Competition and Economic Growth: a Critical Survey of the Theoretical Literature

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Abstract

The paper examines the relationship between competition and economic growth, in the theoretical framework described by endogenous growth models, but with a specific interest in the policy implications. In this perspective, the key issue in the debate can be presented as follows: do competition policies always create the best conditions for promoting innovation and growth? Or do they also produce some disincentives for the investment decisions in R&D, such to limit the development of industries with higher innovation?

In order to answer these questions, the paper presents a survey of the theoretical literature on competition and growth and it discusses the main models of endogenous growth, both the ones based on horizontal innovation, such as Romer (1990) or Rivera-Batiz and Romer (1991), and the ones based on vertical innovation, like Aghion and Howitt (1992) or Aghion, Dewatripont and Rey (1997). In particular, specific attention is paid to the most recent models of Schumpeterian growth, which show the existence of a non-linear relationship between competition and growth, by considering either the initial degree of competition (Aghion, Blundell, Bloom, Griffith and Howitt, 2005) or the distance from the technological frontier. (Acemoglu, Aghion and Zilibotti, 2006).

Finally, the review of the previous models of endogenous growth allows to draw some conclusions about further and possible developments of research on the relation between product market competition and economic growth.

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Keywords: expanding product varieties, increasing product quality, incentives for innovation, creative destruction, escape-competition effect, distance to frontier

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1. Introduction

The present paper presents some of the most important developments in the theoretical literature on the relationship between competition and economic growth. The questions that lead such discussion are the following ones. How can competition affect the relevant factors for long-run growth? Does competition always have a positive impact on productivity growth? Or can it also produce a negative effect?

Many different aspects must be considered in order to discuss this issue. According to a common view, also supported by empirical evidence, competition can generate strong incentives for innovation, because firms can succeed in a really competitive environment only if they are able to introduce significant improvements in the quality of the products and in the efficiency of the production processes. But, on the contrary, according to another view, dating back to the Schumpeterian idea of creative destruction, competition policies which reduce the monopoly rents gained by successful innovators can also lower the incentives for the investments of firms in R&D, and then compromise the future perspectives for technological progress.

Some explanations have been proposed to reconcile these different views and to understand which of these aspects prevails, and under which conditions. Then, in order to tackle the issue, we will firstly present the basic models in the literature on endogenous growth theory and after we will discuss some of the solutions suggested in the literature on the new Schumpeterian growth models. Finally we will draw some conclusions about the current state of the literature on this topic in order to identify new directions for future research.

1.1 Endogenous Growth Theory

The main theoretical contributions for the analysis of the relationship between competition and economic growth have been offered in the macroeconomic literature on endogenous growth theory. This literature aims at explaining long-term per capita growth by endogenizing technological progress, that is by treating the rate of technological change as an endogenous variable of the model, which is determined by a series of process innovations and product innovations.

In endogenous growth literature, technological progress is modelled either as an expansion of the number of product varieties or as an improvement of the quality of products[1]. In the first case, technological change is presented as horizontal innovation, given that the introduction of a new type

[1] Barro R. and Sala-i-Martin X. (2004), *Economic Growth*, MIT Press, Second Edition

of product doesn't imply a displacement of existing varieties, and then productivity increases because of the presence of more product varieties. In the second case, technological progress is defined as vertical innovation, because higher quality products replace existing varieties, and then innovation determines immediate obsolescence of previous innovations (creative destruction).

Both types of endogenous growth models are characterized by the presence of two or three sectors: a sector of final goods, purchased by consumers; a sector of intermediate goods (or capital goods), used for producing consumption goods; a research sector, developing new ideas for product or process innovations. In some cases the firms engaged in the intermediate sector are also involved in the research activity, since the elaboration of a new idea allows to produce either a new variety of capital goods (in case of horizontal innovation) or a higher quality capital good able to replace the existing ones (in case of vertical innovation).

While the market of final goods is generally assumed to be perfectly competitive, the market of intermediate goods is composed of firms having a given market power. So, an important issue for the theoretical analysis is how to introduce a market structure consideration in a macroeconomic model of endogenous growth. So, it is necessary to identify an appropriate measure of market power which can be easily embedded in the analytical framework, in such a way to derive a clear prediction about the relation between the degree of market power, or inversely the degree of competition, and the growth rate of the economy.

1.2 Market structure issues

In the economics of competition policy, market power is defined as the ability of a firm to profitably increase the price above the competitive level, independently from the decisions of the other firms and from the preferences of consumers. Then, given that the lowest possible price that a firm can set in a perfectly competitive market is equal to the marginal cost, the market power can be determined as a function of the difference between the price and the marginal cost[2].

In particular, a measure of market power coherent with this notion is the Lerner index, which is defined as the difference between the price and the marginal cost, divided by the price, as follows.

$$L = \frac{p - \frac{\partial C(q)}{\partial q}}{p} \qquad (1)$$

[2] Motta M. (2004), *Competition Policy. Theory and Practice*, Cambridge University Press

The idea of measuring market power through the Lerner Index implies some observations about price elasticity of demand. In fact, the Lerner Index is a decreasing function of the demand elasticity, given that a higher demand elasticity makes impossible to charge a relevant profit margin, while a lower demand elasticity allows firms to apply a larger profit margin without revenue losses. In particular, for the basic case of a single product monopolist, it can be shown that the Lerner index is equal to the inverse of the demand elasticity. This proof comes from the solution of a profit maximization problem for a monopolist[3]. Let define the quantity of good produced by a monopolist as q and the production cost of q units of good as $C(q)$, such that $C'(q)>0$. Let assume that the firm's output is equal to the consumers' demand for the good, then $q=D(p)$. A monopolistic firm determines the price such that it maximizes the following profit function:

$$\pi_M = pD(p) - C(D(p))$$

The first-order condition can be written, dividing both members by p, as follows:

$$\frac{p - C'(D(p))}{p} = -\frac{D(p)}{pD'(p)}$$

The elasticity of demand with respect to price is:

$$\varepsilon = -\frac{d\,D(p)}{d\,p}\,\frac{p}{D(p)}$$

Then the Lerner index is equal to the inverse of the demand elasticity.

$$L = \frac{p - C'(D(p))}{p} = \frac{1}{\varepsilon} \qquad (2)$$

The demand elasticity is a determinant factor for market structure: in fact, markets with a high elasticity of demand are more likely to be competitive, because of the pressures exerted by the consumers willing to shift their demand towards other goods; at the same time, markets with a low elasticity of demand are more likely to be characterized by the existence of a unique firm gifted with a very large market power, since individuals don't react to variations in prices.

In the considered case, as it results from (2), the elasticity of demand can only assume some values such that $\varepsilon \in (1,\infty)$, because the monopolist firm operates only in a price region with an elasticity $\varepsilon > 1$. In particular, in the case where $\varepsilon \to 1^+$, the first member of the equation $\{[p - C'(D(p))]/p\} \to 1^-$, so the Lerner index is asymptotically smaller than 1: this means that the profit margin (that is the difference between price and marginal cost) explains almost exclusively the determined price, while the marginal cost represents an irrelevant fraction of the price. This is the case correspondent to the largest market power that a firm can have.

[3] Tirole J. (1988), *The Theory of Industrial Organization*, MIT Press

On the contrary, in the extreme case where $\varepsilon \to \infty$, the difference $\{ p - C'(D(p)) \} \to 0$, so the profit margin is almost absent: then the firms, setting a price asymptotically equal to the marginal cost, don't have market power almost at all. This is a case substantially correspondent to a competitive market.

From these observations we can conclude that the price elasticity of demand, by influencing the structure of the market, inversely determines the amount of profit margin that a firm can charge. Then, the market power of a firm, as measured by the Lerner index, is inversely related to the demand elasticity, such that a higher (or lower) demand elasticity favours a weakening (or strengthening) of the firm's market power.

1.3 A model of growth with expanding product varieties

Firstly, we consider an endogenous growth model with horizontal innovation, known as the lab-equipment model of R&D, elaborated by Rivera-Batiz and Romer (1991). In particular, in the description of the model we follow Barro and Sala-i-Martin (2003).

In this framework the state of technology is identified by the number of product varieties, such that an increase of this number is an expression of technological progress. In particular, this element of variety is considered in the representation of the production sector. In fact, it is characterized by two different types of firms: producers of final goods and research firms.

The firm producer of final goods employs labour (L_i) and a combination of N different types of intermediate goods (X_{ij}) according to the following Cobb-Douglas production function:

$$Y_i = AL_i^{1-\alpha} \cdot \sum_{j=1}^{N} \left(X_{ij} \right)^{\alpha} \quad \text{where} \quad 0 < \alpha < 1,\ A > 0$$

This formulation[4] implies an assumption of independence between different types of capital goods. In fact, given the additively separable form used for the various components $(X_{ij})^{\alpha}$ of capital input, the marginal product of an intermediate good is independent of the employed quantity of

[4] We could also consider a more general form for the production function:

$$Y_i = AL_i^{1-\alpha} \cdot \left[\sum_{j=1}^{N} \left(X_{ij} \right)^{\sigma} \right]^{\frac{\alpha}{\sigma}} \quad \text{with } 0 < \sigma < 1$$

where σ is a parameter indicating the monopoly power of the firm owner of the patent on the intermediate good j. This means that the production function considered in the model corresponds to the case where $\alpha=\sigma$, that is the factor share for capital goods is equal to the parameter expressing the monopoly power. A similar distinction is used in the paper by Bianco (2008), *An Inverted-U Relationship between Product Market Competition and Growth in an Extended Romerian Model: a Comment*, Rivista di Politica Economica, forthcoming, where he shows the existence of a positive relationship between competition and growth, as in the basic Romerian model of endogenous growth.

another intermediate good. This assumption is particularly important for the introduction of a new type of intermediate product invented by R&D firms: since it is not a substitute good neither a complementary good, the usage of the new capital good doesn't affect the marginal product of the existing varieties. On the contrary, in the models of endogenous growth with vertical innovation, since the innovation allows to produce a substitute good of higher quality, the employment of this capital good (showing greater marginal product) implies the obsolescence of the existing products of lower quality.

The demand of each firm *i* for an intermediate good *j* is given by:

$$X_{ij} = A^{\frac{1}{1-\alpha}} L_i \alpha^{\frac{1}{1-\alpha}} P_j^{-\frac{1}{1-\alpha}}$$

Then, given that each firm *i* demands the same quantity of X_{ij}, the total amount of the intermediate good X_j demanded by the producers of final goods is equal to:

$$X_j = \left(\frac{A\alpha}{P_j}\right)^{\frac{1}{1-\alpha}} L$$

The demand elasticity of X_j is equal to:

$$\varepsilon = \frac{1}{1-\alpha}$$

The intermediate sector is composed of research firms, which are involved both in R&D activity and in production of capital goods. In fact they produce intermediate goods using an innovative idea, protected by a perpetual patent, which was elaborated thanks to R&D activity. This implies that each research firm supplying a capital good has the monopoly on this type of product. The decisions of these firms about research and production are articulated according to a two-stage decision process: in the first stage, each firm decides whether to devote an amount of resources to R&D activity, considering the present discounted sum of profits obtainable in the future thanks to the exploitation of a new idea and comparing them with R&D cost; in the second stage, after inventing a new product variety, the firm has to determine the price of this capital good in order to maximize profits.

In this simplified version, R&D cost is assumed to be equal to η units of Y: then research firms, in order to invent a new product, have to devote a fixed amount of final goods to R&D activity. This is another important assumption for the results of the model. In fact, R&D cost may depend on the amount of existing varieties, since the existence of some previous ideas may make, depending on the circumstances, easier or more difficult the invention of new ideas. Moreover, given that the output of research activity is not deterministically obtained from the employment of given inputs, the amount of time necessary to produce a new idea may change according to a stochastic factor and then it can imply some consequences on R&D cost.

So, assuming a fixed cost for research activity, firms are willing to enter R&D business only if they expect that the present value of returns is equal to R&D cost, according to the following free-entry condition:

$$V(t) = \eta$$

The present value of returns *V(t)* can be expressed as follows:

$$V(t) = \int_t^{\infty} \pi_j(\upsilon) \cdot e^{-\bar{r}(t,\upsilon)\cdot(\upsilon - t)} d\upsilon$$

where $\pi_j(\upsilon)$ is the profit at time υ and $\bar{r}(t, \upsilon)$ is the average interest rate between time *t* and time υ.

If this condition is satisfied, research firms elaborate new ideas protected by a patent and then produce new capital goods. Each firm is a monopolist with regard to the intermediate good produced, then it can apply a profit margin over the marginal cost. Assuming that marginal cost is equal to 1, the research firm *j* maximize the following profit function:

$$\pi_j = (P_j - 1)\left(\frac{A\alpha}{P_j}\right)^{\frac{1}{1-\alpha}} L$$

Then the firm *j* determine the price P_j , which is equal to:

$$P_j = \frac{1}{\alpha} > 1$$

Substituting P_j in the profit function π_j , it is possible to rewrite the present value of returns *V(t)* as follows:

$$V(t) = LA^{\frac{1}{1-\alpha}}\left(\alpha^{\frac{1+\alpha}{1-\alpha}} - \alpha^{\frac{2}{1-\alpha}}\right) \cdot \int_0^{\infty} e^{-\bar{r}(t,\upsilon)\cdot(\upsilon - t)} d\upsilon$$

Given the price, it is possible to determine the Lerner index, which is equal to the inverse of the demand elasticity:

$$L = 1 - \alpha = \frac{1}{\varepsilon}$$

Obviously, this result for the Lerner index depends on the formulation of the production function for final goods [5]. Anyway, it can be useful in order to identify a good indicator for the

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[5] In the general case for the production function, the result for the Lerner index is different but the equality between the Lerner Index and the inverse of the demand elasticity is confirmed. In fact, the demand for an intermediate good *j* is:

$$X_{ij} = \alpha^{\frac{1}{1-\sigma}} Y_i^{\frac{1}{1-\sigma}} X_i^{-\frac{1}{1-\sigma}} p_j^{-\frac{1}{1-\sigma}}$$

where $X_i = \sum_{j=1}^{N} (X_{ij})^{\sigma}$. Then, assuming that X_i and Y_i are constants, even in the case of a variation of p_j, the demand elasticity of X_{ij} is given by:

$$\varepsilon = \frac{1}{1-\sigma}$$

degree of competition, and then to evaluate the effects of market structure on the growth rate of economy, as determined in the model. In fact, given that the Lerner index is an appropriate measure of market power, we observe that market power is a decreasing function of α. So α can be considered as a parameter indicating the degree of competition in a market.

Now we have to consider the consumption side of the economy. In this model households consume final goods by maximizing the following utility function:

$$U = \int_0^\infty \frac{c_t^{1-\vartheta} - 1}{1-\vartheta} e^{-\rho t}\, dt \qquad \text{where } \vartheta > 0,\ \rho > 0$$

The consumers' budget constraint is the following:

$$\dot{a}_t = \frac{d a_t}{dt} = wL + r_t a_t - c_t$$

From the solution of this optimal control problem we obtain the Euler equation:

$$\gamma_{c_t} = \frac{\dot{c}_t}{c_t} = \frac{1}{\vartheta}(r_t - \rho)$$

Then we have to analyze the general equilibrium of the economy. From the production side, deriving the free-entry condition with respect to time, we can compute the interest rate r_t:

$$r_t = \frac{\pi}{\eta} = \frac{L}{\eta} \cdot A^{\frac{1}{1-\alpha}} \cdot \left(\alpha^{\frac{1+\alpha}{1-\alpha}} - \alpha^{\frac{2}{1-\alpha}} \right) \qquad (3)$$

Substituting the interest rate in the Euler equation, we can obtain the growth rate of consumption, which is equal to the growth rate of income per capita:

$$\gamma_{y_t} = \gamma_{c_t} = \frac{1}{\vartheta}\left[\left(\frac{L}{\eta} \right) \cdot A^{\frac{1}{1-\alpha}} \cdot \left(\alpha^{\frac{1+\alpha}{1-\alpha}} - \alpha^{\frac{2}{1-\alpha}} \right) - \rho \right] \qquad (4)$$

In order to understand the effect of competition on the growth rate of income per capita, we differentiate γ_{y_t} with respect to α, given that this variable can be considered as a good indicator for the degree of competition in the market.

$$\frac{\partial \gamma_{y_t}}{\partial \alpha} = \frac{1}{\vartheta} \cdot \frac{L}{\eta} \cdot A^{\frac{1}{1-\alpha}} \cdot \frac{1}{(1-\alpha)^2} \cdot \left\{ \ln A \cdot \left(\alpha^{\frac{1+\alpha}{1-\alpha}} - \alpha^{\frac{2}{1-\alpha}} \right) + \alpha^{\frac{2\alpha}{1-\alpha}} \cdot [1 - \alpha(\alpha - 2\ln\alpha)] - 2\alpha^{\frac{1+\alpha}{1-\alpha}} \cdot [1 - \alpha(1 - \ln\alpha)] \right\}$$

Simplifying, we can write this derivative as:

At the same time, a research firm, maximizing its profit, determines a price:

$$p_j = \frac{1}{\sigma} > 1$$

Then, even with a generalized production function, we obtain that the Lerner Index is equal to the inverse of the demand elasticity.

$$m = 1 - \sigma = \frac{1}{\varepsilon}$$

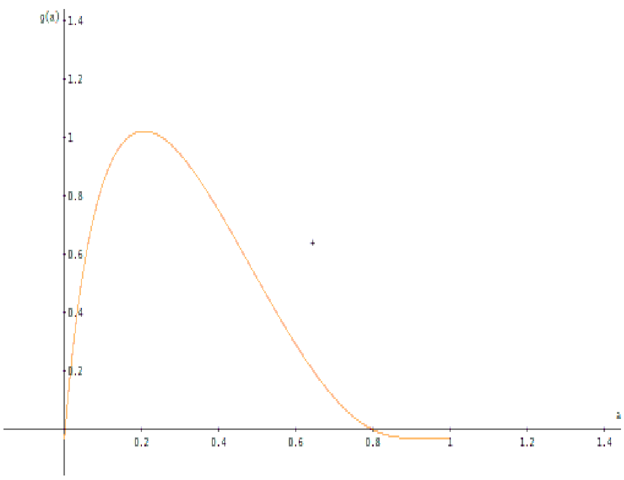
$$\frac{\partial \gamma_{y_t}}{\partial \alpha} = \frac{1}{\vartheta} \cdot \frac{L}{\eta} \cdot A^{\frac{1}{1-\alpha}} \cdot \alpha^{\frac{1+\alpha}{1-\alpha}} \cdot \frac{1}{(1-\alpha)} \cdot \left\{ \ln A + \underbrace{\alpha^{-1}}_{>0} + \underbrace{2\ln \alpha - 1}_{<0} \right\} \quad (5)$$

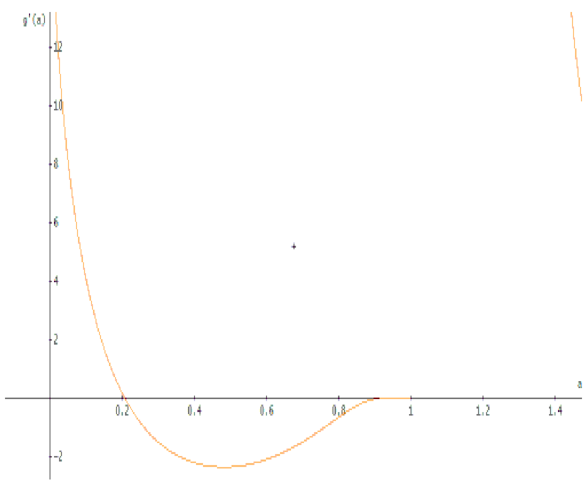
By assumption about the production function, we know that $A > 0$ and that $0 < \alpha < 1$. By assumption about the utility function, we also know that $\vartheta > 0$. The amount of labour employed must be positive, then $L > 0$. And also R&D cost must be positive, so $\eta > 0$. Then, the sign of the derivative depends on the sign of the expression in the parenthesis, and in particular on the values of *A* and *α*.

For this reason, in order to determine the effect of the degree of competition on the growth rate, we have to use a graphical representation. Then we represent separately: the growth rate of income per capita γ_{y_t}, as a function of the parameter *α*, using equation (4); the marginal variation of the growth rate $\partial \gamma_{y_t} / \partial \alpha$, as a function of the parameter *α*, using equation (5). Moreover, for the level of technology A [6], we consider two paradigmatic cases: the first one with A=1/2 (low level of technology); the second one with A=2 (high level of technology). The distinction between the two cases is fundamental in order to understand how the level of technology included in the production function for final goods can influence the sign and the value of the examined relations.

Finally, we can assign predetermined values to the other variables: *θ=1*, *L=35*, *η=1*, *ρ=0.03*.

So let consider the first case, for *A=1/2*. The graph on the left represents the growth rate, that is $\gamma_{y_t} = g(\alpha)$, while the graph on the right represents the marginal variation of the growth rate, that is $\frac{\partial \gamma_{y_t}}{\partial \alpha} = g'(\alpha)$.

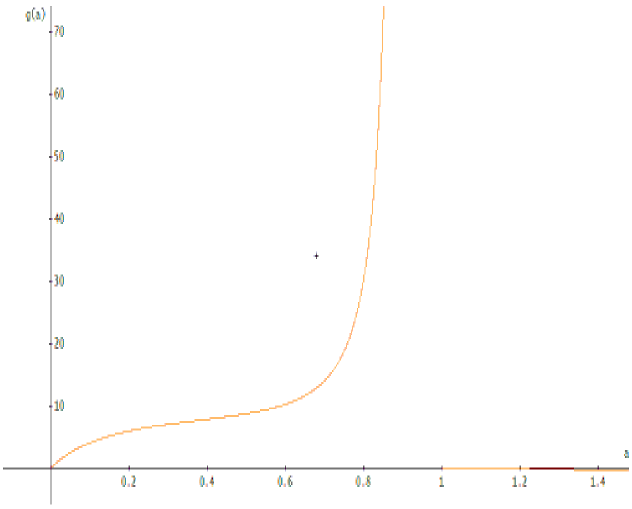


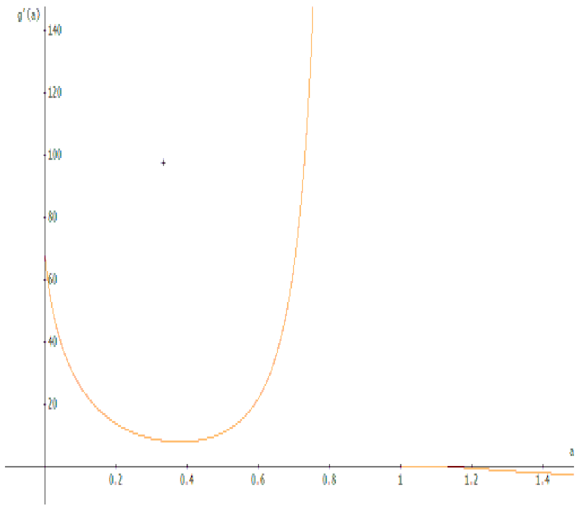


[6] The role of the technological parameter A in this model needs to be clarified: given that the number of product varieties in the intermediate sector captures the technological progress endogenously generated by the invention of new ideas in R&D activity, A can be interpreted as a form of labour-augmenting and exogenous technological progress, regarding the production of final goods.

As we observe, for a low level of labour-augmenting technology (the same result holds for each value of A such that $0 < A \leq 1$), the relation between competition and growth assumes the form of an inverted U-relationship. So, for a low degree of competition, the growth rate increases because each firm in the intermediate sector, in order to escape competition, has to innovate inventing new capital goods. But, for a medium-high degree of competition, the growth rate tends to decrease and at the end it becomes slightly negative: in fact, the decrease of the profit margin due to the rise of α reduces the incentives for R&D activity.

So let consider the second case, for $A=2$. The two graphs are represented as before.





In this case, for a high level of labour-augmenting technology, the relation between competition and growth is always positive: the growth rate augments as the degree of competition rises, even if the marginal variation of the growth rate is before decreasing and after increasing. Here the disincentive effect coming from the reduction of the mark-up is not so relevant as in the first case. This is because the escape competition effect is much stronger: in fact, given that workers operating in the final goods sector are more productive, they are able to employ the capital goods produced by the intermediate sector in a more efficient way. So research firms have more incentives to elaborate new ideas and create new intermediate products in order to better satisfy the demand for capital goods and then to escape competition.

In conclusion, in this model, the relation between competition and growth depends on the level of labour-augmenting technology employed for the production of consumption goods. This cannot be an exhaustive conclusion: in fact the sign of this relation is determined by the value of an exogenous parameter, which is fixed outside the model. So this analytical framework is not able to explain how the degree of competition may endogenously affect the growth rate of the economy in a balanced growth path. From this point of view the model cannot offer useful answers to the proposed question.

Moreover, the results of the model are crucially determined by three simplifying assumptions: the production of new ideas in R&D sector requires only some units of final output; the labour input is employed only in the production of final goods; the cost of R&D activity is fixed for any number of available ideas. Removing these assumptions about the research sector may significantly change the conclusions of the model about the sign of the relation between competition and growth, as it will be clear from the following discussion.

1.4 Temporary Patent Protection and Erosion of Monopoly Power

The basic version of the endogenous growth model with product differentiation uses a very simplifying assumption about the protection of intellectual property provided by patents, since it assumes that patents guarantee a perpetual monopoly to the owner firm. In fact this idea is not supported by the observation of real world, where patent protection is just temporary because intellectual property laws assign an exclusive right to use the patented idea only for a limited period of time. Then, after the expiration of the patent, the idea can be freely exploited by everyone and as a consequence the previous titular loses the corresponding monopolistic position. But this is not the only reason that may determine the erosion of monopoly power of the patent's owner: also imitation can reduce the market power of a research firm, inventor of a new type of intermediate product, if imitation is not enough sanctioned by copyright laws or if the imitator is not punished for this infringement.

These considerations suggest the opportunity to model endogenous growth also in a framework where the successful innovator may lose the monopoly power on the new idea. An appropriate way to consider this possibility, firstly presented in a paper by Judd (1985), is to assume that monopolistic goods become competitive products with a probability measured by a Poisson process. For example, an intermediate good invented in time *t* by a firm *A* has a probability *p* to become competitive at date *v*, and then reversely the probability for the same product of being still monopolized at time *v* is $e^{-p(v-t)}$.

So let consider the implications of this assumption concerning the duration of patent protection for the results of the endogenous growth model of the previous section, as presented in Barro and Sala-i-Martin (2003). In particular, let analyze the consequences on the behaviour of intermediate firms both in production and in innovation decisions. Firstly, because of the erosion of the market power, the intermediate good cannot be sold anymore at a price $p_j^M = (1/\alpha) > 1$, but it must be supplied at a price $p_j^C = 1$, which is equal to the marginal cost. This implies that the producer of capital good *j* faces a larger demand in a competitive situation than in a monopolistic one. In fact:

$$X_j^C = A^{\frac{1}{1-\alpha}} L\alpha^{\frac{1}{1-\alpha}} > A^{\frac{1}{1-\alpha}} L\alpha^{\frac{2}{1-\alpha}} = X_j^M$$

As a consequence of the competitive pricing, the firm producer of the intermediate good completely loses its monopolistic profits, such that:

$$\pi_j^C = 0 < LA^{\frac{1}{1-\alpha}} \alpha^{\frac{1+\alpha}{1-\alpha}} (1-\alpha) = \pi_j^M$$

In such an environment, a research firm which decides to invest in R&D activity, with the purpose of producing a new variety of intermediate good, has to compute the expected value of innovation taking into account only the profit flow obtainable as long as the intermediate product is a monopolistic one. Then:

$$E[V(t)] = \int_t^\infty \pi_j^M \cdot e^{-[p+\bar{r}(t,v)]\cdot(v-t)} dv$$

Given the assumption of a fixed research cost, the free-entry condition can be formulated as:

$$E[V(t)] = \eta$$

Now we have to consider the general equilibrium of the economy. From the solution of the utility maximization problem of the household, we have the usual Euler equation:

$$\gamma_{c_t} = \frac{\dot{c}_t}{c_t} = \frac{1}{\vartheta}(r_t - \rho)$$

From the production side, deriving the free-entry condition with respect to time, we can compute the interest rate r_t:

$$r_t = \frac{\pi^M}{\eta} - p = \frac{L}{\eta} \cdot A^{\frac{1}{1-\alpha}} \cdot \left(\alpha^{\frac{1+\alpha}{1-\alpha}} - \alpha^{\frac{2}{1-\alpha}} \right) - p$$

The interest rate derived in this extended model is almost the same obtained in the previous model, but with an only difference. In fact, the result is computed by subtracting the parameter *p*, that is the probability that a monopolized product becomes a competitive one. This means that such probability further reduces the private rate of return and then enlarges the difference with the social rate of return coming from investment in research.

Substituting the interest rate in the Euler equation, we obtain the growth rate of consumption:

$$\gamma_{c_t} = \frac{1}{\vartheta} \left[\left(\frac{L}{\eta} \right) \cdot A^{\frac{1}{1-\alpha}} \cdot \left(\alpha^{\frac{1+\alpha}{1-\alpha}} - \alpha^{\frac{2}{1-\alpha}} \right) - p - \rho \right]$$

In this model, because of the assumption regarding the intermediate sector, we cannot immediately state whether the growth rate of consumption is equal to the growth rate of income, then we have to prove the existence of a balanced growth path where all the variables grow at a constant rate. Firstly, since the intermediate goods are distinguished in monopolistic and competitive ones, it is necessary to identify the fractions of N belonging to each of these categories. Let define N^C as the number of intermediate products which have become competitive and N^M as the amount of capital goods still monopolized. Then, given that monopolized products are likely to become competitive ones with a probability p, the variation of the number of competitive products in time t is given by:

$$\dot{N}^C = p \cdot \left(N - N^C\right)$$

If we define the growth rate of competitive intermediate goods as γ_{N^C}, the ratio between the number of competitive products and the total number of capital goods can be expressed as:

$$\frac{N^C}{N} = \frac{p}{p + \gamma_{N^C}}$$

Given that in a steady state the growth rate of competitive intermediate goods γ_{N^C} is constant, the ratio $\left(N^C/N\right)^*$ must also be constant. This implies that in a steady state N^C and N grow at the same rate $\gamma = \gamma_N = \gamma_{N^C}$

From the production function of final goods, considering the fractions of intermediate products in different market contexts and substituting the obtained result for the ratio $\left(N^C/N\right)$ we can compute the level of aggregate output in the steady state:

$$Y^* = A^{\frac{1}{1-\alpha}} \alpha^{\frac{2\alpha}{1-\alpha}} LN \cdot \left[1 + \left(\frac{p}{p+\gamma}\right) \cdot \left(\alpha^{-\frac{\alpha}{1-\alpha}} - 1\right)\right]$$

From this equation, it can be proved that the aggregate output Y^* and the total number of intermediate product varieties N^* grow at the same rate in the steady state, given that all the other terms are constant, then $\gamma = \gamma_Y = \gamma_N$.

The economy-wide resource constraint, indicating the amount of resources to be employed in research activity after the other usages, is the following:

$$\eta \dot{N} = Y - C - N^C X^C - \left(N - N^C\right) X^M$$

where $\dot{N} = \gamma_N N$ in the steady state. Then, we can determine the level of aggregate consumption, substituting for Y, X^C and X^M:

$$C = N \left\{ A^{\frac{1}{1-\alpha}} (1-\alpha) \alpha^{\frac{2\alpha}{1-\alpha}} L \cdot \left[\frac{(1+\alpha)\gamma + p\alpha^{-\frac{\alpha}{1-\alpha}}}{p+\gamma}\right] - \eta\gamma \right\}$$

Since all the terms in the curly brackets are constant in a steady state, it can be shown that C and N grow at the same rate in a steady state, then $\gamma = \gamma_C = \gamma_N$. As a consequence, there exists a balanced growth path where Y, C, N and N^C grow at a constant rate γ. So the growth rate of the economy in BGP is:

$$\gamma = \frac{1}{\vartheta}\left[\left(\frac{L}{\eta}\right)\cdot A^{\frac{1}{1-\alpha}}\cdot\left(\alpha^{\frac{1+\alpha}{1-\alpha}} - \alpha^{\frac{2}{1-\alpha}}\right) - p - \rho\right]$$

Following the observation already proposed for the interest rate, the growth rate of the economy in this extended model is lower than the growth rate in the basic model for the subtraction of a term equal to *(p/θ)*. In fact, the probability that a monopolized product becomes a competitive one, as it reduces the private rate of return, also diminishes the incentives for innovation in the intermediate sector. Then, the expiration of patent protection and the imitation of competitors negatively affect the long-term growth rate, since any positive value of the parameter p decrease the rate γ. This shows the importance, from the viewpoint of dynamic efficiency, of a long-term perspective of monopolistic profits for investments in R&D activity and for economic growth. As a corollary, an increase of the probability parameter, determined by a competition-enhancing policy of the government, further reduces the growth rate of the economy. In fact, from a comparative statics analysis, we have:

$$\frac{\partial\gamma}{\partial p} = -\frac{1}{\vartheta} < 0$$

On the other hand, the limited duration of patent protection is required for reasons of static efficiency, which can be explained with reference to the equation of the aggregate output level. In fact, given that $\alpha^{-\frac{\alpha}{1-\alpha}} > 1$, any positive value of the parameter p increases the output level by a measure $A^{\frac{1}{1-\alpha}}\alpha^{\frac{2\alpha}{1-\alpha}}LN\left[\left(\frac{p}{p+\gamma}\right)\cdot\left(\alpha^{-\frac{\alpha}{1-\alpha}} - 1\right)\right]$ with respect to the case where the monopolist firms always keep their market power. In fact, the existence of a competitive market for some intermediate products, stimulating the demand of these capital goods by the producers of final commodities, favours a rise of the production levels. As a corollary, an exogenous increase of the value p, induced by a briefer duration of patent protection or by a larger diffusion of patented ideas, produces a rise of the output level. In fact, from a comparative statics exercise, we observe:

$$\frac{\partial Y^*}{\partial p} = A^{\frac{1}{1-\alpha}}\alpha^{\frac{2\alpha}{1-\alpha}}LN\cdot\left[\frac{\gamma}{(\gamma+p)^2}\cdot\left(\alpha^{-\frac{\alpha}{1-\alpha}} - 1\right)\right] > 0$$

From the previous observations, a clear trade-off between dynamic and static efficiency arises in the determination of patent policy and in the design of competition policy, as well as in the interaction between the two policies. Since the objectives of the two policies are opposite, at least in this theoretical framework, the choice of the appropriate policy depends on the preferences of the government about the priorities (current total welfare or long-run growth). In any case, the solution of the problem is subject to a time-inconsistency concern: in fact, the government is interested in promising a strong and lasting patent protection for promoting innovation and growth in the future, but is also involved in increasing total welfare in the present through more competitive markets. Then, as long as it promotes current competition by removing entry barriers in monopolistic markets, its promises about patent protection and monopolistic rents for innovators might not be credible. This implies that any compromise solution regarding the interaction between these policies must consist of sure and definite rules, to be implemented in such a way to induce the formation of rational expectations about the future attainment of the fair reward for innovation effort.

The idea of modelling the dynamic process of market transformation through a probability parameter allows to improve the theoretical analysis of the relation between competition and growth, as compared to the basic model with expanding product varieties, for two main reasons. Firstly, in this theoretical framework, the effect of competition on growth is more clearly identified through the parameter p than through the parameter α. In fact, the growth rate γ is evidently an inverse function of the probability parameter p, such that an increase of p always implies a decrease of γ. On the contrary, the relation between the growth rate γ and the parameter α is ambiguous, since the sign of the derivative depends on the value of the exogenous technological parameter A: the observations presented in the previous section about the growth rate and the degree of competition can be repeated also in this case, given that the derivative of γ with respect to α is exactly the same.

Secondly, the probability parameter p is able to capture the exogenous variations in competition policy better than the parameter α, which is used for explaining the effect of market structure on pricing decisions in an economy with imperfect competition. In fact, while p allows to determine the number of intermediate products expected to become competitive, α inversely defines the value of the mark-up chosen by monopolistic firms in fixing prices. In other words, p and α play different roles in the measurement of competition. As a consequence, the reforms aimed to increase the degree of competition, through the liberalization of the markets, rise the value of p but don't necessarily affect the value of α, given that it refers to the goods which are still monopolized.

Moreover the parameter p, indicating the probability that a monopolized good becomes a competitive one, takes into consideration at the same time various possible events, such as the expiration of a patent, the illegal imitation of a patented product by a competitor, the enforcement of antitrust law against a monopolistic firm condemned to license its patent to other producers [7]. So,

[7] When a patent is useful for inventing a new product for which there is a potential demand, and if the new product cannot be developed without the information contained in the patent, competition authorities can oblige the owner of the patent to license it to the other interested producers. In fact, in these cases, the patent must be considered as an essential facility, that is a non duplicable

given that the facts which may produce this change of market structure for a given product are quite different, it is worth to consider whether a unique probability parameter is adequate for expressing all these possible events, even those which are not apparently related to a probabilistic factor.

In particular, this question can be proposed for the case of the expiration of a patent: given that the duration of intellectual property rights is clearly defined by law, why should we employ a Poisson process in order to determine the time when the monopolized product is likely to become a competitive one? An appropriate reply to this observation raises the issue of the enforceability of patents: in fact the formal recognition is not enough for effectively ensuring the exclusive exploitation of the protected idea, since other producers might violate the patent and produce the same good without any permission. So it is necessary to verify whether the owner of a patent, in an eventual law-suit, is likely to obtain a favourable verdict from the courts. Given that the outcome of a civil suit can be predicted only as a probabilistic event, even in the case of a law praxis based on court precedents, the enforceability of a patent can be reasonably defined through a probability parameter.

For this purpose, it is useful to recall the observations on patent enforceability presented in the empirical paper by Marco and Rausser (2008), regarding the impact of patent rights on industry structure. The authors show that the existence of some complementary patents in a given industry may provide incentives for consolidation processes among various firms, since they need to share the contents of their patents in order to produce new goods (in the discussed case plant biotechnologies). This confirms the idea that a system of intellectual property protection favours a transformation of market structure through a reduction of the previous producers and an increase of the market power of the existing firms.

Anyway, the intensity of this consolidation process depends especially on patent enforceability, that is “the ability of firms to appropriate patent value, or to threaten to block use of technology”. Patent enforceability is important not only for punishing the already occurred infringements, but especially for avoiding future violations and for allowing the owner firms to transact at arms length with competitors. So there is a problem of credibility in patent protection, which depends on the history of court decisions. For this reason one important explanatory variable of the relation between patent protection and industry consolidation is patent enforceability, meant as the predicted probability that a court would rule the patent valid and infringed, where the probabilities of validity and infringement are assumed to be independent in the analysis. As it results from empirical evidence, enforceability rises the likelihood of all types of mergers on the buy-side, and makes firms more willing to spin off subsidiaries on the sell-side.

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input which is deemed necessary for all industry participants to operate in a given industry. Anyway, an excessive implementation of the essential facility doctrine can be dangerous for the effects on the private incentives to innovate.

In conclusion, the idea to parameterize the dynamic process of market transformation through a Poisson process may offer a reasonable approach to the problem of finite patent protection. As a consequence, future developments of research on this topic should take into account this solution and exploit this intuition in the construction of other models of endogenous growth.

1.5 The Romerian Model of Endogenous Technological Change

In this section we introduce some extensions to the basic version of the endogenous growth model with horizontal innovation, in order to present the analysis of Endogenous Technological Change, as proposed by Romer (1990). In fact, this model is considered in the literature as the benchmark of endogenous growth theory with expanding product varieties, given that many other contributions on the same issue have been offered departing from this general framework. In this presentation we follow Barro and Sala-i-Martin (2003) and also Gancia and Zilibotti (2005).

The consumption side of the economy works in the same way as in the previous section, while the production side shows some differences, in particular about the non-competitive sector producing intermediate goods.

First of all, the research sector uses labour instead of final goods as an input for the production of new ideas. This assumption is reasonable, also because the invention of a new product is the result of the creative activity of a researcher, who employs his work to this only purpose. This implies that in the Romerian model labour is used both in the final sector (L_Y) and in the research sector (L_R), but not in the intermediate sector. Then we can write a feasibility condition for the total amount of labour input in the economy:

$$L \geq L_Y + L_R$$

In equilibrium, since all the labour input is employed, this feasibility condition must hold as an equality. Moreover labour is assumed as an homogenous input and then it is remunerated by the same wage, whatever sector employs it [8]. So we have:

$$w_t = w_{Y\,t} = w_{Rt}$$

A second assumption regards the cost of R&D activity: in fact it is defined as a decreasing function of the number of existing product varieties, because the availability of some previous ideas makes easier to elaborate a new idea, and then to invent a new intermediate good. This implies that

[8] This latter assumption is perhaps less reasonable, given that the amount of wage paid to a worker is also a function of the human capital that he has accumulated and then is able to offer. For this reason we could suppose that a worker employed in the research sector gets a wage higher than the wage paid to a worker in the final sector.

the generation of an innovative idea produces a positive externality for the labour productivity of future researchers, who will have access to a greater stock of knowledge [9]. This assumption is expressed through the following law of motion for the production of new designs (N_t):

$$\dot{N}_t = \frac{1}{\eta} N_t L_R \qquad \text{where } \eta > 0$$

So the variation of the number of designs depends positively on the number of existing ideas and on the amount of labour employed in the research activity. If $\dot{N}_t = 1$, the invention of a new idea requires a labour input equal to η/N_t and then the cost of invention is equal to $\eta w_{Rt} / N_t$.

Given these assumptions, the firms are willing to invest in R&D activity only if they expect that the present discounted value of profits coming from the exploitation of a new idea is equal to the cost of research activity [10]. In this particular case, the free-entry condition must be written as follows:

$$V(t) = \frac{\eta w_{Rt}}{N_t}$$

The instantaneous profit flow of a firm *j* producer of capital goods is given by:

$$\pi_{jt} = L_Y A^{\frac{1}{1-\alpha}} (1-\alpha) \alpha^{\frac{1+\alpha}{1-\alpha}}$$

Given the profit function π_{jt}, the present discounted value of profits from the exploitation of a new design of intermediate good is equal to:

$$V(t) = \underbrace{L_Y A^{\frac{1}{1-\alpha}} (1-\alpha) \alpha^{\frac{1+\alpha}{1-\alpha}}}_{\pi_{jt}} \cdot \int_t^{\infty} e^{-\bar{r}(t,\upsilon)(\upsilon - t)} d\upsilon$$

Now we have to analyze the general equilibrium of the economy. From the profit maximization problem in the sector of final goods, we obtain the real wage:

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[9] This observation makes evidence of another aspect of inefficiency which arises in the Romerian model of Endogenous Technological Change, when we compare the outcome of a decentralized economy and the result of a social planer solution. In fact, given that the social planner takes into account the social benefits coming from the invention of a new idea, while the decentralized economy considers only the private benefits deriving from research activity, this implies that the social planner solution ensures a better remuneration for R&D activity and then offers more incentives for innovation than a decentralized economy. So the problem that public intervention should solve is how to valorise this externality by rewarding adequately the effort in research activity.

[10] In this case we assume, as in the previous section, that the firms in the intermediate sector are involved in the research activity and then have to decide whether and how much invest in R&D. But we could also suppose, without changing the results of the model, that the production of intermediate goods and the research activity are carried out by different firms, on the condition that research sector is perfectly competitive. So, in this hypothesis, research firms which invent a new design may license it to the producers of capital goods for a price equal to the cost of the new invention. Then the firms operating in the intermediate sector are willing to buy the license only if they expect that the present discounted sum of profits coming from the exploitation of the new design is equal to the price of the license, and then to the cost assumed by the research firm to invent the new product.

$$w_{Yt} = w_{Rt} = A^{\frac{1}{1-\alpha}}(1-\alpha)\alpha^{\frac{2\alpha}{1-\alpha}} N_t \qquad (6)$$

From the solution of the utility maximization problem of the household, we have the usual Euler equation:

$$\gamma_{c_t} = \frac{\dot{c}_t}{c_t} = \frac{1}{\vartheta}(r_t - \rho)$$

It can be shown that the growth rate of per capita consumption (c_t) is equal to the growth rate of the other variables N_t, Y_t and w_t . This implies the existence of a balanced growth path (BGP), where all the variables grow at a constant rate. Then, by the Euler equation, also the interest rate r_t is constant in the BGP. So we can compute the interest rate as the ratio between the instantaneous profit flow (in equilibrium $\pi_t = \pi_{jt}$) and the present discounted value of innovation $V(t)$:

$$r_t = \frac{\pi_t}{V(t)} = \frac{L_Y A^{\frac{1}{1-\alpha}}(1-\alpha)\alpha^{\frac{1+\alpha}{1-\alpha}}}{\frac{\eta w_{Rt}}{N_t}} \qquad (7)$$

Substituting w_{Yt} for w_{Rt} and simplifying, the interest rate is:

$$r = \frac{L_Y \alpha}{\eta}$$

In order to determine the growth rate of the economy in the balanced growth path, but also the amount of labour in the final sector and in the research sector, it is necessary to solve the following system of equations, given the Euler equation as a stability condition of the system:

Interest rate	$r = \frac{L_Y \alpha}{\eta}$
Labour market	$L = L_Y + L_R$
Innovation rate	$\gamma = \frac{\dot{N}_t}{N_t} = \frac{L_R}{\eta}$

The solutions of this system of equations are:

$$L_Y = \frac{L\vartheta + \eta\rho}{\vartheta + \alpha}$$

$$L_R = \frac{\alpha L - \eta\rho}{\vartheta + \alpha}$$

$$\gamma = \frac{\alpha L - \eta\rho}{\eta(\vartheta + \alpha)} \qquad (8)$$

The most interesting result for our purposes is the last one, corresponding to the growth rate of the economy in a balanced growth path. In order to understand the effect of the degree of competition on the growth rate of the economy, we differentiate γ with respect to α and then we study the sign of the derivative:

$$\frac{\partial \gamma}{\partial \alpha} = \frac{L\eta\left(\vartheta + \alpha\right) - \eta\left(\alpha L - \eta\rho\right)}{\eta^2\left(\vartheta + \alpha\right)^2}$$

Simplifying, we can write the derivative as:

$$\frac{\partial \gamma}{\partial \alpha} = \frac{\left(L\vartheta + \eta\rho\right)}{\eta\left(\vartheta + \alpha\right)^2} > 0$$

So, in this model, the effect of competition on growth is always positive. Comparing this result with the outcome of the basic model with expanding product variety, we can observe that the growth rate of the economy doesn't contain the technological parameter A. This is a consequence of the assumption about the production function of the research sector, including labour as an input: in fact, given that the cost of R&D activity is a function of the real wage, defined as in equation (6), the interest rate, computed in equation (7), doesn't present the parameter A, because the corresponding terms in the profit function and in the real wage cancel out. Then, the growth rate of the economy is not determined by the value of A and – what is more important - the relation between competition and growth is not affected by this productivity parameter exogenously fixed.

This implies that the model shows a clear positive relation between competition and growth, which can be explained endogenously through a resource allocation effect regarding labour input. In fact, as competition increases in the intermediate sector, and so the price of capital goods decreases, the producers of final goods tend to substitute labour input with capital input. If there is full employment in the economy, this causes a reallocation of labour from the final sector to the research sector. So, given that the rate of innovation, measured as the growth rate of product varieties, is an increasing function of the labour employed in the research sector, a rise of L_R produces an increase of the innovation rate, and then of the growth rate.

But this explanation requires some additional observations. A first critical consideration concerns the idea of a perfect mobility of workers between final sector and research sector, which is based on the initial assumption about the homogeneity of labour input and then on its corollary about the equality of real wages across different sectors. So it is worth to verify whether, supposing different wage levels for workers in the final sector and in the research sector, the results of the model about the growth rate and the effect of competition on growth remain unchanged. In particular, if we assume that there exists a fixed proportion between w_R and w_Y , the results don't change significantly for our purposes, because the growth rate of the economy is confirmed to be an increasing function of the degree of competition. Nevertheless, we can deduce some important conclusions about the relation between wage levels and growth.

For instance, let consider the case where $w_R = \lambda w_Y$ such that $\lambda > 1$. Then the solutions of the system of equations are the following ones, compared with the solutions obtained for the general case where $w_R = w_Y$:

$$L_Y^* = \frac{\lambda\left(L\vartheta + \eta\rho\right)}{\lambda\vartheta + \alpha} \qquad L_Y^* > L_Y$$

$$L_R^* = \frac{\alpha L - \lambda\eta\rho}{\lambda\vartheta + \alpha} \qquad L_R^* < L_R$$

$$\gamma^* = \frac{\alpha L - \lambda\eta\rho}{\lambda\eta\left(\lambda\vartheta + \alpha\right)} \qquad \gamma^* < \gamma$$

If the wage paid to the workers in the research sector is higher than the wage paid to the final sector according to a fixed proportion λ, the amount of labour employed for the production of final goods is greater, while the quantity of labour required for research activity is smaller. At the same time, the growth rate is lower, while the derivative of the growth rate with respect to α is still positive, but slightly smaller than in the general case.

$$\frac{\partial\gamma^*}{\partial\alpha} = \frac{\left(L\vartheta + \eta\rho\right)}{\eta\left(\lambda\vartheta + \alpha\right)^2} > 0 \qquad \frac{\partial\gamma^*}{\partial\alpha} < \frac{\partial\gamma}{\partial\alpha}$$

These facts can be intuitively explained as follows. In fact, given that the workers in the research sector receive a superior wage, the cost of R&D activity is higher for firms. Then, in order to satisfy the free-entry condition, the value of innovation required for a profitable investment in R&D sector must also be higher. This means that firms have less incentives to promote research. As a consequence, a reduced amount of labour supply is employed in R&D sector and the growth rate of product varieties, equal to the growth rate of income per capita, is lower. So, in this case, an increase of the degree of competition may produce a positive effect on growth, which is however smaller than in the general case.

In conclusion, homogeneity of labour supply is not a necessary condition for obtaining the described results for the growth rate and the relation between competition and growth. However, a distinction of wages, aimed to promote the accumulation of human capital for R&D workers, may attenuate the magnitude of the resource allocation effect coming from a rise of competition in the market.

A second critical observation regards the determinant role played by the scale effect of labour supply in R&D sector, in order to determine the growth rate of the economy and then also the relation between competition and growth. In fact, the resource allocation effect, subsequent to an increase of the degree of competition, explains the positive effect of competition on growth, just because an expansion of labour supply in R&D sector produces a rise of the growth rate of product varieties, equal to the growth rate of income per capita.

But this specification of the rate of technological progress is not necessarily consistent with the empirical evidence, as reported by Jones (1995). In fact he presents some data about the increase of the number of researchers in many industrialized countries over the years 1970-1990, showing that a wider employment of labour in R&D sector doesn't imply automatically a rise of the growth rate of the economy. This is because the output of research activity is not deterministically produced from a given quantity of inputs, but it depends also on the outcome of a stochastic factor.

Then the idea that Jones wants to develop is the construction of a research-based growth model, able to explain the growth process without exploiting any scale effect induced by the amount of labour employed in R&D sector. In particular, in order to maintain the basic structure of R&D based models, he introduces the following law of motion for the number of product varieties:

$$\dot{N}_t = \frac{1}{\eta} L_R N_t^{\varphi} l_R^{\lambda-1}$$

N_t is the number of product varieties: the value of the exponent φ defines the measure, positive or negative, of the externalities induced by the existing stock of knowledge for productivity of research activity. L_R is the amount of labour employed in the research activity and exploited for the invention of new ideas. l_R is the amount of labour engaged in the research sector but not useful for promoting technological progress because of duplications in the research process. In equilibrium $L_R = l_R$, so the contribution of research work for the rate of technological progress is expressed by L_R^{λ}, where $0 < \lambda \leq 1$.

This specification of the research equation solves two issues: it allows to consider different types of externalities, both positive and negative, coming from the amount of existing varieties; it permits to eliminate any scale effect of labour supply from the determination of the growth rate. But the counterpart of this specification is that the long-run growth rate, obtained from the growth rate of product varieties, is dependent on exogenous parameters such as φ, λ and n (which is the growth rate of population). In fact, the growth rate is equal to:

$$\gamma = \frac{\lambda n}{1-\varphi}$$

But, in this case, the alternative specification of the research equation implies another problem for the determination of the growth rate, given that the model is not able to explain endogenous growth. In fact, the determinant role of these exogenous parameters contradicts the idea of a technological progress, which is endogenously generated by product and process innovations, intentionally and rationally promoted by economic subjects. So, in this case, the elimination of scale effects doesn't guarantee that the model can offer useful answers for the determinants of the growth rate and for the relation between competition and growth.

1.6 Some extensions of the Romerian Model of Endogenous Growth

The idea to elaborate an endogenous growth model with expanding product varieties, able to reproduce in a theoretical framework the same results obtained from the empirical analysis, has induced some extensions of the Romerian model in the last few years. In particular, the empirical observation of an inverted-U relationship between product market competition and innovation, firstly presented in the papers by Scott (1984) and Levin - Cohen - Mowery (1985), more recently shown in the article by Aghion – Bloom – Blundell – Griffith – Howitt (2002), has promoted some new contributions, also in the field of horizontal innovation – driven growth models, with the specific aim to give a theoretical foundation for explaining this type of relationship.

More precisely, Bucci (2007) proposes an extended Romerian model where he introduces a different assumption about the employment of labour input across different sectors of the economy. In particular, he assumes that labour is used as input also in the production of intermediate goods and so he extends the idea of a perfect mobility of labour across all the sectors of the economy. The production function for capital good producers engaged in a monopolistic competition is the following:

$$x_j = l_j$$

This means that the production of one unit of intermediate good requires one unit of labour input. So each firm maximizes the following profit function with respect to the quantity of capital good produced:

$$\pi_j = \left(\underbrace{\alpha x_{jt}^{\alpha-1} L_Y^{1-\alpha}}_{p_j} - w_j \right) x_{jt}$$

The price determined by the firm is given by:

$$P_j = \frac{w_j}{\alpha}$$

As in the standard model, the fraction *1/α* indicates the mark-up which is charged over the marginal cost, which is equal in this case to w_j . The real wage in the intermediate sector is equal to the real wage in the other sectors. This homogeneity of labour input is essential in order to explain the working of the resource allocation effect across all the sectors of the economy, and in particular towards the intermediate sector.

In fact, if product market competition increases, because of a rise of the parameter α, the decrease of the price of intermediate goods implies a greater demand from producers of final goods, which tend to substitute labour with capital. The amount of labour which is not employed in the final sector is required not only in the research sector, as described in the standard Romerian model, but also in the intermediate sector, given that these firms employ labour for production purposes. So the increased demand for capital goods also implies a higher demand of labour in the intermediate sector. In any case, the model fulfils the condition for full employment. So the labour supply is entirely employed in one of the three economic sectors. Then:

$$L = L_Y + L_j + L_R$$

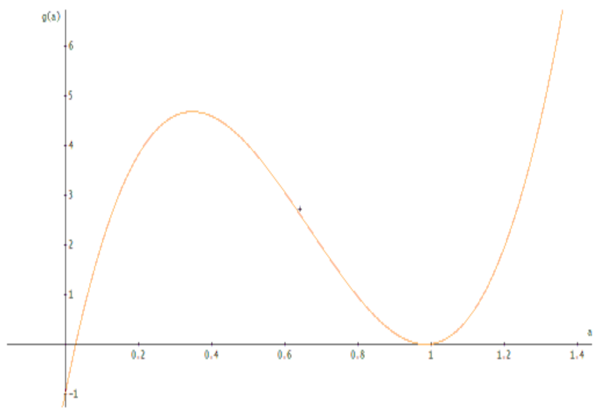
Apart from this different assumption about the usage of labour input across the sectors of the economy, the model works in the same way as the standard Romerian model. Then we have to determine the general equilibrium of the model by solving a system of equations including as variables the interest rate, the amount of labour employed in each sector L_Y, L_j and L_R, the growth rate of the economy. In particular, the most important result regards the growth rate of income per capita in a balanced growth path, which is equal to :

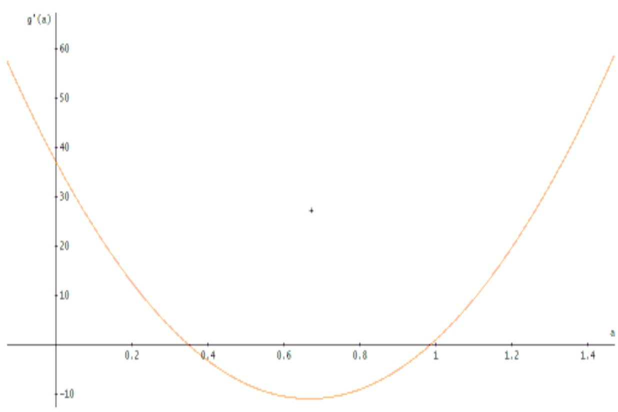
$$\gamma_Y = \frac{\alpha(1-\alpha)^2 L + \eta\rho\left[\alpha\left(\alpha^2 - 2\alpha + 2\right) - 1\right]}{\eta} \qquad (9)$$

In order to understand the effect of competition on growth, we derive the growth rate with respect to α and we obtain:

$$\frac{\partial \gamma_Y}{\partial \alpha} = \frac{\alpha(3\alpha - 4)(L + \eta\rho) + L + 2\eta\rho}{\eta} \qquad (10)$$

Given this derivative, we could have the certainty that the sign is positive if and only if α=4/3, which is impossible, given that by assumption 0<α<1. So, in order to define the effect of competition on growth, we need to use a graphical representation. As in section 1.2, we represent separately: the growth rate of income per capita γ_Y, as a function of the parameter α, using equation (9); the marginal variation of the growth rate $\partial\gamma_Y/\partial\alpha$, as a function of the parameter α, using equation (10). Then we can assign the same predetermined values to the other variables: $L=35$, $\eta=1$, $\rho=0.03$. The graph on the left represents the growth rate, that is $\gamma_Y = g(\alpha)$, while the graph on the right represents the marginal variation of the growth rate, that is $\frac{\partial \gamma_Y}{\partial \alpha} = g'(\alpha)$.





The graphical representation shows that the growth rate firstly increases until a level of competition that we can define as α*, but after this level it decreases even remaining positive. So the described model allows to represent the relation between competition and growth as an inverted U-relationship. This behaviour of the growth rate can be explained through the interaction between the profit incentive effect and the resource allocation effect.

The profit incentive effect shows the variation of profits for the firms of the intermediate sector, which is consequent to a variation of the degree of competition (and then of the amount of mark-up charged over the marginal cost). When α increases, the price P_j decreases and then also the profits diminish, so these firms have less resources for investing in R&D activity or for buying licenses from research firms. This disincentive effect for research activity implies that the profit incentive effect is always negative for a rise of the degree of competition.

On the contrary, the resource allocation effect, due to the mobility of labour input across the sectors, is positive for values of α such that $\alpha<\alpha^*$, while it would be negative for values of α such that $\alpha>\alpha^*$. In fact, for low levels of product market competition, an increase of α determines a reduction of labour employed in the final sector, but a growth of labour used in the intermediate sector and in the research sector. Instead, for high levels of competition, a rise of α produces a decrease of labour in the final sector, but also in the research sector, and however an increase of labour in the intermediate sector. In other words, when $\alpha>\alpha^*$, the increase of labour demand for the production of capital goods would be so strong to determine also a reduction of labour in the R&D sector.

This explanation, as presented in the paper, cannot be considered satisfying, because the argument for a change of sign in the resource allocation effect is not supported by a clear explanation of the reason why the flows of labour input to the research sector are immediately inverted as soon as $\alpha>\alpha^*$. Moreover, if we consider the resource allocation effect as a positive effect whatever level of α, a more reasonable justification for the inverted U-relationship could be presented as follows: for $\alpha<\alpha^*$, the resource allocation effect would be greater than the profit incentive effect, so the global effect is positive; for $\alpha>\alpha^*$, the resource allocation effect would be smaller than the profit incentive effect, so the global effect is negative.

1.7 A Model of Growth through Creative Destruction

The issue of the relationship between competition and growth is also analyzed in the endogenous growth literature based on vertical innovation, which exploits the original intuition of Schumpeter about creative destruction for developing some analytical models, aimed to show the effects of market structure on the incentives for innovation and then on technological progress.

According to Schumpeter (1942), the basic element of capitalism is the process of creative destruction, meant as the continuous change of the economic structure, due to the invention of new consumption goods and new methods of production, which replace the previous ones and then erode the profits of the existing firms. This idea is formally developed in the article by Aghion and Howitt (1992), who construct a model of endogenous growth presenting the innovation process as in the patent-race literature.

In this framework industrial innovations improve the quality of products, in particular of the intermediate ones employed in the manufacture of final commodities. As a consequence, the new capital goods replace the previous ones, which are less productive and then are subject to a process of obsolescence. The firms which introduce a new type of capital good thanks to a new idea obtain a patent for its production and can exploit it in a monopolistic position; at the same time the producers of the existing intermediate goods completely lose their profits because their products are not demanded anymore. This implies that the monopolistic rents gained by a firm owner of a patent last only until a new product is invented.

Aghion and Howitt consider a simplified economy composed of three sectors: a final sector, an intermediate sector and a research sector. Labour is employed in all the sectors but it is defined as a heterogeneous factor: unskilled labour (*M*) is used only in the final sector; skilled labour (*N*) is occupied both in the intermediate sector and in the research sector; specialized labour (*R*) is employed only in the R&D sector.

In the final sector firms produce an homogeneous consumption good, according to the following per capita production function, assuming that M is fixed :

$$y_t = A_t\, x_t^{\alpha} \qquad \text{where } 0<\alpha<1$$

In particular, A_t is a technological parameter related to the usage of the intermediate good. Given that there are different versions of the intermediate good, such that each one is better than the previous ones, A_t can be expressed as follows:

$$A_t = A_0 \gamma^{t} \qquad (11)$$

where A_0 is the initial value of the productivity parameter while $\gamma>1$ is the factor measuring the growth of productivity as a consequence of the invention of a higher quality product; finally t indicates the time interval starting from the t^{th} invention and ending to the $t+1^{st}$ invention.

From the profit maximization of the producers of final good, the inverse demand function for the intermediate good x_t is given by:

$$p_t = A_t \alpha x_t^{\alpha-1}$$

In the intermediate sector firms use skilled labour for production according to the following production function:

$$x_t = L_N$$

Then, one unit of skilled labour is employed in order to produce one unit of intermediate good. But, since skilled labour is employed not only in the intermediate sector, but also in the research sector (in fact $N = x_t + n_t$, where n_t is the amount of skilled labour used in the research sector), we can also indicate x_t as:

$$x_t = N - n_t \qquad (12)$$

Because of the process of creative destruction, the intermediate sector is monopolized by a firm owner of a patent, which chooses the quantity of x_t by maximizing the following profit function:

$$\pi_{x_t} = \left(\underbrace{A_t \alpha x_t^{\alpha-1}}_{p_t} - w_t^N \right) x_t$$

The wage w_t^N for skilled labour is given by:

$$w_t^N = A_t \alpha^2 x_t^{\alpha-1} \qquad (13)$$

The price of the intermediate product x_t is equal to:

$$p_t = \frac{w_t^N}{\alpha} > w_t^N$$

where the price is determined by charging a mark-up given by $1/\alpha$ over the marginal cost equal to the wage.

Finally, the research sector employs both skilled labour and specialized labour in order to develop new ideas to be exploited in the intermediate sector. But the innovation process is stochastic, since the length of time required for creating a new product depends on the arrival rate of innovation, modelled according to a Poisson distribution. This rate is also determined by the amount of labour employed in R&D activity, in such a way that a greater number of workers in research activity increases the probability of introducing a higher quality product in the market. In fact the arrival rate of innovations is given by:

$$i = \lambda \varphi(n_t, R)$$

where λ is a constant parameter indicating the intensity of discovery probability. By assumption, skilled labour is an essential factor for research sector, that is $\varphi(0, R) = 0$. Then we will consider for simplicity the case of a linear function $\varphi(n_t, R) = \varphi(n_t)$, which holds for $R=0$, taking into account that $\varphi'(n_t) > 0$ and $\varphi''(n_t) \leq 0$.

The research sector is assumed as perfectly competitive: so the firms are willing to conduct R&D activity if the flow of expected revenues from research is equal to the cost of research. Then the firms choose the amount of labour input by maximizing the following profit function:

$$\pi_R = \lambda\varphi(n_t, R)V_{t+1} - w_t^N n_t - w_t^R R$$

This specification of the research objective function implies that R&D activity is not financed by the monopolist in the intermediate sector, but by the outside research firms, which expect to discover a new idea in order to obtain the value V_{t+1} coming from the exploitation of the $t+1^{st}$ innovation. In fact, the incumbent monopolist has no incentives for financing research activity because, even if a new idea was discovered, it would get an expected flow of profits only equal to V_{t+1}-V_t .

Then, assuming $R=0$, the first-order condition from the profit maximization problem for n_t defines the arbitrage condition in R&D:

$$w_t^N = \lambda\varphi'(n_t)V_{t+1} \qquad (14)$$

This equation means that research firms are willing to hire a new skilled worker if the wage equals the marginal productivity coming from an additional research worker.

In general, the value of innovation V_t is the present discounted value of the monopoly profits that an intermediate firm can gain for a time period, until an innovation occurs with a probability defined by the arrival rate of innovation $i = \lambda\varphi(n_t)$. For this reason, the necessary condition for financing research activity can be expressed as follows:

$$V_t r = \pi_{x_t} - V_t \lambda\varphi(n_t)$$

Assuming that financial sector is perfectly efficient, households are willing to buy shares of the intermediate firm if and only if the flow of monopoly profits in the interval t is equal to the income obtainable from investing an asset V_t in riskless securities at an interest rate r. Then, rearranging terms and substituting π_{x_t} , the value of innovation can be written as:

$$V_t = \frac{\pi_{x_t}}{r + \lambda\varphi(n_t)} = \frac{\frac{1-\alpha}{\alpha} w_t^N x_t}{r + \lambda\varphi(n_t)} \qquad (15)$$

Given that equation (13) holds for every t, we can determine the value V_{t+1}:

$$V_{t+1} = \frac{\frac{1-\alpha}{\alpha} w_{t+1}^N x_{t+1}}{r + \lambda\varphi(n_{t+1})} \qquad (16)$$

Then, combining equations (11), (12), (13), (14) and (16), we can obtain the following condition expressing the equality between the marginal cost of research (on the left-hand side) and the marginal benefit of research (on the right-hand side):

$$\frac{(N-n_t)^{\alpha-1}}{\lambda\varphi'(n_t)} = \frac{\gamma \frac{1-\alpha}{\alpha}(N-n_{t+1})^{\alpha}}{r + \lambda\varphi(n_{t+1})} \qquad (17)$$

This equation also shows the relationship between research employment in time t and in time $t+1$, given that all the other terms are constant. In particular, n_t is negatively dependent on n_{t+1} because of two different effects, related to the marginal benefit of research. The first one corresponds to the process of creative destruction and can be explained through the denominator of the right-hand side: if a greater amount of skilled labour is expected to be employed in research in the next period, the arrival rate of innovation increases and then the marginal benefit of research decreases; consequently, research firms are willing to hire a smaller amount of workers. The second effect is a general equilibrium one, due to the increase of wage for skilled labour: in fact, if the demand for skilled labour is expected to rise in the following period, the wage is also expected to augment; then the profits that a monopolist can obtain by exploiting a new discovered idea decrease and research firms demand less workers for the current period.

A stationary equilibrium in the model exists for a given value of n^* such that $n_t = n_{t+1}$, that is the amount of skilled labour in the research sector n remains constant. At this point, given the equation (12), also the quota of skilled labour in the intermediate sector x is constant. Moreover, also the productivity-adjusted wage of skilled labour ω_t , defined as the ratio w_t /A_t , is constant; this implies that, like A_t, also w_t grows at a rate γ for each invention, such that $w_t= w_0 \gamma^t$.

Now, we want to determine the optimal level of n which corresponds to the stationary equilibrium. Then, assuming the linear research technology $\varphi(n_t)=n_t$ and considering that in the stationary equilibrium $n_t=n_{t+1}=n$, $x_t=x_{t+1}=x$ and also $w_{t+1}=\gamma w_t$, we can rewrite the arbitrage condition and the value of $t+1^{st}$ innovation as follows:

$$w_t^N = \lambda V_{t+1} \qquad (18)$$

$$V_{t+1} = \frac{\frac{1-\alpha}{\alpha}\gamma w_t^N x}{r+\lambda n} \qquad (19)$$

Combining equations (18) and (19), we can compute the optimal level of n* in the stationary equilibrium:

$$n^* = \frac{\lambda\gamma\frac{1-\alpha}{\alpha}N - r}{\lambda\left[1+\gamma\frac{1-\alpha}{\alpha}\right]} \qquad (20)$$

In order to understand the effect of competition on research employment and ultimately on growth, we differentiate the expression for n^* with respect to α:

$$\frac{\partial n^*}{\partial \alpha} = -\frac{\gamma\frac{1}{\alpha^2}\left(\lambda L + r\right)}{\lambda\left(1+\gamma\frac{1-\alpha}{\alpha}\right)^2} < 0$$

Given that the sign of the derivative is negative, an increase of degree of competition in the intermediate sector implies a decrease of the amount of skilled labour employed in the research sector. In fact, if α rises, the price of the intermediate good p_t diminishes and then the monopolistic profits of the intermediate firm owner of the patent decrease. This explains why the incentives for investment in R&D sector are smaller in a more competitive market.

By equation (20), the parameter α cannot be greater than a given threshold, in order to assure a positive value of n^*. In fact, for having a positive numerator we must have:

$$\frac{\lambda\gamma\left(\frac{1-\alpha}{\alpha}\right)N}{r} > 1$$

Then, given that $0 \leq r < 1$, a sufficient condition for $n^* > 0$ is given by:

$$\alpha^* = \frac{\lambda\gamma N}{\lambda\gamma N + 1} < 1$$

This means that a positive value of research employment can exist only if the market for intermediate goods is not a perfectly competitive market. Otherwise, there are not enough incentives for financing research activity.

The stationary equilibrium for n^* displays a balanced growth path: then we are interested in determining the growth rate of the economy in the equilibrium. Let define a measure of continuous time τ. In a balanced growth path real output y increases when a new idea is discovered and implemented in the production of an intermediate good: it occurs with a probability defined by the arrival rate $\lambda\varphi(n^*)$ and in this case the productivity parameter of the production function grows by a factor $\gamma>1$. So the log of real output follows a time path characterized as a random walk with a constant positive drift, where the size of each innovation step is given by the constant $\ln \gamma$ and the interval between each innovation is exponentially distributed according to the parameter $\lambda\varphi(n^*)$. In particular:

$$\ln y(\tau+1) = \ln y(\tau) + \lambda\varphi(n^*)\ln\gamma + e(\tau)$$

Since $e(\tau)$ is an iid variable, $E(e(\tau)) = 0$. Then the average growth rate of the economy is equal to:

$$g_y \equiv \ln y(\tau+1) - \ln y(\tau) = \lambda\varphi(n^*)\ln\gamma$$

In conclusion, the average growth rate of the economy g_y is an increasing function of the arrival rate of innovation $\lambda\varphi(n^*)$ and then of the optimal amount of skilled labour in research n^*, given that $\varphi'(n^*) > 0$. As a consequence, the observations proposed for illustrating the negative relationship between n^* and α hold for the relationship between g_y and α. In fact, the average growth rate g_y is a decreasing function of the degree of competition α or, reversely, an increasing function of the Lerner index of market power $1-\alpha$. Since the engine of endogenous growth is research activity, an increase of competition which reduces the monopoly rents gained by a successful innovator diminish the incentives for R&D activity and then reduces the average growth rate of the economy.

1.8 Corporate Governance, Competition Policy and Industrial Policy

Although the Schumpeterian model of endogenous growth predicts a negative relationship between competition and growth, some empirical works developed in the following years, such as Geroski (1995), Nickell (1996) and Blundell, Griffith and Van Reenen (1999), have observed a positive correlation between product market competition and innovative activity. For this reason some new models of endogenous growth have been successively proposed in order to reconcile the theoretical predictions with the empirical evidence. The main extensions of the Schumpeterian growth model, elaborated in order to tackle this issue, have been developed in several directions: classifying firms according to their objectives, such to distinguish profit-maximizing firms and managerial firms; introducing the idea of a step-by-step innovation; differentiating industries and countries on the basis of their distance to the technological frontier. Each of these aspects will be examined in the following paragraphs, starting from the present one.

In general, the endogenous growth framework presented in the previous sections assumes a modelling of the decision-making process of each firm, which is based on the idea of a profit-maximizing firm. But this assumption about the behaviour of firms is not consistent with the observation of real world, where many firms managerially conducted follow different objectives in production and innovation decisions. In particular, this issue regards large firms, which are owned by many shareholders and are administered by managers usually different from owners. Moreover – what is more important - large firms are more engaged in research activity than small firms: empirical evidence suggests that most R&D expenditure is financed by firms of large size, since they have more financial resources, and that consequently the majority of new patented ideas is discovered by these firms [11].

For this reason, it is important to examine whether the conclusions of the basic Schumpeterian model about competition and growth are destined to be reversed in a different

[11] To give an idea of this observation, Aghion and Griffith (2005), showing a pattern seen across a large number of datasets, consider the number of patents taken out at the U.S. Patent Office by firms listed at the London Stock Exchange and distribute firms according to their size, measured by the amount of sales. Then they observe that the smallest firms, located in the first decile, account only for 2% of the number of patents, while the largest firms in the tenth decile account for almost 50% of the number of patents.

framework, where firms are not profit-maximizers but are guided by a conservative management, interested in preserving private benefits from control and in minimizing effort at the same time. The relevance of the principal-agent relationship in innovation decisions of managerial firms is presented in the article by Aghion, Dewatripont and Rey (1997), where the effect of competition on innovation crucially depends on the type of firm: it is negative for profit-maximizing firms, but it is positive for managerial firms.

A first important assumption is that in the final sector firms produce a homogeneous good according to the following Dixit-Stiglitz production function:

$$y = \int_0^N A_i x_i^{\alpha} di \qquad 0<\alpha<1$$

This formulation implies that each firm uses at the same time the intermediate goods supplied by N different firms, where each intermediate variety *i* is monopolistically produced by a specific firm and has a productivity level measured by the parameter A_i . Then, more varieties of intermediate product can coexist, even if they correspond to a different technological level. From the profit-maximization problem of final firms the price for the intermediate good *i* is given by:

$$p(x_i) = A_i \alpha x_i^{\alpha-1}$$

Intermediate firms have to take two types of decision. Firstly, given the evolution of technology, they have to decide when to buy a new technology, that is the most recent one: this allows to improve the efficiency of the production processes, but it also implies some adjustment costs in terms of reorganization of the production structure. Secondly, given the available technology in each moment, they have to determine the level of production. In order to examine this two-stage decision process let solve the model backward.

The production decisions are taken by intermediate firms according to the usual paradigm of profit maximization. Then, assuming a production function with a one-to-one technology $x_{t,\tau} = l_{t,\tau}$, where $x_{t,\tau}$ is an intermediate good of vintage τ produced in time *t*, an intermediate firm determines the amount of output by maximizing the following profit function:

$$\pi_{t,\tau} = \underbrace{A_\tau \alpha x_{t,\tau}^{\alpha-1}}_{p_{t,\tau}} \cdot x_{t,\tau} - w_t x_{t,\tau}$$

Defining the productivity-adjusted wage ω as $\omega = w_t / A_\tau$ and considering that in a steady state both the leading-edge technology A_τ and the wage rate w_t grow at the same rate *g*, the output flow of the intermediate firm is:

$$x_{t,\tau} = \left(\frac{w_t}{\alpha^2 A_\tau} \right)^{\frac{1}{\alpha-1}} = \left(\frac{\omega}{\alpha^2} \right)^{\frac{1}{\alpha-1}} e^{\frac{g(t-\tau)}{\alpha-1}}$$

where $u \equiv t - \tau$ is the age of the firm's technology. Then the productivity-adjusted profit flow of an intermediate leading-edge firm (for which $t=\tau$) is:

$$\pi = \tilde{\pi}(\omega) = \frac{\pi_{t,\tau}}{A_\tau} = \frac{1-\alpha}{\alpha}\,\omega\left(\frac{\omega}{\alpha^2}\right)^{\frac{1}{\alpha-1}}$$

In order to understand the decisions of intermediate firms about technological adoption, we must take into account that they have to face a fixed operating cost (also in terms of labour), defined as $k_{t,\tau}$, such that $k_{t,\tau} = w_t k e^{\rho(t-\tau)}$. So the net profit flow of an intermediate producer can be rewritten as:

$$\Pi_{t,\tau} = \left\{\pi\, e^{-\frac{g(t-\tau)}{1-\alpha}} - \omega k e^{\rho(t-\tau)}\right\} e^{gt} = \psi(\omega, g, u)e^{gt}$$

where $\psi(\omega, g, u)>0$ for $u=0$ and $\psi(\omega, g, u)<0$ for u large, and also $\psi_u<0$.

Moreover, an intermediate firm which is interested in using a new technology has to bear a sunk cost f (in labour units) in order to implement the leading-edge technology, then the adoption cost is $f_\tau = f w_\tau = f\omega e^{g\tau}$. In a steady state, where each intermediate firm takes the leading-edge technology every T units of time and the age of the firm's technology is uniformly distributed on the interval $[0, T]$, the aggregate flow of new technological adoptions per unit of time is $1/T$ while the aggregate flow of research labour is $n = f/T$. Finally, given that technological adoption implies an increase of growth rate by $\ln \gamma$ per unit of innovation, the steady-state growth rate is:

$$g = \frac{\dot{A}}{A} = \frac{\ln\gamma}{T}$$

So, assuming that the size of the technological step is fixed, the innovation rate, as well as the growth rate of the economy, depends on the length of time interval T for the adoption of a new technology [12]. The timing of innovation is determined by the intermediate firms and this decision is taken by managers depending on their objective function.

Then we consider the case of non profit-maximizing firms, which are directed by managers having the following utility function:

[12] Aghion and Griffith (2005) propose a simplified version of the endogenous growth model with principal-agent problem, where the intermediate producers have to choose not the frequency of innovations, but the size of the productivity improvements. Anyway, the result is the same which is obtained in the discussed paper: for profit-maximizing firms, an increase of product market competition implies a reduction of the optimal size of innovation, while, for non profit-maximizing firms, it causes an increase of the size of innovation, since a rise of competition reduces the free-cash available for managers and then acts as an incentive mechanism to invest more in technological improvements. Also debt financing is an instrument which reduces managerial slack and induces managers to react more quickly to exogenous variations of market competition.

$$U_0 = \int_0^{\infty} B_t e^{-\delta t} dt - \sum_{j \geq 1} C e^{-\delta \left(T_1 + \ldots + T_j\right)}$$

where B_t is the private benefit that managers gain from controlling a firm in time t, such that $B>0$ if the firm has survived up to t and $B=0$ otherwise; C is the private cost that managers have to face for adopting a new technology; δ is the subjective discount rate of managers. This utility function is the objective function that managers maximize in order to determine the optimal time for technological adoption. This means that, according to a lexicographic preference ordering, managers are interested in keeping a positive net financial wealth, just enough for covering the adoption cost, such that they can exploit the private benefit of control. At the same time, once satisfied this objective, they want to delay the next innovation as much as possible, in order to avoid the private cost related to technological adoption.

But, at a given point, managers have to innovate because otherwise profits would become negative and then they would lose the firm's control. In fact the function $\psi(\omega, g, u)$ has an inverted U shaped trend with respect to T, so it is increasing for small values of T, decreasing and even negative for large values of T. This implies that firms have to adopt a new technology for avoiding insolvency and then bankruptcy. As a consequence, the maximum time interval $\tilde{T}$ for technological adoption is defined in such a way that the profits accumulated until the innovation (on the RHS) are equal to the adoption cost at that date (on the LHS), as it appears from the following equation:

$$\omega f e^{-(r-g)T} = \int_0^T \underbrace{\left[\tilde{\pi}(\omega) e^{-\frac{gu}{1-\alpha}} - \omega k e^{\rho u} \right]}_{\psi(\omega, g, u)} e^{-(r-g)u} du$$

From this equation, it is possible to intuitively explain the reason why more competition may cause a reduction of the optimal time interval $\tilde{T}$, and then a sooner adoption of a new technology. In fact, an increase of the degree of competition, lowering the flow of profits, reduces the amount of financial wealth of the intermediate firm and then diminishes the period of time when conservative managers can keep the same technology without incurring the firm's insolvency and then bankruptcy.

In order to better understand this effect of a tougher competition, we have to identify an appropriate measure of competition whose variation produces significant changes on the flow of profits of intermediate firms. Given that the production of final goods requires the usage of various intermediate products, whose substitutability is indicated by the parameter α, a change of this parameter can be interpreted as a variation of the degree of product market competition.

For this purpose, the equilibrium condition for the technological adoption policy must be combined with the labour market clearing condition in the steady state, which is defined as follows:

$$\frac{e^{\rho T}-1}{\rho T}\cdot k+\frac{f}{T}+x_{t,\tau}\cdot\left[\frac{1-e^{-\frac{\ln\gamma}{1-\alpha}}}{\frac{\ln\gamma}{1-\alpha}}\right]=L$$

where, on the LHS, the first term is the aggregate operating cost, the second term is the aggregate demand for research labour and the third one is the aggregate demand for manufacturing labour. Using the labour market clearing condition for obtaining the amount of leading-edge demand $x_{t,\tau}$ and substituting it in the equilibrium optimal adoption policy, the reduced-form arbitrage equation is:

$$f e^{-rT+\ln\gamma}=\int_0^T\left\{\frac{1-\alpha}{\alpha}\left[\frac{\frac{\ln\gamma}{1-\alpha}}{1-e^{-\frac{\ln\gamma}{1-\alpha}}}\right]\left[L-\frac{f}{T}-\frac{e^{\rho T}-1}{\rho T}\cdot k\right]e^{-\frac{\ln\gamma\, u}{T(1-\alpha)}}-ke^{\rho u}\right\}e^{-\left(r-\frac{\ln\gamma}{T}\right)u}du$$

As it can be verified from a comparative statics analysis, an increase of the degree of competition, measured by the degree of substitutability α between intermediate products, determines a decrease of the net profit flow, as indicated by the expression in curly brackets and corresponding to the function $\psi(\omega, g, u)$. This reduction of the net financial wealth for intermediate firms works as an incentive scheme for conservative managers in order to anticipate the adoption of the most recent technology. Then, after an increase of α and a decrease of the value $\psi(\omega, g, u)$, the optimal time interval for technological adoption by each intermediate firm is $\tilde{T}_1$, such that $\tilde{T}_1<\tilde{T}_0$, where $\tilde{T}_0$ is the optimal adoption policy chosen before the variation of the degree of product market competition. Finally, substituting the new optimal adoption policy $\tilde{T}_1$ in the growth rate, we obtain:

$$g_1=\frac{\ln\gamma}{\tilde{T}_1}>\frac{\ln\gamma}{\tilde{T}_0}=g_0$$

This means that in a context with non-profit maximizing firms, guided by a conservative management, an increase of competition produces an increase of the innovation rate as well as of the growth rate of the economy. On the contrary, an industrial policy aimed to subsidize the firms' investments in innovation through a reduction of the sunk cost for technological adoption *f* generates an opposite effect, given that it allows a conservative management of non-profit maximizing firms to further delay the time of adoption of a new technology.

This model with principal-agent problem shows how the introduction of a different assumption about the behaviour of firms in innovation decisions may radically change the conclusions about the effect of competition on growth. In this case, more competition plays an innovation-enhancing role especially for process innovations in intermediate firms, because the acquisition of a new technology allows to produce more efficiently and then to avoid a fall of the net profit flow, otherwise dangerous for the financial situation of each firm [13].

On the contrary, no effect is observed about product innovation, since the number of intermediate goods *N* is fixed. In fact, in this model, a further product differentiation would mean an increase of the *N* varieties of intermediate goods and then would imply an exogenous rise of the degree of competition. If this occurred, the increased competition in the intermediate sector would induce more innovation for the producers of capital goods, but always in terms of process innovations.

The reasonable conclusion here presented about the innovation choices of managerial firms however departs from a quite contradictory presentation of the internal decision-making process: in fact production decisions (how many units of intermediate good to produce) are taken according to the solution of a profit-maximization problem, while innovation decisions (when to buy the most recent technology) are taken according to the solution of a utility-maximization problem of the managers' objective function. The idea to articulate the decision criteria of a managerial firm in a different way, depending on the type of choice that managers have to adopt, may denote a lack of internal coherence in the construction of the model. Perhaps more consistent conclusions about the behaviour of managerial firms might be reached if both production and innovation decisions were modelled according to a univocal paradigm corresponding to managerial incentives.

1.9 The Inverted-U Relationship between Competition and Innovation

In this section we will consider another important evolution of the basic Schumpeterian model, that is the idea of a step-by-step innovation, as developed in the articles by Aghion, Harris and Vickers (1997) and by Aghion, Harris, Howitt and Vickers (2001), and presented with the support of the empirical evidence in the paper by Aghion, Bloom, Blundell, Griffith and Howitt (2005). These models modify a basic assumption of the Schumpeterian model introducing a more gradualist idea of the innovation process: the firms with an initially lower technology cannot immediately acquire a technological leadership through innovation, because they firstly have to

[13] A similar conclusion about the preference of managerial firms for process innovation is obtained, in a different theoretical framework, in the paper by Cellini and Lambertini (2008), where the behaviour of managerial firms regarding investment in product and process innovations is analyzed through a differential game approach. The presented result is that firms managerially conducted tend to overinvest in process innovations, if compared with profit-maximizing firms. In general, managers are interested in increasing the level of production because of the type of incentives. Assuming that operative costs depend on the effort in process innovations, a manager wants to reduce marginal cost, such that it is possible to further rise the level of production.

reach the same level of the firms with the leading-edge technology and only after they can compete in order to achieve the leadership in the industry. This different assumption is sufficient for producing new theoretical results because it changes the incentives which induce the investments of firms in research.

In the models of step-by-step innovation, what really matters for profitability of firms is not the technological level in absolute terms, but the technological advantage of a firm compared with the position of the other firms. From this point of view, the markets can be in two different states: if the existing firms have the same technological level, and then they present the same unit costs, this is a neck-and-neck industry; if a firm has a better technology than the other firms, and then it bears lower production costs, this is an unlevelled industry. The difference is important also for classifying the effects determined by an increase of product market competition.

In general, a rise of competition may produce both an escape-competition effect and a Schumpeterian effect, where the prevailing one is determined according to the level of competition in the market and the industry characteristics.

In particular, by the escape-competition effect, more competition can generate strong incentives for innovation because firms, in order to succeed in a really competitive environment, have to introduce significant improvements in the quality of the products and in the efficiency of the production processes. So firms are induced to invest in R&D and to promote innovation in order to keep or improve their market shares. For a given industry, this effect is dominant for low levels of competition. But, across the sectors, it is more relevant in the industries with close technological rivals, or neck-and-neck industries: there more competition raises the incremental profits that a firm earns by innovating, because of the difference between pre-innovation and post-innovation rents.

On the contrary, by the Schumpeterian effect, an increase of product market competition, as it reduces the monopoly rents gained by successful innovators, can also lower the incentives for the investments of firms in R&D, and then compromise the future perspectives for technological progress. For a specific industry, this effect prevails for high levels of competition. But, among various sectors, it is more significant in the unlevelled industries, where investments in research are promoted by technological followers only if they expect to obtain very high profits from the exploitation of the acquired market power.

Given the intuition, let examine how Aghion, Harris, Howitt and Vickers (2001) and Aghion, Bloom, Blundell, Griffith and Howitt (2005) analytically constructed the model with step-by-step innovation in order to reach the conclusion of an inverted-U relationship between competition and innovation. The theoretical framework includes both the consumption side and the production side of the economy.

In the consumption side of the economy a representative household has the following utility function:

$$u = \int_0^1 \ln x_j \, dj$$

where x_j is an aggregate of goods x_{Aj} and x_{Bj}, which are produced by two duopolist firms operating in industry j. This also explains the type of competition which is considered in the model, that is an intra-industry competition between duopolists, producers of two goods highly substitutable each other. In particular, we will consider the case where the subutility function x_j assumes the following form:

$$x_j = \left(x_{Aj}^{\alpha_j} + x_{Bj}^{\alpha_j}\right)^{\frac{1}{\alpha_j}}$$

The consumer chooses the amount of x_{Aj} and x_{Bj} by maximizing the subutility function subject to the following budget constraint:

$$p_{Aj} x_{Aj} + p_{Bj} x_{Bj} = 1$$

where the amount of expenditure for the aggregate x_j, normalized to 1, is equal for each x_j .

In the production side, each firm uses only labour as a production factor. Then the output flow generated by one unit of labour currently employed by a firm is:

$$A_i = \gamma^{k_i}$$

where k_i is the technological level of a firm i in the industry j while γ is the size of a leading-edge innovation such that $\gamma>1$. Then, the cost function for a firm having a technology k_i is given by:

$$c(x) = x\gamma^{-k_i}$$

If a firm invests in research in order to reach a higher technological level, the cost of research in units of labour is equal to:

$$\psi(n) = \frac{\beta n^2}{2}$$

where n is the innovation rate, that is the probability of moving one technological step ahead, measured by a Poisson hazard rate. This function holds both for the leader and for the follower, but also for neck-and-neck firms. In particular, if m is the technological gap between the leader and the follower, n_m (n_{-m}) is the innovation rate for a firm being m steps ahead (behind). Moreover, given that a follower firm can move one step ahead simply through imitation with a hazard rate h, $\psi(n)$ also measures the research cost for a firm which can improve its technology by one step with a probability $h+n$.

Assuming that firms are owned by households, an equilibrium condition in capital markets is that the annuity value rV (where V is the present discounted value of a firm) must be equal to the effective profit flow of the same firm, measured after considering R&D cost, as well as expected capital gains or losses. Then we define this equilibrium condition by writing the following Bellman equations for a leader, for a follower and for neck-and-neck firms.

Leader: $$rV_m = \pi_m + n_m\left(V_{m+1} - V_m\right) + \left(n_{-m} + h\right)\left(V_{m-1} - V_m\right) - \frac{w\beta\left(n_m\right)^2}{2}$$

Follower: $$rV_{-m} = \pi_{-m} + n_m\left(V_{-m-1} - V_{-m}\right) + \left(n_{-m} + h\right)\left(V_{-m+1} - V_{-m}\right) - \frac{w\beta\left(n_{-m}\right)^2}{2}$$

Neck and neck: $$rV_0 = \pi_0 + n_0\left(V_1 - V_0\right) + n_0\left(V_{-1} - V_0\right) - \frac{w\beta\left(n_0\right)^2}{2}$$

where π_m (π_{-m}) is the profit flow of a firm with a *m* technological advantage (disadvantage), while *w* is a fixed wage. An expected capital gain can arise when the firm moves one step ahead (for example from V_m to V_{m+1} for a leader or from V_{-m} to V_{-m+1} for a follower), while an expected capital loss occurs when the other firm improves its technology by one step (for example a leader has a loss when the follower moves one step ahead from V_{m-1} to V_m). Each firm maximizes the Bellman equation in order to choose the appropriate R&D intensity. In fact, the chosen rate of innovation is determinant for explaining the research incentives of each firm.

In order to illustrate the working of the model, let consider the case where the maximum technological gap between leader and follower is given by $m=1$ [14], as in the paradigmatic hypothesis presented in the original paper by Aghion, Harris and Vickers (1997). In the one-step case, if the industry is unlevelled, only the follower has incentives to innovate, in order to catch up with the leading-edge technology, while the leader is not willing to undertake any innovation, because the follower would imitate its previous technology and then the gap would always be equal to 1. Otherwise, if the industry is a neck-and-neck one, each firm is interested in innovating in order to obtain the technological leadership in the industry. Given these observations, and assuming that $w=\beta=1$ and that $h=0$, the Bellman equations can be written as follows:

Leader: $$rV_1 = \pi_1 + n_{-1}\left(V_0 - V_{-1}\right)$$

Follower: $$rV_{-1} = \pi_{-1} + n_{-1}\left(V_0 - V_{-1}\right) - \frac{\left(n_{-1}\right)^2}{2}$$

Neck-and-neck: $$rV_0 = \pi_0 + n_0\left(V_1 - V_0\right) + n_0\left(V_{-1} - V_0\right) + \frac{\left(n_0\right)^2}{2}$$

The first-order conditions for the follower and for the neck-and-neck firms are the following:

$$n_{-1} = V_0 - V_{-1}$$

$$n_0 = V_1 - V_0$$

[14] The other cases for a large *m* can admit a solution of the general model, but it may be difficult to find closed form solutions, so in these cases the best thing to do is just a numerical solution.

Substituting the FOC in the system of Bellman equations and solving the system for n_0 and n_{-1}, we obtain the following results:

$$n_0 = -r + \sqrt{r^2 + 2(\pi_1 - \pi_0)}$$

$$n_{-1} = -(r + n_0) + \sqrt{r^2 + n_0^2 + 2(\pi_1 - \pi_{-1})}$$

In order to study the effect of an increase of competition on innovation decisions of firms, we use as indicator of competition the value of π_0 , that is the profit flow of neck-and-neck firms. In fact, given that they have the same technology and then the same production costs, the duopolists engage a Bertrand competition, where the degree of the competition is denoted by the reduction of price p_j (in fact $p_j = p_{Aj} = p_{Bj}$ must hold in equilibrium) and then by the decrease of profits π_0. For instance, a smaller amount of π_0 means a lower level of collusion between oligopolist firms, and then a higher degree of competition in the market [15]. The different effects of a rise of competition (and then of a decrease of π_0) on innovation can be analyzed by differentiating the innovation rates n_0 and n_{-1} with respect to π_0). In fact:

$$\frac{\partial n_0}{\partial \pi_0} = -\frac{1}{\sqrt{r^2 + 2(\pi_1 - \pi_0)}} < 0$$

$$\frac{\partial n_{-1}}{\partial \pi_0} = \frac{\partial n_0}{\partial \pi_0}\left(-1 + \frac{n_0}{\sqrt{r^2 + n_0^2 + 2(\pi_1 - \pi_{-1})}}\right) > 0$$

For a neck-and-neck firm, a decrease of π_0 (because of a stronger competition) implies an increase of R&D intensity: so the firm is induced to invest more in research since post-innovation rents (π_1) are sensibly higher than pre-innovation rents (π_0). In fact, thanks to innovation, a neck-and-neck firm can obtain the technological leadership (escape competition effect). On the contrary, for a follower firm in an unlevelled industry, a decrease of π_0 causes a reduction of R&D intensity: given that in the one-step case a move ahead means the acquisition of the leading-edge technology, and then after innovation the duopolists are neck-and-neck competitors, a diminution of π_0 implies a decrease of post-innovation rents. As a consequence, for a higher degree of competition, the

[15] This definition of competition can be considered appropriate for an oligopolist market, where firms are in the same (or at most in a similar) technological position. In these cases, the interaction between firms through the creation of eventual price cartels is the key element to be considered for evaluating the degree of competition in that market. But if the technological gap is so strong that the followers cannot contrast the leadership of the incumbent (then for a large m), since the market is clearly characterized by a dominant position of a firm, the best way to analyze market structure in that industry is to use a measure of competition which is inversely related to the market power of the dominant undertaking, as already seen in the previous models. For this reason, Aghion, Bloom, Blundell, Griffith and Howitt (2002) continue to use, as alternative indicator of competition, especially for the empirical analysis, the inverse of the Lerner index, that is the parameter α.

difference between post-innovation rents (π_0) and pre-innovation rents (π_{-1}) is smaller, so the incentives for innovation are weaker (Schumpeterian effect).

In order to analyze the combined result of the two effects for an industry, we are interested in determining the average innovation rate in the steady-state. Let define μ_1 (μ_0) as the steady-state probability of being an unlevelled (neck-and-neck) industry. Since these are the only possible states for an industry, $\mu_0 + \mu_1 = 1$. Then the steady-state equilibrium in this Markov process is given by:

$$2\mu_0 n_0 = \mu_1 n_{-1}$$

This means that in the steady state the probability that a neck-and-neck industry becomes an unlevelled one (because one of the duopolists innovates) must be equal to the probability that an unlevelled sector becomes a neck-and-neck one (because the follower innovates). So the average innovation rate is equal to:

$$I = \mu_0 2n_0 + \mu_1 n_{-1} = 2\mu_1 n_{-1} = \frac{4n_0 n_{-1}}{2n_0 + n_{-1}} \qquad (21)$$

In order to understand the effect of competition on innovation, we derive the average innovation rate I with respect to π_0 and we obtain:

$$\frac{\partial I}{\partial \pi_0} = \frac{\overbrace{4\frac{\partial n_0}{\partial \pi_0} n_{-1}}^{<0} \overbrace{+4n_0 \frac{\partial n_{-1}}{\partial \pi_0}}^{>0} \overbrace{-8n_0 n_{-1} \frac{\partial n_0}{\partial \pi_0}}^{>0} \overbrace{-4n_0 n_{-1} \frac{\partial n_{-1}}{\partial \pi_0}}^{<0}}{\left(2n_0 + n_{-1}\right)^2}$$

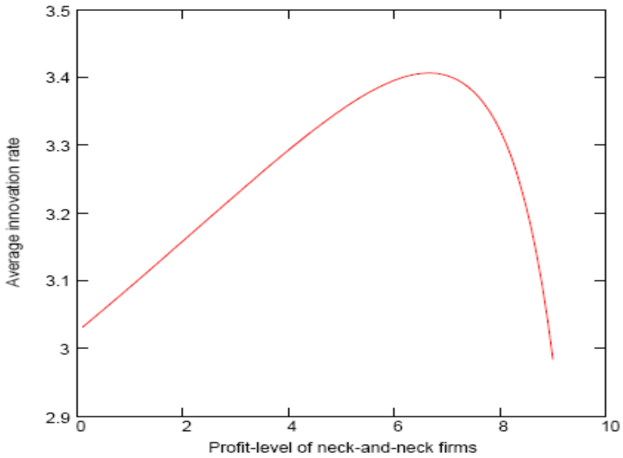
In this comparative statics analysis, it is not possible to determine the sign of the derivative, then the effect of competition on innovation is ambiguous. For this reason it is necessary to use a graphical representation of the average innovation rate I as a function of the profit level for neck-and-neck firms π_0, that is $I = f(\pi_0)$, substituting the values of n_o and n_{-1} in the equation (21). Then:

$$I = \frac{4\left[-r + \sqrt{r^2 + 2(\pi_1 - \pi_0)}\right] \cdot \left\{-\sqrt{r^2 + 2(\pi_1 - \pi_0)} + \sqrt{3r^2 - 2r\sqrt{r^2 + 2(\pi_1 - \pi_0)} + 4\pi_1 - 2(\pi_0 + \pi_{-1})}\right\}}{2\left[-r + \sqrt{r^2 + 2(\pi_1 - \pi_0)}\right] - \sqrt{r^2 + 2(\pi_1 - \pi_0)} + \sqrt{3r^2 - 2r\sqrt{r^2 + 2(\pi_1 - \pi_0)} + 4\pi_1 - 2(\pi_0 + \pi_{-1})}}$$

Firstly we have to assign some predetermined values to the other variables: $r=0.04$, $\pi_1=10$, $\pi_{-1}=0$. So, given that the profit of a neck-and-neck firm cannot be higher than the profit of a technological leader and lower than the profit of a technological follower, that is $0 < \pi_0 < \pi_1$, we consider the values of the function $I = f(\pi_0)$ for a domain $\pi_0 \in (0,10)$.

As already mentioned, π_0 is a measure of collusion between the duopolists: in fact, for $\pi_0 \to 0^+$ the collusion is absent, so there is a very high degree of competition; while, for $\pi_0 \to 10^-$, the collusion is really strong, so there is not any competition at all. For this reason, if we are interested in the effect of competition on innovation, we have to observe the trend of the function from the right to the left.

For a low degree of competition (and then for a high level of collusion), when π_0 decreases the average innovation rate is increasing, because the escape-competition effect prevails: indeed, the firms operating in neck-and-neck industries are induced to invest in research activity, in order to



Source: Aghion P., Bloom N., Blundell R., Griffith R. and Howitt P. (2002), *Competition and Innovation: an Inverted U Relationship*, NBER Working Paper 9269

improve their profits thanks to the difference between pre-innovation rents (π_0) and post-innovation rents (π_1). For low levels of competition, the proportion of neck-and-neck industries (or with close technological rivals) is higher, and in fact these are the industries where the escape-competition effect is more relevant.

Instead, for a high degree of competition (and then for a low level of collusion), when π_0 decreases the average innovation rate is decreasing, because the Schumpeterian effect dominates: indeed, the technological followers working in unlevelled industries are discouraged from promoting R&D activity. For high levels of competition, the fraction of unlevelled industries is greater, and in fact these are the industries where the Schumpeterian effect is more significant.

So, for a given industry, the relationship between competition and innovation can be clearly described as an inverted-U relation. But, if we are interested in describing such relationship at an aggregate level, we also have to consider the technological structure of each industry. In other words, we have to know how many industries in the economy are neck-and-neck and how many are unlevelled: in fact, the overall effect of competition on innovation for the entire economy must be represented as a weighted average of the effects registered for each single industry, on the basis of the technological features of each sector.

Moreover, the fractions of industries belonging to one of the two states are not predetermined but may change over time. In fact, competition can also affect the composition of the economic structure for different industries. In particular, since a stronger competition favours technological innovation comparatively more in the neck-and-neck industries than in the unlevelled industries, then a rise of product market competition may induce the change of many sectors from neck-and-neck industries to unlevelled ones, but not also the modification from unlevelled industries to neck-and-neck ones. Then, at the end, the fraction of industries with neck-and-neck firms is decreasing while the proportion of unlevelled industries is increasing: as a consequence, the new composition of industries in the economy implies, for the effect of competition on innovation at an aggregate level, that the Schumpeterian effect will be more relevant than the escape-competition effect. For this reason, especially for high levels of competition, the composition effect reinforces the Schumpeterian effect, in determining a negative relation between competition and innovation.

1.10 Distance to Frontier, Selection and Growth

At the current state of research, the last important contribution on the topic has been offered in the literature on world technology frontier and economic growth, which has analyzed how product market competition and in particular entry deregulation can produce different effects on long-run growth, depending on the position of the country relative to the technological frontier. In particular, a seminal paper in this field is the article by ***Acemoglu, Aghion and Zilibotti (2006)***, which proposes a distinction between an investment policy, based on accumulation of capital and on imitation of existing technologies, and an innovation policy, based on technological progress at the world frontier and on selection of high-skill entrepreneurs. The main argument of the model is that a growth-maximizing strategy requires the adoption of an investment-based policy for the economies far from the technological frontier and of an innovation-based policy for the countries close to the frontier. In fact, as long as a country presents a low level of technology, it can exploit imitation in order to promote technological improvement; but, as soon as it attains the technological frontier, it cannot take advantage of imitation but it has to support innovation, by investing in research and development, in order to elaborate new ideas and invent new products or improve the quality of the existing ones. In this perspective, the paper also analyzes the issues of political economy related to the transition from one to another growth policy, in order to study how to induce an optimal convergence path towards the world technology frontier.

The model considers an economy with overlapping generations of risk-neutral agents, where each generation consists of two types of individuals: capitalists, endowed with property rights on firms, and workers, gifted with labour skills. The workers can be employed in production activities, and in this case they have the same productivity, or can act as entrepreneurs, but in this situation they show different skills: more precisely, they are high-skill with a probability λ, and low-skill with a probability $1-\lambda$.

The economy is composed of a final sector and an intermediate one. In the final sector a unique final good is produced, using labour and a continuum one of intermediate goods, according to the following production function:

$$y_t = \frac{1}{\alpha} N_t^{1-\alpha} \left(\int_0^1 \left(A_t(v)\right)^{1-\alpha} x_t(v)^{\alpha} \, dv \right) \quad (22)$$

where N_t is the number of workers employed in production activities, $A_t(v)$ is the productivity in the intermediate sector v and $x_t(v)$ is the amount of intermediate good v used in the production of final good.

In each intermediate sector v, final product is used as an input for the production of intermediate goods. Only one firm can exploit the most advanced technology $A_t(v)$ and then it can transform one unit of final product in one unit of intermediate good. The other firms can imitate this technology but they face higher production costs, so they need χ units of final good in order to produce one unit of intermediate good, where $\chi>1$. The parameter χ captures the degree of product market regulation of the economy: the higher is the regulation of entry, the higher are the costs for the follower firms. Then the leading firm sets a price equal to the marginal cost for the follower firms, that is χ. From the solution of the profit maximization problem for a firm producer of final goods, given that $p_t(v)=\chi$, we can derive the equilibrium demand for the intermediate product and then we can write the equilibrium profit for a leading firm in the intermediate sector v:

$$\pi_t(v) = \left[p_t(v) - 1\right] x_t = \delta \, A_t(v) N_t \quad (23)$$

where δ is a measure of the extent of monopoly power by the leading firm and it is equal to:

$$\delta = (\chi - 1)\chi^{-(1/1-\alpha)} \quad (24)$$

Assuming that $\chi \leq 1/\alpha$, δ is increasing in χ, i.e. a higher price implies a higher monopoly power and a lower degree of competition in the market.

Each leading firm has to be managed by an entrepreneur, whose skills are not known at the beginning but are revealed after he works for the first period. Entrepreneurs are involved in two different tasks: adoption of the existing technologies, which doesn't require any particular skill; innovation, which needs high level of skills. After experiencing the entrepreneur's level of skills, the capitalist can decide whether to keep the same manager or whether to hire another entrepreneur. Then, if the entrepreneur has demonstrated high skills, he is retained in order to run large projects. But if the existing manager has displayed low skills, the firm can be interested in taking a young entrepreneur in the second period: in this case, the capitalist could benefit from the eventually higher abilities of the new manager, but he also has to renounce to the investment of the retained earnings of the previous manager. The continuation decision with low-skill entrepreneurs R_t is taken according to the following criteria:

$$R_t=0 \quad \text{if} \quad E_t V_t^*(e=Y) \geq V_t^*(e=O, z=L) \qquad (25.a)$$

$$R_t=1 \quad \text{if} \quad E_t V_t^*(e=Y) < V_t^*(e=O, z=L) \qquad (25.b)$$

That is, the manager is fired if the expected value of the firm run by a young manager is equal or greater than the value of a firm run by an old entrepreneur with low skills (25.a); otherwise the manager is maintained (25.b).

The principal-agent relationship between the capitalist and the entrepreneur also involves a typical moral hazard problem, due to the imperfect monitoring of the manager's activity by the capitalist. In fact, it is assumed that the entrepreneur is able to divert a fraction μ of the returns for his own use without never being prosecuted. Then, in order to solve this problem of asymmetric information for the capitalist and to fulfil the incentive compatibility constraint for the entrepreneur, profits must be always shared between the capitalist and the entrepreneur, in such a way that the former takes a share 1-μ and the latter obtains a share μ.

Another decision of the capitalist, which is strictly related to the managerial organization of the firm, regards the size of the projects and then the financing of their execution. The size of the project $s_t(v)$ can assume different values, being equal to $s_t(v)=\sigma<1$ for small projects and to $s_t(v)=1$ for large projects. The projects can be financed in two different ways: either by borrowing from financial intermediaries collecting funds from the consumers, or by investing the retained earnings of the old entrepreneur. Then, if the capitalist chooses to replace the entrepreneur, he has to entirely finance the cost of the project, although he knows that in the future he won't be able to get all the profits from his investment, simply because he receives just a share 1- μ of the profits. This implies that, in the case corresponding to $R_t=1$ (termination of the contract with an old low-skill entrepreneur), even if a large profitable project is available, the capitalist could not be willing to make such investment and then he could decide to implement a small project: hence, underinvestment can occur in equilibrium. Of course, the underinvestment problem, due to an appropriability effect, can always affect the decisions of the capitalist: but it takes more relevance when firms choose young entrepreneurs without previous wealth. For this reason, the capitalist interested in implementing a large project could be induced to keep the same entrepreneur just in order to obtain the investment of his retained earnings for the project. In this way, the retained earnings can mitigate the underinvestment problem but can also be exploited by old entrepreneurs as a means for shielding themselves from the competition with young managers. So, the investment of retained earnings in part solves the credit issue for large projects, but also reduces selection for managers.

The productivity of each intermediate good v can be expressed as:

$$A_t(v) = s_t(v)\left[\eta \bar{A}_{t-1} + \gamma_t(v) A_{t-1}\right] \quad (26)$$

where $s_t(v)$ indicates the size of the project, η is a constant, $\overline{A}_{t-1}$ is the world technology frontier at time $t-1$, $\gamma_t(v)$ is the skill level of the entrepreneur and A_{t-1} is the average level of technology in the economy at time t-1. In order to implement the project, the entrepreneur can imitate the existing technology from the world frontier $\overline{A}_{t-1}$ or can innovate on the basis of the technology stock A_{t-1} in the economy by using his skill $\gamma_t(v)$. In this way, such equation shows the two alternative ways to promote productivity growth in the intermediate sector v.

It is possible to aggregate the values of productivity in each intermediate sector v in order to compute the average level of technology in the economy A_t, that is:

$$A_t \equiv \int_0^1 A_t(v)dv \quad (27)$$

Substituting (26) in (27) and dividing A_t by A_{t-1}, the growth rate of aggregate technology is:

$$\frac{A_t}{A_{t-1}} \equiv \frac{\int_0^1 A_t(v)dv}{A_{t-1}} = \int_0^1 s_t(v)\left[\eta \frac{\overline{A}_{t-1}}{A_{t-1}} + \gamma_t(v)\right]dv \quad (28)$$

This equation clearly shows the role of the distance from the technological frontier in determining the choice between investment and innovation. When the economy is far from the frontier, because $\overline{A}_{t-1} >> A_{t-1}$, the major source of productivity growth is due to imitation of well-established technologies. On the contrary, when the country is near to the frontier, since the ratio $\overline{A}_{t-1}/A_{t-1}$ is close to 1, innovation is more important for productivity growth and then it is necessary for the firm to choose high-skill entrepreneurs able to run such innovation process.

Let define the proximity to frontier a_t, that is the inverse of the distance to frontier, as the ratio between the average technology level A_t in a given economy and the world technology frontier $\overline{A}_t$. The world technology frontier $\overline{A}_t$ moves according to the following law of motion:

$$\overline{A}_t = \overline{A}_0(1+g)^t \quad (29)$$

where g is the aggregate growth rate of technology at the frontier.

The transition from an investment-based policy to an innovation-based policy in an economy is associated to a given value of the proximity to frontier. This threshold can be determined by some institutional settings, such as the degree of product market competition, and then inversely the extent of market power δ of the leading firms in the intermediate sectors. But it is also affected by the measure of appropriability μ of the profits generated by the leading firm. For these reasons such transition value is indicated as $a_r(\mu, \delta)$ and it corresponds to the level of proximity to frontier, such that below this threshold low-skill old entrepreneurs are still retained but above it they are replaced by young entrepreneurs.

Depending on the position of the actual threshold $a_r(\mu,\ \delta)$ and on the implementation of different institutional settings, the model can present four possible equilibria. Firstly, the paper presents a growth-maximizing equilibrium, in the case that the actual threshold $a_r(\mu,\ \delta)$ corresponds to the optimal value for transition $\hat{a}$, as it is determined by the intersection between the two growth path for $R=1$ and $R=0$; in such situation (graph 1), the economy benefits from the highest possible growth rate, because it pursues a strategy of $R=1$ for $a_{t-1}<\hat{a}$ and of $R=0$ for $a_{t-1}>\hat{a}$.

Secondly, the model shows an underinvestment equilibrium, when $a_r(\mu,\ \delta)<\hat{a}$: in this situation, small projects are run, because capitalists and entrepreneurs are not willing to invest more due to an appropriability effect (that is, nobody of them is able to get all the profits generated by his investments). In this underinvestment equilibrium, public intervention could be implemented either directly through investment subsidies, or indirectly through a transitory increase of product market regulation, which would imply augmented profits for the existing leading firms: clearly, these interventions should be temporary, in order to avoid distortions in product market and just to induce higher rate of growth only for the considered interval.

Thirdly, a sclerotic equilibrium can arise if $\hat{a}<a_r(\mu,\ \delta)$ (graph 2): such case is a consequence of a prolonged implementation of an investment strategy, eventually due to a high degree of regulation. Here the retained earnings of the entrepreneurs, as well as the market power of the incumbent firms, delay the transition to a more efficient organizational form, but the economy finally reaches the world technology frontier.

Finally, a non-convergence trap equilibrium occurs when $\hat{a}<a_{trap}< a_r(\mu,\ \delta)$ (graph 3): in this situation, the protection in favour of incumbent firms is so strong that the economy will never transition to an innovation-based equilibrium and will never attain the world technology frontier. In a political economy perspective, appropriate institutions are needed, in order to avoid the capture of politicians by special interest groups, interested in low market competition and high profits for the incumbent firms.

Given the existence of many possible equilibria for economic growth, the results of this model can suggest a new theory of leapfrogging, able to explain the different performances of some economies in terms of technological progress. While the step-by-step assumption suggests that an initially backward economy must before adopt the leading-edge technology and only after can achieve a technological leadership, the leapfrogging paradigm admits that a previously backward economy is able, thanks to innovation, to suddenly get over the existing frontier and to develop directly a higher level of technology. Just to give an idea, let consider the case that two countries with the initial level of technology pursue two different growth paths: country A follows an investment-based strategy, also supported by some measures of anticompetitive policy, while country B adopts an innovation-based approach and keeps it for all the time. In the initial period, A can experience higher growth rates than B, thanks to the adoption of the existing technologies. But in the second period, B can exploit the innovations generated thanks to the R&D activity and then obtain a higher technological progress and achieve a more sustained growth, while A experiences lower growth rates and finally reaches a non-convergence trap.

The description of the transition path towards the world technology frontier shows that some policy interventions can be implemented in order to promote higher growth rates. Then this introduces some political economy considerations regarding the adoption of such actions by the governments. In particular, the paper discusses the implications of those policies designed to increase the level of investments and to encourage the adoption of technology for the countries far from the frontier. Even if investment subsidies are the most direct instruments to face underinvestment issues, they are difficult to implement in relatively backward economies and then an alternative solution is given by regulatory policies in favour of the incumbent firms, such to increase their profits and to stimulate their investments in technology adoption. But, given that these policies may have negative effects in the long-run, potentially favouring non-convergence traps, it is important to ensure that they are really limited to a transitory period and that the pressures of interest groups don't influence the timing of their implementation. The issue also arises because the anticompetitive policies which increase the barriers to entry for some protected industries further augment the economic power of such incumbents. So at the end the groups of old capitalists could exploit such power in order to exert some pressures aimed at obtaining a longer duration or a permanent implementation of such anticompetitive measures (which would contradict the temporary purposes of the initial intervention). Then the political economy problem discussed in the last part of the paper is how to avoid that enriched interest groups, through lobbying and bribery, may capture politicians in order to obtain the adoption of anticompetitive policies.

Assuming that capitalists are willing to pay the revenues obtained in the first period in order to increase their monopoly power, they will be successful in bribing politicians if the amount of money paid to them is equal or higher than the pay-off that the politicians would obtain by behaving honestly. Supposing that this pay-off is an increasing function of the average technology level in the previous time, and then is given by $h\ A_{t-1}$, the condition which expresses this case is:

$$\delta_{t-1}(1-\mu)\sigma N\left(\eta+\lambda\gamma a_{t-1}\right)\geq ha_{t-1} \quad (30)$$

where the LHS indicates the earnings of the firm in the period t-1, while the RHS denotes the pay-off of the honest politician. So, at the end, the success of this pressure depends on the amount of money that the capitalist is able to offer to the politicians, and then on the total earnings that he can get during the first period. And this amount is larger when δ_{t-1} is higher, that is when the market power of the incumbent firms is stronger, given that this also implies the realization of richer profits.

In this framework, politicians have to choose the degree of product market regulation χ_t within an interval $\chi_t \in [\underline{\chi}, \overline{\chi}]$, and consequently they determine the extent of market power of the incumbents δ_t within an interval $\delta_t \in [\underline{\delta}, \overline{\delta}]$. When $\delta_t = \overline{\delta}$ (lowest degree of competition), the condition (37) for successful bribing is satisfied as an equality for a value of the proximity to frontier corresponding to a_L : this means that capitalists will manage to bribe politicians as long as $a_{t-1} \leq a_L$. At the same time, when $\delta_t = \underline{\delta}$ (highest degree of competition), a_H is the value of the distance to frontier for which condition (30) is satisfied as an equality: this means that capitalists will successfully corrupt politicians as long as $a_{t-1} \leq a_H$. As already observed, the old capitalists can exert a stronger pressure on politicians for lower levels of product market competition: this implies that $a_L > a_H$, since in such case they can obtain the desired policy outcome also for higher values of the proximity to frontier.

On the basis of these premises, we can distinguish three possible cases for the outcomes of the political lobbying by old capitalists. If $a_0 < a_H$, that is when the starting point of the economy is very far from the world technological frontier, the capitalists can easily induce politicians to implement an anticompetitive policy: this strategy will ensure growth until the economy reaches a non-convergence trap, then such situation displays a political economy trap. If $a_0 > a_L$, when the economy is close to technological frontier, the capitalists don't have enough funds to bribe politicians: then, as implied by the technological structure of the economy, a procompetitive policy is implemented in order to enhance innovation. Finally, when $a_0 \in (a_H, a_L)$, the outcome depends on the initial level of competition: in fact, if $\delta_{t-1} = \overline{\delta}$, the capitalists of the incumbent firms, benefiting from strict product market regulation, obtain high monopoly profits and then can successfully bribe politicians; while, if $\delta_{t-1} = \underline{\delta}$, the low profits due to the highly competitive environment don't permit the old capitalists to exert a significant pressure on politicians and then a competitive policy leading the economy to the technology frontier is implemented.

The extension of the growth model to such political economy considerations allows to identify a multiplicity of steady state political equilibria: one consists in the implementation of a competitive policy and ensures that the economy will achieve the world technology frontier; the other, based on an investment policy, displays a political economy trap and excludes convergence to the frontier.

In conclusion, the literature on distance to frontier and economic growth, developed in the last few years, has given an important contribution to the understanding of the impact of competition and regulation policies on productivity growth. In fact, the numerous studies which have analyzed the effects of product market rigidities on economic growth have presented very disparate results: either no effect, or a positive or a negative impact. This is because the existing studies have ignored the relevant heterogeneity across different countries and industries. Then this literature, pointing out the importance of the position of a country or an industry relative to the technological frontier, has provided a determinant explanation for such disparity.

Moreover, the theoretical model by Acemoglu, Aghion and Zilibotti (2006) has examined in the same framework two aspects that are usually considered in different analyses, that is the effect of political process on the adoption of economic reforms and the impact of policy interventions on economic growth. In order to fully understand the effects of these policies on the economy, it is surely important to endogenize the political process which determines the decisions about these reforms. Nevertheless, the extent of the analysis, due to the global comprehension of the two aspects, may also imply a disadvantage, in terms of a less detailed examination of the political economy aspects relevant in regulation and competition policies. In fact, in the discussed model, the success of the political lobbying exerted by the old capitalists simply depends on the amount of money that they are able to pay directly to politicians through bribery, so building on the assumption that economic power consequently determines political power. But this limitation of lobbying activity to bribery doesn’t capture the real nature of the political pressure that the interest groups can exert on politicians in order to obtain the adoption of anticompetitive measures, or better there are many other ways by which interest groups may affect the outcomes of the political process in favour of their interests. Then it would be interesting to introduce in this political economy framework a consideration of the non-monetary aspects of the lobbying process, which may be relevant in influencing the decisions taken by politicians: in this way, it would be possible to have a wider view on the determinants of economic reforms as well as on the factors of political opposition to their implementation.

1.11 Conclusions and perspectives for further research

The review of the previous models of endogenous growth is useful for drawing some conclusions about further and possible developments of research on the relation between product market competition and economic growth.

In fact, the discussed models present different results about the sign and the magnitude of the relation: while the basic Romerian model of endogenous growth predicts a positive relationship between competition and growth, the basic Schumpeterian model indicates a negative relation between those variables. The subsequent variants of the first and of the second model add some important extensions, more consistent with the observation of real world, but in general they don't offer a clear and definitive solution for the theoretical analysis of the topic. Anyway, a comparison between the different approaches shows an analytical superiority of the models based on vertical innovation over the models of horizontal innovation. In general, the models with expanding product varieties don't suggest an exhaustive solution to the problem, both for an excessive importance of the exogenous parameters in the determination of the final results, and for the existence of scale effects depending on the amount of labour force. On the contrary, the models with increasing product quality present a more rigorous explanation of the innovation process as endogenously determined by the decisions of firms interested in obtaining the appropriate reward for innovation. This is the reason why the models with vertical innovation are probably more appropriate to form a future basis for further perspectives of research on the issue.

In any case, independently from the previous observation, the presentation of the models makes evidence of two main problems which arise in the theoretical analysis of the relationship between competition and growth.

The first issue regards the difficulty of introducing a market structure consideration in a macroeconomic model of endogenous growth: in fact it is necessary to identify an appropriate indicator of competition which allows to derive some clear conclusions about the type of relation observable at aggregate level. Even if the majority of these models uses the Lerner Index as a measure of market power in a market characterized by the dominance of a monopolistic firm, some analysis take into account the substitutability between differentiated products in a market with monopolistic competition, while other works employ the profit level of duopolistic firms in neck-and-neck industries as an indicator of the degree of collusion in oligopoly markets. The variety of possible indicators is also the proof of the numerous market situations to be considered and then also the demonstration that a unique measure of competition is not enough for satisfying the complexity of the possible market structures in the real world.

The second problem concerns the empirical verifiability of the results obtained in these models: in fact the applied literature on competition and growth often propose conclusions which are opposite to the results derived in some theoretical models, especially in the case of the basic Schumpeterian model of endogenous growth. But, even when the results of the empirical analysis are analogous to those ones of the theoretical studies, as it occurs for the models based on horizontal innovation or for the second-generation models of vertical innovation, the applied outcomes show some aspects of complexity, which are not fully captured by the analytical models. For example, while empirical studies are conducted by distinguishing the specific features of the various industries, for example through panel data analysis with industry effects, analytical models tend to adopt univocal conclusions for the aggregate economy, although the effects of competition on growth can be different in sign and magnitude depending on the particular needs of each industry.

So, in order to develop this idea about the distinction between industries, a reasonable approach could be to study the relation between competition and growth by differentiating the effects for various types of industries. But, in order to develop this research line, we need to identify the elements that distinguish industries from the viewpoint of the innovation decisions. In this perspective, the new models of endogenous growth, both the one on the inverted U relationship between competition and innovation, and the one on the impact of the distance to frontier on growth, provide some reasonable solutions in order to explain the effect of competition on productivity growth: in fact, they distinguish the effects depending on the initial level of competition as well as on the proximity of the economy to the world technological frontier.

In particular, a useful approach is proposed in the paper by Aghion, Bloom, Blundell, Griffith and Howitt (2005), where the distinction between neck-and-neck industries and unlevelled industries is used in order to derive different conclusions about the relation between competition and growth. This classification is based on the technological structure of an industry and then on a comparison regarding the technology level reached by each firm in the industry: so the willingness to invest in research depends on the position of each firm and on the distribution of the other firms in an innovation scale. Moreover this article suggest an interesting way to aggregate these separate results through the solution of a Markov process aimed at determining the fixed fractions of the two types of industry in the steady state and then at computing an average innovation rate.

The other possible distinction is suggested in the article by Acemoglu, Aghion and Zilibotti (2006), where the distance to the world technology frontier is determinant for choosing the optimal growth policy for a country. In fact, while a country far from the world technology frontier should adopt a strategy based on an investment policy, on the contrary a country close to technology frontier ought to implement a selection-based growth policy, through the elimination of all the entry barriers. As clarified by the authors, this reasoning about technology frontier, originally considered for a cross-country comparison, can be extended to a cross-industry comparison, then suggesting that the organization of production should be different in industries which are closer to technology frontier.

Both the solutions proposed in the cited papers use the technological structure of an industry, defined either as the distribution of the technology levels across firms or as the distance of the industry from the technology frontier, as the distinctive criterion for explaining the different effects of competition on growth. In both cases the technology level is relevant for determining the production costs, given that the firm which has access to the leading-edge technology can produce the output more efficiently, with lower production costs, and then it has a higher profit than the other firms.

Finally, an important progress can be noticed in the recent literature regarding the notion of competition, since new attention has been paid to the idea of potential competition, which could be enhanced through the abolition of the previous barriers to entry. This choice acquires a lot of importance for its policy implications, in particular in the European case. In fact, the practice of competition authorities until now has focused more on competition among incumbent firms, rather than on entry in the market. This literature now suggests that the threat of entry by new firms can play a very important role in inducing incentives for innovation among the incumbent firms. So, the conclusions of these models can provide some guidelines in order to design the appropriate growth policies that should be promoted in Europe in order to promote technological progress and to tackle the issue of the productivity slowdown observed in the last two decades.

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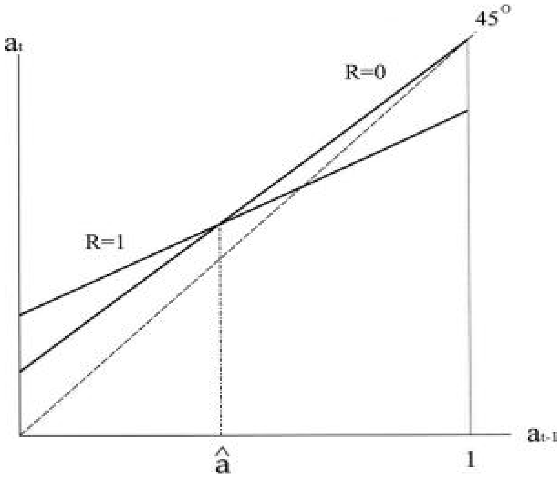
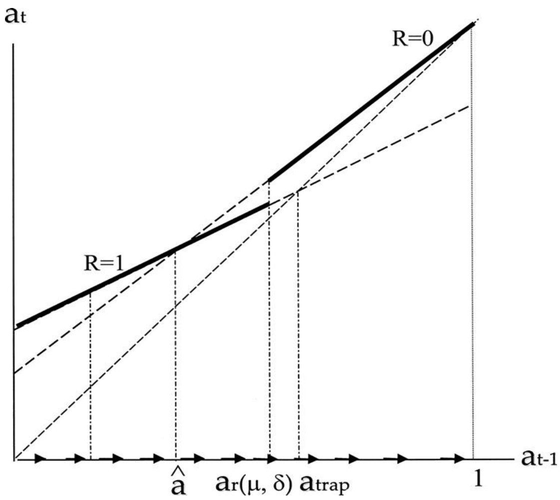
Graph 1. Growth-maximizing equilibrium $\hat{a}=a_r(\mu,\ \delta)$



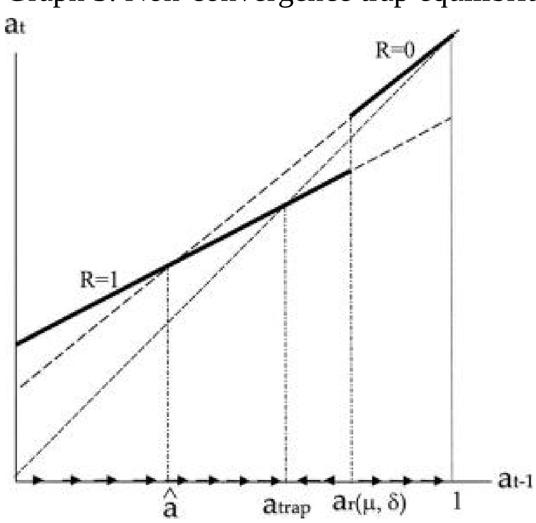
Source: Acemoglu, Aghion and Zilibotti (2006)

Graph 2. Sclerotic equilibrium $\hat{a}< a_r(\mu,\ \delta)$



Source: Acemoglu, Aghion and Zilibotti (2006)

Graph 3. Non-convergence trap equilibrium $\hat{a}<a_{trap}< a_r(\mu,\ \delta)$



Source: Acemoglu, Aghion and Zilibotti (2006)