UNIVERSITÀ DEGLI STUDI DI NAPOLI
"PARTHENOPE"
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ACADEMIC RESEARCH, SOCIAL INTERACTIONS AND ECONOMIC GROWTH

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ACADEMIC RESEARCH, SOCIAL INTERACTIONS AND ECONOMIC GROWTH

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1 Introduction

The aim of this article is to construct an analytical approach to economic growth which captures the essential features of the interaction between the work of the scientific community and long-period economic activity.

The traditional theory of growth, which originated with Solow (1956), considers the scientific world to be exogenous with respect to the economy. As in the case of other public goods, the production of knowledge is the task of the state. Scientific as well as technological advances constitute Solow's 'residual' - the unexplained part of the growth of per capita output. Exceptions in this theoretical tradition are the works of Karl Shell (1969, 1970), in which the production of knowledge is endogenous. The state collects resources from the activities of private agents in order to finance basic research, which is the public input to the private sector. The economic problem analysed in these works is essentially that of the dynamic allocation of resources between the production of goods and the production of knowledge. Still unexplored is the scientific research sector in relation to its forms of organization and the incentives - economic and otherwise - which motivate those who work in it.

With the advent of 'endogenous growth theory' - the new scientific paradigm for the analysis of growth - innovation has become a central topic of inquiry. The works of Romer (1990), Aghion and Howitt (1992), and Grossman and Helpman (1991) have generated a rich Schumpeterian strand in growth theory which draws heavily on the microeconomic literature on industrial innovation. These models, too, relegate the production of new opportunities for technological progress to a residual domain exogenous to the economy. The case of growth models with general purpose technology are emblematic of the limitations of this approach. GPTs, in fact, are radical changes in technologies which improve production possibilities in a wide range of sectors. These changes should certainly be associated with scientific advances which alter the constraints to which technologies are subject, but there is no trace of this phenomenon in these models.

Applied research which assesses the importance of the production of scientific knowledge for innovation and firms' productivity shows that this linkage has been responsible for the unprecedented growth of the Western world (Rosenberg).

And yet, economists (Arrow, 1962; Nelson 1959) have long concerned themselves with the world of scientific research. Indeed, the studies of the past two decades have given rise to what has been termed the 'economics of science' (see Stephan, 1966). This comprises the numerous empirical works that have investigated the connections between scientific production and technological innovation, as well as those which study the scientific labour market. Recently, a number of theoretical analyses have shown the substantial differences between the activities of scientific research and those of technological innovation. Dasgupta and David (1987; 1994) have constructed a theoretical framework - still highly general and open - comprising the components essential for the analytical representation of the production of basic knowledge. The state organizes the scientific sector, given that the output from scientific research is considered to be a public good because of its non-rival nature and because of the full disclosure rule adopted by researchers when they obtain new results.

The 'quest for priority' as the essential motivation of researchers is a decisive aspect of the conceptualization of research imported from the sociology of science (Merton, 1957). Researchers compete against each other for rewards, which take the form - in the case of success - of important publications and the consequent advantages in terms of income, prestige and reputation. Hence, unlike the objective of those who work in applied and technological research, that of scientists is to achieve the widest possible circulation of their findings, rather than secrecy.

In these winner-take-all contexts there is great uncertainty over the outcome of the contest, and the problem of incentives is particularly acute because of the difficulty of monitoring effort. The literature on academic research agrees that the incentives system prevalent in the sector efficiently motivates workers, so that problems of shirking are rare. The organization of work in academic research is strongly characterized by different forms of cooperation and knowledge-sharing, albeit in the presence of strictly personal goals and fierce competition. Peer evaluation and reciprocal recognition of the value of discoveries are forms of social interaction which closely influence the productivity of individual researchers.

The model analysed in this paper represents the working of an economy which consists of agents with heterogeneous innate skills and who may choose to work either in the goods production sector or in scientific research. These two economic activities are organized according to different objectives and rules. Research is financed by the state out of taxes, and its output is a public good that benefits all firms and improves their productivity. The researcher receives an income which depends on his/her research results. S/he is engaged in a research project in competition with other researchers and obtains a result before the others with a probability which is a function of his/her effort, of his/her innate talent for research, and his/her interactions with other researchers. In each of these races the state rewards only the winner, doing so with a sum that is added to his/her income.

The paper is organized as follows. the second section surveys the applied and theoretical literature on the relationship between science and economic growth. The third section sets out the basic theoretical model. The fourth section analyses the model's equilibrium solution.

2 Science and economic growth

2.1 The empirical evidence

The influence of scientific advances on technological innovation, and on the productivity of economic systems, has been the subject of applied inquiry for a number of years. The headlong technological development of recent decades has shortened the distance between basic and applied research, so that a substantial part of the former is today carried out internally to firms (Rosenberg, 1990).Diverse approaches have been used by studies on the matter. Some examine the intensity of technological innovation by firms, others estimate the effects of academic research on indicators of firms' productive performance.

The studies by Mansfield (1991, 1995) are based on surveys of firms' opinions on the importance - which they report to be substantial - of scientific advances for innovation in products and processes. The first study was based on a sample of 76 of the largest USA firms and found that in the period 1975-1985 around 11% of new products and 9% of new processes could not have been developed without the results of academic research conducted in the previous fifteen years. Mansfield estimates that the lags implicit in the science/innovation relation are significant - 7 years on average - and moreover that the social rate of return on investments in academic research is of the order of magnitude of 28%.

An equally direct approach has been used by Adams (1990), who estimates the contribution of scientific knowledge to productivity growth in 18 manufacturing sectors. The main feature of this study is its meticulous construction of an indicator of the stock of scientific knowledge obtained by considering both the number of publications in scientific fields closest to the sector's technology since the 1930s, and the scientific personnel employed in the sector. Adams then hypothesises the transmission of knowledge via the information media. He estimates a model of the productivity dynamic in which he includes a direct effect of sectoral knowledge and a research spillover effect, finding significant values in both cases.

Another strand of studies consider the spatial effects of research spillover effects on the innovative activities of firms, and therefore those that derive from contact or proximity between the two areas of research. Among the most important of these studies is Jaffe (1989), which considers data on corporate patents in each state of the USA. A model of simultaneous equations describes the relations among expenditure on academic research, expenditure by firms, and the patenting activity of the later. Estimation of the model furnishes important spillover values for academic research, especially for the pharmaceuticals and chemicals industries.

2.2 The economics of science

Dasgupta and David (1987) investigate the fundamental differences between the production of knowledge in the contexts of science and technology. This important paper laid the basis for the modern economic theory of science. The main differences between the worlds of science and technological innovation reside, not in the research object and methods of the two contexts, but in their organization and the goals pursued. The fundamental difference between them concerns the dissemination of results, which is immediate and complete in scientific research as academic researchers seek to publish their discoveries as soon as possible and obtain, through peer evaluation, recognition by the scientific community of the validity of their results.This is contrary to what happens in technological research where new knowledge is kept secret..

The scientific community on the one hand enjoys the advantage of complete information; on the other, it is concerned to ensure the researcher's property right on the item of new knowledge that s/he has produced. Because full disclosure is the optimal solution from the point of view of society's well-being, this social norm adopted in the scientific community serves that purpose. Obviously, full disclosure conflicts strongly with the secrecy necessary to be able to profit from technological innovation. Firms, in fact, obtain a return on investments in R&D in relation to the degree of market power that a patent or the restricted circulation of an innovation may generate for them. Radically different from this objective is the 'quest for priority' in attribution of the paternity of a discovery that motivates academic researchers. The latter immediately submit the results of their work for publication which will certify their priority in the discovery. From this derives recognition in monetary terms (career advancement, awards, etc.) and in terms of reputation and prestige in the scientific community.

The incentives system that operates in research is characterized by great uncertainty and by the principal's difficulty of monitoring effort. The evolution of state-organized academic research seems to have struck a balance between the private motivations of researchers and the needs of society. Individual scientists take part in contests in which those who obtain a innovative result first receive recognition from the scientific community and the advantages that ensure therefrom. Because the work of those who do not win is valueless, the contest belongs to the category of tournaments in which the winner takes all (Dasgupta, 1989; Lazear, 1997). Comparison with reality shows that this system efficiently incentivizes academic researchers, in that they are generally highly motivated and committed to their research. In effect, this result also derives from the assurance of an income, often from teaching duties, which mitigates the effects of the risk in research.

The rules of the academic world favour the spread of forms of collaboration and information-sharing which have important externalities. Scientific work is often carries out by teams of researchers, in that the advantages deriving from obtaining priority are generally indivisible, while the pooling of kindred and specialized skills considerably increases the chances of success (Stephan and Levin, 1992). Data on publications show that collaborations have increased over time. The transmission of tacit knowledge takes place in academic departments whose composition is an important factor in the work of individual researchers. This relationship may also hold among researchers belonging to different institutions but who work in the same field and interact with each other to form 'invisible colleges' (David, 1998).

The theme of incentives for academic researchers also relates to the aggregate size of the scientific research sector compared with that of technological research and the economy in general. From a long-period perspective, scientific knowledge is a crucial input to technological innovation. Consequently, in the long period, it is necessary for a balance to be struck between the incentives for scientific research work and the economic advantages in technological research increased by innovations.

3 The model

We consider an economy consisting of non-overlapping generations. Each generations lives in one period and is constituted by N individuals with different levels of ability. There is one single final good, which is the numeraire and is produced, using only the labour factor, by the consumption good sector, which is perfectly competitive. In period t, which also constitutes the generation t, output is produced according to the following production function:

$$Y_t = a_t L_t \tag{1}$$

where a_t is the parameter measuring the level of the technology available in generation t, L_t is the labour factor, a_t grows from one generation to the next with the introduction of innovations produced by the research sector. Innovations increase the productivity of workers by an amount proportional to the productivity of the previous period. If an innovation increases the productivity of the previous period by an amount b > 0, and γ is the number of innovations obtained in period t (or generation t), the change of productivity over time can be described as follows:

$$a_t = a_{t-1}(1 + \gamma_t b) \tag{2}$$

A fundamental assumption made by this paper is that the number of potential innovations in each individual period is limited. This assumption, which is at variance with that usually made in the literature on innovation-driven innovation (Aghion and Howitt 1992, Romer 1990), was first introduced in a growth model by Zeira (2003). Its principal implication is that the innovative race is such that a certain number of potential innovators seek to produce the same innovation. However, only one of them will be the first to do so and obtain the reward. As Zeira (2003) has shown, a race of this kind arises only when the number of innovations is limited: otherwise, each researcher would seek to produce a different innovation in order to maximize his/her chances of obtaining the reward. Only if the number of potential innovations is limited will a number of researchers greater than one seek the same innovation. Another implication of the assumption on a limited number of potential innovations is that research is not generic but focused on specific innovations. In other words, the researcher identifies what advances are possible and concentrates his/her research effort on those.

We have made this assumption because, in our opinion, the type of contest that ensues from it successfully captures what happens in the scientific world, where innovations or advances in a scientific discipline are limited, and scientific communities are often engaged with problems on which there is consensus as to their importance for advancing scientific knowledge.

Following Zeira (2003), we assume for the sake of simplicity that the number of possible innovations is given and equal to one, so that $\gamma = 1$ if the innovation is introduced, $\gamma = 0$ if it is not.

Another assumption is that innovation is a public good produced by the scientific sector within universities and transferred cost-free in the same period to the consumption goods sector. Innovation yields a reward for whoever produces it first. This reward consists in greater remuneration financed by the state. In scientific communities, the remuneration for the researcher usually consists in both a greater monetary reward and greater prestige or reputation. For the moment we assume that it consists substantially in a monetary reward.

We now describe the scientific sector in greater detail.

3.1 The research sector

Research is carried out within scientific communities such as universities or other research bodies financed largely by the state and regulated by the institutional rules typical of academia. These rules consist in 1) *priority*, 2) *full disclosure*, and 3) *the importance of relations and interactions among colleagues*, which intervene both in the new idea formation phase and in evaluation of what is produced. There is therefore a strong community component which has effects on both the process by which innovations are produced and on public recognition of those innovations. The latter are diffused by scientific publications or public media subject to the peer review process. Relations with colleagues are therefore extremely complex, and since they determine both recognition of the innovation and its diffusion, they determine both the possibility of obtaining the reward for its introduction, as well as the productivity of the entire research sector (when referring to these innovations, David, 1998, has used the term 'invisible colleges'). Social interactions among researchers therefore influence the likelihood that a researcher will produce a particular innovation recognised by the scientific community. As a consequence, they constitute a context variable for all those involved which we call the '*social interactions effect*'. To capture this effect we hypothesised that the probability of an innovation being produced by the entire scientific community is a function of those interactions. In other words, relations among colleagues influence the probability $p(I)$ that an innovation will be produced in the research sector. This implies that ex ante the expected level of technology is given by:

$$\widetilde{a_t} = a_{t-1}(1 + p(I)b) \tag{2.b}$$

Meoreover, research is carried out by individual researchers who, although they enjoy the same context variable, have different probabilities of being the first to produce the specific innovation. The probabilities depend directly on the resources that the individual researcher devotes to the research, and inversely on the resources devoted to the same research activity by other researchers. The latter therefore constitute another context variable, which we may call the *'competition effect'*. This captures the effect of the innovative contest to be the first to produce a specific innovation. Consequently, the more the resources employed by others, the less the researcher's likelihood of being first.

In short, the probability that an individual researcher will be the first to obtain an innovation is as follows:

$$p_{i,t} = p(E|I) \tag{3}$$

where E is the event 'an individual is the first to obtain an innovation' and I is the event 'an innovation occurs in that scientific context'. If the two events are independent, (3) becomes $p_{i,t} = p_i(E)p(I)$.

Hence, $p_i(E)$ depends directly on the resources that the individual researcher devotes to his/her research, denoted by h_i, and inversely on the resources that all the other researchers devote to that same research activity, devoted by H. Formally: $p_i(E) = \frac{h_i}{H}$,.

The resources used by the individual researcher consist substantially in effort - which has a cost in terms of utility that is greater, the higher the level of the technology to be achieved - and in the researcher's mental abilities, δ_i, which are hypothesised to be heterogeneous among individuals and distributed among the population according to a given distribution function $F(\delta)$. More specifically, it is assumed that mental ability increases the likelihood of being first to produce an innovation, and that it is very important only in the case of activity research, whilst it does not influence the productivity of these same agents if they work in the consumption good sector. If mental ability is productive only if it is applied to research, it follows that only more able individuals undertake that activity - given that they will have a higher relative pay-off from it - while less able ones will undertake the alternative activity. This implies that there is a threshold level of ability $z > 0$ such that if $\delta_i < z$, the individual will choose the alternative activity; if $\delta_i \geq z$, s/he will choose to enter the research sector. Overall, the set of resources devoted to research by an individual researcher is given by $h_i = \delta_i e_i$, where e_i is the effort of the i-th researcher, whilst the set of resources used by all the researchers is given by

$$H = \int_z^\infty h(\delta) dF(\delta)$$

. Substituting, one obtains $p_i(E) = \frac{e_i \delta_i}{\int_z^\infty h(\delta) dF(\delta)}$.

As regards the probability that the research sector as a whole will achieve an innovation $(p(I))$ is, as said, determined by the system of interactions among the agents belonging to that sector. To capture this effect we hypothesised that:

$$p(I) = s \left[\int_z^\infty h(\delta)^{\frac{\varkappa - 1}{\varkappa}} dF(\delta) \right]^{\frac{\varkappa}{\varkappa - 1}}$$

where we hypothesised that $N = 1$. This indicator has been used by Bernabou (1996a and 1996b) to capture the effects of social interactions on the formation of local human capital. In the case analysed by us, the context effects which influence the probability of achieving an innovation constitute a social capital typical of the research sector that can be used by all those who belong to it. The choice of this indicator is suggested by the fact that it makes it possible to capture various aspects of social interactions according to the value taken by the parameter $\varkappa$

In fact, if $\frac{1}{\varkappa} > 0$, then the agents are complementary and heterogeneity between agents is costly . Hence the presence of individuals who have committed a low amount of resources greatly reduces that probability, whereas if $\frac{1}{\varkappa} < 0$, individuals are substitute and heterogeneity in terms of resources devoted to the research does not represent a cost. Benabou (1996a, 1996b) shows that complementarity or substitutability among agents may be connected with social behaviours whereby conformism prevails in the former case (*peer effect*), and the search for status in the latter (*role-model effect*). Which of the two types of behaviour is more probable in the research sector is not clear a priori. Some authors maintain that conformism is very widespread, but there is no definitive evidence on this, for which reason it is important to admit both hypotheses.

Description of the research sector is completed with introduction of the expected utility function: from this can be derived the optimum level of effort devoted by the individual researcher to his/her research. Given the hypotheses introduced previously, this will be given by the expected income minus the disutility of the effort:

$$u_{i,R} = m\widetilde{a}_t p(I) p_i(e, \delta_i, H) - \frac{d\widetilde{a}_t e_i^{1+\sigma}}{1+\sigma} \tag{4}$$

where $d > 0$ and $0 < \sigma < 1$ are two parameters which capture the disutility deriving from the effort, while $m\widetilde{a_t}$ is the monetary reward deriving from the innovation, proportional to the level of the technology. On substituting the expressions found for $p_i(E)$ and for $p(I)$ into (4), it becomes:

$$u_{i,R} = m\widetilde{a}_t \frac{e_i \delta_i}{\int_z^\infty h(\delta) dF(\delta)} \left(\int_z^\infty h(\delta)^{\frac{\varkappa-1}{\varkappa}} dF(\delta) \right)^{\frac{\varkappa}{\varkappa-1}} - \frac{d\widetilde{a}_t e_i^{1+\sigma}}{1+\sigma} \tag{5}$$

which when maximized with respect to e_i gives the optimum effort level chosen by the researcher, given the amount of resources invested by other researchers, and given the entire sector's probability of achieving the innovation (the level of social interactions). This is given by:

$$e_i^* = \left[\frac{ms\delta_i}{d\int_z^{\infty} h(\delta)dF(\delta)} \left(\int_z^{\infty} h(\delta)^{\frac{\varkappa-1}{\varkappa}} dF(\delta) \right)^{\frac{\varkappa}{\varkappa-1}} \right]^{\frac{1}{\sigma}} \tag{6}$$

Evinced by (6) is that as individual ability increases so do the resources invested in the research activity. Hence more able individuals are more likely to be the first to produce an innovation, not only because their ability directly influences that probability and because they are those most incentivized to invest in the research activity. Given individual ability, the two context indicators show that this effort also depends on the expected value of the amount of resources invested by other researchers $h(\delta)$.

In this regard we assume rational expectations in the sense that the expected value is the optimum value chosen by the other researchers when they consider the behaviour of the others as given. On this hypothesis, we can rewrite the two context variable in terms of the model's parameters as follows:

$$\begin{aligned} &\int_z^{\infty} h(\delta)dF(\delta) \\ &= \left(\frac{ms}{d}\right)^{\frac{1}{\sigma}} \left[\int_z^{\infty} \delta^{\frac{1+\sigma}{\sigma}} dF(\delta) \right]^{\frac{1-\sigma}{\sigma(1+\sigma)}} \left[\int_z^{\infty} \delta^{\frac{(\varkappa-1)(1+\sigma))}{\varkappa\sigma}} dF(\delta) \right]^{\frac{\chi}{\sigma(\chi-1)}} \end{aligned} \tag{7}$$

$$\left(\int_z^{\infty} h(\delta)^{\frac{\varkappa-1}{\varkappa}} dF(\delta) \right)^{\frac{\varkappa}{\varkappa-1}} = \left(\frac{ms}{d\int_z \delta^{\frac{1+\sigma}{\sigma}} dF(\delta)} \right)^{\frac{1}{\sigma}} \left(\int_z \delta^{\frac{(\varkappa-1)(1+\sigma))}{\varkappa\sigma}} dF(\delta) \right)^{\frac{(1+\sigma\chi)}{\sigma(\chi-1)}} \tag{8}$$

Substituting (7) and (8) in (6) and then again (5) yields the maximum level of utility given by:

$$u_{i,R} = \frac{d\widetilde{a}_t\sigma}{1+\sigma} \left(\frac{ms\delta_i}{d\int_z \delta^{\frac{1+\sigma}{\sigma}} dF(\delta)} \right)^{\frac{1+\sigma}{\sigma}} \left(\int_z \delta^{\frac{(\varkappa-1)(1+\sigma)}{\varkappa\sigma}} dF(\delta) \right)^{\frac{1+\sigma}{\sigma}} \tag{9}$$

The i-th individual's maximum level of utility increases with his/her ability, and follows a non-univocal pattern with respect to the ability level representing the ability threshold above which individuals enter the research sector ($z > 0$). More precisely, the maximum utility increases with the increase in z if the competition effect predominates among the various researchers. In fact, an increase in the i-th individual's maximum level of utility increases with his/her ability, and follows a non-univocal pattern with respect to the ability level representing the ability threshold above which individuals enter the research sector ($z > 0$). More precisely, the maximum utility increases with the increase in z if the competition effect is strong enough. In fact, an increase in z is equivalent to a decrease in the number of individuals engaged in research, so that there is less competition and consequently a greater probability of being first. By contrast, if the interactions effect predominates, a reduction of the research sector (i.e. an increase in z) reduces the maximum utility obtainable in the research sector.

More particularly figures (1) and (2) show the indirect utility function, which is increasing and convex in δ_i, in the two situations. In fig. (1) *competition effect* prevails, then an increse in the ability of the marginal researcher that enters in the sector (i.e an increase in z), provokes a movement along the u_i curve, and in the same time an upwards shifts of the curve, since this reduce the number of competitors. While when *social interactions effect* prevails an increase in z will induce the same movement along the curve but also a downwards shift of it.

Fig.1 and 2 here

3.2 The consumption good sector

In the consumption good sector, as said, we assume that ability is not important in determining labour productivity. Each worker can supply inelastically one unit of labour factor, and there is no disutility connected with the work activity. This means that once the ability level beyond which individuals choose the research sector has been determined, the labour supply is infinitely elastic until it reaches the ability limit value. Given these assumptions, the utility obtainable in this sector is given by:

$$u_y = c \tag{10}$$

which is maximized under the constraint that $c \leq w_y$, where w_y is the wage obtainable in that sector.

This sector receives technology from the research sector at no cost, but it pays taxes that the state uses to fund the research sector. Considering the production function (1) and bearing in mind that this sector operates in perfect competition, profits net of taxes are defined as follows: $\pi = (1 -$

$\tau)Y_t - w_y L_t$, where τ denotes the tax rate. Maximization of this function yields the wages in the consumption good sector, as given by:

$$w_y = (1-\tau)\widetilde{a_t}. \tag{11}$$

3.3 The public sector

The state levies taxes on the consumption good sector in order to finance production of the public good by the research sector. The financing consists in an amount of monetary income which is distributed only to those who win the innovation contest. It has been repeatedly emphasised, in fact, that the income of researchers working in the public sector consists of a share connected with innovative activity - i.e. a reward paid only if innovation is produced - and a share which is instead independent of production of innovation, and which shelters researchers against the risk of not producing any innovation.

Given these hypotheses, the state's budget constraint can be represented as follows:

$$m\widetilde{a_t}p(I) = p(I)\tau\widetilde{a_t}L_t \tag{12}$$

4 Equilibrium

In order to determine the general equilibrium, it is necessary to define what share of workers enter the research sector and what instead enters the consumption good sector. To this end, we must determine what, in equilibrium, is the ability level that divides the group of those who select the consumption good sector from those who select the research sector. This will be the ability level at which the marginal worker is indifferent between the two sectors, which comes about when the following condition holds: $u_{t,y} = u_{t,R}(z)$. Substituting equations (1), (9), (10), (11) and (12) into this condition yields:

$$\left((1-\tau)\frac{\sigma+1}{\sigma d}\right)^{\frac{\sigma}{1+\sigma}} = \frac{sF(z)z}{d\int_z \delta^{\frac{1+\sigma}{\sigma}} dF(\delta)} \left(\int_z \delta^{\frac{(\chi-1)(1+\sigma)}{\chi\sigma}} dF(\delta)\right)^{\frac{\chi}{\chi-1}} \tag{13}$$

From the solution of this equation one obtains the equilibrium value of z that determines the percentage of individuals who enter the research sector (given by $1-F(z)$) and the percentage of those who enter the consumption good sector. In order to simplify the analysis, we assume that ability is distributed uniformly among the entire population, with values in the interval $(0;1)$. In this case (13) becomes:

$$\left((1-\tau)\frac{\sigma+1}{\sigma d}\right)^{\frac{\sigma}{1+\sigma}} = \\ = \frac{\lambda s}{d}z^2\left(\frac{\chi\sigma}{(\chi-1)(1+\sigma)+\sigma\chi}\right)^{\frac{\chi}{\chi-1}}\left(1-z^{\frac{(\chi-1)(1+\sigma)+\sigma\chi}{\chi\sigma}}\right)^{\frac{\chi}{\chi-1}}\frac{2\sigma+1}{\sigma}\left(1-z^{\frac{2\sigma+1}{\sigma}}\right)^{-1} \quad (14)$$

The choice of the uniform distribution of individuals' abilities entails the following assumption concerning the parameters:

Assumption: $\chi \notin \left(0, \frac{1+\sigma}{1+2\sigma}\right)$.

The right hand side represents the utility that the marginal researcher derives form choosing the research sector. It depends on z for two reasons. First of all it directly affects the productivity of the marginal researcher, given that the ability of a worker modifies the probability of obtaining an innovation. However z determines also the size of the research sector, which in turn determines the social interactions effect, the competition effect and the premium derived from innovation. Therefore the RHS of eq. (14) picks either individual effects of changes in the ability, either contextual effects of changes in z. Graphically, the RHS of equation (14) rapresents both movement along the u_i,due to changes in the ability of worker, as well as its translations due to changes in contextual effects caused by changes in the size of research sector.

The left-hand side of this equation represents the oppurtunity cost of the research sector choice, in equilibrium the marginal worker must be indifferent between the two choices.

In order to find the solution(s) of eq. (14), we rewrite it as follows:

$$\left((1-\tau)\frac{\sigma+1}{\sigma d}\right)^{\frac{\sigma}{1+\sigma}}\frac{\sigma}{2\sigma+1}\left(1-z^{\frac{2\sigma+1}{\sigma}}\right) = \quad (14.b) \\ = \frac{\lambda s}{d}z^2\left(\frac{\chi\sigma}{(\chi-1)(1+\sigma)+\sigma\chi}\right)^{\frac{\chi}{\chi-1}}\left(1-z^{\frac{(\chi-1)(1+\sigma)+\sigma\chi}{\chi\sigma}}\right)^{\frac{\chi}{\chi-1}}$$

The LHS of this equation is always decreasing and concave in z. While as concern the RHS, according to the values assumed by χ, it may be always increasing; or it may increase for a stretch and then decrease. This implies that, as the case may be, there is a single equilibrium value of z, or two possible equilibria. In this regard the results can be summed up by the following:

Proposition 1 • *When $\frac{1+\sigma}{1+2\sigma} < \chi < 1$ i.e. the cost of heterogeneity is high (there is an high degree of complementarity) there exists a single stable equilibrium with $z < 1$.*

- *When -$\infty < \chi < 0$, or $1 < \chi < +\infty$, i.e the cost of heterogeneity is low (the degree of complentarity is low, or there is substitutability among agents), there may be multiple equilibria: one in which $z = 1$, the other in which $z < 1$.*

- *Which equilibrium prevails depends on the initial value of z.*

  For high values of z, i.e. when the research sector is very low, equilibrium with no research sector prevails (no-growth trap).

  While if the initial dimension of research sector is not low, the equilibrium with a positive research sector will emerge.

- *When the equilibrium is characterized by $z < 1$, an increase in the parameters s and τ and a decrease in the parameter d give rise to an increase in the research sector.*

Proof.

- When the left-hand side of equation (14.b) (hereafter LHS) is calculated in $z = 0$, it assumes a positive value, whereas in $z = 1$ it is nil. Moreover, it is decreasing and concave in z.

  As regards the right-hand side (RHS), when $\frac{1+\sigma}{1+2\sigma} < \chi < 1$, the RHS calculated in z= 0 is nil, whilst when calculated in $z = 1$ it tends to$+\infty$ and the derivative is always increasing.

  This entails that the equilibrium (z) exists and is unique; moreover, $z < 1$.

- When -$\infty < \chi < 0$, and $1 < \chi < +\infty$, the LHS is still decreasing, concave and LHS(0)=0 and LHS(1)=0, while $RHS(0) = 0$ and $RHS(1) = 0$, and it is increasing for values of z within the range $\left[0, \frac{2\sigma(\chi-1)}{(\chi-1)(3\sigma+1)+\chi\sigma}\right[$, while it is decreasing for values of z within the range $\left]\frac{2\sigma(\chi-1)}{(\chi-1)(3\sigma+1)+\chi\sigma}, 1\right]$.

Moreover it is concave for z within $[0, b[$, while it is convex for z within $]b, 1]$ where $b > \frac{2\sigma(\chi-1)}{(\chi-1)(3\sigma+1)+\chi\sigma}$. This implies that there may be two cases: a single equilibrium, characterized by $z = 1$, otherwise there may be three equilibria, of which one is unstable and two are stable.

The two stable equilibria are characterized by $z < 1$ and $z = 1$.

In fig. (3) we represent the equilibrium condition (eq.14) when $\frac{1+\sigma}{1+2\sigma} < \chi < 1$, while in fig. (4) the same condition when -$\infty < \chi < 0$ and $\chi > 1$.On the stability of equilibria see appendix. ■

Fig.3 and 4 here

This result highlights that, if the heterogeneity is costly (in other words if there is an high degree of complementarity), there will be always an equilibrium with a positive research sector. While when the cost of heterogeneity is not high (i.e. there is a low degree of complementarity or there is substitutability) then the initial size of the research sector is decisive for determining the type of equilibrium that will prevail. A too small research sector is at risk of disappearing altogether, leading the economy to an equilibrium without growth. If instead the research sector is initially of sufficient size, then in equilibrium there will be a positive share of the population that enters the research sector.

This result can be explained by considering that a high degree of complementarity implies a low social exchange between agents, then the effect of externalities deriving from social interactions is low, this implies that the initial dimension of the research sector is not relevant to determine the final result. While if there is a low level of complementarity or there is substitutability between agents, this indicates that there is an high social exchange between agents, then the initial size of research sector is important in determining the relevence of externalitites effect and then the final result.

Finally proposition 1 states that when z<1, policies aimend to increase individual efficiency in research (a reduction of d), or to support research activity itself with greater state funding (an increase in τ), increase the equilibrium size of the research sector.

We now determine the growth rate of this economy, showing the relation between it and the size of the research sector.

5 The steady-state growth rate

In this economy the growth rate will be an expected value, given that innovation is not certain ex ante. This is defined as:

$$\overline{g} = E(\frac{Y_t - Y_{t-1}}{Y_{t-1}}) = p(I)b \tag{15}$$

where $p(I) = s\left(\int_z^\infty h(\delta)^{\frac{\varkappa-1}{\varkappa}} dF(\delta)\right)^{\frac{\varkappa}{\varkappa-1}}$ is the probability that the research sector as a whole will produce an innovation. On substituting equations (8) and (12) into this expression and into the expression defining the expected growth rate, we obtain:

$$\overline{g} = b\left(\frac{z^* s(2\sigma+1)}{d\sigma(1 - z^{*\frac{2\sigma+1}{\sigma}})}\right)^{\frac{1}{\sigma}} \left(\frac{\chi\sigma}{(\chi-1)(1+\sigma)+\chi\sigma}\left(1 - z^{*\frac{(\chi-1)(1+\sigma)+\sigma\chi}{\chi\sigma}}\right)\right)^{\frac{(1+\sigma)\chi}{\sigma(\chi-1)}} \tag{16}$$

As shown by (16) the relation between the expected growth rate and the size of the research sector is not univocal. More specifically, it may be that the function enables identification of an optimum value of z which establishes the size of the research sector that maximizes the growth rate. In fact, extreme values of z entail an industrial (or research) sector that is too small and as a consequence slows down the economy's growth rate.

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6 Appendix

Equilibrium requires that no worker changes the sector of activity, this happens when the utility which the marginal researcher derives from the alternative sector is equal to the utility derived from research sector. To see the stability of equilibrium points consider what happens in different points.

Graphically the equilibrium can be represented as follows:

Fig. 5 here

Point A is a stable equilibrium since points on the right hand side (left hand side), indicates situations where the utility which the marginal worker derives from the research sector is higher (lower) than the utility s/he derives from the alternative sector.This implies a decrease (increase) in z. Point B is not a stable equilibrium, since in points on the right hand side, the utility derived from the alternative sector is higher than the utility drerived from research sector, this implies an increase in z, which continues until it reaches its maximum value.

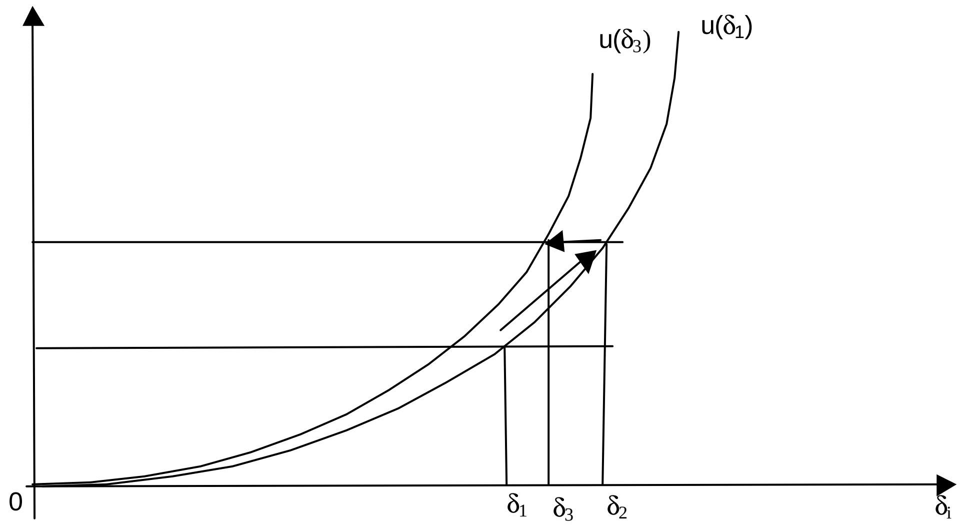


Figure 1: Variations of utility function when competition effect prevails

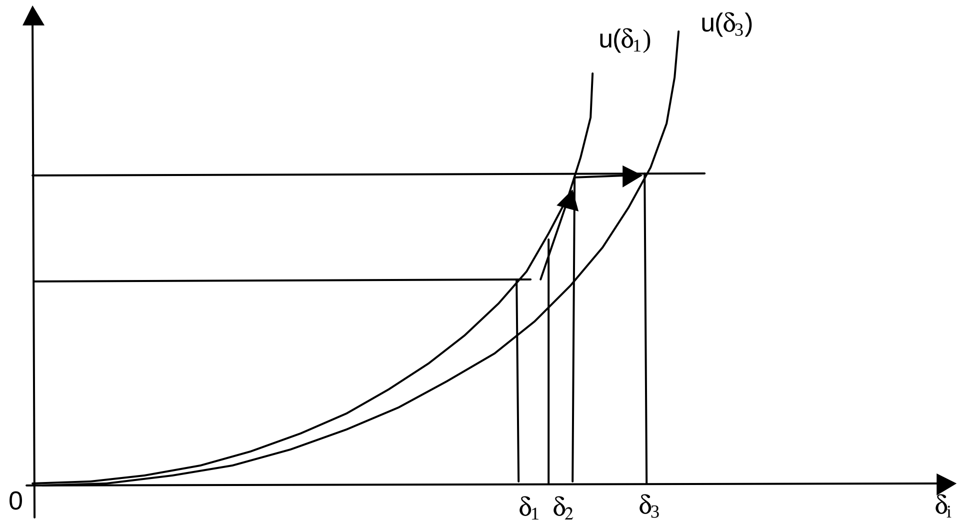


Figure 2: Variations in utility function when social interactions effect prevails

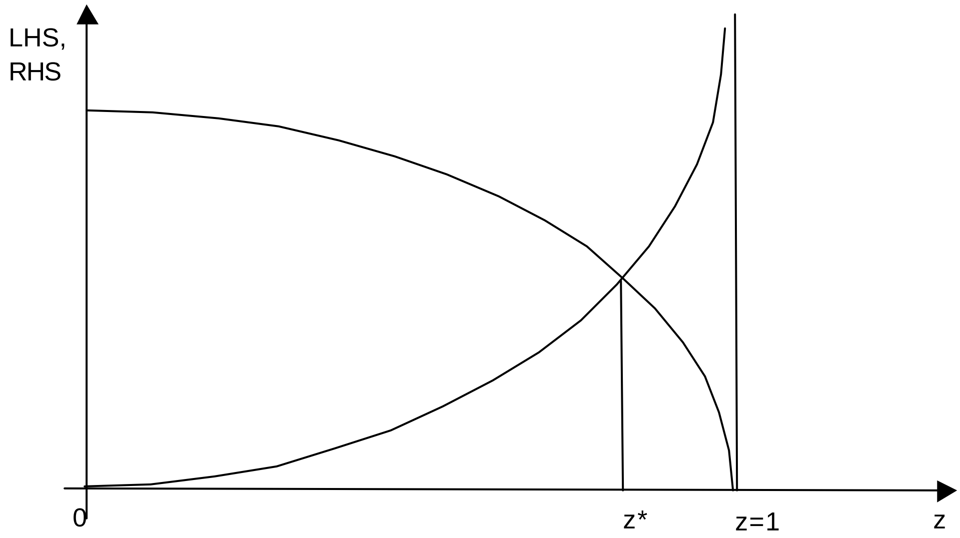


Figure 3: Equilibrium when the cost of heterogeneity is high

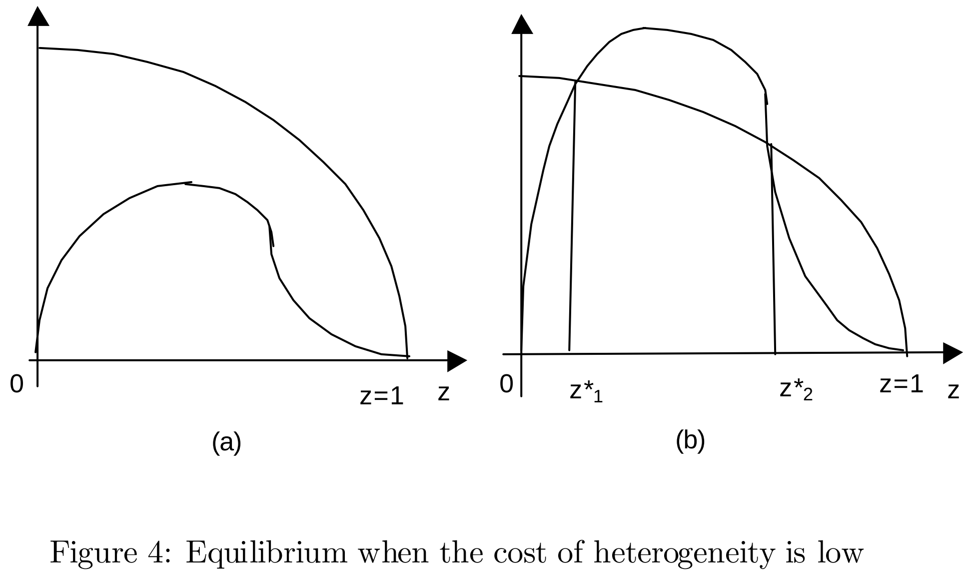
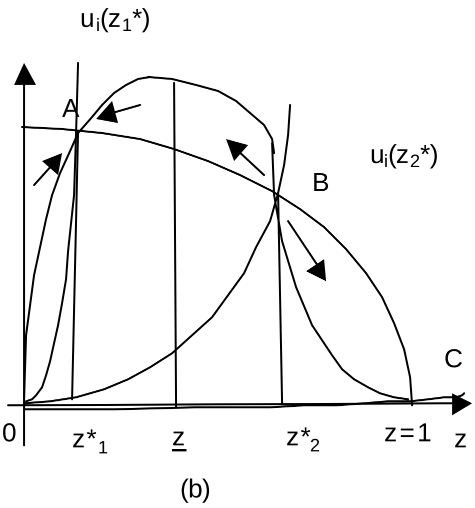


Figure 4: Equilibrium when the cost of heterogeneity is low



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