = p(H_{t-l})$, where l is a lag of at least two periods for ensuring that people are not internalizing changes in life expectancy when optimizing their human capital level. We impose some restrictions on $p(H)$, in order to get simple results. $p(0) = p_0 > 0$ avoids the extreme case of a disappearing old age, while $\frac{\partial P(H)}{\partial H} = p_H > 0$ replicates the empirical evidence of a positive correlation between life expectancy and education. Because p is a probability, we assume that $\lim_{H \to +\infty} p(H) = p^L \leq 1$. Simple algebra and the equilibrium identity $h_t = H_t$ allow us to rewrite the expression of human capital accumulation (3.10):

$$h_{t+1} = \Gamma_1(h_t; i_t)h_t^{\epsilon}$$

The function Γ_1 is always greater than zero, increasing in h and, for the restrictions imposed on the function p, limited from above by some finite number. In the case of both innovation and no innovation it is possible to show that multiple finite equilibria can arise, as we show in figure 3. In this figure we represent the case of innovation, where $i_t = i$: h^{S1} and h^{S2} are stable equilibria, while h^{U1} is the unstable equilibrium. Of course, in the case of innovation the whole graph of h_{t+1} lies below the one of no innovation: it can be, therefore, the case that if innovation takes place there is room, due to the depreciation of human capital, for two stable steady states, while in the case of no innovation only one stable steady state arises. In figure 4 we show the case of no innovation ($i_t = 0$):

historical evidence suggests that the level of human capital profoundly affect the longevity of people. For example, the evidence presented by Mirowsky and Ross (1998) supports strongly the notions that better educated people are more able to coalesce health-producing behaviour into a coherent lifestyle, are more motivated to adopt such behaviour by a greater sense of control over the outcomes in their own lives, and are more likely to inspire the same type of behaviour in their children. Schultz (1993, 1998) evidences that children's life expectancy increases with parent's human capital and education. On the other hand, there is evidence that the human capital intensive inventions of new drugs increases life expectancy (Lichtenberg, 1998, 2003) and societies endowed with an higher level of human capital are more likely to innovate, especially in research fields like medicine (Mokyr, 1998b).

the graph of h_{t+1} is higher and only one stable steady state, h^{S3}, arises.

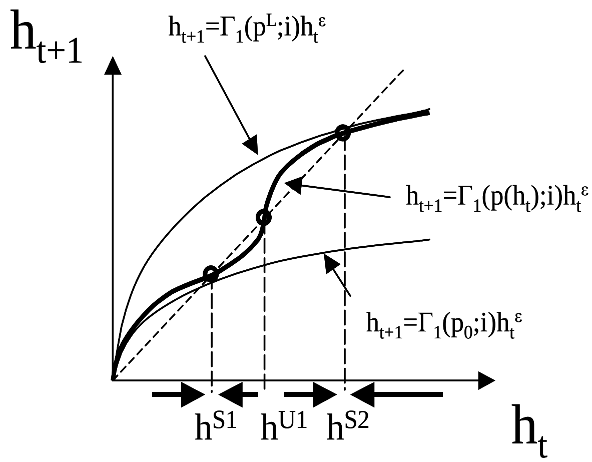


Fig.3. Equilibria of human capital level in the case of innovation and endogenous life expectancy.

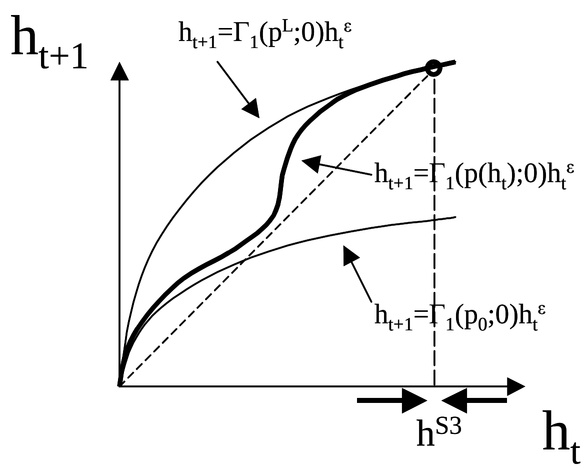


Fig.4. Equilibrium of human capital level in the case of no innovation and endogenous life expectancy.

Apart from the innovation policy, increases of α, λ, γ and ϵ shift h_{t+1} upward, leading both to higher level of human capital for any steady state and to the disappearance of the low steady state, h^{S1} in figure 3.

The fact that (i) the growth of human capital is bounded from above and (ii) human capital is the only factor of production and its accumulation function does not depend upon the *value* of the TFP parameter allows us to study, in an "additive" way, how human capital and production evolve. For example, once human capital reaches a steady state, using (3.6) we can keep track of the final production just looking at the innovation policy undertaken. Therefore the steady state production is a constant level in the case of no innovation ($y^* = A_0(h^{S*})^\gamma$), while it will be an increasing level (at the constant rate θ) in the case of innovation ($y_t = A_0(1+\theta)^t(h^{S*})^\gamma$). The value h^{S*} represents one of the stable steady states that we can find in figure 3 or 4.

3.3.4 Endogenous innovation policy

Up to this point the innovation policy has been taken as given, either innovation or no innovation, and the same in every period. From now on we will use, when necessary, I or N, respectively. Now we allow agents to vote upon the innovation policy, and the decisions aggregate by means of a majority mechanism. With our setup the shares of young, adult and old voters are $\frac{\eta}{\eta+1+p_t}$, $\frac{1}{\eta+1+p_t}$ and $\frac{p_t}{\eta+1+p_t}$, respectively. The more the life expectancy increases, the more important is the relative weight of old and the less important are the weights of young and adult in the political process.

Proposition 1 *For values of life expectancy smaller than*

$$\hat{p} = 1 - \eta$$

a "workers' dictatorship" arises: no matter what young and old prefer, adult alone will set the agenda in terms of innovation. There are no values of p_t such that another form of dictatorship (i.e. a single age group has the absolute majority) can arise.

Proof. Adult get the absolute majority if and only if their share is bigger than $\frac{1}{2}$: imposing $\frac{1}{\eta+1+p_t} > \frac{1}{2}$ we obtain, solving for p_t, the expression in the proposition. For similar considerations it is possible to show that both $\frac{\eta}{\eta+1+p_t}$ and $\frac{p_t}{\eta+1+p_t}$ can not exceed $\frac{1}{2}$. ■

In early stages of development process the political power is, therefore, in the hands of adult alone, while the more the human capital increases, the longer life expectancy is and the smaller the share of adult is. It can be the case that p_t exceeds $\hat{p}$: from this moment on decisions about innovation need the consensus of two age groups over three, so the political process becomes a little more complex. We call this stage *"diluted power"*. The specific cost-benefit setup of the innovation implies that old people are always against innovation: they are supposed to pay today a fraction of their income for a new technology that will be available once they are dead. This simplifies our analysis: in the case of *"workers' dictatorship"* this feature is not influential, since only adult decide, while in the case of $p_t > \hat{p}$ we need to know, to be sure that innovation will be voted, whether both adult and young will vote for I. Otherwise N will be the implemented policy.

Our strategy is to check, for all the three-period sequences of policies,[11] if agents' vote and policy outcome is consistent with the configuration under

[11] Being the two states of voting variable $\{I; N\}$ and the three periods that an agent live, the possible streams of policies are $2^3 = 8$: $\{I_t; I_{t+1}; I_{t+2}\}$; $\{I_t; I_{t+1}; N_{t+2}\}$; $\{I_t; N_{t+1}; I_{t+2}\}$; $\{I_t; N_{t+1}; N_{t+2}\}$; $\{N_t; I_{t+1}; I_{t+2}\}$; $\{N_t; I_{t+1}; N_{t+2}\}$; $\{N_t; N_{t+1}; I_{t+2}\}$; $\{N_t; N_{t+1}; N_{t+2}\}$.

analysis. Let us now define some variables that will be useful in the policy setting framework and describe agents' behaviour in the three different stages of their life.

We call v_t^j the choice of innovation policy voted by an agent of type j (with $j \in J = \{Y; A; O\}$) at time t and it can take the values $\{\iota, \nu\}$, that stand for innovation and no innovation, respectively. Note that old's choice is always to vote against innovation, as will be clear below: $v_t^O = \nu, \forall t \in \mathbb{N}^+$. In every period the function M_t aggregates the votes of the three generations alive and its outcome is the majority choice:

$$M_t(v_t^Y; v_t^A; v_t^O) = \begin{cases} I & \text{if} \begin{cases} v_t^Y = v_t^A = \iota \text{ and } p_t > \hat{p} \\ v_t^A = \iota \text{ and } p_t < \hat{p} \end{cases} \\ N & \text{otherwise} \end{cases} \tag{3.11}$$

A new innovation will be, therefore, implemented at time $(t+1)$ if and only if $M_t = I$.

Now the optimization problem for the agent is to vote, in every period of her life, upon the innovation policy and, taking the outcome of the voting mechanism in every periods as given, to allocate her youth time between schooling and working. We study the choice of the three generations backward, from the old to the young, at time t. Thus, the individuals under analysis are old agents born at time $(t-2)$, adult agents born at time $(t-1)$ and young born at time t. The time structure of our political problem can be represented in figure 5.

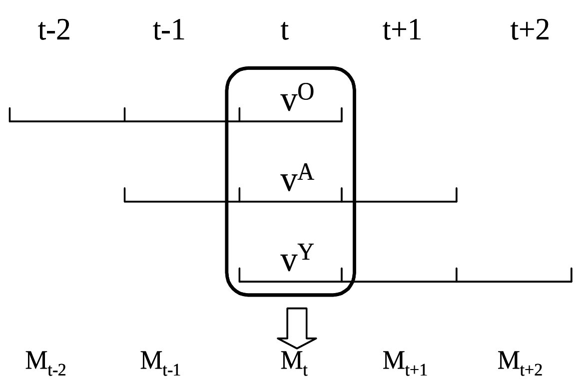


Fig.5. Scheme of votes aggregation.

Old

As we stated above, old people, in the case of innovation policy, only incur in costs: once the new technology is in place, they will be dead. Their optimal choice is always to vote against, since v_t^O is their only choice that has to be made. Moreover, they do not need to anticipate future political outcomes.

Adult

When adult, agents vote over the innovation that will be implemented next period. In principle, the decision to vote for an innovation or not depends on the differential utility that has to be computed for every future outcome of the majority choice M_{t+1}. Due to the functional form of the utility, adult do not care about tomorrow's outcome of the innovation policy: income and substitution effects cancel out for what concerns tomorrow's cost of innovating. They decide to innovate, iff:

$$\Delta u_t^A(M_{t+1} = I) = \Delta u_t^A(M_{t+1} = N) = u_t^A(v_t^A = \iota) - u_t^A(v_t^A = \nu) > 0 \quad (3.12)$$

where u_t^A depends on h_{t-1} and M_{t-1}. Writing explicitly (3.12), we find:

$$\Delta u_t^A = \alpha \log(1 - i - s) + p_t \log(1 + \theta) + p_t \gamma \log(1 - \delta) - \alpha \log(1 - s) > 0 \quad (3.13)$$

Let us assume from now on that $\theta > (1 - \delta)^{-\gamma} - 1$: this condition on the relative magnitude of TFP improving parameter and human capital depreciation parameter states that, in the case that an innovation takes place, the improvement in the production of final good exceeds the worsening of the quality of human capital used in production. Algebraically, this condition makes the denominator of P^A to be positive. It is easy to show that the same consideration will be effective also for P^Y, which we will define in the next paragraph. Moreover, note that $\lim_{i \to 0^+} p^A = 0$ and $\lim_{i \to (1-s)^-} p^A = +\infty$.

In (3.13), under the assumption above, adults enjoy a higher utility, in the case of innovation, the higher is their life expectancy: they experience a benefit from the technology parameter θ that augments, *proportionally with* p_t, their pension when old. Conversely, they experience a cost, proportional with p_t, from the depreciation of their children's human capital (even though this cost is mitigated by the elasticity of human capital in the production of the final good).

Simple calculations lead to the following expression, where p^A is the value of life expectancy above which adults are in favour of innovation:

$$p_t > \frac{\alpha \log\left(\frac{1-s}{1-s-i}\right)}{\log(1 + \theta) + \gamma \log(1 - \delta)} \equiv p^A \quad (3.14)$$

Adults vote for an innovation if and only if they will get higher resources (net of innovation costs) when old, in the form of pensions paid by their children[12]. The threshold P^A is a positive function of i: the more expensive the adoption of a new innovation is, the less the adult will be innovation-prone. The same consideration holds for δ: due to the adoption of a new technology, the more the human capital depreciates, the less the adult will be in favour of implementing the new technology itself. Conversely, an increase in the growth rate of TFP is conducive for a new technology to be preferred by adult. Note that the elasticity of past human capital in the production of the new human capital (ϵ)

[12] In the meantime, adult's children are became adult themselves.

is not involved in adult's decisions: we will see below that only young take into account how the past level of human capital affects the next period's human capital accumulation. The higher the share is of adult's income going to finance old's pensions, the less the adult will vote for innovation.[13] The more people are oriented toward adult age consumption (i.e. for high values for α), the less they will be in favour of innovation. Lastly, an increase in the elasticity of human capital in the production of final good (γ) works against innovation: to innovate is to make a part of human capital achieved during youth depreciate, and the higher its effectiveness in production is, the higher the loss is in terms of pensions paid by adult.

Young

Young vote over innovation taking into account both M_{t+1} and M_{t+2}, so in principle there are four possible future configurations: $\{I_{t+1}; I_{t+2}\}$, $\{I_{t+1}; N_{t+2}\}$, $\{N_{t+1}; N_{t+2}\}$ and $\{N_{t+1}; I_{t+2}\}$. For the same argument stated above, what will happen at time $(t+1)$ and $(t+2)$ does not influence young's vote today. Thus, they only base their decision on achieved state variables. The condition under which young will be in favour of innovation is:

$$\begin{aligned} \Delta u_t^Y(M_{t+1} &= I; M_{t+2} = I) = \Delta u_t^Y(M_{t+1} = I; M_{t+2} = N) = \\ &= \Delta u_t^Y(M_{t+1} = N; M_{t+2} = N) = \Delta u_t^Y(M_{t+1} = N; M_{t+2} = I) = \\ &= u_t^Y(v_t^Y = \iota) - u_t^Y(v_t^Y = \nu) > 0 \end{aligned} \tag{3.15}$$

and again u_t^Y depends on h_{t-1} and M_{t-1}. An explicit expression of (3.15) is:

$$\Delta u_t^A = \log(1-i) + \alpha\log(1+\theta) + \alpha\gamma\log(1-\delta) + p_t\log(1+\theta) + p_t\epsilon\gamma\log(1-\delta) > 0 \tag{3.16}$$

Here young, in case of innovation, again directly benefit from the technologic parameter θ, but now it impacts both their labour income when adults and the pension benefits when retired. In this last case the benefit from innovation is proportional to p_t, so a longer life gives more time to enjoy higher consumption. The cost structure is similar: a constant cost is due to the depreciation of human capital when young become adults, through a smaller marginal productivity in the production of final good. Another cost, proportional to p_t, takes into account the depreciation of human capital of young's children: two periods later, in fact, today's young will get a pension that will be, in terms of human capital, depreciated because of today's choice to innovate. Therefore the depreciation term is mitigated by two terms, ϵ and γ: the first takes into account the elasticity between the production of new human capital and the past stock of human capital, the latter the elasticity of human capital in the production of final good.

[13] There is a strand of literature that studies how pension systems are implemented, why they are so big, which policies are enforceable in this context, etc. For simplicity we take s as given, but we think this could be one of the first improvements to our work.

Simple calculations lead to the expression of p^Y, the value of life expectancy above which young are in favour of innovation:

$$p_t > \frac{-\left[\log(1-i)+\alpha\log(1+\theta)+\alpha\gamma\log(1-\delta)\right]}{\log(1+\theta)+\epsilon\gamma\log(1-\delta)} \equiv p^Y \tag{3.17}$$

Young's choices over innovation shows similar determinants as adult's. Again the threshold level is negatively correlated with the TFP growth rate (θ) induced by innovation. The depreciation of human capital in the case of innovation (δ) is a factor that discourages young, as long as adult, to vote for innovation. Moreover, with the assumption about the sign of the denominator made above, we can state what follows.

Proposition 2 *For small values of the innovation costs young are in favour of innovation, whatever value the other parameters take.*

Proof. We need that $p^Y < 0$ for some small values of i. With the assumption that $\log(1+\theta)+\gamma\log(1-\delta) > 0$, being $\log(1-\delta) < 0$ and $0 < \varepsilon < 1$, $\log(1+\theta)+\epsilon\gamma\log(1-\delta) > 0$ and $0 < \frac{\log(1+\theta)+\gamma\log(1-\delta)}{\log(1+\theta)+\epsilon\gamma\log(1-\delta)} < 1$. Since $p^Y(i)$ is continuous and increasing in $0 < i < (1-s)$ and $\lim_{i\to 0^+} p^Y = -\alpha\left(\frac{\log(1+\theta)+\gamma\log(1-\delta)}{\log(1+\theta)+\epsilon\gamma\log(1-\delta)}\right) < 0$, the proposition is proved. Moreover, if $\lim_{i\to(1-s)} p^Y(i) < 0$, young are in favour of innovation for any value of innovation costs. ■

The effect of the elasticity of past human capital in the production of human capital (ϵ) can be, in principle, either negative or positive. The interesting range of p^Y is, however, the positive one: here $\frac{\partial p^Y}{\partial \epsilon} > 0$. A high inertia in the transmission of human capital from one generation to the other leads to less interest in innovation because, as in Boucekkine et al. (2002), human capital depreciates and the more it ages, the more its obsolescence makes it less productive. Conversely to the case of adult, for young a higher concern for adult age consumption α is conducive to innovation: since they can, innovating, boost the production in adult age, they are in favour of new technologies.

3.3.5 Political outcome

We now deal with the political analysis: we show, for different parameters' ranges and initial conditions of life expectancy, which innovation policy is undertaken and which policy implications are implied. In table 1 we resume the partial effects that the single parameters have on the thresholds we defined above, in particular p^A, p^Y and $\hat{p}$. They correspond to the value of life expectancy above which adults are in favour of innovation, young are in favour of innovation and the value below which adults alone choose (since they represent the absolute majority of the constituency), respectively.

	p^A	p^Y	$\hat{p}$
η	0	0	-
α	+	-	0
θ	-	-	0
i	+	+	0
δ	+	+	0
γ	+	+	0
ϵ	0	+	0
s	+	0	0

Tab.1. Partial effects of parameters on thresholds.

In fig. 6, we represent, for generic values of parameters, the function (3.11) indicating which are the choices of agents. Shaded areas represent the sets in the space $\{i, p_t\}$ in which innovation is undertaken. Since $v_t^O = \nu$, $\forall t \in \mathbb{N}^+$, we only report on the graph the choice vector of adult and young, $Ct = (v_t^A; v_t^Y)$. Resuming, below the line $\hat{p}$ adult choose the policy, no matter what young choose. Above p^A and p^Y adult and young are in favour of innovation, respectively. Note that above $\hat{p}$, in order to implement an innovation, both adult and young have to be innovation-prone. On the horizontal axis we put the cost of innovation, while on the vertical axis we have the life expectancy at time t.

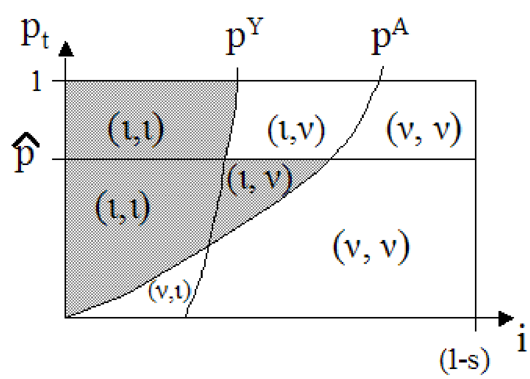
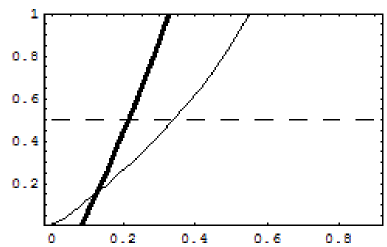


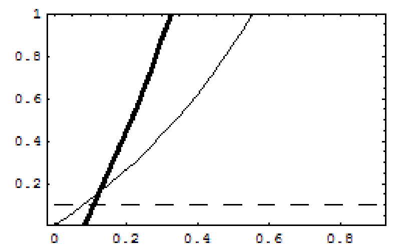
Fig.6. Political choices and outcomes. Shaded areas mean "innovation". In brackets, votes of adult and young.

In figure 6 young are particularly hostile to innovation: only for very small values of i they vote ι. Innovation is ensured, however, for higher values of i and intermediate values of life expectancy, in the shaded area characterized by the choice vector (ι, ν): here adults are *"dictators"* and they choose innovation, against young's will. In figure 7 we again show the function (3.11) for eight different configurations of parameters: the first (a) is what we call the benchmark, the other seven are graphed changing, one by one, the values of the parameters $\eta, \alpha, \gamma, \theta, \delta, \epsilon$ and s.



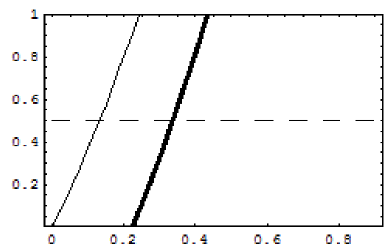
a)

η	α	γ	θ	δ	ϵ	s
0.5	0.3	0.5	0.4	0.1	0.5	0.1



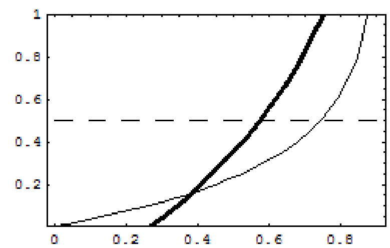
b)

η	α	γ	θ	δ	ϵ	s
0.85	0.3	0.5	0.4	0.1	0.5	0.1



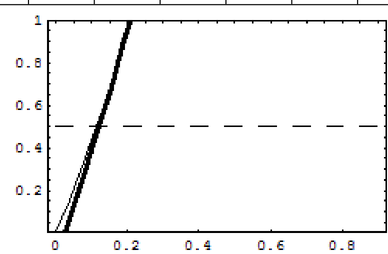
c)

η	α	γ	θ	δ	ϵ	s
0.5	0.9	0.5	0.4	0.1	0.5	0.1



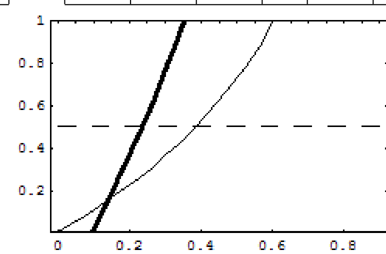
d)

η	α	γ	θ	δ	ϵ	s
0.5	0.3	0.5	2	0.1	0.5	0.1



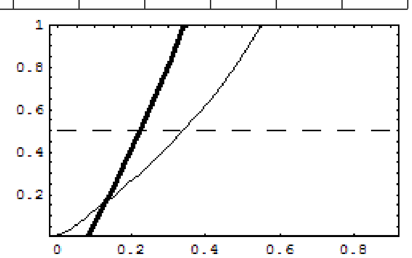
e)

η	α	γ	θ	δ	ϵ	s
0.5	0.3	0.5	0.4	0.4	0.5	0.1



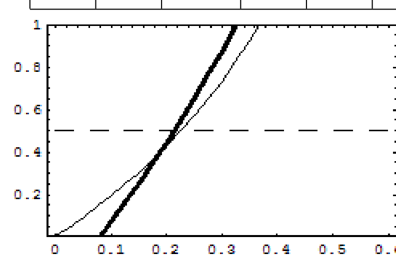
f)

η	α	γ	θ	δ	ϵ	s
0.5	0.3	0.02	0.4	0.1	0.5	0.1



g)

η	α	γ	θ	δ	ϵ	s
0.5	0.3	0.5	0.4	0.1	0.05	0.1



h)

η	α	γ	θ	δ	ϵ	s
0.5	0.3	0.5	0.4	0.1	0.5	0.4

Fig.7. Plots of p^A (thin line), p^Y (bold line) and $\hat{p}$ (dashed line) for different parameters' configurations.

Analyzing fig.6, in case (b) a larger representativeness of young (i.e. higher η) leads to the vanishing of the region in which adult alone decide for innovation. In case (c) we note that a high concern of adult age consumption leads the two curves $p^A$and p^Y to separate: the former shifts up, the latter shifts down. Moreover, in case the two curves do not intersect, the position of $\hat{p}$ does not affect the political outcome: adult's threshold binds for all $(p_t; i)$ pairs, so they have a veto power against young's willingness to innovate. A general result:

Remark 3 *In the case $p^A > p^Y : \forall i \in (0, 1-s)$ the political outcomes in the case of "workers' dictatorship" and "diluted power" are the same.*

Case (d) shows the intuitive effect of an increase in θ: both the curves shift down, leading innovation to be preferred for a wide set of i and p_t. $\hat{p}$ does not move and there is room for adult's choice of innovation in early stages of development (i.e. when life expectancy is short). In (e) a higher depreciation rate of human capital in the case of innovation makes both adult and young less favourable to innovate. p^Y is more sensitive than p^A to this change: for young a depreciation of human capital reflects in less labour income when adult *and* less pensions when old. A very low elasticity of human capital in the final sector, γ in case (f), makes education almost useless in terms of adulthood income and people choose to work the most of their youth time, see (3.9), and so innovation is relatively more preferred because it substitutes human capital in production. A decrease in the elasticity of past human capital in the production of human capital, ϵ in case (g), shows a similar effect. An increase in the share s of adult income going to pension contribution (h) leaves unchanged p^Y and $\hat{p}$, while p^A shifts upward, shrinking the set of i and p_t where innovation is implemented.

Resuming the *purely political* stage of the analysis, we can conclude that at *individual* level, people's willingness to innovate increases with life expectancy, the growth rate of innovation itself and, for young, the preference for adult age consumption. Conversely it decreases with the cost of innovation, the depreciation rate of human capital introduced by innovation, the elasticity of human capital in final production and, for adult, the share of income going to paying old people's pensions. Once we turn to the *aggregate* level, that is the political choice implemented, we look, at the same time, to p^A, p^Y and, more important, to $\hat{p}$: given the structure of the generations, the economy as a whole chooses to implement a new technology if and only if the majority of its voting inhabitants are in favour of innovation. In the case of $p_t < \hat{p}$ this maps one to one to the decision of adult, while for values of p_t above $\hat{p}$ we need adult and young to be contemporaneously in favour. In the case that, for some configurations of parameters, young are relatively more averse to innovation[14] than adult (i.e. small α, large θ, small γ), for small values of life expectancy innovation is not implemented, if life expectancy of agents increases a bit, then innovation is implemented without the consensus of young. One more increase in life expectancy can lead again to stop innovation due to the loss of absolute majority

[14] With "more averse" we mean that there are regions of the parameters' space where $p^Y > p^A$.

by adult. In the case that a further increase of life expectancy can again bring innovation, then young support innovation and form a coalition with adult. We show this example in the next section, analyzing the political and the economic mechanisms jointly.

3.4 A simple dynamic exercise

In this section we simulate the behavior of an economy characterized by the features described at the end of the section above. The reason is that this example *can* embrace dynamically all the four interesting political configurations described: (i) an aversion to innovation caused by a too short life expectancy; (ii) a short-lived innovation period guaranteed by adult workers' absolute majority; (iii) another period without innovation caused by young's aversion and (iv) again innovation, once the life expectancy is long enough. Since we want to show the possibility of multiple equilibria, we run the simulation for both high and low initial human capital: with same parameters, in the former case the economy reaches, in the end, sustained growth, while in the latter it ends in a poverty trap, with short life expectancy, no innovation and not much education. We make some simplification in order to have easily readable results. First of all we assume that, in the case an innovation takes place, the human capital does not depreciate (i.e. $\delta = 0$). In this way the human capital accumulation function is the same in both the cases of innovation and no innovation. With this assumption, it comes out that the parameter ϵ affects only the shape of the human capital accumulation function and not p^Y. About $p(h_t)$, among many functions characterized by a mapping $[0, \infty) \to (0, 1]$, we opt out for the simple, but flexible, specification chosen by Blackburn and Cipriani (2002)[15]:

$$p(h_t) = \frac{\underline{p} + \overline{p}\phi h_t^\sigma}{1 + \phi h_t^\sigma}, \quad with\ \phi, \sigma > 0$$

Where ϕ and σ jointly determine the speed at which the function goes from $\underline{p}$ to $\overline{p}$ and the value of h_t where the function shows the turning point that separates the initial convexity with the concavity that characterize higher levels of h_t[16]. In line with Blackburn and Cipriani, we choose to set $\phi = 0.001$, $\sigma = 2$, $\underline{p} = 0.1$ and $\overline{p} = 1$. ϕ is bigger than one in order to ensure that $p''(h)$ is initially positive and then negative, with a turning point in $h^T = 18.2574$. The utility function shows $\alpha = 0.3$. In the human capital production function $\lambda = 5$ and $\epsilon = 0.9$, while in the production of final good $\theta = 0.1$, $\gamma = 0.6$ and $A_0 = 2$. The share of adult's labour income going to fund pensions is $s = 0.1$, while the cost of innovation is a share $i = 0.1$. We assume that the political weight of young is $\eta = 0.5$.

[15] The authors report a detailed analysis of this function: we suggest referring to their work for all the technicalities.

[16] For a given value of $\phi(\sigma)$, an increase (decrease) in $\sigma(\phi)$ reduces the turning point, while for a given value of such a point, an increase (decrease) in $\sigma(\phi)$ raises the speed of transition (the limiting case of which is when $p(.)$ changes value from $\underline{p}$ to $\overline{p}$ instantaneously, which corresponds to the case of a step function).

With this setup, the human capital production function shows the features of figure 3. The steady states are four, alternatively unstable and stable: $h^* = \{0; 0.59; 19.56; 1610.96\}$. In the case initial human capital is below $h_0 = 19.56$, the economy converges, without ever innovating, to a poverty trap where the equilibrium youth time devoted to education is $e^{*P} = 0.189$, old age life expectancy *decreases* until $p^* = 0.100134$, and human capital level decrease until the lowest stable steady state value 0.59.

In case the initial human capital is above $h_0 = 19.56$ (which corresponds to an initial life expectancy $p_0 = 0.349$), human capital starts to increase. We refer to figure 8 in order to give a graphical intuition to the explanation.

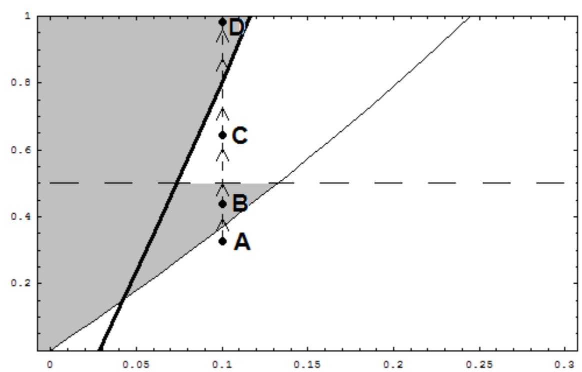


Fig.8. The evolution of life expectancy when h_0>19.56. Shaded areas mean "innovation".

The initial state is point (A): here life expectancy is below both p^A and $\hat{p}$, so adult alone decides not to innovate. Human capital, however, accumulates and life expectancy, in turn, increases. This occurs for some periods, then life expectancy lengthening makes adult prefer innovation (B): the economy experiences some periods during which both human capital and production (the latter at a higher speed than the former) grow. Then life expectancy passes the threshold $\hat{p}$: at this time adults lose the absolute majority and young, being against innovation ($p_t > \hat{p}$), force the political outcome to be "no innovation" (C). Here the economy evolves, again showing increases in both human capital and final good production level, but at the same pace. Once young also feels the net benefits of innovation (D), the economy reaches the upper bound of life expectancy $\overline{p}$, the higher steady state of human capital $h^{*H} = 1610.96$, the schooling time $e^{*H} = 0.4185$ and the production of final good increases at a rate θ.

Of course the aim of this exercise is not to show the real evolution of a given economy, but to understand what the political and economic forces are that lead the economy toward its destiny: to understand the *type* and the *timing* of the policies that need to be implemented is crucial when constraints on human capital accumulation and/or innovation are in place.

3.5 Conclusions

Over the past century, all OECD countries were characterized by a dramatic increase in economic conditions, life expectancy and qualities and quantities of different kinds of knowledge. So, it is natural to suppose that the increase in longevity of citizens is an important factor in determining the life-cycle behaviour of individuals. At the same time, it is unnatural to suppose that life expectancy is exogenous and independent of economic conditions. The purpose of this paper is to provide a theory that explains how an economy might evolve when the longevity of its citizens both influences and is influenced by the process of economic development, especially when choices are upon two dimensions: the *private* choice of education and the *public* one of innovation policy.

Assuming, confidently, that longevity is positively correlated with the level of human capital, the increase of life expectancy that economies are experiencing is, in principle, growth-enhancing. However, its effectiveness can be harmed by, at least, two phenomena. First, building on Blackburn and Cipriani (2002), we reach their same conclusions about the *pure economic* effects of an increase in longevity: due to the positive effect of human capital on expected life expectancy, it can be the case that lower levels of human capital lead to a too short life, and this in turns disincentives people to invest in education, giving rise to a poverty trap. At this stage of development, life expectancy is short and human capital stock is small. Second, we deal with the political features of an economy where the engines of growth are human capital accumulation and *systemic* technologic innovation. Our idea is that, as we are stressing from the introduction onward, a variation in life expectancy affects the individual incentives to innovate and it alters also the aggregate choices of the economy, since political representativeness of different age classes changes. Our argument is that during first stages of development, when human capital is negligible, life expectancy is short and retired people are few, the political power is in the hand of adult workers alone. The decision to innovate or not coincides, therefore, with adult's choice. In the case their incentives to innovate are small (for example a large share of labour income going to finance the PAYGO pension system, a large elasticity of the human capital used in production or a high concern in adult age consumption) they impose to the whole economy a no innovation regime. In developed economies, where life expectancy is higher, human capital endowment is large, life expectancy is long and retired people are several, a political majority that enforces an innovation policy can be achieved only by means of a coalition. Since elderly people are innovation averse, the only way for an innovation to be implemented is that both young and adult are in favour of innovation. Therefore, if on the one hand a longer life expectancy pushes people's incentives toward innovation, on the other hand it makes the political weight of old increase, making the achievement of a consensus for innovation potentially more difficult. This is true, in particular, when young's incentives for innovation are lower than the ones of adult, especially in the case of a high inertia in the transmission of human capital from one generation to the next one and when the concern for adult age consumption is small.

The road that leads to sustained growth is far from being straight: we can find path dependency in the human capital accumulation, because in some cases an initial small amount of human capital can lead to a poverty trap, where the equilibrium longevity is not enough for adult (or adult *and* young in the case of not-so-short life expectancy) to vote for innovation. In case the initial level of human capital is high enough (or there is no room, in the accumulation function of human capital, for multiple equilibria), a high equilibrium level of human capital is achieved, with longer life expectancy. Again, an innovation is voted if and only if both adult *and* young are in favour.

With this paper we provide the basis for joining together two strands of the literature on economic growth that are gaining importance in the research and political debate: technologic innovation and aging population. We stress how different links run between these two phenomena, defining the possible conflict of interests among different generations and showing how the lengthening of life expectancy changes the way this conflict of interests is solved. Moreover, we stress how *private* and *public* choices combine (or not) in order to give birth to a human capital abundant, growing economy.

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