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COMPETITION POLICY AND ECONOMIC GROWTH IN AN ECONOMY WITH HIGH-TECHNOLOGY INDUSTRIES

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JEL Classification: K21, L16, O31, O34, O38

Keywords : high-technology industries, competition in the market and for the market, incentives for innovation, endogenous technological progress, intellectual property protection

Competition Policy and Economic Growth in an Economy with High-Technology Industries

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Preliminary Version

Abstract

This paper aims at studying the relationship between competition policy and economic growth in an economy with high-technology industries. In particular, the analysis distinguishes different forms of competition policy – *in* the market and *for* the market - and wants to examine the impact of such policies on technological progress.

The model predicts that a policy aimed at increasing competition *for* the market, through the reduction of barriers to entry, always produces a positive impact on innovation and growth. On the opposite, a policy designed to improve competition *in* the market, by imposing the sharing of the technology invented by the leader, may generate a negative effect: in fact such policy, by eliminating the expected reward due to the innovator, reduces the incentives of firms to invest in R&D and then decreases technological progress in the future.

This dynamic efficiency perspective introduces some elements of discussion about the design and the implementation of competition policy, with particular attention to the cases of abuse of dominance in high-technology industries, which involve an interaction between antitrust law and intellectual property protection.

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1. Introduction

The present work aims at analyzing the relationship between competition policy and economic growth from a theoretical point of view, in order to propose some indications about the optimal design of competition policy in a dynamic efficiency perspective, as well as to contribute to the current debate on the appropriate economic policies for encouraging long-run growth, particularly in industrialized countries. In fact, the policy recommendations usually proposed for promoting sustainable growth suggest to increase the degree of competition in our economies: this outcome should be achieved by liberalizing markets such to favour the entry of new competitors and by implementing a severe antitrust policy in order to correct eventual distortions in market functioning[1].

Notwithstanding this dominant idea in the policy environment, economists have not yet given a definitive answer about the effect of competition on growth. The questions that lead such discussion are the following ones. How can competition policy affect the relevant factors for long-run growth? Does it always have a positive impact on productivity growth? Or can it also produce a negative effect?

The existing literature on endogenous growth theory has not given a clear and definitive reply about the sign of this relationship. The models based on horizontal innovation, like Romer (1990), show a positive effect of competition on growth, while the models based on vertical innovation, such as Aghion and Howitt (1992), present a negative impact of competition on growth. In fact, according to one 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, in the analysis of Schumpeterian models of endogenous growth, 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. In particular, some new Schumpeterian models have provided a more articulated solution to this problem: Aghion, Bloom, Blundell,

[1] In particular, this objective has been strongly emphasized in the economic policies of the European Union, through the creation of the Single Market and through the implementation of the Antitrust Policy. Moreover, in the Lisbon Agenda competition policy is presented as one of the main tools in order to achieve the target of making the European Union "the most dynamic and competitive knowledge-based economy in the world capable of sustainable economic growth". Indeed, according to this policy perspective, a competitive market should induce more innovation and then enhance productivity growth, so resolving the issue of the productivity slowdown observed in Europe in the last two decades.

Griffith and Howitt (2005) describes a U-inverted relationship between competition and innovation, while Acemoglu, Aghion and Zilibotti (2006) identifies a negative effect of competition policy on growth for the countries far from the technological frontier and a positive one for the economies close to the frontier. In general, it seems reasonable that the effect of competition may not be linear and so may depend on some other circumstances (the initial level of product market competition, the distance from the technological frontier, the existence of imperfections in other markets).

Given the current state of the literature, the relationship between competition policy and economic growth can have a more exhaustive explanation, by considering the distinction across various forms of competition. In fact, a policy aimed at increasing the degree of product market competition may pursue different strategies: it can induce a higher rate of entry in a given market by reducing barriers to entry (competition policy *for* the market) or it can impose the same competitive conditions for all the firms in a given industry by removing all the differences among the incumbent competitors in that market, such that they can compete on prices (competition policy *in* the market). In fact these various policies can differently affect the incentives for innovation: so it is expected that different competition policies can produce diverse results on innovation and growth. In conclusion, the objective of this analysis is to clarify the different effects on growth induced by competition *in* the market and competition *for* the market in an economy with high-technology industries.

In particular, high-technology industries are often characterized by vertical integration between research and production activities, such that research costs are included in the profit function of the firms which are involved in the innovation activity. The high entry costs explain the elevated concentration of the market, characterized by a monopoly or by an oligopoly with a technological leadership. In this industry framework, the incentive for innovation is given by the monopolistic rents due to the exploitation of patents, so it is fundamental to preserve the existence of some innovation rents for promoting research. More competition *in* the market implies that innovation rents are shared among all the existing firms and that innovator loses monopoly profits: then this policy would eliminate any incentive for innovation and might discourage technological progress. In the same context, different effects would be produced by a liberalization process designed to reduce entry barriers: in fact, provided that technological progress also depends positively on the number of firms operating in the industry and potentially involved in the research activity, a policy aimed at developing competition *for* the market would induce more firms to invest in R&D, then increasing the innovation rate of the economy.

2. The Model

Let analyze the innovation activity and the growth process in high-technology industries, that we denote by the subscript j. There the production process requires the adoption of an advanced technology, which is developed thanks to the investments of firms in research and development. Research activity requires both capital and labour and then implies higher costs for the firms interested in improving their production technologies.

A specific feature of high-technology industries in our model is the vertical integration between research and production activities. This assumption is generally supported by real-world evidence: in fact, the firms involved in high-technology industries, such as the ones supplying softwares or pharmaceuticals, are directly involved also in the research work which is propedeutic to the production process. Clearly, there are specific rationales for vertical integration in each of these cases[2], but the underlying idea, which generally justifies this choice, is the following one: in a given industry, where innovation plays a fundamental role and can determine the success or the failure of an entrepreneurial project, each firm is naturally interested in directly carrying out such activity, because it cannot rely on the other firms for such an important task.

So, research activity is generally integrated with production activity within the organizational structure of high-technology industries, but in any case not all the firms existing in these industries are initially involved in research activity. In fact we distinguish a leader firm (active in research and production) and some follower firms (involved only in production). As a consequence of this process innovation, the leader employs a production technology A_{jLt}, which is more advanced than the technology A_{jFt} available to the followers, by a technological step x_{jt}.

So, provided that $x_{jt} = A_{jLt} - A_{jFt}$, the size of the technological advantage x_{jt} is determinant in our framework in order to explain the market structure of such industries: in fact, the industry has a monopolistic structure if the leader has a technology level much higher than the follower, while it presents an oligopolistic structure (even with the presence of a leader) if the technological gap is quite low. At the beginning, each high-technology industry is an oligopoly: only when the innovation activity of the leader sensibly increases its technological advantage, production activity becomes much more costly for the followers and then it may induce them to exit the market[3].

[2] For the pharmaceutical firm, we can consider some motivations of medical safety, given that the firm has to be sure about the quality and the effectiveness of the medicine; for the firm producing softwares, we can imagine some reasons of industrial secrecy, since in a market with a limited patentability of the new inventions it is safer to manage directly all the operations related to the software development in order to avoid the diffusion of essential and easily reproducible information to the competitors.

[3] In any case, the market structure of an industry is dynamic: even a monopolized industry can become an oligopolistic one if new firms enter the market using an appropriate technology, such to compete - at least potentially -

In high-technology industries, innovation is the main determinant of the performance of each firm, then it requires an appropriate protection by the law system. For this reason, the innovation corresponding to x_{jt} is protected by a patent, so intellectual property law allows only the leader to use this new technology for the production process. Once the leader obtains the exclusive right to exploit such invention (x_{jt}), the previous innovation (x_{jt-1}) becomes object of public knowledge and then it is available for the exploitation by other firms. As a consequence of that, if technology diffusion occurred without any barrier, also the technology level of the follower should increase by an equivalent measure, because of the availability of this previously protected technology. Then, it should be $A_{jFt} = A_{jFt-1} + x_{jt-1}$.

Nevertheless, some barriers to technology diffusion, due to the technical aspects (such as the need of specialized human capital for technology implementation) or to the conduct of the leader (like exclusionary practices) may prevent the follower, totally or partially, from the adoption of the existing and available technology[4]. In particular, we assume that the follower doesn't have perfect information about the barriers to technology diffusion and then it cannot correctly forecast the impediments that it can encounter in the attempt to adopt an existing available technology: then, even if $\overline{A_{jF}}$ is its effective technology level, the follower considers A_{jFt} as its technology level benchmark and then formulates its optimal production plans on such basis.

We can justify this assumption in various ways depending on the specific nature of the barrier to technology diffusion. In fact, when the barrier is due to technical reasons, the follower firm, which has not directly developed such innovation, but is interested in adopting the available technology, doesn't have a priori the adequate expertise for the implementation and it doesn't know the required type of technical competence[5]. Moreover, when the barrier to technology diffusion is due to an anti-competitive conduct of the leader, it is even more difficult to foresee the future

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with the leader, or if a pro-competitive policy implemented by an antitrust authority imposes the leader to share - partially or totally – its technology level with the followers, then reducing or eliminating the existing technological advantage.

[4] For this reason, we consider two different measures of the follower's technology level: A_{jFt}, that is the technology level ideally available to the follower (and relevant for the maximization of the firm's profit function), which evolves as a consequence of the public availability of existing technologies; $\overline{A_{jF}}$, that is the technology level effectively determined by the barriers to technology diffusion (and relevant for the computation of the aggregate production function of industry j), which is assumed to be constant over time.

[5] For this reason, it cannot organize a detailed plan for technology adoption, and even after it can encounter difficulties in procuring the human resources or in training the human capital. Of course, this lack of experience implies a high possibility of failure, but the follower firm is not able to quantify such probability at the beginning: however, this uncertainty about the final outcome of the project may discourage this activity of technological adoption.

problems in technology adoption: indeed, when the leader wants to limit the diffusion of its previous technology to the followers, since the abuse of dominance is not legal, it adopts some anti-competitive practices where the exclusionary intent is not immediately evident[6].

2.1 The production functions of the leader and of the follower

Let define firstly the production function of the leader. It exploits the technology A_{jL} and uses specialized capital and labour both for production and for research. Depending on their utilization, we can distinguish research capital K_{jR} and production capital K_{jP}, as well as research labour L_{jR} and production labour L_{jP}.

Nevertheless, from the viewpoint of the quality, capital and labour have to be considered as homogenous types of inputs, independently from the specific purposes of their usage (production or research)[7]. As a consequence of that, the same unit of innovative capital or skilled labour can be allocated both to production and to research: the only difference is that, once a given input is utilized for production rather than for research, it contributes differently to total output. This aspect is captured in the production function by the different values of the parameters for each type of input and for each final usage of that factor.

In time t, the leader produces the output Y_{jLt} according to the following function:

$$Y_{jLt} = A_{jLt} K_{jRt}^{\alpha} K_{jPt}^{\beta} L_{jRt}^{\gamma} L_{jPt}^{\delta} \qquad (1)$$

where $0 < \alpha < 1, 0 < \beta < 1, 0 < \gamma < 1, 0 < \delta < 1 \quad \& \quad \alpha + \beta + \gamma + \delta = 1$[8]. The parameters $\alpha, \beta, \gamma, \delta$ indicate the share of each factor in total output and are constant over time. Let assume that the factors employed in research contribute to total output quantitatively more than the factors used for production, because the first ones improve the efficiency of the production process and then present higher productivity: consequently, an increase of the amount of research capital or research labour by a multiplicative factor λ augments total output more than a corresponding rise in the quantity of, respectively, production capital or production labour. Then:

$$\alpha > \beta \qquad (2) \qquad \text{and} \qquad \gamma > \delta \qquad (3)$$

[6] In other words, the follower firm can expect that the leader will adopt some exclusionary strategies but it is not able to forecast the type of conduct and especially it is not sure whether he will manage the prove the anti-competitive intent of the practice beside an antitrust authority.

[7] To explain this assumption, we can argue that high-technology industries are intensive in innovative capital and skilled labour and that the firms operating in these markets can only employ high-quality inputs in order to run both the research activity and the production process.

[8] The observation of the leader's production function suggests an important consideration about the properties of that function. We can note that the production function has constant returns to scale with respect to all the inputs, both production capital and labour, and research capital and labour.

Moreover, the technology level of the leader A_{jLt} in time t is equal to:

$$A_{jLt} = A_{jFt} + x_{jt} \qquad (4)$$

At each time t, the leader can improve its technology level A_{jLt} with respect to the one available to the follower A_{jFt}. Provided that the technology level, and then also the technological gap x_{jt}, can be measured as a discrete variable, we assume that:

$$1 \leq x_{jt} \leq A_{jFt} \qquad (5)$$

Then, for a given time t, the leader can introduce a technological innovation x_{jt}, which is equal or lower than A_{jFt}. This means that in a one-period interval the leader can at most double the technology level available to the follower[9].

The technology level A_{jLt} shifts the production function: then, multiplying A_{jLt} by a factor λ, the total output of the leader is also multiplied by λ. For this reason, we can divide the production function described in equation (1) by the technology level A_{jLt} and then obtain the leader's production function per unit of technology level, that is:

$$y_{jLt} = \frac{Y_{jLt}}{A_{jLt}} = f\left(K_{jRt}, K_{jPt}, L_{jRt}, L_{jPt}\right) = K_{jRt}^{\alpha} K_{jPt}^{\beta} L_{jRt}^{\gamma} L_{jPt}^{\delta} \qquad (6)$$

This is the amount of output that a firm involved in research and production is able to produce using the basic technology $A_{jt} = 1$.

Now we can consider the production function of the follower. It exploits the technology level A_{jFt} and uses capital and labour just for production purposes. It produces a total output Y_{jFt} according to the following function:

$$Y_{jFt} = A_{jFt}\, K_{jPt}^{\alpha+\beta}\, L_{jPt}^{\gamma+\delta} \qquad (7)$$

where $0 < (\alpha + \beta) < 1, \quad 0 < (\gamma + \delta) < 1$ and $(\alpha + \beta) + (\gamma + \delta) = 1$. The parameters of this production function are defined in such a way that they correspond to the same ones used in the leader's production function: $\alpha + \beta$ is the factor share of capital (only used for production), while $\gamma + \delta$ is the factor share of labour (only employed for production). This specification of both production functions will imply important corollaries for the assumption about homogeneity of capital and labour across production and research sector.

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[9] This further implies that, if the follower always keeps the same technology level $\overline{A_{jF}}$, while the leader increases its technological advantage during the interval from 0 to t, after this time the technological gap may be higher than the initial technology level of the follower, then it can be: $x_{jt} \geq \overline{A_{jF}}$. In particular, as it will be explained successively, this is the necessary condition for the leader to profitably invest in research and development.

As in the previous case, we can observe that the technology level A_{jLt} shifts the production function: then, dividing it by A_{jFt}, we obtain the follower's production function per unit of technology level:

$$y_{jFt} = \frac{Y_{jFt}}{A_{jFt}} = f\left(K_{jPt}, L_{jPt}\right) = K_{jPt}^{\alpha+\beta}\ L_{jPt}^{\gamma+\delta} \qquad (8)$$

This is the amount of output that a firm involved only in production is able to produce using the basic technology $A_{jt} = 1$. When the follower adopts an existing advanced technology or when it is allowed to share a new technology developed by the leader, it innovates the production process and increases its technological level by ΔA_{jFt}: then, even using the same quantity of inputs, its total output increases by an amount equal to the product $\Delta A_{jFt}\ y_{jFt}$.

2.2 The implications of the homogeneity assumption for production and profit functions

As explained in the previous paragraph, the assumption about homogeneity of capital and labour across production and research sectors is justified by some economic considerations: the most innovative industries need high-quality capital and high-skilled workers and could not use low-quality inputs either for production or for research. Moreover, this assumption is also useful when we have to compare the production functions as well as the profit functions, in order to draw conclusions about the amount of inputs employed by different firms in high-technology industries. In fact, as a consequence of such homogeneity, we can write the production functions per unit of technology without the subscript:

$$y_{jLt} = K_{jRt}^{\alpha} K_{jPt}^{\beta} L_{jRt}^{\gamma} L_{jPt}^{\delta} = \left[(1+\mu)K_{jt}\right]^{\alpha} \left[(1-\mu)K_{jt}\right]^{\beta} \left[(1+\nu)L_{jt}\right]^{\gamma} \left[(1-\nu)L_{jt}\right]^{\delta} \qquad (9)$$

$$y_{jFt} = K_{jPt}^{\alpha+\beta}\ L_{jPt}^{\gamma+\delta} = K_{jt}^{\alpha+\beta}\ L_{jt}^{\gamma+\delta} \qquad (10)$$

where $0 \le \mu \le 1$ and $0 \le \nu \le 1$. In equation (9), indicating the leader's production function per unit of technology level, the parameters μ and ν are used to define the allocation of capital and labour among production and research activities. In fact, even if we introduce the homogeneity assumption, we don't know a priori how the leader chooses to allocate those inputs.

In particular, we consider[10] an equilibrium with μ* and ν*, equal to or different from 0. For given values of α and β, there exists an equilibrium value μ*, with $0 \le \mu^* < 1$, such that:

$$(1+\mu^*)^{\alpha}(1-\mu^*)^{\beta} = 1 \qquad (11)$$

[10] The existence of an equilibrium with μ^* and ν^*, where $0 \le \mu^* < 1$ and $0 \le \nu^* < 1$, will be confirmed by the result of the profit maximization problem discussed in par.2.3

For given values of γ and δ, there exists an equilibrium value ν*, with $0 \le \nu^* < 1$, such that:

$$(1+\nu^*)^{\gamma}(1-\nu^*)^{\delta} = 1 \qquad (12)$$

Then, for the equilibrium values μ* and ν*, the leader's production function y_{jLt} becomes:

$$y_{jLt} = K_{jt}^{\alpha+\beta}\ L_{jt}^{\gamma+\delta}$$

We can conclude that the output obtained from the production technologies y_{jFt} and y_{jLt} is equal.

$$y_{jLt} = K_{jRt}^{\alpha} K_{jLt}^{\beta} L_{jRt}^{\gamma} L_{jPt}^{\delta} = K_{jPt}^{\alpha+\beta}\ L_{jPt}^{\gamma+\delta} = y_{jFt} \qquad (13)$$

Then it follows that

$$K_{jLt} = K_{jRt}^{*} + K_{jPt}^{*} = 2K_{jt} \qquad \& \qquad K_{jFt} = K_{jt} \qquad \to \qquad K_{jLt} = 2K_{jFt} \qquad (14)$$

$$L_{jLt} = L_{jRt}^{*} + L_{jPt}^{*} = 2L_{jt} \qquad \& \qquad L_{jFt} = L_{jt} \qquad \to \qquad L_{jLt} = 2L_{jFt} \qquad (15)$$

This implies that, if the homogeneity assumption holds, the leader employs an amount of capital (labour) as double as the follower. But the leader uses more capital (labour) for research than for production; then the production capital (labour) used by the follower is higher than the leader's production capital (labour) but lower than the leader's research capital (labour). Indeed we have:

$$K_{jRt}^{*}(L) > K_{jPt}^{*}(F) > K_{jPt}^{*}(L)$$

$$L_{jRt}^{*}(L) > L_{jPt}^{*}(F) > L_{jPt}^{*}(L)$$

A corollary of the homogeneity of capital and labour across sectors is that interest rates and wages are equal among production and research sector. In fact, if the input is the same, it requires the same remuneration.

$$w_t = w_{Rt} = w_{Pt} \qquad \text{and} \qquad r_t = r_{Rt} = r_{Pt}$$

The homogeneity of wages and interest rates across sectors has important implications for the computation of profit. Then the profit functions for the leader and for the follower are:

$$\pi_{jLt} = A_{jLt} K_{jRt}^{\alpha} K_{jPt}^{\beta} L_{jRt}^{\gamma} L_{jPt}^{\delta} - w_t L_{jRt} - w_t L_{jPt} - r_t K_{jRt} - r_t K_{jPt}$$

$$\pi_{jFt} = A_{jFt} K_{jPt}^{\alpha+\beta} L_{jPt}^{\gamma+\delta} - w_t L_{jPt} - r_t K_{jPt}$$

2.3 The maximization problem for the leader and for the follower

Let consider the maximization problem for the leader:

$$\max_{K_{jRt}, K_{jPt}, L_{jRt}, L_{jPt}} \pi_{jLt} = A_{jLt} K_{jRt}^{\alpha} K_{jPt}^{\beta} L_{jRt}^{\gamma} L_{jPt}^{\delta} - w_t L_{jRt} - w_t L_{jPt} - r_t K_{jRt} - r_t K_{jPt} \qquad (16)$$

Given the homogeneity of wages and interest rates across production and research, we can use the results of the profit maximization problem in order to quantify the amount of capital and labour employed by the leader in research or in production.

Since $r_t = r_{Rt} = r_{Pt}$, we can use FOCs to compare the quantities of K_{jPt} and of K_{jRt} used by the leader.

$$\alpha A_{jLt} K_{jRt}^{\alpha-1} K_{jPt}^{\beta} L_{jRt}^{\gamma} L_{jPt}^{\delta} = \beta A_{jLt} K_{jRt}^{\alpha} K_{jPt}^{\beta-1} L_{jRt}^{\gamma} L_{jPt}^{\delta}$$

Simplifying the equation and recalling that $\alpha > \beta$ from (2), we can show that:

$$K_{jRt} > K_{jPt}$$

This means that the leader optimally allocates the existing amount of capital in such a way to have more research capital than production capital.

Given that $w_t = w_{Rt} = w_{Pt}$, using FOCs we can compare the quantities of L_{jPt} and L_{jRt} used by the leader.

$$\gamma A_{jLt} K_{jRt}^{\alpha} K_{jPt}^{\beta} L_{jRt}^{\gamma-1} L_{jPt}^{\delta} = \delta A_{jLt} K_{jRt}^{\alpha} K_{jPt}^{\beta} L_{jRt}^{\gamma} L_{jPt}^{\delta-1}$$

Simplifying the equation and recalling that $\gamma > \delta$ from (3), we can show that:

$$L_{jRt} > L_{jPt}$$

It means that the leader optimally allocates the existing amount of labour in such a way to have more research labour than production labour.

These results are consequential to the assumptions on the parameters of the production function: if an input employed for research increases total output more than the same input used for production, the solution of the profit maximization problem clearly implies an allocation of K_{jLt} such that $K_{jRt} > K_{jPt}$ and of L_{jLt} such that $L_{jRt} > L_{jPt}$ [11].

In order to draw clear conclusions about the input allocation for leader and followers, we also need the results of the profit maximization problem for the follower. So let consider the following maximization problem:

$$\max_{K_{jPt}, L_{jPt}} \pi_{jFt} = A_{jFt} K_{jPt}^{\alpha+\beta} L_{jPt}^{\gamma+\delta} - w_t L_{jPt} - r_t K_{jPt} \qquad (17)$$

The solutions of the profit maximization problem can be used in order to compare the amount of production capital and labour respectively employed by the leader and the follower.

Taking the FOCs from the profit maximization problem for the interest rate on production capital we have:

$$\beta\left(A_{jFt} + x_{jt}\right) K_{jRt}^{\alpha} K_{jPt}^{\beta-1} L_{jRt}^{\gamma} L_{jPt}^{\delta} = \left(\alpha + \beta\right) A_{jFt} K_{jPt}^{\alpha+\beta-1} L_{jPt}^{\gamma+\delta} \qquad (18)$$

[11] This outcome has an important implication also for the allocation of capital and labour among research and production, as discussed in par. 2.2. Indeed, the equilibrium values of K_{jRt} and K_{jPt}, as well as of L_{jRt} and L_{jPt} are determined by the parameters μ and ν: so, among the possible equilibria, the above solution rules out the equilibrium with μ=0 and ν=0 and only admits the equilibrium with $\mu = \mu^* \;\; \& \;\; \nu = \nu^*$ (where $0 < \mu^* < 1 \;\; \& \;\; 0 < \nu^* < 1$).

Recalling the assumptions (2) and (4), we notice that:

$$\beta\left(A_{jFt} + x_{jt}\right) < (\alpha + \beta)A_{jFt}$$

Then, from equation (18), we can write:

$$\underbrace{\left(K_{jRt}^{\alpha} K_{jPt}^{\beta} L_{jRt}^{\gamma} L_{jPt}^{\delta}\right)}_{=y_{jLt}} \left[K_{jPt}(L)\right]^{-1} > \underbrace{\left(K_{jPt}^{\alpha+\beta} L_{jPt}^{\gamma+\delta}\right)}_{=y_{jFt}} \left[K_{jPt}(F)\right]^{-1}$$

Given that in equilibrium $y_{jLt} = y_{jFt}$, as in equation (13), we can rewrite the inequality as:

$$K_{jPt}^{*}(L) < K_{jPt}^{*}(F) \qquad (19)$$

So this means that in equilibrium, where each firm in the industry maximizes its profit, the follower employs a greater amount of production capital than the leader. This is essentially a consequence of the technological gap: since wages for production labour have to be equal in equilibrium across the various firms in the same industry, in order to keep the equality of the marginal product of production labour for follower and leader, the follower must have a higher capital-labour ratio. And then, since the follower has to use more production capital, it has to pay higher costs for such input.

Using the FOCs from the profit maximization problem for the wage of production labour, we obtain:

$$\delta\left(A_{jFt} + x_{jt}\right) K_{jRt}^{\alpha} K_{jPt}^{\beta} L_{jRt}^{\gamma} L_{jPt}^{\delta-1} = (\gamma + \delta) A_{jFt} K_{jPt}^{\alpha+\beta} L_{jPt}^{\gamma+\delta-1} \qquad (20)$$

Recalling the assumptions (3) and (4), we notice that:

$$\delta\left(A_{jFt} + x_{jt}\right) < (\gamma + \delta)A_{jFt}$$

Then, from equation (20), we can write:

$$\underbrace{\left(K_{jRt}^{\alpha} K_{jPt}^{\beta} L_{jRt}^{\gamma} L_{jPt}^{\delta}\right)}_{=y_{jLt}} \left[L_{jPt}(L)\right]^{-1} > \underbrace{\left(K_{jPt}^{\alpha+\beta} L_{jPt}^{\gamma+\delta}\right)}_{=y_{jFt}} \left[L_{jPt}(F)\right]^{-1}$$

Given that in equilibrium $y_{jLt} = y_{jFt}$, as in equation (13), we can rewrite the inequality as:

$$L_{jPt}^{*}(L) < L_{jPt}^{*}(F)$$

This result means that in equilibrium the follower needs a higher amount of production labour than the leader. As already explained for production capital, also this outcome is an effect of the technological gap between the follower and the leader: since the interest rates on production capital have to be equal for the various firms in the same industry, in order to balance the lower technological level, the follower must have a higher labour-capital ratio.

2.4 The aggregate production function for each industry

Aggregating the product across all the firms in a given industry, the total output of industry j is given by:

$$Y_{Jt}=\sum_{1}^{M}Y_{jmt}=Y_{jLt}+\sum_{1}^{M-1}Y_{jmt} \qquad (21)$$

where $\forall m\neq L$, $Y_{jmt}=Y_{jFt}$. Given that only the leader has a higher technological level, all the other firms are followers and then each of them produces the same output, that is Y_{jFt}. Then, substituting the production functions for the leader and for the follower, we can write the aggregate production function of industry j as follows:

$$Y_{Jt}=\left(A_{jFt}+x_{jt}\right)K_{jRt}^{\alpha}K_{jPt}^{\beta}L_{jRt}^{\gamma}L_{jPt}^{\delta}+\left(M-1\right)A_{jFt}K_{jPt}^{\alpha+\beta}L_{jPt}^{\gamma+\delta}$$

Let define $\overline{A_{jF}}$ the technology level of the follower at $t=0$. Given that the follower doesn't invest in research, it keeps the same technology level $\overline{A_{jF}}$ also in time t, unless it manages to implement some of the available technologies: then, in order to determine the effective aggregate production function, we will indicate $\overline{A_{jF}}$ as the technology level of the follower. Moreover, because of the homogeneity of capital and labour across production and research sector, we can write:

$$Y_{Jt}=\left(\overline{A_{jF}}+x_{jt}\right)\left[(1+\mu)K_{jt}\right]^{\alpha}\left[(1-\mu)K_{jt}\right]^{\beta}\left[(1+\nu)L_{jt}\right]^{\gamma}\left[(1-\nu)L_{jt}\right]^{\delta}+\left(M-1\right)\overline{A_{jF}}K_{jt}^{\alpha+\beta}L_{jt}^{\gamma+\delta}$$

We know that in equilibrium $\mu=\mu^{*}$ & $\nu=\nu^{*}$ (such that $0<\mu^{*}<1$ & $0<\nu^{*}<1$), then conditions (11) and (12) hold. So the aggregate production function of industry j is:

$$Y_{Jt}=\left(\overline{A_{jF}}+x_{jt}\right)K_{jt}^{\alpha}\,K_{jt}^{\beta}\,L_{jt}^{\gamma}\,L_{jt}^{\delta}+\left(M-1\right)\overline{A_{jF}}K_{jt}^{\alpha+\beta}L_{jt}^{\gamma+\delta}$$

Then, rearranging, we have:

$$Y_{Jt}=\left(M\overline{A_{jF}}+x_{jt}\right)K_{jt}^{\alpha+\beta}L_{jt}^{\gamma+\delta} \qquad (22)$$

Depending on the size of the technological advantage of the leader, we can have three different cases. Then we define the aggregate production function of the industry for each of them.

If $x_{jt}<\overline{A_{jF}} \quad \forall t\in[1,\infty)$, the aggregate production function of industry j is:

$$Y_{Jt}=M\overline{A_{jF}}K_{jt}^{\alpha+\beta}L_{jt}^{\gamma+\delta} \qquad (23)$$

In this case, the technological advantage that the leader can achieve is too small for R&D investment to be profitable. In fact, if $x_{jt}<\overline{A_{jF}}$, the firm active in research might not recover the costs related to research activity and then could have a negative profit, or even if it obtained a positive profit, this would be lower than the profit gained by an equivalent firm active only in production. In such situation, no firm is willing to invest additional resources in research and development, then all the firms are involved in production. In conclusion, the aggregate production function is simply a M-multiple of the follower's production function.

If $x_{jt}=\overline{A_{jF}} \quad \forall t\in[1,\infty)$, the aggregate production function of industry j is:

$$Y_{Jt} = (M+1)\overline{A_{jF}} K_{jt}^{\alpha+\beta} L_{jt}^{\gamma+\delta} \qquad (24)$$

Finally, if $x_{jt} > \overline{A_{jF}} \quad \forall t \in [2,\infty)$, the aggregate production function of industry j is:

$$Y_{Jt} = \left(\overline{A_{jF}} + x_{jt}\right) K_{jRt}^{\alpha} K_{jPt}^{\beta} L_{jRt}^{\gamma} L_{jPt}^{\delta} \qquad (25)$$

Differently from the previous cases, this result can occur only for $t \in [2,\infty)$. In fact, by assumption (4), we know that $1 \le x_{jt} \le A_{jFt}$; then, assuming that the follower doesn't improve its technology level and then maintains the same level $\overline{A_{jF}}$, the leader cannot reach in $t=1$ a technological advantage higher than $\overline{A_{jF}}$, but it can attain it after a time interval of at least 2 periods. In this case, since the technological advantage of the leader is quite relevant, it is much more costly for the follower to compete in the same market, then it is forced to exit because otherwise it would have negative profits.

2.5 The Dynamics of Production

Given the expressions for the aggregate production function of industry j, let compute the growth rates of output per industry.

If $x_{jt} < \overline{A_{jF}} \quad \forall t \in [1,\infty)$, the aggregate production function is defined as in equation (23). Then the growth rate of output is given by:

$$\frac{\dot{Y}_{Jt}}{Y_{Jt}} = \frac{\dot{M}_t}{M_t} + (\alpha+\beta)\frac{\dot{K}_{jt}}{K_{jt}} + (\gamma+\delta)\frac{\dot{L}_{jt}}{L_{jt}} \qquad (26)$$

If $x_{jt} = \overline{A_{jF}} \quad \forall t \in [1,\infty)$, the aggregate production function is indicated in (24). The growth rate of output is equal to:

$$\frac{\dot{Y}_{Jt}}{Y_{Jt}} = \frac{\dot{M}_t}{M_t+1} + (\alpha+\beta)\frac{\dot{K}_{jt}}{K_{jt}} + (\gamma+\delta)\frac{\dot{L}_{jt}}{L_{jt}} \qquad (27)$$

Finally, if $x_{jt} > \overline{A_{jF}} \quad \forall t \in [2,\infty)$, the aggregate production function is expressed in (25). Given the homogeneity of capital and labour across production and research, the growth rate of output is:

$$\frac{\dot{Y}_{Jt}}{Y_{Jt}} = \frac{\dot{x}_{jt}}{\overline{A_{jF}} + x_{jt}} + (\alpha+\beta)\frac{\dot{K}_{jt}}{K_{jt}} + (\gamma+\delta)\frac{\dot{L}_{jt}}{L_{jt}} \qquad (28)$$

Using the results for the growth rates of output, we can compute the rate of technological progress for industry j as the Solow residual, in such a way to exclude the variation in capital and labour.

If $x_{jt} < \overline{A_{jF}} \quad \forall t \in [1,\infty)$, from equation (26) we have:

$$a_{Jt} = \frac{\dot{Y}_{Jt}}{Y_{Jt}} - (\alpha+\beta)\frac{\dot{K}_{jt}}{K_{jt}} - (\gamma+\delta)\frac{\dot{L}_{jt}}{L_{jt}} = \frac{\dot{M}_t}{M_t} \qquad (29)$$

If $x_{jt} = \overline{A_{jF}} \quad \forall t \in [1,\infty)$, from equation (27) we have:

$$a_{Jt} = \frac{\dot{Y}_{Jt}}{Y_{Jt}} - (\alpha+\beta)\frac{\dot{K}_{jt}}{K_{jt}} - (\gamma+\delta)\frac{\dot{L}_{jt}}{L_{jt}} = \frac{\dot{M}_t}{M_t+1} \qquad (30)$$

If $x_{jt} > \overline{A_{jF}} \quad \forall t \in [2,\infty)$, from equation (28) we have:

$$a_{Jt} = \frac{\dot{Y}_{Jt}}{Y_{Jt}} - (\alpha+\beta)\frac{\dot{K}_{jt}}{K_{jt}} - (\gamma+\delta)\frac{\dot{L}_{jt}}{L_{jt}} = \frac{\dot{x}_{jt}}{\overline{A_{jF}} + x_{jt}} = \frac{\dot{x}_{jt}}{A_{jLt}} \qquad (31)$$

From the above results, we can notice that, when $x_{jt} \le \overline{A_{jF}}$, that is when the technological advantage of the leader is lower than or equal to the technology level of the follower, the key determinant of technological progress is the rate of entry in the industry, that is the growth rate of the number of firms. In fact, an increase of potential competition stimulates innovation, also among the firms initially active only in production, since the reduction of the profit margin due to the higher number of competitors may induce firms to invest capital and labour in research activity. On the opposite, when $x_{jt} > \overline{A_{jF}}$, that is when the technological step of the leader is higher than the technology level of the follower, the main determinant of technological progress is the variation of the leader's technological advantage: if the leader introduces further innovations and then increases its technological level, so enlarging the advantage with respect to the follower, this implies a positive rate of technological progress for industry j. For these reasons, we are now interested in studying the dynamics of these two important variables, that is the number of firms in the industry (M_t) and the technological advantage of the leader (x_{jt}).

2.6 The Dynamics of Market Structure

The dynamics of M_t has to take into account both the firms which enter the industry and the firms which exit the market. So the variation in time t of M_t is equal to the difference between the new firms active in the market and the old firms now out of the market. The entry decision is determined by various factors: the expectation about future profits, the type of entry barriers in the market, the availability of new technologies for an entrant firm (for example for foreign firms implementing direct investments). The exit decision can be caused by firm-specific factors, such as its financial condition, as well as by economy-wide factors, like the quality of bankruptcy law, the existence of imperfections in credit market. Then we can write the law of motion of firms in industry j as follows:

$$\dot{M}_t = E_t\left[\frac{\pi_{jE\,t+1}}{\tilde{\pi}_{jt}}\right]\varphi\eta L_{Jt} - \chi M_t \qquad (32)$$

where $E_t\left[\pi_{jEt+1}/\tilde{\pi}_{jt}\right]$ is the expected profit ratio (that is the ratio between the expected profit of the entrant and a reference measure of profit for a follower firm in such industry); φ is the parameter of a Poisson distribution indicating the hazard rate of entry for new firms; η is a variable indicating the type of barriers to entry, such that $0 < \eta < 1$, where a value $\eta = 1$ defines a completely free-entry situation while $\eta = 0$ means no entry possibility in the industry; L_{Jt} is the total amount of workers, such that each of them, availing of a new technology or a new idea, can become an entrepreneur and start a new firm; χ is a parameter of a Poisson distribution denoting the hazard rate of exit for the existing firm. If the number of entrants is higher than the number of exiting firms, $\dot{M}_t$ is positive and then the total number of firms in the industry increases.

In particular, we must pay attention to the expected profit ratio, which defines the profitability of an entry decision. In particular, we compute the expected profit from entry as the ratio between the aggregate profit of industry j and the number of existing firms increased by one unit[12]. Then we compare this expected profit with a reference measure of profit, that is the profit obtained by a follower active in that industry:

$$\tilde{\pi}_{jt} = A_{jFt}K_{jt}^{\alpha+\beta}L_{jt}^{\gamma+\delta} - w_t L_{jt} - r_t K_{jt}$$

The ratio between these two variables can be equal to, lower or higher than 1. If $E_t\left[\pi_{jEt+1}/\tilde{\pi}_{jt}\right]$>1, the entry is profitable and then this induces more firms to enter the market, while, if $E_t\left[\pi_{jEt+1}/\tilde{\pi}_{jt}\right]$<1, the entry is not profitable and then firms are discouraged from entering such industry.

The aggregate profit of industry j varies depending on the number of existing firms and on their technological level: then, in order to compute it, we have to distinguish three different cases, as for the determination of the aggregate output. In fact, we define the aggregate profit as follows:

$$\Pi_{Jt} = \sum_{1}^{M}\pi_{jmt} = \pi_{jLt} + \sum_{1}^{M-1}\pi_{jmt}$$

Then, substituting the profit functions for the leader and for the follower, we obtain:

$$\Pi_{Jt} = \left(A_{jFt} + x_{jt}\right)K_{jRt}^{\alpha}K_{jPt}^{\beta}L_{jRt}^{\gamma}L_{jPt}^{\delta} - w_t L_{jRt} - w_t L_{jPt} - r_t K_{jRt} - r_t K_{jPt} + (M-1)\left[A_{jFt}K_{jPt}^{\alpha+\beta}L_{jPt}^{\gamma+\delta} - w_t L_{jPt} - r_t K_{jPt}\right]$$

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[12] Given that we don't know the aggregate profit of the industry in time $t+1$, we use as an approximation the aggregate profit in time t: then we assume that aggregate profit remains the same and that, because of such entry, it has to be divided among the existing firms plus the entrant firm.

Applying the homogeneity assumption for production and research inputs as well as for wages and interest rates and defining $\overline{A_{jF}}$ as the technology level of the follower, we have:

$$\Pi_{Jt} = \left(\overline{A_{jF}} + x_{jt}\right)\left[(1+\mu)K_{jt}\right]^{\alpha}\left[(1-\mu)K_{jt}\right]^{\beta}\left[(1+\nu)L_{jt}\right]^{\gamma}\left[(1-\nu)L_{jt}\right]^{\delta} - w_t\left[(1+\mu)L_{jt}\right] + \\ - w_t\left[(1-\mu)L_{jt}\right] - r_t\left[(1+\nu)K_{jt}\right] - r_t\left[(1-\nu)K_{jt}\right] + (M-1)\left[\overline{A_{jF}}K_{jt}^{\alpha+\beta}L_{jt}^{\gamma+\delta} - w_tL_{jt} - r_tK_{jt}\right]$$

We know that in equilibrium $\mu = \mu^*$ & $\nu = \nu^*$ (such that $0 < \mu^* < 1$ & $0 < \nu^* < 1$), then conditions (11) and (12) hold. So, rearranging terms, the aggregate profit function of industry j is:

$$\Pi_{Jt} = \left(M_t\overline{A_{jF}} + x_{jt}\right)K_{jt}^{\alpha+\beta}L_{jt}^{\gamma+\delta} - (M_t+1)\left(w_tL_{jt} + r_tK_{jt}\right)$$

Then we can compute the expected profit for the three different cases.

If $x_{jt} < \overline{A_{jF}} \quad \forall t \in [1,\infty)$, the expected profit for an entrant in industry j is:

$$E_t\left[\pi_{jEt+1}\right] = \pi_{jEt} = \frac{\Pi_{Jt}}{M_t} = \frac{M_t}{M_t+1}\underbrace{\left[\overline{A_{jF}}K_{jt}^{\alpha+\beta}L_{jt}^{\gamma+\delta} - w_tL_{jt} - r_tK_{jt}\right]}_{=\tilde{\pi}_{jt}}$$

Then the expected profit ratio is given by:

$$E_t\left[\frac{\pi_{jE\,t+1}}{\tilde{\pi}_{jt}}\right] = \frac{M_t}{M_t+1} < 1 \qquad (33)$$

This implies that, when the technological advantage of the leader is so small to discourage innovation activity, the expected profit from entry is even lower than the current follower's profit and then entry is not profitable.

If $x_{jt} = \overline{A_{jF}} \quad \forall t \in [1,\infty)$, the expected profit is:

$$E_t\left[\pi_{jEt+1}\right] = \pi_{jEt} = \frac{\Pi_{Jt}}{M_t+1} = \frac{M_t+1}{M_t+1}\underbrace{\left[\overline{A_{jF}}K_{jt}^{\alpha+\beta}L_{jt}^{\gamma+\delta} - w_tL_{jt} - r_tK_{jt}\right]}_{=\tilde{\pi}_{jt}}$$

So the expected profit ratio is given by:

$$E_t\left[\frac{\pi_{jE\,t+1}}{\tilde{\pi}_{jt}}\right] = 1 \qquad (34)$$

Finally, if $x_{jt} > \overline{A_{jF}} \quad \forall t \in [2,\infty)$, the expected profit is:

$$E_t\left[\pi_{jEt+1}\right] = \pi_{jEt} = \frac{1}{2}\left\{2\underbrace{\left[\overline{A_{jF}}K_{jt}^{\alpha+\beta}L_{jt}^{\gamma+\delta} - w_tL_{jt} - r_tK_{jt}\right]}_{=\tilde{\pi}_{jt}}\right\} + \frac{1}{2}\left(x_{jt} - \overline{A_{jF}}\right)K_{jt}^{\alpha+\beta}L_{jt}^{\gamma+\delta}$$

Then the expected profit ratio is given by:

$$E_t\left[\frac{\pi_{jE\,t+1}}{\tilde{\pi}_{jt}}\right] = 1 + \frac{1}{2}\frac{\left(x_{jt} - \overline{A_{jF}}\right)K_{jt}^{\alpha+\beta}L_{jt}^{\gamma+\delta}}{\overline{A_{jF}}K_{jt}^{\alpha+\beta}L_{jt}^{\gamma+\delta} - w_tL_{jt} - r_tK_{jt}} > 1 \qquad (35)$$

As we have seen in equations (33), (34) and (35), the expected profit ratio may assume three different values, depending on the size of the technological advantage of the leader x_{jt}. In particular, if $x_{jt} < \overline{A_{jF}} \quad \forall t \in [1, \infty)$, the expected profit ratio is lower than l, while if $x_{jt} = \overline{A_{jF}} \quad \forall t \in [1, \infty)$ or $x_{jt} > \overline{A_{jF}} \quad \forall t \in [2, \infty)$, the expected profit ratio is equal to or higher than 1. So we can conclude that the expected profit ratio is higher if the technological advantage of the leader is larger.

2.7 Competition Policy in the Market and for the Market

The analysis of market structure in high-technology industries allows us to identify the variables which better define the intervention and the impact of competition policy. As anticipated in the introduction, we want to distinguish the various effects of competition in the market and competition for the market.

The policies designed to favour competition *in* the market follow the purpose to guarantee the same competitive conditions for all the firms operating in a given industry through the sharing of the same technology or of the same product design, such that they can compete on prices. For the perspective of the analysis, compulsory licensing is a clear example of a policy promoting competition *in* the market. A typical situation which can eventually require this type of intervention by a competition authority is known in antitrust policy as refusal to deal. Let consider an innovative firm which has obtained a near-monopolistic position thanks to the exploitation of its own invention, protected by a patent. Another firm is interested in entering the same market or an adjacent market but, in order to supply a given product, needs to know the idea which is object of intellectual property protection. The leader doesn't have any incentive to provide the entrant with its own idea, because by revealing the details of the patent it would share such innovation with other firms, which at this point would be able to reproduce it and to compete with the innovator supplying the product at a lower price. In the practice of competition authorities, such refusal to deal may be considered as an anti-competitive behaviour under some conditions[13]: if the requested intellectual property is indispensable to compete; if the refusal to deal causes the complete foreclosure of the market; and if the refusal prevents the emergence of markets for new products for which there is substantial demand. In these cases, compulsory licensing can be adopted as a remedy against the innovator. But this decision, which improves competition *in* the market, can be very detrimental for the incentive to innovate, especially if the product to be developed by the licensor can be in direct

[13] These are the three conditions usually required in the legal practice by the European Commission and by the European Court of Justice in order to define the anti-competitive nature of the innovator's conduct and in order to argue the pro-competitive effects of compulsory licensing.

competition with the one of the intellectual property holder, and even more if the licensor exploits the innovative idea also to supply the same product of the patent holder.

As a result, this competition policy *in* the market eliminates the technological advantage of the leader and it also reduces or removes the profit of the firm leader in research. But especially, this policy can sensibly modify the structure of the entire industry. After one period, the expected profit of a firm in industry j tends to decrease in the following period, due to such time-inconsistency in research policy. But a firm has no incentive to invest in R&D if it knows that, notwithstanding the protection of intellectual property, it can be obliged to share the same technology with the followers: as a consequence of that, no firm will be finally active in research.

In our theoretical framework, the disincentive to innovate can be explained with reference to the variation of the expected profit ratio, as induced by this competitive policy. In fact, the implementation of the competition policy *in* the market, by eliminating the technological advantage of the leader, determines a reduction of the expected profit ratio $E_t\left[\pi_{jEt+1}/\tilde{\pi}_{jt}\right]$ to the minimum level. Then we can argue that a stronger competition in the market, or alternatively a weaker protection of intellectual property of innovations, reduces the technological advantage of the leader and then implies a lower value of the expected profit ratio[14].

Finally, we have to consider the policies aimed at improving competition *for* the market, which pursue the objective to increase the number of firms supplying a given product, by allowing more firms to enter that market. They can operate through various instruments, such as the reduction or the abolition of regulatory entry barriers or the introduction of R&D tax credits for new firms. In particular, for the scope of the analysis, a liberalization process aimed at reducing regulatory barriers is a typical example of a policy designed to enhance competition for the market. In this model, the level of barriers to entry is measured by the variable η, that we could also define as a free-entry variable, since it measures the freedom of entry in the industry: then a competition policy for the market augments the value η and, through the reduction of barriers to entry, increases the number of entrants. So we can infer that a low level of η implies less competition *for* the market and more entry barriers.

2.8 The Dynamics of the Technological Gap

The technological advantage of the leader is an outcome of R&D activity, then it is an increasing function of the amount of inputs devoted to research, as well as of the number of firms

[14] In a corresponding way, we can also state that a weaker competition in the market, and then a higher protection of intellectual property, allows for a larger technological advantage of the leader and so implies a higher expected profit ratio.

involved in the considered high-technology industry. In particular, we define the technological gap as follows:

$$x_{jt} = g\left(K_{jRt}, L_{jRt}, M_t\right) = \left(K_{jRt}\ L_{jRt}\right)^{M_t} \qquad (36)$$

So research capital and labour, which we have already seen as inputs of the production function, are relevant in this case as determinants of the technological advantage of the leader, because they are used in the innovation process for improving its production technology. Moreover, the number of firms operating in the same market positively affects the productivity of this research activity. In fact, for a given amount of research capital and labour, an increase of the number of potential competitors produces an exponential rise in the technological advantage of the leader. This is because the leader is induced to better exploit the research activity in order to obtain substantial improvements in its technology level: so the threat of entry has a clearly positive effect on the outcome of the innovative activity of the leader.

In order to analyze the dynamics of the technological gap between the leader and the follower, we have to compute the growth rate of x_{jt}. The technological advantage of the leader is defined in equation (36). Then, taking logs and deriving with respect to time, we obtain:

$$\frac{\dot{x}_{jt}}{x_{jt}} = M_t\left(\frac{\dot{K}_{jRt}}{K_{jRt}} + \frac{\dot{L}_{jRt}}{L_{jRt}}\right) + \dot{M}_t\left(ln\,K_{jRt} + ln\,L_{jRt}\right) \qquad (37)$$

2.9 The Rate of Technological Progress

After studying the dynamics of the number of firms in the industry $\left(M_t\right)$ and of the technological advantage of the leader $\left(x_{jt}\right)$, we can determine the rate of technological progress in industry j and analyze its determinants, with particular attention to the variables referring to competition in the market and for the market. So let consider the results obtained from equations (29), (30) and (31) and let substitute the expressions for $\dot{M}_t$ and $\dot{x}_{jt}$.

If $x_{jt} < \overline{A_{jF}} \quad \forall t \in [1, \infty)$, from equation (29) we have:

$$a_{Jt}\left(x_{jt} < \overline{A_{jF}}\right) = \frac{\dot{M}_t}{M_t} = \frac{E_t\left[\dfrac{\pi_{jE\,t+1}}{\tilde{\pi}_{jt}}\right]\varphi\eta L_{Jt} - \chi M_t}{M_t} \qquad (38)$$

where the expected profit ratio can assume only the minimum value, that is :

$$E_t\left[\frac{\pi_{jE\,t+1}}{\tilde{\pi}_{jt}}\right] = \frac{M_t}{M_t + 1} < 1$$

Substituting this value for the expected profit ratio in equation (38), we obtain:

$$a_{Jt}\left(x_{jt+1} < \overline{A_{jF}} \middle| x_{jt} < \overline{A_{jF}}\right) = \frac{\dot{M}_t}{M_t} = \frac{\varphi\eta L_{Jt}}{M_t + 1} - \chi \qquad (39)$$

In this case, the technological structure of the industry is such that no investment in research and development can be profitable and then no firm is interested in acquiring a technological leadership. For this reason, we can say that the equilibrium with $x_{jt} < \overline{A_{jF}} \quad \forall t \in [1,\infty)$ is a sclerotic equilibrium, in the sense that it is expected to persist because of the unwillingness of the existing firms to promote research and development. This explains why public authorities, and in particular competition authorities, should avoid to lead the economy to such equilibrium, given that the economy, once it has reached this equilibrium, cannot move away from it. Nevertheless, since the rate of technological progress can be however positive, some variables may influence such rate.

As we can infer from equation (39), a_{Jt} is an increasing function of η and of L_{Jt}. The first observation implies that a competition policy for the market, aimed at reducing barriers to entry, promotes technological progress because it augments the number of firms potentially engaged in the innovation activity. In fact:

$$\frac{\partial a_{Jt}}{\partial \eta} = \frac{\varphi L_{Jt}}{M_t + 1} > 0$$

The second consideration presents a scale effect related to the number of workers in industry j: since potentially each worker could become an entrepreneur, a higher amount of labour force determines a positive effect on technological progress because, given a hazard rate of entry φ, new entrepreneurs can enter the market.

$$\frac{\partial a_{Jt}}{\partial L_{Jt}} = \frac{\varphi\eta}{M_t + 1} > 0$$

If $x_{jt} = \overline{A_{jF}} \quad \forall t \in [1,\infty)$, from equation (30) we have:

$$a_{Jt}\left(x_{Jt} = \overline{A_{jF}}\right) = \frac{\dot{M}_t}{M_t + 1} = \frac{E_t\left[\frac{\pi_{jE\,t+1}}{\tilde{\pi}_{jt}}\right]\varphi\eta L_{Jt} - \chi M_t}{M_t + 1} \qquad (40)$$

where the expected profit ratio may assume several values. In fact:

$$E_t\left[\frac{\pi_{jE\,t+1}}{\tilde{\pi}_{jt}}\right] = \left\{\frac{M_t}{M_t + 1}; 1; 1 + \frac{1}{2}\frac{\left(x_{jt+1} - \overline{A}_{jF}\right)K_{jt}^{\alpha+\beta}L_{jt}^{\gamma+\delta}}{\overline{A}_{jF}K_{jt}^{\alpha+\beta}L_{jt}^{\gamma+\delta} - w_t L_{jt} - r_t K_{jt}}\right\}$$

Even before substituting the various possible values for the expected profit ratio, we can observe that also in this case the rate of technological progress a_{Jt} is an increasing function of the free-entry variable η and of the number of workers in the industry L_{Jt}. Moreover, we can also see that a_{Jt} is a positive function of the expected profit ratio $E_t\left[\pi_{jEt+1}/\tilde{\pi}_{jt}\right]$:

$$\frac{\partial a_{Jt}}{\partial E_t\left[\frac{\pi_{jE\,t+1}}{\tilde{\pi}_{jt}}\right]} = \frac{\varphi\eta L_{Jt}}{M_t+1} > 0$$

Indeed, if the expected profit ratio increases, not only more firms are induced to enter the market, but also the existing firms are induced to invest in R&D because in this way they can get a profit from the technological leadership and this can be higher than current profit.

In particular, if $x_{jt} = \overline{A_{jF}}$ but $x_{jt+1} < \overline{A_{jF}} \quad \forall t \in [1,\infty)$, we have:

$$a_{Jt}\left(x_{jt+1} < \overline{A_{jF}} \middle| x_{jt} = \overline{A_{jF}}\right) = \frac{\dot{M}_t}{M_t+1} = \frac{M_t}{M_t+1}\left(\frac{\varphi\eta L_{Jt}}{M_t+1} - \chi\right) \qquad (41)$$

Moreover, if $x_{jt} = \overline{A_{jF}}$ and $x_{jt+1} = \overline{A_{jF}} \quad \forall t \in [1,\infty)$, we have:

$$a_{Jt}\left(x_{jt+1} = \overline{A_{jF}} \middle| x_{jt} = \overline{A_{jF}}\right) = \frac{\dot{M}_t}{M_t+1} = \frac{\varphi\eta L_{Jt}}{M_t+1} - \chi\frac{M_t}{M_t+1} \qquad (42)$$

Finally, if $x_{jt} = \overline{A_{jF}}$ and $x_{jt+1} > \overline{A_{jF}} \quad \forall t \in [1,\infty)$, we have:

$$a_{Jt}\left(x_{jt+1} > \overline{A_{jF}} \middle| x_{jt} = \overline{A_{jF}}\right) = \frac{\dot{M}_t}{M_t+1} = \frac{\varphi\eta L_{Jt}}{M_t+1} + \frac{1}{2}\frac{\left(x_{jt+1} - \overline{A}_{jF}\right)K_{jt}^{\alpha+\beta}L_{jt}^{\gamma+\delta}}{\overline{A}_{jF}K_{jt}^{\alpha+\beta}L_{jt}^{\gamma+\delta} - w_t L_{jt} - r_t K_{jt}}\frac{\varphi\eta L_{Jt}}{M_t+1} - \chi\frac{M_t}{M_t+1} \qquad (43)$$

So, given that the rate of technological progress a_{Jt} is a positive function of the expected profit ratio $E_t\left[\pi_{jEt+1}/\tilde{\pi}_{jt}\right]$ and since the latter is increasing in the technological advantage of the leader x_{jt+1}, we can notice that a_{Jt} is an increasing function of x_{jt+1}. In fact, if we compare the previous expressions for a_{Jt}, we can observe that:

$$a_{Jt}\left(x_{jt+1} < \overline{A_{jF}} \middle| x_{jt} = \overline{A_{jF}}\right) < a_{Jt}\left(x_{jt+1} = \overline{A_{jF}} \middle| x_{jt} = \overline{A_{jF}}\right) < a_{Jt}\left(x_{jt+1} > \overline{A_{jF}} \middle| x_{jt} = \overline{A_{jF}}\right) \qquad (44)$$

This implies that, provided that $x_{jt} = \overline{A_{jF}} \quad \forall t \in [1,\infty)$, the rate of technological progress augments if the technological advantage of the leader in the following period is higher. This depends not only on the innovation effort of the firms active in research, but also on the perspective of future profits that the leader is able to collect thanks to the protection of intellectual property.

In fact, if the antitrust authority imposes the leader to share its technology level with the followers, because it considers such technology as an essential facility for conducting a given economic activity, in the following period it will be $x_{jt+1} < \overline{A_{jF}}$, then the leader won't be able to get any profit from its previous effort in innovation. The consequence is that the firm active in research, after losing its technological leadership because of the compulsory licensing, won't have any other incentive to invest in R&D because the commitment of the government to protect the intellectual property on the new ideas won't be considered anymore as credible. And this lack of credibility in patent protection will affect not only the previous leader, but also the other firms, such that no firm will be interested in innovating its technology without any guarantee about the appropriate reward for research effort.

If $x_{jt} > \overline{A_{jF}} \quad \forall t \in [2,\infty)$, from equation (31) we have:

$$a_{Jt}\left(x_{jt} > \overline{A_{jF}}\right) = \frac{\dot{x}_{jt}}{A_{jLt}} = M_t\left(\frac{\dot{K}_{jRt}}{K_{jRt}} + \frac{\dot{L}_{jRt}}{L_{jRt}}\right)\frac{x_{jt}}{A_{jLt}} + \underbrace{\left\{E_t\left[\frac{\pi_{jE\,t+1}}{\tilde{\pi}_{jt}}\right]\varphi\eta L_{Jt} - \chi M_t\right\}}_{=\dot{M}_t}\left(ln\,K_{jRt} + ln\,L_{jRt}\right)\frac{x_{jt}}{A_{jLt}} \qquad (45)$$

where the expected profit ratio may assume several values. In fact:

$$E_t\left[\frac{\pi_{jE\,t+1}}{\tilde{\pi}_{jt}}\right] = \left\{\frac{M_t}{M_t+1};\, 1;\, 1+\frac{1}{2}\frac{\left(x_{jt+1} - \overline{A}_{jF}\right)K_{jt}^{\alpha+\beta}L_{jt}^{\gamma+\delta}}{\overline{A}_{jF}K_{jt}^{\alpha+\beta}L_{jt}^{\gamma+\delta} - w_t L_{jt} - r_t K_{jt}}\right\}$$

Also in this case, we notice from equation (45) that the rate of technological progress is an increasing function of the free-entry variable η, of the number of workers in the industry L_{Jt} and of the expected profit ratio $E_t\left[\pi_{jEt+1}/\tilde{\pi}_{jt}\right]$. Then, substituting the different values of the expected profit ratio, we obtain the specific expressions for a_{Jt}.

In particular, if $x_{jt} > \overline{A_{jF}}$ but $x_{jt+1} < \overline{A_{jF}} \quad \forall t \in [2,\infty)$, we have:

$$a_{Jt}\left(x_{jt+1} < \overline{A_{jF}} \middle| x_{jt} > \overline{A_{jF}}\right) = \frac{\dot{x}_{jt}}{A_{jLt}} = M_t\left(\frac{\dot{K}_{jRt}}{K_{jRt}} + \frac{\dot{L}_{jRt}}{L_{jRt}}\right)\frac{x_{jt}}{A_{jLt}} + \underbrace{\left\{\frac{M_t}{M_t+1}\varphi\eta L_{Jt} - \chi M_t\right\}}_{=\dot{M}_t}\left(ln K_{jRt} + ln L_{jRt}\right)\frac{x_{jt}}{A_{jLt}} \qquad (46)$$

Moreover, if $x_{jt} > \overline{A_{jF}}$ and $x_{jt+1} = \overline{A_{jF}} \quad \forall t \in [2,\infty)$, we have:

$$a_{Jt}\left(x_{jt+1} = \overline{A_{jF}} \middle| x_{jt} > \overline{A_{jF}}\right) = \frac{\dot{x}_{jt}}{A_{jLt}} = M_t\left(\frac{\dot{K}_{jRt}}{K_{jRt}} + \frac{\dot{L}_{jRt}}{L_{jRt}}\right)\frac{x_{jt}}{A_{jLt}} + \underbrace{\left\{\varphi\eta L_{Jt} - \chi M_t\right\}}_{=\dot{M}_t}\left(ln\,K_{jRt} + ln\,L_{jRt}\right)\frac{x_{jt}}{A_{jLt}} \qquad (47)$$

Finally, if $x_{jt} > \overline{A_{jF}}$ and $x_{jt+1} > \overline{A_{jF}} \quad \forall t \in [2,\infty)$, we have:

$$a_{Jt}\left(x_{jt+1} > \overline{A_{jF}} \middle| x_{jt} > \overline{A_{jF}}\right) = \frac{\dot{x}_{jt}}{A_{jLt}} = M_t\left(\frac{\dot{K}_{jRt}}{K_{jRt}} + \frac{\dot{L}_{jRt}}{L_{jRt}}\right)\frac{x_{jt}}{A_{jLt}} + \underbrace{\left\{\left[1+\frac{1}{2}\frac{\left(x_{jt+1} - \overline{A}_{jF}\right)K_{jt}^{\alpha+\beta}L_{jt}^{\gamma+\delta}}{\overline{A}_{jF}K_{jt}^{\alpha+\beta}L_{jt}^{\gamma+\delta} - w_t L_{jt} - r_t K_{jt}}\right]\varphi\eta L_{Jt} - \chi M_t\right\}}_{=\dot{M}_t}\left(ln K_{jRt} + ln L_{jRt}\right)\frac{x_{jt}}{A_{jLt}} \qquad (48)$$

The comparison among equations (46), (47) and (48) allow us to draw some conclusions about the impact of the technological advantage of the leader on the rate of technological progress. In fact, we observe that:

$$a_{Jt}\left(x_{jt+1} < \overline{A_{jF}} \middle| x_{jt} > \overline{A_{jF}}\right) < a_{Jt}\left(x_{jt+1} = \overline{A_{jF}} \middle| x_{jt} > \overline{A_{jF}}\right) < a_{Jt}\left(x_{jt+1} > \overline{A_{jF}} \middle| x_{jt} > \overline{A_{jF}}\right) \qquad (49)$$

As discussed for the inequalities presented in (44), technological progress is higher when the distance between the leader and the follower is expected to be larger in the following period. This is because the leader is induced to invest more in R&D when it expects that it will get the exclusive right to exploit the new technology and that it will obtain the appropriate reward for innovation. A policy aimed at improving competition in the market, by imposing the sharing of an innovation, can reduce the technological distance between the leader and the follower in the following period. For this reason x_{jt+1} can be used as a measure of competition policy in the market: a low value of x_{jt+1}(such as $x_{jt+1} < \overline{A_{jF}}$) is caused by a full implementation of such policy, while a high value of x_{jt+1}(such as $x_{jt+1} > \overline{A_{jF}}$) is the result of a limited application of this policy. In conclusion, competition in the market decreases the technological advantage of the leader in the future period but, at the same time, it also reduces the rate of technological progress by lowering the incentives for innovation.

So, in high-technology industries, competition policy may produce different effects depending on the objectives and on the instruments. In fact, competition for the market generally produces a positive effect on technological progress because it increases the number of firms in a given market and then stimulates the investments in research and development. On the opposite, competition in the market may have a negative impact on technological progress, because it reduces the expected reward for the innovator and then eliminates the incentive to invest in R&D.

3. Conclusions

The present paper analyzes the relationship between competition policy and economic growth in an economy with high-technology industries and it aims at extending the existing literature on the topic by introducing the distinction between competition in the market and competition for the market. In fact, the literature on competition and growth has focused the attention on a notion of competition, which considers only the actual interaction among the existing firms in the market and then neglects the role of entry in determining potential competition. In particular, the entry threat plays a very important function in high-technology industries, where market structure is extremely dynamic, both because new firms may enter the industry thanks to a leapfrogging technology, and because the boundaries of the market are not clearly defined and are subject to a constant evolution. Moreover, the distinction among various types of competition policy is worthy of interest, because competition in the market and for the market can produce different effects on technological progress and economic growth.

Using this distinction, our analysis of the relation between competition policy and economic growth also provides some policy implications for the design and the implementation of antitrust policy in a growth-enhancing perspective. In particular, this study shows that a policy aimed at increasing competition for the market always produces a positive impact on innovation and growth. On the opposite, a policy designed to improve competition in the market may generate a negative effect in high-technology industries. In fact, in such industries, firms are induced to innovate because they are interested in obtaining the monopolistic profits due to the exploitation of a patent: then, a competition policy which compromises this expected return from innovation may discourage firms from running a research activity and then it can lower technological progress in the long-term.

Consequently, this result raises some doubts on the dynamic efficiency, in a long-run perspective, of those competition policies which prosecute the monopolistic firms that take advantage of their dominant position, even if they have gained this monopoly power thanks to important innovations protected by a patent. For example, the implementation of antitrust policy in Europe shows that in some cases the abuse of dominance is defined and sanctioned no matter how a firm has obtained that position. Then, the key issue for the policy-maker is to judge whether a competition policy like this one can be detrimental for long-run growth and, in case, how this policy should be designed in order to avoid negative effects on economic growth. In particular, it is worth to pay specific attention to the issue of the intersection between antitrust policy and intellectual property protection: in fact, the approach adopted by the Antitrust Authorities on this point might require a revision, in the direction of introducing a specific consideration for IP protection.

In any case, as the results of the model demonstrate, the best competition policy to be implemented in a high-technology industry is a policy designed to facilitate the entry of new firms in the market, through the reduction of previous entry barriers. In fact, in these industries the threat of entry by new innovating firms, since it increases potential competition, induces the incumbent firms and in particular the leader firm to invest more in research and development.

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