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Basic Research, Development and Endogenous Growth

by

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Abstract

We introduce the distinction between basic research and development inside a standard horizontal innovation framework. Multi-stage R&D is performed by private agents only. Basic research has the highest level of generality, implying inter-sector spillovers. Development spillovers benefit development only. In this set up, the counterfactual scale effect characterizing standard horizontal innovation literature disappears endogenously. In terms of R&D policy, the model shows that the social optimum is attained by subsidizing only basic research. The implied fiscal policy on R&D is consistent with US data on federal support to privately performed R&D.

1 Introduction

There is now a large and influential literature acknowledging the importance of R&D as an engine for growth (*i.a.* Romer, 1990; Gancia and Zilibotti, 2003; Barro and Sala-I-Martin, 2004). However, this literature does not address questions related to the effects of the different components of an R&D process on growth, even tough there are some well-established results showing that the distinction between R&D components is relevant in economic terms. Data show that private agents perform multi-stage R&D processes, where both development and basic research are carried on. Furthermore, economic theory and empirical works have highlighted meaningful distinctions between basic research and development along a variety of dimensions. These observations suggest that there may be scope for investigating the consequences on growth and welfare of distinguishing basic research (R) from development (D). In this paper, we consider these peculiarities, by introducing basic research in R&D-based models of endogenous growth along with development activity.

Before providing more details on the relevant features typifying each R&D component, we provide their definition following what has been established by the National Science Foundation of United States and subsequently adopted in the literature on R&D (Audrestch *et al.*, 2002). Basic research is defined as a systematic study directed towards greater knowledge or understanding of the fundamental aspects of phenomena and of observable facts without specific application towards procedures and products in mind. Development is defined as a systematic application of knowledge towards the production of useful materials, devices, systems and methods, to meet specific requirements (Eisenman *et al.,* 2002).

The idea of distinguishing basic research from the other research activities when studying endogenous growth builds on the two broad arguments mentioned above. Here we explore these arguments on which our theoretical assumptions will be based.

First, basic research appears to play a relevant role both in US data and Government's agenda. To this respect, we list several relevant facts. *(i)* R&D activity in the US is carried on mainly at industry level and it is performed by private agents[1] (NSF[2], 2003); *(ii)* private agents perform basic research (NSF, 2003).

Second, economic literature has addressed questions about the economic effects of basic research starting from Nelson's seminal contribution "The Simple Economics of Basic Scientific Research" (Nelson, 1959) and further discussed and analyzed by other authors (Link *et. al.,* 1981; Pavitt, 2001, Audretsch *et. al.,* 2002). These contributions have identified several distinguishing features which we briefly present:

- Basic research is the R&D activity whose output is the most likely to fail to be directly economically exploitable to produce new intermediate goods. "Although risk is associated with all forms of R&D, uncertainty is an inherent characteristic of basic research. Not surprising that the outcome and the direction of basic research is often unpredictable" (Link et. al., 1981); "Moving from the applied research end of the spectrum to the basic research end, the degree of uncertainty about results of specific research projects increases and the goals become less clearly defined and less closely linked to the solution of a specific object" (Nelson, 1959).

- The same elements implying that not all the designs developed by basic research efforts are economically exploitable, while the designs resulting from development efforts are more likely to be so, also entail that basic research is more likely to generate breakthrough innovations than development activity (Nelson, 1959; Theis and Horn 2003). Development refers to testing or improving existing goods, processes or prototypes: as a research activity, it is aimed towards improvement of something known rather than discovery of the unknown. Basic research, on the contrary, does not have any precise goods, process or prototype to work on. Its aim is mainly the exploration of the unknown. Obviously, new, breakthrough innovations are more likely to come out from new understanding of something that was previously unknown than from improvement and enhancement of

[1] 70% of US R&D expenditure in 2003 is performed by industry. In 2003, Federal Government performs directly 8.8% of all US R&D. *Source: NSF*

[2] National Science Foundation

what is already known. If we look at the literature on R&D, we see much emphasis devoted to the role of basic research in generating breakthrough innovations (Audretsch et al., 2002; Theis and Horn, 2003)[3].

- Even when a basic research design is economically exploitable, it usually needs further efforts to be suitable for the production of an intermediate good (Nelson, 1959).
- Literature on industrial economics has asserted that basic research generates positive and significant spillovers affecting the economy across sectors, whereas spillovers associated to development activity are generally weak and do not spur across different sectors (*i.a.* Lichtemberg and Siegel, 1991; Kesteloot and Veugelers, 1995; Funk, 2002).

One last comment refers to R&D policy. It is widely documented that basic research has been playing a key role in US political agenda since the 40s. To this respect, basic research is considered fundamental to get major achievements in many different fields, therefore, keeping US leading position as exporter of goods and services (PCAST, 2002; OSPT, 2003b; OMB[4], 2004) and it is acknowledged to be "both necessary and sufficient for technical progress" (Stokes, 1997; Pavitt, 2001). This political vision has actually determined the continuous flow of public funding for basic research both at academic and firm level that we see in US data. To this respect, we list several facts: *(i)* US Government promotes public funding for R&D at industry level of R&D performance[5] (PCAST[6], 2001; PCAST, 2002; OSTP[7], 2003a);data on federal support to R&D in US shows that different fiscal incentives are used depending on R&D composition. In particular, federal support is mainly directed towards basic research activity. *(ii)* more than half of total privately performed basic research is financed by US Government (NSF, 2003)[8]; *(iii)* federal support to private R&D is directed mainly to certain industry sectors which perform long-term basic research (NSF, 2003). Nowadays, there is an international debate on the adoption of similar policies in other countries (Trunmbull, 2004).

[3] There are many examples of private firms declaring to invest in basic research for strategic reasons: Microsoft Corp., has made notable research investment in recent years, including hiring some excellent mathematical physicists; Intel Corp. is investing in a series of research labs located in close proximity to some top universities; IBM is investing in new materials, new architectures and algorithms. Bell Labs efforts in fundamental research on nonlinear optics, optical properties of rare earth ions and soliton dynamics have produced breakthrough innovations granting long term positive payoff for the company.

[4] Office of Management and Budget.

[5] R&D investments by private agents cycle with business patterns and focus on short terms results by emphasizing development of existing technologies rather than establishing new frontiers

[6] President's Council of Advisors on Science and Technology

[7] Office of Science and Technology Policy

[8] 57.4% of total basic research performed by industry in 2003 is financed by the Government, 21.4% of total applied research performed by industry in 2003 is financed by the Government and the percentage drops to 7.2% when it comes to development activities. *Source: NSF*

In standard R&D-based endogenous growth frameworks the fiscal policy needed to reach the first best allocation is neutral with respect to R&D composition as R&D is treated as homogeneous in terms of its composition. Therefore, no fiscal instrument devoted specifically to privately performed basic research arises. Our model, instead, allows to discuss an optimal fiscal policy when basic research is disentangled from development to check whether the observed differences in fiscal incentives are good in terms of welfare.

We will rely on a well-established horizontal innovation framework which we modify to allow for the distinction between basic research and development along the lines we have presented above. In particular, R&D is modelled as a multi-stage process where basic research output is used as an input in development. Basic research generates inter-sector spillovers affecting productivity in final good production, whereas spillovers from development are just intra-sector. Finally, we assume that not all R&D investments delivers positive payoffs to innovators to capture the likelihood of economically useless ideas inherent to basic research activity.

The first major result of this framework is the absence of the so-called "scale effect". Therefore, if the labour endowment of the economy changes, the growth rate of the economy is unaffected. Standard horizontal innovation models are generally affected by the scale effect and this feature has been widely criticized as it is counterfactual (Jones, 1995; Barro and Sala-I-Martin, 2004). In our model the scale effect disappears endogenously thanks to the externality played by basic research, allowing for the conclusion that the introduction of multi-stage research processes with differences in spillovers as suggested by reality contributes to better predictions.

A second relevant finding refers to industrial policy for R&D. Private agents determine an equilibrium which is not Pareto optimal and we find that the Government could induce the private sector to attain the social optimum by engineering a tax-subsidy policy where basic research receives support whereas development does not. Fiscal support to basic research is needed to increase the private rate of return of an R&D investment.

The paper is organized as follows: Section 2 describes the economy. Section 3 analyzes the decentralized equilibrium. Section 4 presents the Social Planner outcome and some welfare considerations about optimal fiscal policy. Section 5 concludes.

2 The Economy

Both literature and evidence suggest that we have to distinguish basic research from development along the following lines: *(i)* basic research is the preliminary step of a multi-stage research process; *(ii)* development activity can be performed without basic research, by innovating along the margin of existing knowledge; *(iii)* basic research generates positive spillovers which affect the economy across sector; *(iv)* spillovers associated to development activity are weak and do not spur across different sectors within the economy.

Points *(i)* to *(iv)* affect the structure of payoffs from R&D efforts with respect to standard horizontal innovation literature, technology of good production (spillovers) and the structure of the research process.

We still rely on the horizontal innovation framework (Romer, 1990; Rivera-Batiz and Romer, 1991), which we modify to allow for the new elements documented above about the role of R&D on growth and technology and to the R&D paradigm we are considering.

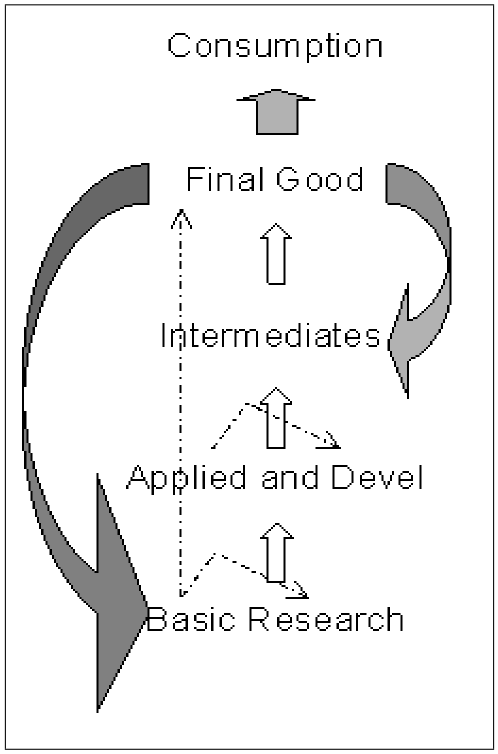
We briefly recall that standard horizontal innovation frameworks consider R&D as a single step activity. As we have argued in previous chapters, these models could be suitable to describe an economy performing only development activity, with the drawback consisting of the perpetual monopolistic payoff that each innovator enjoys. This disadvantage has already been pointed out in the literature (Barro and Sala-I-Martin, 2004) and it has been faced through the introduction of erosion of monopolistic power in the model to account for imitation and close substitution effects. We have used this feature to characterize the low level of innovation typical of development-intensive designs in the previous chapter. Here, since we are considering an economy in which only basic-research-intensive activity is performed, we rule out erosion by assumption.

We consider an economy characterized by a unique multi-stage R&D sector: first, firms perform basic research, then basic research output is employed in the second research activity to produce an applied design for a new variety of intermediate good. As usual, intermediate goods are used in the production of the final good. As in Romer's seminal contribution, we assume that each variety, once introduced, will be used in the final good sector forever.

The main ingredients we are accounting for are: *(i)* uncertainty with respect to the economic exploitation of basic research designs, *(ii)* basic research designs as intermediate output for the creation of designs, *(iii)* positive spillovers.

The structure of the economy is summarized in Figure 1[9].

[9] Upward pointing white arrows show the sequence of processes needed to produce final output. Gray arrows highlight the different purposes of final output. Dotted arrows show the direction of externalities.



2.1 Set up

There are three types of agents in the model. Households maximize utility subject to their budget constraint. They hold shares of intermediate sector firms and they invest in new ideas. Final good producers hire labour and intermediate goods and combine them to produce a final good, which is sold at unit price. This final good, as seen in Figure 1, serves different purposes: consumption, input for intermediate good production and input for basic research activity. Applied research does not use final output as input, since it transforms basic research ideas into applied designs using only research products and labour as costly inputs.

R&D firms devote resources to discover new designs. Differently from standard horizontal innovation set up and from the model in Chapter 2, here we deal with basic-research-intensive designs only. This focus implies that there is a unique research process made of two steps, each one characterized by a specific technology. Basic research ideas are created first, and then they are employed by another technology which tries to transform them into new exploitable designs. We assume that there is uncertainty with respect to exploitability of the final design coming from the manipulation of basic research ideas. This assumption is consistent to the literature, since we are accounting for the fact that fundamental discoveries which are realized without any specific economic aim may fail to be useful to create a new product or process. This failure is revealed only after further research is applied to the basic research idea.

Firms choose whether to enter or not, knowing in advance the characteristics of the economy. All designs and ideas are patented. We keep the standard assumption about perpetual patent: once a design has been patented, the owner of the patent holds the exclusive and perpetual right about its potential economical exploitation.

2.2 The model

Final good sector. Producers of final good have access to a production technology which combines a number of intermediate inputs and labour to produce final output, which is then sold in the market at unit price. Formally,

$$Y = \left(\frac{Z}{N}\right)^{1-\alpha} \left(\int_0^{lN} x_j^{\alpha} dj\right) L_Y^{1-\alpha} \tag{1}$$

where $0 < \alpha < 1$. First, note that the final good sector aggregates in a Cobb-Douglas fashion two costly inputs: intermediate goods and labour, L_Y. x_j is the employment of the jth type of intermediate good and lN is the total number of varieties of intermediates in the economy. Note that lN does not corresponds to the total stock of designs produced, which is given by N. This happens because not all the designs obtained transforming basic research ideas are economically exploitable. To this respect, we assume that there is a probability l, $0 \leq l \leq 1$, that the transformation of basic research ideas into designs gives a patent which allows for a new variety of intermediate good. At each point in time we have N designs obtained from the transformation of Z basic research ideas. Out of this stock, only a fraction allow for new varieties of intermediate goods. For the law of large number, this fraction equals lN.

Final good production is affected by positive externalities determined by the average stock of basic research available to new innovators. This assumption relies on the level of generality of this research activity which allows for both intra-sectoral and inter-sectoral spillovers, as pointed out both in the literature and in the empirical evidence about the externality effects of basic research on productivity (Lichtemberg, 1990; Funk, 2002). The positive externality is captured by the term $\left(\frac{Z}{N}\right)^{1-\alpha}$. Z is the stock of basic research ideas, N is the number of patent holders. Therefore, we are assuming that the positive externality effect played by the is partly offset by patent holders trying to do their best to assure the maximum level of secrecy or noise around basic research ideas as they represent strategic ingredients in developing new designs. We model these efforts as proportional to the number of patent holders.

Final good is used for consumption, input for the production of intermediate goods and input for creation of basic research ideas.

We take the price of Y as the numeraire.

Note that eq.(1) can be rewritten as $Y = \left(\frac{Z}{N} L_Y\right)^{1-\alpha} \left(\int_0^{lN} x_j^{\alpha} dj\right)$, implying that basic research spillovers are labour-augmenting.

Intermediate good sector. Each intermediate good producer holds a patent which grants the exclusive right to produce a specific variety of intermediate good. Every patent allowing for a new variety grants perpetual monopolistic profits to producer. However, buying a patent does not guarantee positive payoffs with certainty, since the patent may turn out to be unexploitable to produce a new intermediate good.

We assume that an intermediate good , once invented, costs one unit of Y to produce and, as eq.(1) shows, it is used in the production of final good forever.

Research firms. New firms wishing to enter intermediate good production must invest in research first. An entrant has to invest in basic research first and then to use its output as an input to try to get a useful design, granting monopolistic payoffs forever. Therefore, entry implies a bigger and risky research effort. Moreover, entry obliges firms to go through all the research stages before knowing whether their investment leads to a positive payoff or not. This happens because basic research ideas alone are not enough to predict their potential economic value. This two-stage research process captures both the idea that a basic research design leads to production of goods only if some applied research activity is performed afterwards and that creating breakthrough innovation is not as easy as innovating along existing knowledge.

At a point in time, the technology exists to produce Z basic research ideas, which, using another research technology, are transformed into N new designs. Out of this stock of designs, lN varieties of intermediate goods are created.

We summarize the structure of the entry game in Figure 2:

Where E stands for entry and NE for no entry.

Firms face the two stage decision process typical of standard models of horizontal innovation. First, they decide whether to enter or not. Entrants will invest in R&D if the market value of the firm producing the new variety of intermediate good is at least as large as the R&D expenditure they have to bear to start the firm. Then, they decide the optimal price at which to sell their new intermediate goods to final good sector firms. This price determines the demand they face and, as a consequence, the expected future profits. We solve the two stage problem backward. We start by deriving the optimal price for new intermediate good, assuming that a new design which translates into a new good has already been invented. Then, we find the value of the firm and compare it to the R&D cost. Since we assume that there is free entry into the business of being an inventor, we will deal with a free entry condition that holds in equilibrium such that entry occurs when the market value of the firm equals the R&D cost.

The market value of a new intermediate good firm is given by

$$V = \int_t^{\infty} e^{-\int_t^s r(\tau)d\tau} E_t \pi(s) ds, \tag{2}$$

where π are the instantaneous profits from intermediate good production and E_t is the expectation operator, conditional on information at time t. Expected profits at time s as seen from time t from entry are given by $E_t\pi(s) = l\pi + (1 -$

$l)0$, since an exploitable design granting perpetual monopolistic profits happens with probability $l, 0 < l < 1$. An intermediate good costs one unit of Y to produce, therefore, profits accruing to firm producing variety j are given by $\pi_j = (\tilde{p}_j - 1)x_j$, where $\tilde{p}_j$ is determined by profit maximization in the final good sector. The market values for a new intermediate good firm is given by

$$V = l\frac{\pi}{r} + (1-l)0, \tag{3}$$

We assume a R&D cost determined by R&D firms profit maximization problems. The R&D cost that entrants must pay corresponds to the price of a new patent. We are dealing with a two-step process for new design creation. First, firms must undertake basic research, which delivers new ideas according to the following law of motion

$$\dot{Z} = \frac{1}{\eta}\left(\frac{Z}{N}\right)^{\frac{1-\delta}{2}} M \tag{4}$$

where η is an exogenous productivity parameter and M is the fraction of final output devoted to design production in the sector. Note that the stock of basic research ideas affects through spillover effect also productivity in its own sector, even if there is a noise effect played by patent holders. At each point in time, the stock of basic research ideas is used in another research activity, which transforms it in attempt to produce a new exploitable design. This second research activity delivers new designs according to

$$\dot{N} = [(1-l)N]^{\frac{1+\delta}{2}} Z^{\frac{1-\delta}{2}} L_N. \tag{5}$$

As eq.(5) shows, final designs are created using the stock of basic research ideas and a fraction labour. Then there is a positive externality given by the stock of useless final designs produced in the sector.

Empirical evidence on R&D spillovers shows that basic research exerts the biggest and pervasive externality effects, both inter and intra-sector. The size and the pervasiveness of spillovers declines significantly when we consider development. Therefore, our assumption about spillovers due to the different components of R&D is consistent with the data.

Households. Households maximize utility over an infinite horizon. They are endowed with constant aggregate flows of labour which they supply inelastically, $\bar{L} = L_N + L_Y$. Their objective function is given by

$$U(C) = \int_0^\infty \left(\frac{C^{1-\sigma}-1}{1-\sigma}\right) e^{-\rho t} dt$$

Households own shares of intermediate goods firms and receive the wage rate on fixed aggregate quantities of sector-specific labour. They discount the future at rate ρ. In a closed economy, the total of households' assets equals the market value of firms and they have to choose between consuming now or accumulating new patents in the two sectors. Their budget constraint is given by

$$C + \dot{asset} = w_Y L_Y + w_N L_N + r\,(asset)\,,$$

so that the consumption plan they set when maximizing utility subject to the constraints satisfies standard Euler equation

$$\frac{\dot{C}}{C} = \frac{1}{\sigma}(r - \rho) \tag{6}$$

3 Decentralized equilibrium and BGP

3.1 BGP

As a consequence of the modifications that we have introduced, we need to check whether the growth rates of the number of intermediates, lN, of the number of designs, N, of basic research ideas, Z and of the level of output, Y still equal the growth rate of consumption. To this respect, the following Proposition holds.

Proposition 1 *As long as all R&D activities grow at the same rate, that is* $\frac{\dot{N}}{N} = \frac{\dot{Z}}{Z}$*, then all variables in the economy will grow at the same rate given by*

$$\frac{\dot{N}}{N} = (1-l)^{\frac{1+\delta}{2}} \left(\frac{N}{Z}\right)^{\frac{\delta-1}{2}} L_N \tag{7}$$

Proof. *Eq.(1) shows that* $\frac{\dot{Y}}{Y} = \frac{\dot{N}}{N}$*. Then, we need to show that also consumption grows at the same rate. We take the economy-wide resource constraint, given by*[10]

$$Y = C + M + lNx, \tag{8}$$

We take the derivative with respect to time of eq.(8) and recalling that, for $\frac{\dot{Z}}{Z}$ *to be constant along the BGP, we need* M_Z *to grow at the same rate as* Z*, we see that if* $\frac{\dot{N}}{N} = \frac{\dot{Z}}{Z}$*, then* $\frac{\dot{C}}{C} = \frac{\dot{Y}}{Y}$*. Therefore, as long as all R&D stocks grow at the same rate, all the variables in the economy grow at the same rate, given by* $\frac{\dot{N}}{N} = (1-l)^{\frac{1+\delta}{2}} \left(\frac{N}{Z}\right)^{\frac{\delta-1}{2}} L_N$. ■

Now, we need to find the equilibrium expression for this growth rate, therefore, we need to solve for the decentralized equilibrium for this economy.

3.2 Decentralized equilibrium

Definition (Interior Solution). *An equilibrium, given* N *and* Z*, is a set of prices for intermediate goods,* $\tilde{p}_j$*, that maximize the profits of intermediate good monopolists, intermediate good demand,* x_j*, that maximize producers' profits, a set of prices for research output,* $\hat{p}$ *and* $\hat{q}$*, that maximize the profits of research firms and factor and products prices,* w_Y*,* w_N*,* P_Y *that clear the markets.*

[10] Formal derivation of eq.(8) can be found in the Appendix.

Proposition 1 implies that, along the BGP all variables grow at the same rate. This result is important because enables a specification which facilitates computation: the ratio $\hat{Z} \equiv \frac{Z}{N}$. Profits from final good production are given by

$$\max_{\{x\}_{j=0}^{lN}} \hat{Z}^{1-\alpha} \left(\int_0^{lN} x_j^{\alpha} dj \right) \left(\bar{L} - L_N \right)^{1-\alpha} - w_Y \left(\bar{L} - L_N \right) - \int_0^{lN} \tilde{p}_j x_j dj$$

w is the wage rate for labour, $\tilde{p}_j$, is the price of the jth monopolized intermediate good. Final good sector is competitive, therefore input prices are taken as given. Instantaneous profit maximization gives the following first order conditions, once symmetry has been imposed

$$\tilde{p} = \hat{Z}^{1-\alpha} \alpha x^{\alpha-1} \left(\bar{L} - L_N \right)^{1-\alpha}, \tag{9}$$

$$w_Y = (1-\alpha) \, lN \hat{Z}^{1-\alpha} \left(\frac{x}{\bar{L} - L_N} \right)^{\alpha} \tag{10}$$

Eq.(9) is the inverse demand functions faced by intermediate good producers. Recall that we assume that an intermediate good no matter its type and sector, once invented, costs one unit of Y to produce; this assumption together with the demand functions allow us to write the profit flows for intermediate goods. If we deal with the jth monopolized intermediate good, the profit flow is given by

$$\pi_j = (\tilde{p} - 1) \, x_j,$$

where $\tilde{p}$ is given by eq.(9). Since monopolists set marginal revenues equal to marginal cost, we get that $\tilde{p} = \frac{1}{\alpha}$, $x = \alpha^{\frac{2}{1-\alpha}} \hat{Z} \left(\bar{L} - L_N \right)$. Therefore, symmetry across all the monopolized intermediate goods implies that

$$\pi_j = \pi = \left(\frac{1-\alpha}{\alpha} \right) \alpha^{\frac{2}{1-\alpha}} \hat{Z} \left(\bar{L} - L_N \right) \tag{11}$$

Monopolistic profits represent the positive payoffs from R&D investment, thus providing the right incentive to innovate. Innovation is a costly activity and its cost affects entry decision. We need to determine this cost. R&D evolves following two stages: we may think that the R&D process is carried on by a vertically integrated firm performing both stages. The intertemporal problem of the typical firm is to maximize the present discounted value of instantaneous profits subject to the law of motion of basic research. The current-value Hamiltonian for this problem is

$$H = \hat{p} \left[(1-l) N \right]^{\frac{1+\delta}{2}} Z^{\frac{1-\delta}{2}} L_N - M - w_N L_N + \hat{q} \frac{1}{\eta} \hat{Z}^{\frac{1-\delta}{2}} M$$

where $\hat{p}$ is the price for a new useful design and $\hat{q}$ is the co-state variable corresponding to the shadow price of basic research. The state variable is the stock of basic research and the controls are the amount of resources to be devoted to basic research activity and labour. First order conditions imply

$$r = \hat{p}\frac{(1-\delta)\,(1-l)^{\frac{(1+\delta)}{2}}}{2\eta}\hat{Z}^{-\delta}L_N, \tag{12}$$

$$w_N = \hat{p}(1-l)^{\frac{1+\delta}{2}}\hat{Z}^{\frac{1-\delta}{2}}N, \tag{13}$$

$$\hat{q} = \eta\hat{Z}^{\frac{\delta-1}{2}}. \tag{14}$$

In equilibrium, wages must be equal. We set eq.(10) equal to eq.(13) and we solve for $\hat{p}$. We get

$$\hat{p} = \frac{l(1-\alpha)\alpha^{\frac{2\alpha}{1-\alpha}}}{(1-l)^{\frac{1+\delta}{2}}}\hat{Z}^{\frac{1+\delta}{2}}. \tag{15}$$

So, the price for a final design depends positively on the average stock of basic research ideas available. We set eq.(15) equal to eq.(12) and we solve for the interest rate to get

$$r = \frac{(1-\delta)(1-\alpha)l\alpha^{\frac{2\alpha}{1-\alpha}}}{2\eta}\hat{Z}^{\frac{1-\delta}{2}}L_N \tag{16}$$

Imposing free entry and using the expression for $\hat{p}$ given by eq.(15), we get that

$$r = \alpha(1-l)^{\frac{1+\delta}{2}}\hat{Z}^{\frac{1-\delta}{2}}(\bar{L}-L_N). \tag{17}$$

Then, we set eq.(16) equal to eq.(17), to get

$$L_N = \Phi\bar{L}, \tag{18}$$

where $\Phi = \frac{2\eta(1-l)^{\frac{1+\delta}{2}}}{(1-\delta)(1-\alpha)l\alpha^{\frac{3\alpha-1}{1-\alpha}}+2\eta(1-l)^{\frac{1+\delta}{2}}}$. Recall that, in equilibrium, all variables grow at the same rate. This result, together with eq.(7) and the Euler equation, eq.(6), imply that

$$r = \sigma(1-l)^{\frac{1+\delta}{2}}\left(\frac{Z}{N}\right)^{\frac{1-\delta}{2}}L_N + \rho \tag{19}$$

Then, we set eq.(16) equal to eq.(19) after having substituted for L_N using eq.(18). Solving for $\left(\frac{Z}{N}\right)^{\frac{1-\delta}{2}}$

$$\left(\frac{Z}{N}\right)^{\frac{1-\delta}{2}} = \frac{\rho}{\left[1-\sigma(1-l)^{\frac{1+\delta}{2}}\right]\Phi\bar{L}} \tag{20}$$

Finally, we get the equilibrium expression for the BGP growth rate

$$\gamma = \frac{2\eta\rho(1-l)^{\frac{1+\delta}{2}}}{(1-\delta)(1-\alpha)l\alpha^{\frac{2\alpha}{1-\alpha}} - 2\eta\sigma(1-l)^{\frac{1+\delta}{2}}}. \tag{21}$$

Therefore, the following Proposition is verified:

Proposition 2 *The economy is characterized by a unique interior solution, where the scale effect is ruled out endogenously.*

3.3 Comparative Statics

This set up has accounted for specific features characterizing a research process where different steps are performed. Each step produces a different kind of output and it is characterized by a specific technology. Moreover, the preliminary research step, basic research, exerts positive spillovers on productivity of final good and basic research itself.

The most evident consequence of this choice is the absence of any scale effect on the growth rate. This finding is important, since there is no empirical evidence supporting a positive scale effect of population on growth (Jones, 1999; Barro and Sala-I-Martin, 2004). Also in the two-industry-version of this set up we have pointed out the absence of the scale effect due to labour force employed in the basic-research-intensive industry. However, there we were unable to completely rule out any scale effect, since we were dealing also with an industry-specific factor of production in the development-intensive sector. In this simpler framework, absence of any scale effect is unambiguous.

Second, we are interested in knowing how the probability of economic exploitability of a given research effort affects the growth rate. This probability is exogenously given in the model and it is denoted by l. The growth rate for this economy is negatively affected by an increase in l. This result gives some interesting insight in terms of R&D policy: Government should commit to patronize research fields with a level of economic exploitability which is not really high.

4 Social Planner

In the baseline horizontal innovation framework, the decentralized equilibrium is notoriously inefficient, due to monopolistic competition. In this section we demonstrate that the outcome in the decentralized economy is not Pareto optimal. Failure to reach Pareto optimality is due to monopolistic competition together with externalities.

In order to assess Pareto optimality, we compare the BGP growth rate of the decentralized economy with the corresponding growth rate determined by the social planner. The planner maximizes the utility of the representative household taking into consideration the economy-wide resource constraint and the laws of motion for N and Z. The solution of this maximization problem implies the following expression for the growth rate[11]

$$\gamma_{SP} = \frac{2\eta\rho(1-l)^{\frac{1+\delta}{2}}(1-\alpha)}{(1-\delta)l\alpha^{\frac{\alpha}{1-\alpha}} - 2\eta\sigma(1-l)^{\frac{1+\delta}{2}}(1-\alpha)} \tag{22}$$

The planner solution differs from the solution determined by the decentralized economy. In particular, the Social planner sets a BGP growth rate which is higher than the decentralized one. Note, however, that the scale effect does not appear.

[11] Formal derivation of eq.(22) can be found in the Appendix

4.1 Optimal Fiscal Policy

The decentralized equilibrium is not Pareto optimal. In order to reach the first best outcome, the Government should implement a fiscal policy matching well-established tools for this type of economy with *ad hoc* instruments to correct for new distortions generated by spillovers and multi-stage research process.

First, the Government should set a subsidy on the purchase of intermediate goods at the rate $(1-\alpha)$. This fiscal instruments is typical in standard horizontal innovation model and it provides static and dynamic gain in efficiency through an expansion of the quantity of intermediates (Barro and Sala-I-Martin, 2004).

Then, two more instruments are needed. A subsidy to input purchasing in basic research production and a subsidy to employment in the final good sector. The subsidy in basic research production at rate $(1-\alpha)$ increases the rate of return from an R&D investment, thus promoting a higher level of entry. The subsidy to employment in the final good sector is needed to avoid excess of employment in the research sector as a consequence of the basic research subsidy. This third instrument must be at rate $(1-\alpha)^{\frac{1}{2}}$.

The three forms of subsidy must be financed through lump-sum tax on households.

This simple framework, accounting for the most important characteristics identifying a research process in which basic research is performed, shows that a fiscal aid to support basic research is needed to reach the first best.

5 Conclusion

Both economic literature and historical evidence highlights that the distinction between basic research and development is important because they are endowed with different characteristics, that may play significant roles in determining the economic outcomes and effect of R&D in an economy. However, horizontal innovation literature has thus far neglected these issues and their consequences on growth.

We have addresses this topic by explicitly modelling R&D as a multi-stage process, made of consequent steps each one characterized by specific economic features in a typical R&D-based model of endogenous growth and analyzing the results in terms of growth and welfare. Note that, disentangling basic research from development allows to model spillovers associated to R&D according to both economic literature and empirical evidence: the most significant spillover effects are related to basic research and they spur throughout the economy; development activity is characterized by small spillovers, mainly directed towards R&D itself.

We have seen that the model we have analyzed presents some interesting insights which do not appear when R&D is treated as a homogeneous good.

The first result refers to the scale effect. Models with an expanding variety of products generally imply equilibrium outcome which depends on the size of the population: the bigger the size, the more the economy grows. This implication has been criticized empirically because the rate of productivity growth has been relatively stable despite upward trends in population size (Jones, 1999). As a consequence, many contributions have been made to get rid of the scale effect in horizontal innovation economies. The equilibrium growth rate of our economy is not affected by any scale effect, which is endogenously ruled out by the externality effect played by basic research. Therefore our model, by relying on established results on research spillovers, rules out the counterfactual scale effect.

Then, there are also interesting implications in terms of welfare. Basic research spillovers, together with other distortions, imply that the decentralized outcome fails to be Pareto optimal: the BGP growth rate determined by the agents is lower than the one determined by the planner. With respect to Pareto optimality, we find that subsidizing basic research is Pareto improving. Moreover, basic research is the unique research activity deserving fiscal aid. In standard horizontal innovation literature either there is no need for subsidizing research (*i.a.* Rivera-Batiz and Romer, 1991) or fiscal support goes generically to R&D (*i.a.*Romer, 1990). This finding is consistent with the literature on R&D: basic research is the research activity where the elements implying distortions (failure to grasp full economic benefits due to externality, likelihood of zero payoffs) are stronger, therefore it is the activity calling for the strongest support. This fiscal policy advice supports the adoption of fiscal aid to R&D mainly directed towards basic research, a kind of policy which has been undertaken by US Government in past years (NSF, 2004) and that is now debated in many European countries.

Our model contains another policy advice about R&D. Among other features, R&D is characterized by the possibility that out of a certain investment, the output may be economically useless. This feature is particularly true when basic research is performed, since it starts an research process by exploring the unknown. We have accounted for this by assuming that a fraction of R&D output does not deliver any new variety of good. In equilibrium we have found that a reduction in the fraction of economically useless designs reduces the growth rate, by shrinking the positive externality of R&D on productivity. Many Governments affect the kind of R&D performed in the economy (also when privately performed) by patronizing some research fields instead of others. Our model suggests that the design of such policy should consider the likelihood of economic exploitability of research investments per fields, choosing to campaign also research fields with a low probability of delivering positive payoffs for investors.

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6 Appendix

6.1 Economy-wide Resource Constraint

Households' budget constraint is given by

$$C + \dot{asset} = w_Y L_Y + w_N L_N + r\,(asset)\,.$$

Consider the RHS first. Recall eq.(10) and use it inside $w_Y L_Y$, we get

$$w_Y L_Y = (1-\alpha)Y.$$

Then, take eq.(13) and eq.(5) and use them inside $w_N L_N$, to get

$$w_N L_N = \hat{p}\dot{N}.$$

Finally, households' assets are given by shares in firms $r\,(asset) = r\,(V_N N + V_Z Z)\,.$ Entrants' discounting future implies that $rV_N N = \tilde{\pi} N$; zero profits implies that $rV_Z Z = 0$. To summarize, we can rewrite the households' budget constraint as follows[12]

$$C + V_N\dot{N} + V_Z\dot{Z} = (1-\alpha)Y + \hat{p}\dot{N} + \tilde{\pi}N$$

On the LHS, eq.(14) and eq.(4) imply that $V_Z\dot{Z} = \hat{q}\dot{Z} = M$ and free entry gives $V_N\dot{N} = \hat{p}\dot{N}$. Finally, using the equilibrium expressions for $\tilde{\pi}$ and Y, we get the economy-wide resource constraint

$$C + M + lNx = Y$$

6.2 The Planner problem

The planner maximizes the utility of the representative household taking into consideration the economy-wide resource constraint and the law of motion for the state variables:

$$\max_{C,x,M,L_N} \frac{C^{1-\sigma}-1}{1-\sigma},$$

[12] we are considering that the economy is in equilibirum, therefore $\dot{V}_h = 0, h = N, Z$.

$$
\begin{aligned}
s.t.\quad \dot{Z} &= \frac{1}{\eta}\hat{Z}^{\frac{1-\delta}{2}}M \\
\dot{N} &= (1-l)^{\frac{1+\delta}{2}}\hat{Z}^{\frac{1-\delta}{2}}NL_N \\
Y &= C + lNx + M \\
Y &= lNx^{\alpha}\hat{Z}^{1-\alpha}(\bar{L}-L_N)^{1-\alpha} \\
\bar{L} &= L_Y - L_N \\
& \quad Z_0, N_0
\end{aligned}
$$

We write the current value Hamiltonian for this problem as

$$
\begin{aligned}
H &= \frac{C^{1-\sigma}-1}{1-\sigma} + \mu(1-l)^{\frac{1+\delta}{2}}\hat{Z}^{\frac{1-\delta}{2}}N_R L_N + \omega\frac{1}{\eta}\hat{Z}^{\frac{1-\delta}{2}}M + \\
&\quad +\lambda\left[lNx^{\alpha}\hat{Z}^{1-\alpha}(\bar{L}-L_N)^{1-\alpha} - C - lNx - M\right]
\end{aligned}
$$

The relevant FOCs for this problem are

$$C^{-\sigma} = \lambda \tag{23}$$

$$\alpha^{\frac{1}{1-\alpha}}\hat{Z}(\bar{L}-L_N) = x \tag{24}$$

$$\lambda = \mu\frac{(1-\alpha)(1-l)^{\frac{1+\delta}{2}}}{l\alpha^{\frac{\alpha}{1-\alpha}}}\hat{Z}^{-\frac{(1+\delta)}{2}} \tag{25}$$

$$\lambda = \frac{\omega}{\eta}\hat{Z}^{\frac{1-\delta}{2}} \tag{26}$$

$$\frac{(1-\delta)l\alpha^{\frac{\alpha}{1-\alpha}}}{2\eta(1-\alpha)}\hat{Z}^{\frac{1-\delta}{2}}L_N = -\frac{\dot{\omega}}{\omega} + \rho \tag{27}$$

$$(1-l)^{\frac{1+\delta}{2}}\hat{Z}^{\frac{1-\delta}{2}}\left[(1-\alpha)^2(\bar{L}-L_N) + \left(\frac{1+\delta}{2}\right)L_N\right] = -\frac{\dot{\mu}}{\mu} + \rho \tag{28}$$

Where eq.(27) and eq.(28) have been determined using eq.(24)-(26). Then, eq.(23) together with eq.(25) and eq.(26) imply that $\gamma_{SP} = \frac{\dot{C}}{C} = -\frac{1}{\sigma}\frac{\dot{\mu}}{\mu} = -\frac{1}{\sigma}\frac{\dot{\lambda}}{\lambda} = -\frac{1}{\sigma}\frac{\dot{\omega}}{\omega}$. Therefore

$$-\frac{\dot{\omega}}{\omega} = \sigma(1-l)^{\frac{1+\delta}{2}}\hat{Z}^{\frac{1-\delta}{2}}L_N \tag{29}$$

We set eq.(27) equal to eq.(28) and we solve for L_N to get

$$L_N = \Lambda\bar{L} \tag{30}$$

where $\Lambda = \frac{2\eta\alpha^{\frac{2}{\alpha-1}}(1-l)^{\frac{1+\delta}{2}}(1-\alpha)^3}{(1-\delta)l\alpha^{\frac{\alpha}{1-\alpha}}+\eta(1-\alpha)(1-l)^{\frac{1+\delta}{2}}\left[2\alpha^{\frac{2}{\alpha-1}}(1-\alpha)^2-1-\delta\right]}$. Using this result inside eq.(27) and eq.(29) and setting them equal we get

$$\hat{Z}^{\frac{1-\delta}{2}} = \frac{2\eta(1-\alpha)\rho}{\left[l\alpha^{\frac{\alpha}{1-\alpha}}(1-\delta) - \sigma(1-l)^{\frac{1+\delta}{2}}2\eta(1-\alpha)\right]\Lambda\bar{L}}. \tag{31}$$

Then, we substitute this expression together with eq.(30) inside the expression for the growth rate, $\gamma_{SP} = (1-l)^{\frac{1+\delta}{2}} \hat{Z}^{\frac{1-\delta}{2}} L_N$

$$\gamma_{SP} = \frac{2\eta(1-\alpha)\rho}{(1-l)^{-\frac{1+\delta}{2}} l\alpha^{\frac{\alpha}{1-\alpha}}(1-\delta) - \sigma 2\eta(1-\alpha)}.$$