Low returns in R&D due to the Lack of Entrepreneurial Skills

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Abstract

This paper proposes a model of endogenous growth where innovating requires both researchers, who produce inventions, and entrepreneurs who implement them. As research and entrepreneurship compete in the allocation of aggregate resources, the relation between growth and research effort is hump-shaped. When entrepreneurs appropriate too little rents from innovation, too few resources are allocated to entrepreneurship and returns to R&D are low because of this lack of entrepreneurial skills. When so, innovation should be promoted by encouraging entrepreneurship rather than research.

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1 Introduction

Since the Malthusian (1798) and Ricardian (1817) prophecies of the eventual coming of a stationary state, the spectre of diminishing returns has hovered over economics. Arguably, such diminishing returns may arise because of the progressive exhaustion of investment opportunities which makes the returns to R&D effort decrease over time.[1] According to Schumpeter (1943, 1946) this is, however, just one of two competing explanations of the "state of decay" of the "capitalist society". A "more plausible" one is that "the individual leadership of the entrepreneur tends to lose importance".

According to this view, entrepreneurial ability is as important as research ability in determining the growth rate of an economy. Indeed, Schumpeter (1947) stresses the distinction between the inventor and the entrepreneur: "The inventor produces ideas, the entrepreneur 'gets things done' [...] an idea or scientific principle is not, by itself, of any importance for economic practice". Hence, in order to grow, an economy requires both researchers who produce inventions and entrepreneurs who implement them.[2] Scientific knowledge has no economic impact unless some effort is made to spread it.[3]

In order to model the aggregate trade off between allocating resources to research and entrepreneurship, I consider an endogenous growth model where an innovation requires the matching of an entrepreneur with a successful invention. In the model,

[1] Recent empirical evidence seems to support some form of diminishing returns in research over time. For example, Griliches (1990) and Kortum (1993) note that, in the US, the ratio of the number of patent applications to the scientists and engineers involved in R&D has fallen over time in the post-war period, while Jones (1995a, 1995b) points out that the economy growth rates have remained constant and even declined despite an increase in the amount of R&D effort. Indeed, Griliches (1979) concludes that "the exhaustion of inventive and technological opportunities remains a major suspect for the productivity slow-down in the 70's".

[2] The history of innovation is full of examples of successful inventor-entrepreneur partnerships. For example, Mokyr (1990) notices that even James Watts would have hardly succeeded in the implementation of the steam engine without the help of his partner, Matthew Boulton.

[3] Economists are well aware of the importance of allocating resources to both research and entrepreneurial activities. They must allocate their time between the studying required to write new papers and teaching students, talking with colleagues, presenting work at the NBER meetings, etc.

individuals face the choice of whether to become researchers, who produce inventions, or entrepreneurs who implement them.[4] Hence an economy that allocates too many individuals to the research sector produce too many inventions which will be wasted because there will not be enough entrepreneurs to implement them. Thus the relationship between productivity growth and research effort is hump-shaped.

The existence of search frictions in the process whereby entrepreneurs and researchers are matched produces a natural incompleteness of contracts. Hence, the share of the rents from innovation appropriated by either researchers or entrepreneurs does not necessarily reflect their contribution to innovation. In general equilibrium, however, such rents determine whether individuals choose to become researchers or entrepreneurs. Consequently, the allocation of skill sustained in equilibrium might depart substantially from the socially efficient one. Interestingly, any point on the growth-research effort technological frontier can be sustained as a decentralized equilibrium of the economy.

One of the key results of the paper is that the innovation process can suffer because of the lack of either research effort or entrepreneurial skills. Economic history may provide examples of either case. Islamic civilization at the end of twelfth century may be an example of the former. Indeed Mokyr (1990) argues that it declined because it "was not capable of adding much new to the existing stock of ideas it retrieved and applied so brilliantly". Mokyr also discusses notorious examples of societies, such as the Greeks and the Romans, that suffered because of the lack of entrepreneurial skills. Such deficit may also well explain the economic decline of the late Victorian Britain usually attributed to the inability of British entrepreneurship in promoting

[4] Schumpeter (1949) was concerned that his model resembled a model of "exogenous" technological growth: "a stumbling block" of the theory "may be expressed by saying that the entrepreneur simply does nothing but take advantage of technological progress, which therefore appears, implicitly or explicitly as something that goes along entirely independently of entrepreneurial activity [...] It is perhaps not difficult to understand that technological progress, so obvious in some societies and so nearly absent in others, is a phenomenon that needs to be explained". My model stresses the role of the entrepreneurial function in an endogenous growth framework.

the diffusion of new and advanced production methods.[5]

Some relation to the Literature. By positing that innovation requires the random matching of entrepreneurs with valuable inventions, my model borrows elements from the standard search model (e.g. Pissarides 1990). This setting is, however, extended to capture two important features of the innovation process. First, I introduce a technological externality generated by firm creation that leads to endogenous growth. Secondly, I allow the skill allocation to be endogenous by permitting agents to decide on whether to become an entrepreneur or a researcher.[6] In this context I generalize earlier results, originally due to Diamond (1982) and Hosios (1990), on the efficiency of economies subject to search frictions. In particular I show that restoring efficiency under the presence of technological externalities requires research to have more bargaining power relative to the Hosios's benchmark.

The paper also relates to those strands of the growth literature that have analyzed the relation between growth and R&D effort. It shares with Helpman and Trajtenberg (1994) the premise that inventions have widespread economic consequences only if implemented. The finding that research effort can be excessive arises also in Tirole (1988, p.399), in Aghion and Howitt (1992), and in Aghion and Howitt (1998, chapter 6), while the emphasis on the allocation of talent is shared with Baumol (1990) and Murphy, Shleifer and Vishny (1991). It is the interaction between these strands of the literature that is new here.

The model has also some implications for the recent literature which has analyzed the relation between growth and the scale of the economy.[7] Jones (1995b), Kortum (1997), Young (1998) and Howitt (1999) propose a theoretical solution to the observed

[5] The 1998 White Paper by the British Government argues that the UK is still lacking in entrepreneurial skills. The recent experience of "Silicon Fen " —the cluster of over 1,600 high tech firms that have grown up around Cambridge University— is sometimes perceived as a successful attempt to revert this secular deficit in entrepreneurship.

[6] See Acemoglu (1996, 1997) for an analysis of workers' decision to accumulate human capital in a labour market subject to search frictions.

[7] See Jones (1999) for a survey.

absence of relation between the scale of R&D effort and growth. Their models have in common the assumption that the output cost of an innovation is increasing with the level of development. Due to this form of exhaustion of investment opportunities, the amount of research effort increases over time to keep growth constant. Importantly such decreasing returns to R&D arise as the efficient response of a competitive economy to the increase in its scale.[8]

The paper might propose a complementary reading of the same empirical facts. I show theoretically that the returns to R&D might be decreasing if they are the result of an inefficient equilibrium shift that increases the amount of research effort to the detriment of more socially useful entrepreneurial skills. Furthermore, I show that the data are consistent with the existence of a constant-returns-to-scale matching function that links a measure of innovation (number of patent applications) to a measure of research effort (number of scientists involved in R&D) and entrepreneurship (population of self-employed). This implies that, at the optimal allocation, the returns to R&D never decrease since well-balanced increases in the amount of research and entrepreneurial effort always exhibit a constant marginal effect on the innovation rate.

Section 2 expounds the general set-up while Section 3 solves for the steady state equilibrium. Section 4 deals with efficiency. Section 5 carries out some exercises of comparative statics. Section 6 discusses some empirical implications. The conclusions appear in Section 7. The appendix contains some technical derivations.

2 The Model

The economy is populated by a continuum of agents of size C. Each agent is infinitely lived, risk-neutral and maximizes expected returns in output units discounted at rate $r > 0$. At each point in time agents can choose either to become researchers or

[8] For example, both in Jones (1995b) and Kortum (1997) the economy growth rate is the socially optimal one, while in Young (1998) the total amount of R&D effort is optimal even if its allocation among different dimensions of innovation might not be.

entrepreneurs. I indicate with f_t the time-t fraction of researchers in the population and I refer to it as the level of *research effort* in the economy.

A researcher discovers *inventions* according to a Poisson process with intensity λ. When he makes a discovery, he starts searching for entrepreneurs able to implement it. Keeping the invention up-to-date requires a flow cost of χx_t per unit of time, where x_t represents the leading technology in the economy at time t and $\chi \geq 0$. I assume that the opportunity of transforming an invention into an innovation vanishes according to a Poisson process with rate of arrival ν. This implies that at each point in time the stock of scientific knowledge, k_t, measured by the number of inventions suitable for economic exploitation, increases in response to the discovery of new inventions, while it tends to fall as the old ones become obsolete. This allows one to capture some key characteristics of the process of accumulating scientific knowledge (see Adams, 1990). First, the stock of scientific knowledge is *fundamental* in that its applicability is not immediate. Secondly, it recognizes that the stock of knowledge is made up of *heterogenous* pieces of information since the implementation of an invention requires a costly search for a suitable entrepreneurs. Thirdly, the use of the stock of knowledge is *repetitive,* as an invention can give rise to a "cluster" of innovations concentrated "in certain sectors and their surroundings" (Schumpeter, 1939, pp.100-101). Finally it recognizes its *time specificity*, as scientific knowledge becomes obsolete as time goes by.[9]

An *innovation* requires an invention discovered by a researcher and an entrepreneur. Once they match, a new firm run by the entrepreneur is created. A firm created at time t accesses the leading technology of that date x_t. A firm can produce, at each point in time t, a flow of goods equal to Px_t and is shut down according to a Poisson

[9] The model could be extended by assuming that the rate ν at which inventions become obsolete, depends on the rate of growth of the leading technology of the economy x_t so that technological progress causes the obsolescence of scientific knowledge —an effect reminiscent of Schumpeter's idea of creative destruction. The main implications of the model would remain however unchanged.

process with rate of arrival δ.[10]

The entrepreneur can be either running a firm or working at home (see Benhabib et al., 1991). When the entrepreneur runs a firm, he receives a profit flow π_t. Profits of the entrepreneur are chosen, so as to share with the researcher the gains from running the firm, by using a generalized Nash bargaining solution. The bargaining powers of the entrepreneur and the researcher are β and $1-\beta$, respectively. When the entrepreneur works at home, he produces a flow of goods equal to hx_t where $h \geq 0$ measures the level of human capital of the entrepreneur who uses it according to the technology available at time t. In equilibrium an entrepreneur running a firm has no incentive to search. Hence only entrepreneurs working at home are "available" for innovating. I will denote their number at time t by s_t and I will refer to it as the amount of *entrepreneurial slackness* available in the economy.

The rate at which free entrepreneurs find suitable inventions is determined by the homogeneous-of-degree-one matching function $m(k_t, s_t)$ (see Pissarides, 1990). This function is increasing and concave in each of its arguments. The matching function allows one to represent in a parsimonious fashion two key characteristics of the innovation process: the fact that both entrepreneurial skills and inventions are heterogenous, so that the search for viable partnerships is time consuming, and the fact that entrepreneurial skills are a scarce resource for which different researchers compete. The probability that an invention matches with an entrepreneur is given by $q(\theta_t) = m(k_t, s_t)/k_t$ where $\theta_t = k_t/s_t$ will be referred to as the level of *knowledge intensity* in the economy. By analogous considerations it follows that $p(\theta_t) = \theta_t q(\theta_t)$ is the instantaneous probability that a free entrepreneur finds a valuable invention. I also assume that

$$p(0) = q(\infty) = m(0, s_t) = m(k_t, 0) = 0, \quad \text{and} \quad p(\infty) = q(0) = \infty \tag{A1}$$

[10] I model firms in this way for analytical convenience. In fact the results of the paper would remain qualitatively unchanged if either firm's death probability or firm's output were assumed to be function of firm's age, as they arguably are in reality.

so as to avoid dealing with uninteresting corner solutions.

Vertical innovations are the only source of growth in this economy. I follow Caballero and Jaffe (1993) and Aghion and Howitt (1998), among others, in assuming that the rate of growth of the technological parameter x_t is given by the product of the size of the innovation, σ, and the frequency of innovation. With the above assumptions, this frequency coincides with the number of innovations introduced in the economy at time t, $\theta_t q(\theta_t) s_t$. Hence the growth rate of the technological parameter x_t is given by $g_t = \sigma\theta_t q(\theta_t) s_t$.[11]

A sufficient condition to assure finite present values is $\sigma C\delta < r$ since it will imply that in steady state equilibrium $g_t < r$. Whereas obtaining a positive equilibrium level of research requires that $\frac{\lambda}{\nu}(1-\beta)(P-h) > 0$. As in Romer (1990), in order to sustain growth we must assign a strictly positive capacity of rent appropriation to researchers, $\beta < 1$, since future rents are the only compensation for the sunk investment in research necessary to produce an invention.

The endogenous variables of the model are the level of knowledge intensity θ, the level of research effort f and the steady state growth rate g.

3 Equilibrium

In this section I first write down value functions and characterize individual behavior. I then analyze the level of research effort and the growth rate that arise in a steady state equilibrium.

[11] A natural interpretation is that there is a continuum of increasingly productive techniques indexed by a real number which corresponds to the log of its productivity parameter. Creation of a new firm means that the entrepreneur has succeeded in discovering a new technique and all entrepreneurs can hereafter search for the next technique in the continuum. So, at any point in time, the rate of technological progress is proportional to the flow of newly created firms.

3.1 The value of research and entrepreneurship

The value of doing research at time t, R_t, solves

$$R_t = E_{\tau \geq 0}\{[(L_{t+\tau} + sup(R_{t+\tau}, H_{t+\tau})]e^{-r\tau}\}, \tag{1}$$

where L_t and H_t are the time-t value of an invention and of being an entrepreneur working at home, respectively. $t + \tau$ is the arrival date of the first invention whose arrival rate is λ, while the second term in the right-hand side captures the option a researcher has of becoming an entrepreneur at a later date.

Since an invention gets obsolete at rate ν and requires a cost of χx_t to remain up-to-date, it has a value L_t to the researcher which follows the asset-type equation

$$(r + \nu)L_t = -\chi x_t + q(\theta)I_t + \dot{L}_t. \tag{2}$$

I_t measures the time-t value to a researcher of an innovation, $\dot{L}_t$ is the time derivative of L_t while $q(\theta)$ is the probability that an invention matches with an entrepreneur. As a firm produces a flow of goods equal to Px_t and entrepreneurs' profits are equal to π_t , I_t can be obtained by solving

$$(r + \delta)I_t = Px_t - \pi_t + \dot{I}_t, \tag{3}$$

where $\dot{I}_t$ represents the time derivative of I_t while δ is the firm's death probability.

Analogously, the value to an entrepreneur of working at home at time t, H_t, solves the asset equation

$$rH_t = hx_t + \theta q(\theta)(E_t - H_t) + \dot{H}_t, \tag{4}$$

where hx_t, E_t and $\dot{H}_t$ are respectively the real flow of goods produced by an entrepreneur working at home, the entrepreneur's value of running a firm and the time derivative of H_t. $\theta q(\theta)$ is the instantaneous probability that a free entrepreneur finds an invention that he can implement. Analogously E_t solves

$$rE_t = \pi_t + \delta[sup(R_t, H_t) - E_t] + \dot{E}_t, \tag{5}$$

where the above equation embodies the option entrepreneurs have of becoming researchers.

Profits are the outcome of bilateral bargaining between the researcher with the invention and the entrepreneur. Hence they maximize the weighted product of the researcher's and entrepreneur's net return from the creation of a new firm equal to I_t and $E_t - H_t$, respectively. Hence

$$\pi_t = \arg\max \ (I_t)^{1-\beta} (E_t - H_t)^{\beta},$$

where H_t is the entrepreneur's outside option which from the point of view of the maximization is taken as constant. As a result, profits are such that

$$I_t = (1-\beta)(I_t + E_t - H_t) = (1-\beta)S_t, \tag{6}$$

where $S_t = I_t + E_t - H_t$ is the private net surplus generated by the creation of a new firm. Of this surplus, researchers and entrepreneurs appropriate fractions $1-\beta$ and β respectively.

3.2 Free entry condition

In steady state each variable is growing at the same rate g as the economy so

$$R_t = Rx_t, \quad I_t = Ix_t, \quad L_t = Lx_t, \quad H_t = Hx_t, \quad E_t = Ex_t. \tag{7}$$

From making use of (7) to rewrite equations (2), (3), (4) and (5) it follows that

$$L = \frac{1}{r-g+\nu}\left[-\chi + q(\theta)(1-\beta)S\right], \tag{2'}$$

$$I = (1-\beta)S, \tag{3'}$$

$$
\begin{aligned}
H &= \frac{1}{r-g}\left[h+\theta q(\theta)\beta S\right], && \text{(4')} \\
E &= H+\beta S && \text{(5')}
\end{aligned}
$$

where $S = I + E - H$ measures (once divided by x_t) the private net surplus associated with the creation of a new firm and is equal to

$$S = \frac{P-h}{r-g+\delta+\theta q(\theta)\beta}. \tag{8}$$

In equilibrium, agents must be indifferent between becoming a researcher or an entrepreneur, so that the *free entry condition* $R_t = H_t$ must hold at each point in time. But then, from using this condition, the fact that $R_t = Rx_t$ and then substituting into (1) it follows that

$$R = \frac{\lambda L}{r-g}.$$

Together with equations (2') and (4') this implies that the condition $R_t = H_t$ reads as

$$h+\theta q(\theta)\beta S = \frac{\lambda\left[-\chi+q(\theta)(1-\beta)S\right]}{r-g+\nu}. \tag{9}$$

The left-hand side of equation (9) represents the relative profitability of being an entrepreneur as an increasing function of the amount of knowledge intensity θ: the larger the stock of scientific knowledge available per entrepreneur, the more profitable is entrepreneurship. Analogously, an increase in θ reduces the profitability of being a researcher because the implementation of inventions becomes progressively more difficult. As a result the right-hand side of equation (9), which measures the relative profitability of being a researcher, is decreasing in θ. Hence, for any given level of the steady state growth rate g, there exists a unique value of knowledge intensity θ such that the right-hand side equals the left-hand side. At such value individuals are indifferent between becoming researchers or entrepreneurs.[12]

3.3 Technological frontier

Since firms are closed at rate δ, entrepreneurial slackness, s_t, evolves according to the differential equation

$$\dot{s}_t = \delta[C(1-f) - s_t] - \theta q(\theta) s_t. \tag{10}$$

so that in steady state it is equal to

$$s_t = s = \frac{\delta C(1-f)}{\delta + \theta q(\theta)}. \tag{11}$$

Analogously, the dynamics of the stock of knowledge, k_t, is governed by

$$\dot{k}_t = \lambda C f - \nu k_t. \tag{12}$$

so that in steady state $k_t = k = \frac{\lambda}{\nu} C f$.

From the assumption that the frequency of innovation is equal to the number of successful matches between k_t and s_t, it follows that the steady state growth rate g of the technological parameter x_t is equal to

$$g = \sigma \theta q(\theta) s = \sigma\, C\, m\left(\frac{\lambda}{\nu} f, \frac{\delta(1-f)}{\delta + \theta q(\theta)}\right), \tag{13}$$

where $\theta = \frac{k}{s}$ solves the simple non-linear equation

$$\theta = \theta\left(f\right) = \frac{\lambda}{\nu} \frac{\left[\delta + \theta q(\theta)\right] f}{\delta(1-f)}. \tag{14}$$

Equation (14) merely expresses knowledge intensity as the ratio of the steady state amount of scientific knowledge to the amount of slackness given by equation (11). Notice that (14) defines an function $\theta(f)$ that associates to each f the corresponding

[12] One can also check that steady state profits π_t are equal to πx_t, where, from substituting (3), (4), (5) into (6), it follows that $\pi = \beta P + (1-\beta) h + \theta q(\theta) \beta I$.

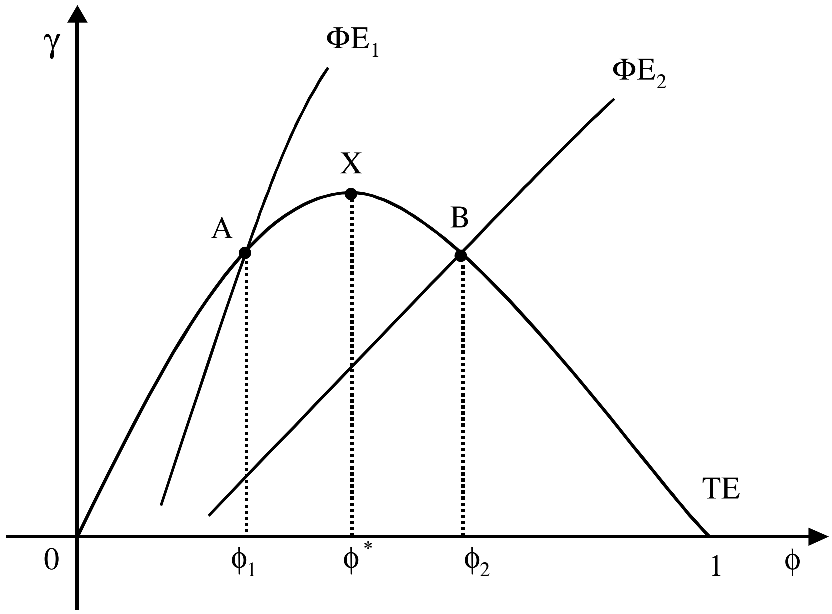

Figure 1: **Steady state equilibrium**

value of θ that solves the equation. Such function is increasing since a larger f associates with a larger k and a lower s. But then, after substituting $\theta(f)$ for θ in (13), one can define a function $g = g(f)$ which relates the level of research effort, f, to the steady state growth rate of the economy. Since the function $g(f)$ determines the frontier of technological possibilities of the economy, I refer to it as the *TE-schedule.* Such schedule is hump-shaped and it satisfies the property that no growth can be the outcome of either too much or too little research effort, $g(0) = g(1) = 0$ (see propositions 1 and 2 in the appendix for a formal proof).[13] As both research and entrepreneurial skills are required to innovate, an over-allocation to either factor harms technological process.

[13]Denote by $0 < \eta < 1$ the elasticity of the matching function with respect to the level of entrepreneurial slackness. Then one can show that $g(f)$ is globally strictly concave if, for example, η is weakly increasing in θ. One can also show that $g(f)$ has a unique maximum under the milder condition: $-\frac{d\eta}{d\theta} < \eta^2$. For example, both conditions would obviously be satisfied in the case of a Cobb-Douglas matching function.

3.4 Equilibrium

Equations (9) and (13), given the constraint imposed by (14), completely solve the model in the research effort, f, growth rate, g, space. Equation (9) determines, for any given level of the growth rate, the relative amount of resources that the economy will end up devoting to research. Given (14) and the associated function $\theta(f)$, equation (9) allows to define the function $g = e(f)$ which relates the level of research effort that solves the free-entry condition to the given level of the growth rate. Hereafter I will refer to the function $e(f)$ as the *FE-schedule*. Such function maps the zero one interval onto the whole real line (see proposition 3 in the appendix). Furthermore $e(f)$ is increasing. To understand why it is so, notice that research requires a longer time than entrepreneurship to become productive and yield some (positive) revenue. Also notice that in the model an increase in the growth rate, g, affects individual decisions through a capitalization effect that reduces the effective discount rate of agents. But a change in the discount factor always tends to have a greater effect on the investment with the longer time horizon so, as a result of the increase in g, the value of both research and entrepreneurship increase but the value of research increases relatively more so f must rise to restore the free entry condition.

The steady-state equilibrium is defined by the point at which the FE-schedule, $e(f)$, crosses the TE-schedule, $g(f)$, like at point A in figure 1. At such point no researcher has an incentive to become an entrepreneur (or vice-versa) and the economy grows at the constant steady state growth rate determined by the technological frontier.

4 Welfare analysis

In this section I compare the equilibrium to the constrained social optimum. I define social welfare $\tilde{W}$ as the net present discounted value of the aggregate income flows produced by entrepreneurs and researchers. The social planner takes as given the search frictions involved in the innovation process. At any point in time, the state of the economy is fully summarized by the quantities k_t and n_t that represent the time-t stock of scientific knowledge and total number of firms, respectively. Given the focus on steady state equilibria, I consider time invariant allocations described by a fixed amount of research effort f.

4.1 The social planner problem

Once multiplied by x_t,

$$y\left(k_t, n_t; f\right) = Pn_t + h[C\left(1-f\right) - n_t] - \chi k_t$$

denotes the net income flow produced by the economy at time t. Also notice that the evolution of the number of firms in the economy is governed by

$$\dot{n}_t = m\left(k_t, C\left(1-f\right) - n_t\right) - \delta n_t \tag{15}$$

while the stock of scientific knowledge grows at a rate $\dot{k}_t$ given by (12). Hence one can implicitly define social welfare as the product of x_t and the function $W(k, n; f)$ which solves

$$rW(k_t, n_t; f) = y\left(k_t, n_t; f\right) + W_k\,\dot{k}_t + W_n\,\dot{n}_t + g_t W(k_t, n_t; f) \tag{16}$$

where $g_t = \sigma m\left(k_t, s_t\right)$ while $W_k = \frac{\partial W}{\partial k_t}$ and $W_n = \frac{\partial W}{\partial n_t}$ measure the social shadow value of an invention and of an additional firm, respectively. Three components account for social welfare in (16): the first is current income, the second is the capital gain associated with changes in the state of the system —the second and third term in (16)— and last the capitalization effect associated with technological progress, the fourth term in (16).

To characterize the constrained socially optimum allocation, denote by g and n the economy's steady state value of the growth rate and number of firms, respectively.

Furthermore let

$$\overline{W} = \frac{Pn + h[C(1-f) - n] - \chi k}{r - g} \tag{17}$$

denote (once divided by x_t) the steady state level of social welfare which is equal to the present discounted value of the level of output net of research costs. Finally let η indicate the elasticity of the matching function with respect to entrepreneurial slackness.[14] Then differentiating (16) with respect to f and after some algebra, the appendix shows that

$$\frac{dW}{df} = -\frac{C}{r-g}\left\{h + \theta q(\theta)\eta S^E - \frac{\lambda\left[-\chi + q(\theta)(1-\eta)S^E\right]}{r - g + \nu}\right\} \tag{18}$$

where

$$S^E = W_n + \sigma\overline{W} = \frac{P - h + \sigma(r - g + \delta)\overline{W}}{r - g + \delta + \theta q(\theta)\eta} \tag{19}$$

is the net social surplus associated with the creation of a new firm. Such surplus is equal to the sum of the shadow value of a new firm W_n plus the gains associated with the technological externality generated by innovation, which have value $\sigma\overline{W}$.

4.2 Results

I can now state my first result on efficiency: the social optimum always lies on the positively sloped arm of the TE-schedule, $g(f)$. To prove this result, the appendix first shows that the steady state growth rate g is maximized at the 'golden rule' level of research effort f^* such that the level of knowledge intensity $\theta^* = \theta(f^*)$ solves

$$\theta^* = \frac{\lambda}{\nu}\frac{1-\eta}{\eta}. \tag{20}$$

Then the appendix shows that the derivative of W with respect to f evaluated at f^* is negative which indeed implies that at the growth maximizing allocation the level of research effort in the economy is too large.

[14] Notice that η is in general a function of θ.

The economic intuition of the result is pretty simple. Given the objective of maximizing the present discounted value of output, the central planner must equate the marginal benefit of increasing research effort to its marginal cost. Notice that equations (13) and (15) imply that the value of f that maximizes the steady state number of operating firms, n, also maximizes the steady state growth rate, g. So the sign of the social marginal benefits of research coincides with that of the derivative of the TE-schedule, $g(f)$. But then, since increasing research always involves a strictly positive marginal cost (relative to increasing entrepreneurship), the social optimum must be at a point where the marginal benefits from increasing f are also strictly positive and this is so only on the strictly increasing arm of TE-schedule.

It is interesting to compare the level of research effort sustained by the decentralized economy to the social optimal one. This can be done by comparing equation (9) with (18) and checking when the decentralized economy implements a level of research effort which induces $\frac{dW}{df} = 0$. One can immediately see that, the two conditions associate with the same level of research effort only if the private and social net-surplus from the creation of a new firm coincide, $S = S^E$. In the absence of technological externalities, $\sigma = 0$, this occurs when entrepreneurs' bargaining power is such that $\beta = \eta$ so that (8) and (19) are identical. Hosios (1990) first proved that, in an economy with search frictions, a constrained efficient allocation of resources requires bargaining power to reflect each side's contribution to the creation of net surplus as measured by the elasticity of the matching function. Here I have generalized this result to an environment where the allocation of skill is endogenous.

When technological externalities are present, $\sigma > 0$, however, the appendix shows that entrepreneurs' bargaining power β must be smaller than η for the decentralized economy to implement the socially efficient allocation. To understand the result, notice that search frictions simultaneously induce a negative externality to agents on the same side of the market (congestion externalities) and a positive one to agents on the other side of the market (thin market externalities). At $\beta = \eta$ the congestion and thin-market externalities balance exactly. Yet, at this point, technological externalities are still operating and tend to discourage activities, namely research, characterized by a longer time horizon and larger initial investment. Hence restoring efficiency requires $\beta < \eta$. There is only one case where the Hosios's rule $\beta = \eta$ still applies even in the presence of technological externalities. This occurs when the type of investment required to specialize in different activities is the same, that is when the instantaneous return from becoming a researcher or an entrepreneur are equal $h = \chi = 0$, (see appendix).

5 Comparative statics

Proposition 4 in the appendix states that, depending on the parameters of the model, any point on the TE-schedule, $g(f)$, can be sustained as an equilibrium of the economy, including those situated on the negatively sloped arm of the TE-schedule, like point B in figure 1. A point like B associates with a Pareto dominated equilibrium since a reduction in research effort would simultaneously lead to an increase in the output level and in the growth rate (both over the transition path and in the new steady state). These types of equilibria can be sustained for reasons similar to those analyzed by Hosios (1990) and Caballero and Hammour (1996). An economy characterized by ex-ante competitive relationships but ex-post bilateral monopolies has no compelling tendency to coordinate itself towards the social optimum, since there is no reason why the amount of rents appropriated by each party should reflect his contribution to the creation of social surplus.

In equilibria like point B in figure 1, research effort crowds out more socially useful entrepreneurial skills and the growth process stagnates precisely because of this *lack of entrepreneurial skills*. Indeed, as the amount of research effort rises, the stock of scientific knowledge increases, but it also becomes progressively more difficult to implement inventions both because more researchers are competing for the same resources (congestion externalities) and because an increase in research effort crowds out useful entrepreneurial skills (thin market externalities). When the stock of scientific knowledge is already large while the amount of entrepreneurial skills is low, an increase in research effort reduces the growth rate of the economy, because it misallocates socially useful resources. For example, an increase in research effort can be translated into stagnant or declining growth rates, if the equilibrium of the economy shifts from point A to point B in figure 1.

Such shift in the equilibrium can occur, for example, in response to a fall in the bargaining power of entrepreneurs β. A fall in β makes research relatively more profitable for any given level of the growth rate so that the FE-schedule shifts to the right while it has no effect on the TE-schedule. Such a fall in β might relate to the Schumpeterian (1943, 1946) claim that cultural and sociological shifts tend to destroy the "protective strata" able to sustain the entrepreneurial function.[15] Since β measures the outcome of a bilateral bargaining problem here specified parsimoniously, one can also argue that, in the presence of some asymmetric information that favors researchers, β might be affected by the technological content of the innovation: innovations that are more technological advanced might associate with a greater ability of the researcher to appropriate rents and therefore with a lower β.

Particularly interesting are the consequences of a change in the firms' destruction rate δ. A change in δ has generally ambiguous effects on the FE-schedule. To see this notice that, a fall in δ requires an increase in the level of knowledge intensity, θ, to restore the free entry condition (9). But equation (14) implies that for given f, a lower δ associate with a larger value of θ, since the amount of entrepreneurial

[15] Culture, understood as prevailing values and beliefs, is often perceived as an important determinant of the level of entrepreneurship in the economy, see Davidson and Wilklund (1997). In terms of the model, a cultural environment more favourable to entrepreneurship may translate into a larger either β or h. This last case may correspond to societies that reward more (in terms of social status) entreprenerial 'success' and 'leadership'.

slackness is reduced. If this last effect is sufficiently strong the FE-schedule, $e(f)$, shifts to the left, otherwise f must rise to restore the free entry condition and $e(f)$ shifts to the right.

What is not ambiguous is the impact of a change in δ on the technological frontier of the economy. A fall in δ implies a downward shift of the TE-schedule, with the hump of the schedule moving leftward. To prove the downward movement, notice that for given f a fall in δ reduces the steady state level of entrepreneurial slackness given by (11) both directly through δ and indirectly through the induced positive effect on θ, see equation (14). The leftward movement of the hump follows from the fact that entrepreneurial slackness falls for any given level of f, so the constraint imposed by the number of free entrepreneurs on the innovation process becomes progressively more binding as f increases. In other words, an economy that liquidates more often (i.e. with a larger δ) has more frequent opportunity to rebuild its productive stock at a higher technological level and grows faster thanks to the inter-temporal spill-overs typical of standard endogenous growth models. Thus the model suggests a channel whereby an increase in the pace of reallocation promotes growth by increasing the amount of resources available for innovating.[16]

6 Empirical implications

I next discuss some empirical implications of the model. The analysis is simply meant to be illustrative of some of the theoretical properties of the model.

If one assumes that the matching function is Cobb Douglas,

$$m(k_t, s_t) = A(k_t)^{\alpha}(s_t)^{\gamma}, \qquad 0 < \alpha, \gamma < 1, \tag{21}$$

then equation (13) suggests to run the following regression

[16] See Mortensen and Pissarides (1998) for a model where the causality between reallocation and growth reverses. In their model an increase in the rate of exogenous technological progress raises the job reallocation rate in the economy.

$$\ln(g_t) = \alpha \ln(f_t\, C_t) + \gamma \ln(s_t) + \alpha\ \ln(\frac{\lambda}{\nu}) + \ln \sigma + \ln(A). \qquad (22)$$

The model has two important testable implications. First, the parameters α and γ must both be positive numbers strictly between zero and one. Indeed this would imply that both entrepreneurial and research skills affect the innovation rate of the economy. Secondly, the matching function (21) exhibits constant returns to scale, that is $\alpha + \gamma = 1$. This would imply that, at the optimal allocation, the returns to R&D can never be decreasing since well-balanced increases in the amount of research and entrepreneurial effort have constant marginal effects on the innovation rate.

To illustrate the methodology, I estimate equation (22) for the US over the period 1950-1990.[17] I follow Griliches (1979, 1990) in taking the total number of patent applications as an index of innovative activity in order to proxy for g_t,[18] and Jones (1995b) in considering the ratio of scientists and engineers involved in R&D over the population if working age as a measure of (relative) research effort f_t. As a proxy for the scale of the economy C_t in equation (22) I take the population if working age. Identifying entrepreneurship is more problematic. According to Schumpeter (1949) the entrepreneurial function can be identified only a posteriori.[19] In fact, Evans

[17]Data before 1970 are taken from "Historical Statistics of the United States: Colonial Times to 1970"; after 1970 they are from various issues of "The Statistical Abstract of the United States".

[18]Whether a patent corresponds more to the notion of invention or innovation, is a topic beyond the scope of this paper. The Patents Laws-United State Code, U.S.C. 101, states that " whoever invents or discovers any new and useful process, machine, manufacture, or composition of matter, or any new and useful improvement thereof, may obtain a patent". The UK Patents Act 1977 states that the invention to be patented must be "capable of industrial application". More generally Cornish (1989) states that "a patent cannot be granted for a thing or process which however interesting or suggestive it might be to scientists, has no known practical application at the priority date". The requisite of "industrial applicability" is not contained in the US law. It seems however, that the requisite of "usefulness" roughly coincides with that of "industrial applicability", so that even if a patent still represents something between an invention and an innovation as defined in this paper, it seems to be closer to the latter.

[19]Indeed, he writes: "our definitions of entrepreneur, entrepreneurial function and so on can only grow out of it *a posteriori*" and again "when we speak of the entrepreneur we do not mean so much a physical person as we do a function, but even if we look at individuals who at least at some juncture in their lives fill the entrepreneurial function it should be added that these individuals do not form a social class. They hail from all the corners of the social universe".

Indep. Variable:	Lagged $\ln(f_t C_t)$	Lagged $\ln(s_t)$	Unempl. Rate	GDP per cap. Growth rate	Vacancy index	R^2	Wald Test (p-value) $\alpha+\gamma=1$
1lags	0.47 (.03)	0.24 (.10)	-	-	-	.84	.005
2lags	0.49 (.03)	0.29 (.10)	-	-	-	.86	.03
3lags	0.50 (.04)	0.37 (.10)	-	-	-	.86	.24
4lags	0.52 (.04)	0.48 (.10)	-	-	-	.86	.94
1lags	0.50 (.04)	0.30 (.10)	-0.02 (.008)	-	-	.86	.06
2lags	0.53 (.04)	0.37 (.10)	-0.02 (.008)	-	-	.88	.36
3lags	0.54 (.04)	0.45 (.10)	-0.02 (.009)	-	-	.88	.97
4lags	0.54 (.05)	0.53 (.11)	-0.01 (.009)	-	-	.87	.62
1lags	0.51 (.04)	0.33 (.10)	-0.02 (.009)	-0.53 (.45)	-	.88	.15
2lags	0.54 (.04)	0.39 (.10)	-0.02 (.009)	-0.33 (.42)	-	.89	.56
3lags	0.54 (.04)	0.44 (.11)	-0.02 (.009)	0.10 (.43)	-	.88	.92
1lags	0.46 (.07)	0.32 (.10)	-0.02 (.009)	-0.54 (.45)	0.08 (.08)	.88	.10
2lags	0.47 (.07)	0.39 (.10)	-0.02 (.009)	-0.34 (.41)	0.10 (.08)	.89	.25
3lags	0.46 (.07)	0.44 (.11)	-0.01 (.01)	0.09 (.42)	0.10 (.07)	.89	.48

Table 1: **Results from running regression (22) in the text**. The regression was ran using OLS, the dependent variable being the (logged) number of patent applications. Similar results are obtained when allowing for first order auto-correlation in the residuals and a non-scalar auto-covariance matrix.

and Jovanovic (1989) note how, in their sample, 20 percent of the individuals who switched into self-employment formed incorporated businesses. That is why I follow Evans and Jovanovic (1989), Evans and Leighton (1989) and Blanchflower and Oswald (1998) in using as a proxy of the amount of entrepreneurship, s_t, the population of self-employed.

In order to control for cyclical disturbances I also consider some additional specifications with the unemployment rate, the growth rate of per capita GDP and an index of the number of vacancies as independent variables.[20] The unemployment rate together with the other cyclical indicators could correct for that part of the population of self employed that does not represent real entrepreneurship but simply people that moved into self-employment from unemployment to find a job.[21]

Table 1 reports the estimates obtained by running the regression (22), allowing for different lags in the relation between research effort, entrepreneurship and innovation. The table shows that, in these data, both implications of the model tends to receive empirical support. In fact α and γ are both positive and significantly different from zero with α ranging between 0.47 and 0.54 while γ ranges from a value of 0.24 to 0.48. This implies that the relation between the number of innovations and research effort $f_t C_t$ turns out to be concave and hump-shaped. Furthermore, the table documents that, if we consider reasonable a lag of over two years before research effort shows up in a patent application, the hypothesis that the matching function (21) exhibits constant returns to scale cannot be rejected even at a 10% level of significance. Moreover, in the specification with the unemployment rate as independent variable, this hypothesis cannot be rejected whatever the number of lags considered.

[20] Data on the unemployment rate, growth rate of GDP per capita and the number of vacancies are taken from the OECD-CEP data set, see Bagliano et al. (1991).

[21] Blanchflower and Oswald (1998) document that flows from unemployment into self-employment are large.

7 Conclusions

This paper has shown how an increase in the amount of resources devoted to research does not necessarily increase the growth rate of the economy. In a world with rent sharing and inter-temporal spill-overs, an increase in research effort can crowd out more socially useful entrepreneurial skills, reduce the growth rate and ultimately lead to an allocation of skills which is Pareto dominated. Thus, the model might provide some foundations to the Schumpeterian warning that the "state of decay of the capitalist society" can ultimately be driven by the lack of entrepreneurial skills.

The question on whether the economy's skill allocation is optimal for growth is likely to be particularly relevant in advanced economies where innovation is so *complex* that a single agent fails to possess both the scientific knowledge and the entrepreneurial ability required to innovate. When so, individuals must specialize and innovation requires the contribution of different, highly specialized agents. Consequently the allocation of skills to different tasks from internal to the *individual* becomes internal to the *market* and the amount of rents from innovating appropriated by each task may become a crucial determinant of the economy's skill allocation. For instance, the division of rents could affect the choice between allocating resources to accumulating either education or experience as well as any occupational choice, especially among those occupations that are likely to participate to the sharing of the rents from innovation —say, whether to become a manager, a politician, a financier or an entrepreneur.

Investigating whether the actual skill allocation tends to depart from the optimal one as the economy develops and gets more specialized, remains however a question for further research that requires more careful micro-based empirical investigation. Looking at the skill composition either by occupations or along the experience-schooling dimension could be a promising avenue to address this question.

8 Appendix

In this Appendix I derive some technical results discussed in the text. Before proceeding, notice that the derivatives of $m(k,s)$ with respect to k and s can be computed as $\frac{dm}{dk} = (1-\eta)\, q(\theta)$ and $\frac{dm}{ds} = \eta\theta q(\theta)$, respectively.

Properties of the function $\boldsymbol{\theta}(\mathbf{f})$

Proposition 1: Equation (14) defines the level of knowledge intensity θ as an increasing function of f, $\theta = \theta(f)$, with the property that $\theta(0) = 0$ and $\theta(1) = \infty$.

Proof: By using $\frac{d\theta q(\theta)}{d\theta} = (1-\eta)\, q(\theta)$, total differentiating (14) with respect to θ and f yields

$$\frac{d\theta}{df} = \frac{\delta + \theta q(\theta)}{\delta + \eta\theta q(\theta)} \cdot \frac{\frac{\lambda}{\nu}\left[\delta + \theta q(\theta)\right] + \delta\theta}{\delta(1-f)} \tag{23}$$

which proves monotonicity. The properties of the function $\theta(f)$ at the boundary follow directly from (14) and $(A1)$ together with the fact that the elasticity of the right hand side of (14) with respect to θ is less than one.||

Properties of the TE-schedule

Proposition 2: Given (14), equation (13) determines the growth rate g, as a function of f, $g = g(f)$ with the property that $g(0) = g(1) = 0$. Steady state growth is maximized at an allocation such that (20) is satisfied.

Proof: Note that (11) together with proposition 1 allow to define entrepreneurial slackness as a decreasing function of f, $s = s(f)$. After substituting in (13), one obtains that

$$g = g(f) = \sigma\, m\left(\frac{\lambda}{\nu} C f, s(f)\right),$$

which explicitly defines the function $g(f)$.

To conclude the proof, notice that from (23), it follows that

$$\frac{ds(f)}{df} = \frac{d\left(\frac{\delta(1-f)}{\delta+\theta q(\theta)}\right)}{df} = -\frac{\delta + \frac{\lambda}{\nu}(1-\eta)\, q(\theta)}{\delta + \eta\theta q(\theta)},$$

thus the derivative of $g(f)$ reads as

$$\frac{d\, g(f)}{d\, f} = \frac{\sigma C \delta q(\theta)\left[\frac{\lambda}{\nu}(1-\eta) - \eta\theta\right]}{\delta + \eta\theta q(\theta)},$$

which proves (20).‖

Properties of the FE-schedule

Proposition 3: Given (14) and the associated function $\theta = \theta(f)$, equation (9) defines the growth rate of the economy g as an increasing function of f, $g = e(f)$, with the properties that $e(0) = -\infty$ and $e(1) = \infty$.

Proof: Multiply the left and right hand side of (9) by $[r-g+\delta+\theta q(\theta)\beta]$. The resulting left hand side of the equation is strictly increasing in θ and equal to $h(r+\delta-g)$ when $\theta = 0$, while the resulting right hand side is strictly decreasing in θ and it approaches infinity when θ goes to zero since $\frac{\lambda}{\nu}(1-\beta)(P-h) > 0$ by assumption. This implies that, for given g, a θ that solves (9) always exists. Furthermore, an increase in g causes a downward (upward) shift in the left (right) hand side so that θ unequivocally increases. As $\theta = \theta(f)$ is increasing, $e(f)$ is also increasing. The properties of the function $e(f)$ at the boundary follow immediately from condition (*A1*), and the properties of $\theta(f)$ established in proposition 1.‖

Proposition 4: There exist values of the parameters such that any point on the TE-schedule, $g(f)$, can be sustained as an equilibrium.

Proof: Note that, for a given level of g, changes in P, h, χ and β modify the value of θ that solves (9) without affecting the function $\theta(f)$. Hence, one can find a combination of parameters such that arbitrary given values of f and g are on the FE-schedule. Since changes in these parameters do not affect the TE-schedule, any point along $g(f)$ can possibly be sustained as an equilibrium.‖

Efficiency results

The derivative of W with respect to f. Partially differentiating (16) with respect to k_t and n_t and after using the fact that in steady state $\dot{k}_t = \dot{n}_t = 0$ yields

$$W_k = \frac{-\chi + (1-\eta)\, q(\theta) \left(W_n + \sigma \overline{W} \right)}{r - g + \nu} \tag{24}$$

and

$$W_n = \frac{P - h - \sigma \eta \theta q(\theta) \overline{W}}{r - g + \delta + \eta \theta q(\theta)}. \tag{25}$$

Differentiating (16) with respect to f and evaluating this derivative in steady state yields

$$\frac{dW}{df} = \frac{C}{r-g}\left[-h - \eta\theta q(\theta)\left(W_n + \sigma\overline{W}\right) + \lambda W_k\right]$$

which after using (24) immediately leads to expression (18) in the main text.

Relation between $\boldsymbol{\theta}^*$ and the social optimum. To prove that the social optimum always lies on the positively sloped arm of the TE-schedule, evaluate (18) at $\theta^* = \frac{\lambda(1-\eta)}{\nu\eta}$. This immediately yields

$$\frac{dW}{df} = -\frac{C}{r-g}\left[h + \frac{\lambda\chi}{r-g+\nu} + \frac{(r-g)\,\eta\theta^* q(\theta^*)\,S^E}{r-g+\nu}\right]$$

which is negative.

The efficient sharing rule. I now prove that it exists $\beta < \eta$ such that the decentralized economy implements the optimal allocation. From (9) it follows that

$$h + \frac{\lambda\chi}{r-g+\nu} = \left[\frac{\lambda(1-\beta)}{r-g+\nu} - \beta\theta\right] q(\theta)S. \tag{26}$$

which substituted into (18) and after using the definition of S^E in (19) yields

$$\begin{aligned}\frac{dW}{df} &= \frac{C(\beta-\eta)\,q(\theta)\left\{\theta(r-g+\delta) - \frac{\lambda[r-g+\delta+\theta q(\theta)]}{r-g+\nu}\right\}S}{(r-g)\,[r-g+\delta+\eta\theta q(\theta)]} \\ &\quad + \frac{\sigma C q(\theta)(r-g+\delta)\left[\frac{\lambda(1-\eta)}{r-g+\nu} - \eta\theta\right]\overline{W}}{(r-g)\,[r-g+\delta+\eta\theta q(\theta)]}.\end{aligned}$$

Evaluating this derivatives at $\beta = \eta$, one can see that the first term is equal to zero while (26) implies that the second term is strictly positive, so that, at this level of β, research effort is too low. Now note that (9) implies that f is negatively related to β, so that β must fall below η for the economy to reach efficiency. There are two exceptions where at $\beta = \eta$, $\frac{dW}{df} = 0$. The former arises when $\sigma = 0$, the latter when $h + \frac{\lambda\chi}{r-g+\nu} = 0$ so that, by (26), $\frac{\lambda(1-\eta)}{r-g+\nu} - \eta\theta = 0$.

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