Defensive Strategies in the Quality Ladders

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Abstract

This paper studies theoretically and empirically the consequences of defensive strategies in R&D races. Using a quality-ladders model, we allow for endogeneous incumbent R&D advantages explained by strategies that seek to limit knowledge diffusion. Market institutions appear to be crucial to foster aggregate R&D intensity and to determine who innovates. Regulatory provisions reducing the possibilities of defensive strategies in the process of production may indeed increase the incentives to carry out R&D. This effect is more likely to be observed when the size of innovation is high. Using time-series cross-section data of manufacturing industries among 17 OECD countries we test the relationship between regulation and R&D expenditure over value added. We allow for a differentiated effect of regulation for industries producing and using ICT. The evidence is consistent with the model's predictions.

Keywords: R&D Contest, Market Regulation, Industry-level Time-Series Cross-Section data.

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1 Introduction

Innovation not only implies the discovery of a new "improved" product. It is also a process influenced by rent seeking strategies aiming at consolidating leading business positions. The so called Coca Cola "formula" or compatibility issues involved in ERP business applications and in operating systems are examples which testify to the fact that particular features of manufactured products are innovation strategies in themselves. Namely, the specific way in which a discovery is fabricated has consequences over the diffusion of knowledge. At least partially, a new product embodies the state-of-the-art information in itself. As shown by several R&D surveys, patent protection is not the only strategy allowing business appropriation. In fact, it is usually accompanied by secrecy, the use of lead time advantages and manufacturing complementarities (see for instance Cohen et al., 2000; Cohen et al., 2002; Levin et al., 1987).

The set of strategies among rivals in R&D activities has therefore multiple dimensions, including manufacturing. In this context, market regulation reforms aiming at exploiting the "trimming fat" effects of competition may trigger defensive reactions rather than pro-innovation ones. Thoenig and Verdier (2003) show how globalisation, by increasing the threat of leapfrogging, induces firms to adopt a technical bias in production. Firms introduce tacitness in the knowledge embodied in production, but they do it at the cost of increasing their skill-labour intensity. Closely related, Dinopoulos and Syropoulos (2007) highlight the role of "rent protecting activities" in quality upgrading innovation. Following this idea, incumbents spend resources in strategies allowing them to preserve their rents. These activities are at the centre of the innovative dynamics and include patent blocking, copyrights, limiting technology diffusion and the like. In line with these theoretical arguments and the evidence provided by R&D surveys, Crépon and Duguet (1997) find within-industry evidence of negative R&D externalities among French manufacturing firms. The authors interpret this result as the outcome of competitors' rivalry. Furthermore, in Amable, Demmou and Ledezma (2007), we found no evidence concerning a positve effect of deregulation on innovation at the leading edge. On the contrary, in most of specifications, regulatory provisions exert a positive effect on innovation at the very top productivity level. As we noticed, if one includes active leaders in the model of Aghion et al. (2005), results are less conclussive.

This paper, focuses in more detail on this defensive strategic behaviour and its impact on R&D effort. We call defensive strategies those actions aiming at protecting the firm's current business position from the risk of loosing the innovation contest. Our main argument is that rivalry among firms, when a set of defensive strategies is available, may reduce the incentives to carry out R&D. This is specially the case when these strategies rely on manufacturing complexity. This kind of manufacturing strategies limiting knowledge spillovers is what we call "technological bias". In these circumstances, regulation can play a role in determining the possibilities of technological bias. Moreover, as new discoveries may represent new entrants, the way through which defensive strategies are constrained (*de jure*) has an impact on market structure (*de facto*). Besides antitrust institutions, some usually called "market barriers" may in fact limit the barriers constructed by incumbents to protect their rents. For instance, procedures of certification and regulation in services used as input in manufacturing (or using manufacturing as input) actually determine the set of possibilities of the manufactured product. These "rules of the game" are taken into account by the innovator when deciding the way in which its new discovery will be fabricated. Thus, they shape the visible properties containing the state-of-the-art knowledge and, as a consequence, the difficulties faced in R&D activities. The latter can be high enough to deter prospective innovators. Hence, the rules constraining the scope of possibilities of technological bias will determine how much R&D effort is performed and who does it. This is one important contribution of this paper since in most Schumpeterian models, incumbents do not innovate. We present a theoretical model featuring these mechanisms. Using time-series cross-section data of manufacturing industries from 17 OECD countries in the period 1987-2003, we provide evidence for this argument.

The model builds on a "quality-ladders" framework, which provides a useful baseline to analyse innovative behaviour. It encompasses, in a tractable manner, the Schumpeterian notion of creative destruction as modelled by Aghion and Howitt (1992) and Segerstrom, Anant and Dinopoulos (1990). In the pioneer model of Grossman and Helpman (1991), innovation improves the quality of goods. Outsider firms carry out risky R&D investment. The successful innovator replaces the current incumbent and becomes the new monopolistic leader, who remains in the market until the next innovation takes place. Each innovator "climbs" the quality-ladder in the industry. The discounted monopolistic profits are the reward for new innovators that "steal" the incumbent's rents.

Quality-ladders models have evolved to solve problems of scale effects in the steady state growth (Segerstrom, 1998; Young, 1998), a property strongly contradicting empirical evidence found by Jones (1995): while resources allocated to R&D increase exponentially in the long-run data, productivity growth remains almost constant. Based on this adapted setup, a new wave of models has recently revisited important issues such as North-South trade (Dinopoulos and Segerstrom, 2007), firm heterogeneity in the open economy (Segerstrom and Gustafsson, 2007) and the possibility of stable saddle path equilibrium with self-fulfilling believes about R&D intensity (Cozzi, 2007). The previously mentioned models of Thoenig and Verdier (2003) and Dinopoulos and Syropoulos (2007) are also built on a quality-ladders setup.

A few contributions in this literature introduce the possibility of innovative leaders (Segerstrom, 2007; Barro and Sala-i-Martin, 2004, Chapter 7). This is an important property for our argument since one of incumbent's strategies to keep its leading position is innovation itself. Because innovation for incumbents also translates into their self-replacement, they take into account the loss of their current state value. On the contrary, outsiders seeking to enter the market have nothing to lose and are willing to perform a higher R&D effort. This is the Arrow replacement effect. In most quality-ladders models, it implies the absence of incumbents in R&D races. However, this result no longer holds true if the incumbent has enough technological advantages in R&D.

We address these technological R&D advantages endogenously. The model reproduces the underlying conditions of two types of steady state equilibrium. Equilibrium with a permanent monopolist arises if the possibilities of technological bias are sufficiently high. In this case the incumbent leader is able to introduce a complexity that renders outsiders' R&D hard enough to induce them to exit the R&D race. Conversely, Schumpeterian replacement equilibrium takes place if technological bias is limited. Differently from the standard case, in this continuous replacement, the incumbent firm will seek to delay its ending date. These results come from the introduction of two ingredients: (a) a Stackelberg type game in which the incumbent leader has the first mover advantage and (b) an endogenous choice of technological bias. For the sake of simplicity we formalise our argument using a semi-endogenous quality ladder model without scale effects. The basic setup is based on Li (2003), which generalises Segrestrom's (1998) framework to consider imperfect inter-industry substitutability. To remove steady state scales effects, Li (2003) assumes that as quality improves new discoveries need more R&D effort. At equilibrium the innovation rate will not depend on the size of labour allocated to R&D but on the rate of population growth.

The Stackelberg building block is based on Barro and Sala-i-Martin (2004). We introduce into their setup an endogenous R&D advantage explained by the privative knowledge in the hands of the current successful innovator. In the Stackelberg game, outsiders can be driven away from R&D races if the leader (incumbent) is able to make a commitment of high R&D investment. In tur, this depends on R&D advantages. Thus the possibilities of technological bias determine whether the leader's commitment is credible. Thus, the model offers an endogenous threshold that defines who innovates. If the leader is not credible, the Arrow replacement effect holds in the usual way: outsiders carry out all R&D effort and a continuous replacement takes place (Schumpeterian replacement equilibrium). If the leader can make a credible commitment, it will do all R&D and will remain in the market indefinitely (permanent monopolist).

The way we model defensives strategies of technological bias also seeks to keep the dynamic of the model as tractable as possible. Quality is represented as a vector whose Euclidean norm is upgraded at each step of innovation. For a given level of the quality magnitude (the Euclidean norm), the firm chooses, among the multiple quality dimensions, the specific quality mix to be manufactured (the direction of the vector). The difference between the new quality mix and the former one gives to the incumbent the possibility of keeping private a part of the state-of-the-art knowledge. This change in the composition of goods captures the technological bias introduced, by the incumbent, in order to reduce spillovers.

Regulation is then modelled as the extent to which the cost of technological bias increases along with the change between the former and the new quality mix. The result is that the share of labour allocated to R&D increases with regulation enforcement in the Schumpeterian replacement equilibrium. Moreover, this effect depends positively on the size of the innovative steps.

The permanent monopolist equilibrium arises when the technological bias induced by the leader firm is big enough to ensure its credibility. In that case, the incumbent does not need further level of bias to deter its rivals because it can (potentially) do a high enough amount of R&D effort. This occurs when the level of regulation is low. In this equilibrium, if regulation increases, but not enough to avoid permanent monopolists, it reduces the R&D intensity since it induces an allocation of labour to defensive activities which is disconnected from costs.

In the model, the possibilities of positive R&D effort for all players (incumbent and outsiders) are ex-ante discarded by the linear form of R&D technologies (the standard assumption). We empirically test the predictions assuming an smoothing approximation in which monopolists are replaced, even if with a low probability. Using several indicators of market regulation provided by the OECD over a sample of 17 industries belonging to 17 OECD countries, we find a positive effect of regulation on R&D intensity that increases for high technological industries. Since the latter are supposed to perform bigger innovative jumps, we interpret this evidence as consistent with the model's predictions. The rest of the paper is organised as follow. Section 2 presents the model and Section 3 the empirical findings. Finally, we briefly conclude in Section 4.

2 The Model

2.1 Households

2.1.1 Instantaneous decisions

Per capita utility at each time t is given by the CES formulation:

$$u(t) = \left[\int_0^1 z(t,\omega)^{\frac{\sigma-1}{\sigma}} d\omega \right]^{\frac{\sigma}{\sigma-1}} \tag{1}$$

Where $z(t,\omega) \equiv \sum_j \gamma^j d(j,t,\omega)$ is the sub-utility function associated to each industry. The demand for the good of quality j at time t in industry ω is denoted by $d(j,t,\omega)$. The term γ^j captures the quality level j of a given good, where $\gamma > 1$ is a parameter representing the size of quality upgrade (see section 2.4). Thus, for a given industry $z(t,\omega)$ captures a situation in which consumers preferences are ordered by the quality of the available varieties. To avoid confusions in notation, all round brackets, $()$, are reserved to the arguments of the functions of the model.

At any time, households allocate their consumption expenditure $E(t)$ seeking to maximise $u(t)$. This static problem can be separated in two components: a within-industry consumption decision and a between-industry one. Giving the perfect substitutability among the quality varieties in each industry ω, all intra-industry expenditure will focus on the good j^* having the lowest quality-adjusted price

$$j^* = \underset{(j)}{\arg\min} \left\{ \frac{p(\gamma^j,t,\omega)}{\gamma^j} \right\}$$

The between-industry problem concerns the allocation of total expenditure $E(t)$ among all $\omega \in [0,1]$. This consists of applying $z^*(t,\omega)$ to (1) and maximising $u(t)$ subject to $\int_0^1 p(j^*,t,\omega)\, d(j^*,t,\omega)\, d\omega = E(t)$, which leads to the well-known CES demands:

$$d(j^*,t,\omega) = \frac{\delta(j^*,t,\omega)}{p(j^*,t,\omega)^{\sigma} \int_0^1 \frac{\delta(j^*,t,\omega')}{p(j^*,t,\omega')^{1-\sigma}} d\omega'} E(t) \tag{2}$$

Where $\delta(j^*,t,\omega) \equiv \gamma^{j^*[\sigma-1]}$ is a quality level index. This demand function (2) reflects a key property of monopolistic competition: each firm (one by industry) is in competition with the whole economy. Indeed, using the utility based index price $P = \left(\int_0^1 \left[\frac{p(j^*,t,\omega')}{\gamma^{j^*}} \right]^{1-\sigma} d\omega' \right)^{\frac{1}{1-\sigma}}$ and noting $C(t) \equiv \frac{E(t)}{P} = u(t)$ the equivalent aggregate good accounting for $u(t)$, (2) is then equivalent to state:

$$d(j^*,t,\omega) = \delta(j^*,t,\omega) \left[\frac{P}{p(j^*,t,\omega)} \right]^{\sigma} C(t) \tag{3}$$

Hence, demand decreases along with the relative quality-adjusted price concerning a particular producer and the average of the economy summarised in P.

2.1.2 Intertemporal decisions

Households are considered as identical dynastic families whose number of members grows at the exogenous rate $n > 0$. Each member of a household supplies inelastically one unit of labour. Without loss of generality, initial population is set to 1, so that the population at time t is $L(t) = e^{nt}$. Using a subjective discount rate $\rho > n$, each dynastic family maximises its intertemporal utility

$$U = \int_0^\infty e^{-[\rho-n]t} \log u(t)\, dt \tag{4}$$

subject to the usual intertemporal budget constraint that links stock market gains, revenue and expenditure. Noting for any variable Δ its infinitesimal variation $\dot{\Delta} \equiv \frac{d\Delta}{dt}$, this constrain in flows implies:

$$\dot{a}(t) = w(t) + r(t)\, a(t) - E(t) - na(t) \tag{5}$$

Where $a(t)$ is the endowment of per capita financial assets and $w(t)$ the wage income of the representative household member. Since $u(t) = \frac{E(t)}{P}$ and each individual takes P as given , the intertemporal program is equivalent to the maximisation of $U = \int_0^\infty e^{-(\rho-n)t} \log E(t)\, dt$ subject to (5). Denoting μ the shadow price of the dynamic constraint, the Hamiltonian can be written as:

$$H = e^{-(\rho-n)t} \log E(t) + \mu \left[w(t) + r(t)\, a(t) - E(t) - na(t)\right]$$

As in most Ramsey-intertemporal consumption, this problem is solved with the help of the transversality condition $\lim_{t\to\infty} \mu(t)\, a(t) = 0$ and the optimality conditions $\frac{\partial H}{\partial E} = 0$;$\frac{\partial H}{\partial a} + \dot{\mu} = 0$. Differencing the resulting relationship leads to the well-known intertemporal optimal rule:

$$\frac{\dot{E}(t)}{E(t)} = r(t) - \rho \tag{6}$$

2.2 Producers and price setting

Labour is the only factor in production and is used in a technology with constant returns to scale. Each firm producing the variety ω sells its output to all members of the representative household. Thus, the firm produces a quantity of $d(j^*, t, \omega)\, L(t)$, sells at price $p(j^*, t, \omega)$ and incurs a production cost $w(t)\, d(j^*, t, \omega)\, L(t)$. After normalising wages $(w(t) = 1)$, the profit of each producer is given by:

$$\pi(j^*, t, \omega) = \left[p(j^*, t, \omega) - 1\right] d(j^*, t, \omega)\, L(t) \tag{7}$$

Standard monopolist profit maximisation leads to a markup over marginal costs: $p(j^*, t, \omega) = \frac{\sigma}{\sigma-1}$. However, the monopolist is also in competition with firms offering lower quality goods. Consider, namely, the firm laying one step behind the leader in the quality-ladder. The lowest price that this firm is able to set equals its marginal cost $w = 1$. Thus, in any industry ω for which the quality level offered by the leader is j^* , the firm one step behind charge the adjusted price of $\frac{1}{\gamma^{j^*-1}}$. Given the perfect substituability within industries, the strategy of the leader will be to charge a quality-adjusted price infinitesimally lower than the one of its competitor. By doing so, it gets all demands. Let be ε this infinitesimal price advantage. The leader will thus charge $p(j^*, \omega, t) = \gamma - \varepsilon$, implying a quality-adjusted price equal to $\frac{p(j^*,\omega,t)}{\gamma^j} = \frac{\gamma}{\gamma^j} - \frac{\varepsilon}{\gamma^j}$. This is the limit pricing rule.

An alternative solution, often used in the literature, is to assume a tie-break rule. For instance, suppose that a consumer facing similar quality-adjusted prices prefers the good with the highest quality. This means that the leader charges $p(j^*, \omega, t) = \gamma$ and gets all demands. For the sake of simplicity we adopt the latter solution as it is "asymptotically" equivalent.

Another issue concerns the fact that price strategies depend on the size of innovation γ and the monopolist power $\frac{\sigma}{\sigma-1}$. If $\frac{\sigma}{\sigma-1} > \gamma$ firms will charge $p(j^*, \omega, t) = \gamma$. On the other hand, if $\frac{\sigma}{\sigma-1} \leq \gamma$ the leader is unconstrained to charge its optimal monopolistic price rule $p(j^*, \omega, t) = \frac{\sigma}{\sigma-1}$. This is an interesting point concerning usual distinctions of radical $\left(\gamma \geqslant \frac{\sigma}{\sigma-1}\right)$ and non radical innovation $\left(\gamma < \frac{\sigma}{\sigma-1}\right)$. What should be stressed is that this distinction depends on the elasticity of substitution. Empirically, it is not so clear what relevant elasticity of substitution should be considered since the national and international scope of the "relevant economy" may vary among goods. Moreover, one of the risk of defining radical innovation by using this criteria is that the distinction may come from a lower economy-wide competition rather than the size of each step of technological upgrade.[1]

Innovation in our framework suppose further quality upgrades of the same good. In this sense, is more plausible to assume that the size of each upgrade is not as big enough to induce the innovator to adopt the same price behavior than a monopolist having no outside competition. Therefore, we restrict $\frac{\sigma}{\sigma-1} > \gamma$ and consider the price setting $p(j^*, \omega, t) = p = \gamma$. Nonetheless, in order to separate the price effects of the size of innovation from those related to technological concerns, we keep p in the exposition of equations.

Putting demands (2) into leader profits (7) and using the fact that p neither depends on j^* nor on ω yields:

$$\pi(j^*, \omega, t) = \frac{[p-1]}{p} \frac{\delta(j^*, \omega, t)}{Q(t)} E(t) L(t)$$

Where $Q(t) \equiv \int_0^1 \delta(j^*, \omega, t)\, d\omega = \int_0^1 \gamma^{j^*[\sigma-1]} d\omega$ is the average quality index. It arises from the monopolistic competition framework as firm's demands are related to the average quality-adjusted price of the economy.

2.3 R&D and Quality Improvements

As in the standard quality-ladders setup, at time $t = 0$, the state-of-the-art quality in each industry is $j = 0$. We suppose that, at this initial stage, in each industry some producer(s) has (have) the knowledge to fabricate a good of quality $j = 0$. Firms then engage in R&D

[1] A deeper economic distinction between radical and incremental innovation, implying endogenous growth and irregular cycles can be found in Amable (1996).

races to discover a new version of the good ω that provides a level of quality $j = 1$. More generaly, at each state-of-the-art quality level j, the successful innovator of the current R&D race improves quality to the level $j + 1$ and climbs the quality-ladder one step ahead. The above exposed framework implies that the successful innovator becomes the sole producer in the industry. Thus, each incumbent is also the monopolist and the leader of the industry. Differently from the standard setup, in our model the incumbent does not wait until the next innovator "steal" its rents, but seeks to deter its potential rivals and to remain in the market. This section is devoted to set the underlying R&D framework allowing for hese mechanisms.

Since at this point we know the determinants of our main variables, we can simplify our subscript notation. This simplification can be done thanks to three features of the model. First, the leader is the only firm producing a positive quantity in an industry. Second, the only difference among industries concerning state variables is the current state-of-the-art quality level j. Finally, all *endogenous* variables depend on t (except prices). Thus we summarise the couple (j^*, ω) into j_ω, which indicates the current state-of-the-art good produced by the leader of industry ω. In order to further facilitate notations, we drop the time index and keep in mind the time dependency of the model.

2.3.1 Quality dimensions

The quality provided by a firm producing in industry ω is given by the quality vector $\overrightarrow{q}(j_\omega) = \{q_1(j_\omega), q_2(j_\omega) ..., q_m(j_\omega)\}$. The magnitude of quality is summarised by the euclidean norm of the vector $\|\overrightarrow{q}(j_\omega)\| = \sqrt{\sum_{k=1}^{m} q_k^2(j_\omega)}$ and the quality mix by its direction (the angle of the vector), which reflect the quality composition. The quality state j_ω is the outcome of step-by-step innovations. Different mix concerning the same industry are just perfect substituable versions of the same product. Thus, consumers only care about quality magnitude. Two different quality mix provide the same utility if the magnitude is equal. However, as we will see, direction matters for the innovator.

The magnitude of the quality vector is upgraded at each step by a factor of γ, the size of innovations. The quality provided by the state-of-the-art j_ω is thus defined as $\|\overrightarrow{q}(j_\omega)\| = \gamma^{j_\omega}$.

2.3.2 Diffusion, R&D difficulty and technical bias

Why should we expect the manufacturing of different mix if the composition does not matter for consumers? Two assumptions allow to understand it: (a) while outsiders competing in a R&D race take the current quality mix as given, the current successful innovator can change it; and (b) the knowledge about the way in which new dimensions of quality can be incorporated into the state-of-the-art product does not diffuse instantaneously. Assumption (a) seeks to capture the innovator's advantages arising from its private knowledge about the new product. Once the new discovery come off, the new blueprint is certainly known by the innovator. The leader firm now has the choice about what "visible" properties the manufactured product should have. Assumption (b) allows for a lag in the way in which private knowledge becomes public knowledge. In a basic quality-ladders framework, outsiders *"via inspection of goods on the market, learn enough about the state of knowledge to mount their own research efforts, even if the patent* *laws (or the lack of complete knowledge about best production methods) prevent them from manufacturing the current generation products"* (Grossman and Helpman, 1991; pag. 47). With assumption (b) we are just specifying that the "lack of complete knowledge" also comes from new dimensions of quality. Current public knowledge may not be enough to allow outsiders to completely understand *all* via the simple "inspection of goods on the market". Rather than to the new dimension itself, the asymmetry of knowledge relates to the way this new dimension must be incorporated into the new product. These knowledge advantages will be used by the incumbent "to bias" its rivals.

Outsiders carry out R&D activities by using labour as input. R&D is governed by a Poisson stochastic process: ℓ units of labour allocated to research during an interval of time dt imply a probability of success $\Lambda_0 (j_\omega + 1) \ell dt$ of a new up-grade. We call R&D productivity the augmenting factor of the probability of innovative success implied by one unit of labour in the R&D process. For the outsider, the R&D productivity is defined as

$$\Lambda_0 (j_\omega + 1) \equiv \frac{hA^\xi}{\delta (j_\omega + 1)}$$

Where h is an exogenous technology parameter. Similarly to Li (2003), this R&D productivity is a function of the upgrade endeavoured $(j_\omega + 1)$. The presence of $\delta (j_\omega + 1) = \gamma^{[j_\omega+1][\sigma-1]}$ in the denominator implies that, as the level of quality increases, the next improvement becomes harder and R&D more costly. The incidence of the quality mix on R&D is captured by A, the scalar product between the unitary vector $\overrightarrow{u}_{j_\omega}$ having the same direction than $\overrightarrow{q}(j_\omega)$ and the unitary vector $\overrightarrow{u}_{j_\omega-1}$, the one having the direction of the previous step $\overrightarrow{q}(j_\omega - 1)$.[2] Let θ_{j_ω} be the angle between vectors $\overrightarrow{q}(j_\omega)$ and $\overrightarrow{q}(j_\omega - 1)$ (and, consequently, between $\overrightarrow{u}_{j_\omega}$ and $\overrightarrow{u}_{j_\omega-1}$). The term A can be written as:

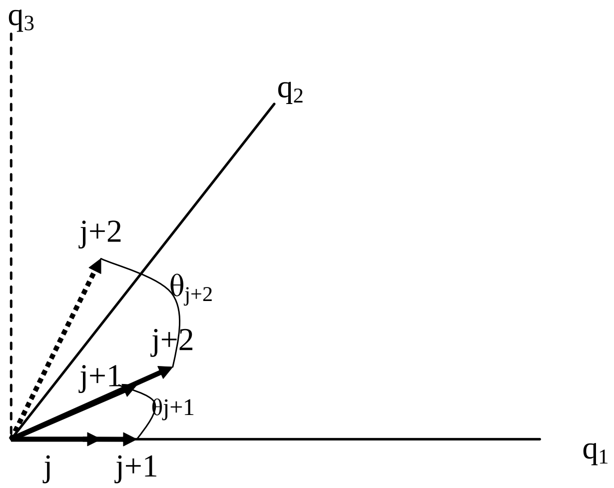
$$A \equiv \overrightarrow{u}_{j_\omega} \times \overrightarrow{u}_{j_\omega-1} = \cos(\theta_{j_\omega})$$

Recall that the $\cos(\cdot)$ function is symmetric and monotonically decreases from 1 to 0 along with $|\theta_{j_\omega}| \in [0; \Pi/2[$ (in Π radians). Hence the change in the quality mix involved in the upgrade of j_ω implies an increase in the R&D difficulty faced by outsiders. This increase is measured by $A^\xi = \cos^\xi(\theta_{j_\omega})$. The instantaneous probability of innovation I_i implied by the R&D effort of outsider i is then:

$$I_i = \ell_i \frac{h \cos^\xi (\theta_{j_\omega})}{\delta (j_\omega + 1)} \tag{8}$$

Any time an innovative firm succeeds, it can add a new quality dimension. Thus, we implicitly suppose that there will always be new dimensions available for the incumbent to bias the outsiders. Our vectorial representation allows to avoid the assumption of an exogenous rate of discovery of new dimensions. Instead, we suppose a certain degree of obsolescence of public knowledge: if during one wave of innovation a quality dimension have not been used, the old way to incorporate it into the product manufacturing no longer applies. Figure 1 illustrates this situation. Let us start from the quality level j , which is totally based on dimension q_1 (implying a horizontal vector). Once the next innovative firm has succeeded in upgrading the quality level to $j + 1$, it introduces a bias by including dimension q_2. The firm then produces the new version of the product with a quality vector having a direction θ_{j+1} far away from the previous one. By doing so, it

[2] The vector $\overrightarrow{u}_{j_\omega}$ is thus a vector of magnitude 1 whose angle (quality mix) equals the one of $\overrightarrow{q}(j_\omega)$.



increases the difficulty of the next R&D race (the one leading to the $j+2$ level) by a factor of $\cos^{\xi}(\theta_{j_\omega+1})$. Then, the next innovation occurs and improves the quality level to $j+2$. If, as in the figure, the new biased mix lies completely on the plan q_2 and q_3, dimension q_1 will be dropped ($q_1(j+2)=0$). Now, if some obsolescence arises after one step of innovation, the next incumbent $(j+3)$ can use again the quality dimension q_1 as a source of bias.

This is one of the advantage of using the scalar product in a vectorial representation . Between two vectors of $\mathbb{R}^n$ representing precedent and current innovation we just need to know the angle between them to model the technological bias.

2.3.3 Leaders' R&D technology and regulation

If the incumbent firm is willing to do positive R&D effort it will not face the difficulty coming from bias. Since this firm has discovered the current state-of-the-art product, it is the sole producer that knows how to incorporate the new dimension in the manufacturing of the good. Hence, the leader R&D productivity is just:

$$\Lambda_L(j_\omega+1)=\frac{h}{\delta(j_\omega+1)}$$

Any leader that changes the mix incurs a variable cost (in units of labour) of adapting the new version of the product with a new quality dimension. This cost is defined as:

$$c(\theta_{j_\omega},\psi)\equiv\frac{f}{\cos^{\psi}\theta_{j_\omega}\Lambda_L(j_\omega)} \tag{9}$$

We summarise in $\psi>1$ the extent to which regulation limits the new version of the product. Regulation implies a cost of technological bias that increases with the size of the bias (i.e. the change of the direction of the quality vector). This cost is all the more important that regulation is higher. Thus we modelise regulatory provisions as inducing fewer possibilities of complexity in the manufactured version of the improved product[3].

[3] Usual representations of regulation consider a fixed cost that limits the entry of firms. Here we are rather interested in regulatory barriers constraining the operation of firms.

$\Lambda_L(j_\omega)$ is the R&D productivity of the leader firm in the former R&D race j_ω (the one that it has won). Thus, the cost of introducing a technological bias in the new manufacturing of a product diminishes with the R&D productivity involved in its discovery. This also means that higher quality goods are more difficult "to bias" since R&D productivity decreases with the quality level of the industry. Finally we include a non consequencial cost parameter $f < 1$ to take into account the measure of units of labour required to activities relating to defensive strategies.

2.4 Strategic Behavior

Productive advantages obtained by the leader may allow it to deter any prospective entrant and become the only innovator. We now explore this possibility. In what follows, unless we explicitly specify the contrary, all R&D productivity functions concern the next R&D race $j_\omega + 1$. Thus we omit this index in the arguments of $\Lambda_o(\cdot)$when dealing with $j_\omega + 1$ and write the outsider's R&D productivity as $\Lambda_o(\theta_{j_\omega}) = \Lambda_L \cos^\xi \theta_{j_\omega}$, where $\left(\frac{\partial \Lambda_o}{\partial \theta_{j_\omega}} < 0\right)$.

2.4.1 Firm's value

In the outsider state a firm i gets no profits and incurs an R&D cost of ℓ_{io}. Its value is denoted by v_o. Thanks to its R&D effort, with instantaneous probability $\Lambda_o(\theta_{j_\omega})\ell_{io}$, the outsider may become the leader of the industry and get an optimal value denoted by $v_L(j_\omega+1)$. The Bellman equation of the outsider is then:

$$rv_o = -\ell_{io} + \Lambda_o(\theta_{j_\omega})\ell_{io}[v_L(j_\omega+1) - v_o] \tag{10}$$

Putting $v_o = 0$, one verifies that outsiders carry out a positive and finite amount of R&D only when:

$$v_L(j_\omega+1) = \frac{1}{\Lambda_o(\theta_{j_\omega})} \tag{11}$$

This is equivalent to state the equality between the expected value of innovation $v_L(j_\omega+1)\Lambda_o(\theta_{j_\omega})\ell_{io}dt$ and the R&D investment during an infinitesimal interval of time $\ell_{io}dt$. This equality applies when free entry occurs. The R&D effort of the outsider for a given value of a successful innovation $v_L(j_\omega+1)$ is then:

$$\ell_{io} = \left\{ \begin{array}{ll} 0 & \text{if } v_L(j_\omega+1) < \frac{1}{\Lambda_o(\theta_{j_\omega})} \\ \infty & \text{if } v_L(j_\omega+1) > \frac{1}{\Lambda_o(\theta_{j_\omega})} \\ \ell_{io} \in \mathbb{R}^+ & \text{if } v_L(j_\omega+1) = \frac{1}{\Lambda_o(\theta_{j_\omega})} \end{array} \right\} \tag{12}$$

Let $\ell_0 = \sum_i \ell_{i0}$ be the whole amount of R&D carried out by outsiders. The Bellman equation of a (potential) innovative leader is

$$rv_L(j_\omega) = \pi_L - \ell_L + \ell_L\Lambda_L[v_L(j_\omega+1) - v_L(j_\omega)] + \ell_o\Lambda_o(\theta_{j_\omega})[v_0 - v_L(j_\omega)] - c(\theta_{j_\omega}, \psi) \tag{13}$$

If the leader carries out R&D, with instantaneous probability $\ell_L\Lambda_L$ its optimal value $v_L(j_\omega)$ can jump to $v_L(j_\omega+1)$ thanks to a new discovery. With instantaneous probability

$\ell_o \Lambda_o(\theta_{j_\omega})$ the leader may be replaced by a successful outsider. In the meantime, the leader firm enjoys its monopolist profits π_L and pays ℓ_L unit of labour for new discoveries as well as $c(\theta_{j_\omega}, \psi)$ units of labour for defensive strategies.

2.4.2 The stackelberg game

Since a leader firm is active in the market, its actions such as technology adoption, advertising and, of course, the quality mix choice, are visible. In an strategic framework, these actions can be seen as a commitment of R&D effort. The consequence is that this commitment of the leader firm can be high enough to deter its rival. This structure is in line with a sequential stackelberg game in which the leader has the so called first mover advantage. Inmediately after innovating, the leader sets the quality mix θ_{j_ω} in order to introduce a technological bias. This information is taken into account by outsiders in their deisions. Assume by the moment that the reaction function of outsiders respond negatively to the leader R&D signal. The credibility of the leader's commitment depends its R&D productivity advantages.

Proposition 1 *A necessary condition to ensure that outsiders can be driven out of the R&D race is given by*

$$\Lambda_L \left[\frac{1}{\Lambda_o(\theta_{j_\omega})} - \frac{\gamma^{-[\sigma-1]}}{\Lambda_o(\theta_{j_\omega - 1})} \right] \geq 1 \tag{14}$$

This credibility condition implies that the leader's R&D effort is irrespective of outsider actions.

Proof. The necessity of this condition comes from the fact that any credible commitment of a high R&D effort depends on the capability of the leader to perform, at least, a positive amount of R&D when free entry is possible. Equation (13) shows that the leader firm does perform R&D when $\Lambda_L [v_L(j_\omega + 1) - v_L(j_\omega)] \geq 1$. If free entry applies, then $v_L(j_\omega + 1) = \frac{1}{\Lambda_o}$. Since $\Lambda_o(\theta_{j_\omega})$ is a function of $\delta(j_\omega + 1) \equiv \gamma^{[j_\omega+1][\sigma-1]}$, we can obtain $v_L(j_\omega)$ by adjusting for one step down in the quality-ladder: $v_L(j_\omega) = \frac{\gamma^{-[\sigma-1]}}{\Lambda_o(\theta_{j_\omega-1})}$. Putting these elements together yields the credibility condition (14). Moreover, because of constant returns to scale of the R&D investment, if (14) holds as an strict inequality, the optimal R&D effort for the leader is unbounded. If (14) holds as equality, the leader can perform any finite amount of R&D effort. In both cases it can invest a positive amount in R&D without taking into account outsiders menace.■

Inuitively, this condition defines a threshold for the R&D productivity of the leader relative to that of the outsiders. Thanks to technoligical bias, this level can be attained. If this is the case, the constant returns of R&D investment imply that the leader can perform as much R&D effort to put outsiders out of competition[4]. Thus, if (14) is ensured, the leading position value (13) can be written as:

$$v_L(j_\omega) = \frac{\pi_L - c(\theta_{j_\omega}, \psi) - \ell_L + \ell_L \Lambda_L v_L(j_\omega + 1)}{r + \ell_L \Lambda_L} \tag{15}$$

[4]See Barro and Sala-i-Martin [2003] pag .333-336 for this stackelberg explanation.

Setting $\frac{\partial v_L(j_\omega)}{\partial \ell_L} = 0$ allows to equating the marginal gain of the R&D effort to its marginal cost.

$$v_L(j_\omega + 1) - v_L(j_\omega) = \frac{1}{\Lambda_L} \tag{16}$$

As usually with constant returns, if (16) applies, the R&D investment of the leader can be positive and finite. Putting the value of $v_L(j_\omega + 1)$ implied by (16) into (15) yields the present optimal value of a permanent monopolist leader.

$$v_L(j_\omega) = \frac{\pi_L - c(\theta_{j_\omega}, \psi)}{r} \tag{17}$$

At equilibrium, the interest rate must verify (16) and (17), otherwise the leader carries out zero R&D effort or an unbounded amount. Using the monopolist profits equation (7) we obtain:

$$r = \frac{p-1}{p}\frac{E\ L\ \left[1 - \gamma^{-[\sigma-1]}\right] h}{Q} \tag{18}$$

We are mainly interested in the steady state properties of the model. For the sake of presentation in (18) we assume that a constant value of $\theta_{j_\omega} = \theta$ exists.[5] Now we can state the sufficiency of the credibility condition:

Proposition 2 *For a constant value of $\theta_{j_\omega} = \theta$ the credibility condition (14) is sufficient to ensure zero outsiders' R&D effort. This condition can be expressed as:*

$$\cos^\xi \theta \leq \left[1 - \gamma^{-[\sigma-1]}\right] \tag{19}$$

Proof. Recalling that $\frac{\Lambda_L}{\Lambda_o(\theta)} = \frac{1}{\cos^\xi \theta}$ and using (14) for $\theta_{j_\omega} = \theta$ inmediatly gives (19). Further, by equation (12), the absence of outsiders in R&D races requires $v_L(j_\omega + 1) < \frac{1}{\Lambda_o(\theta_{j_\omega})}$. Consider the optimal value of the next innovation $v_L(j_\omega + 1)$ by using (17), profits (7) and the definition of $\Lambda_o(\theta_{j_\omega})$. This inequality is then equivalent to: $\frac{\delta(j_\omega+1)-\Theta}{\left[1-\gamma^{-[\sigma-1]}\right]} < \frac{\delta(j_\omega+1)}{\cos^\xi \theta}$, where $\Theta \equiv \frac{c(\theta,\psi)}{\frac{p-1}{p}\frac{E(t)L(t)}{Q(t)}}$. Now consider condition (14) for a constant value of bias : $\frac{1}{\left[1-\gamma^{-[\sigma-1]}\right]} < \frac{1}{\cos^\xi \theta}$. After multiplying both sides of the latter inequality by $\delta(j_\omega + 1)$, since $\Theta > 0$ it immediately appears that credibility condition ensures the absence of outsiders in R&D races.■

Thus, when the bias is strong enough, i.e. $\cos^\xi \theta \leq \left[1 - \gamma^{-[\sigma-1]}\right]$, the leader firm does carries out research effort and the outcome is that the value of the next quality improvement will be lower than the R&D cost incurred by outsiders. As a consequence, outsiders react by setting zero R&D effort, meaning no replacement menace: $I_o = \ell_o \Lambda_o(\theta_{j_\omega}) = 0$. In contrast, if credibility condition does not hold, the leader will do zero R&D effort and will not innovate. All innovation will be done by outsiders. Nevertheless, since the leader firm can render the next R&D race harder it can delay its own replacement, which increases

[5]We show later that $\theta_{j_\omega+1}$ is constant for a constant outsider menace, which is the standard steady state condition of this kind of model.

its value. In our particular setup the R&D advantage is endogenously determined by the technological bias. The possibilities of each scenario are thus endogenously determined.

2.4.3 The choice of the bias

Once the new innovative firm has succeeded and before producing it decides the visible features of the new version of the product. This new version may incorporate a new dimensions of quality, which generate a gap between private and public knowledge about the design of the product. The differences in the quality mix between the new manufactured version and the previous one is what we have called the technological bias (θ_{j_ω}). This bias determines whether the incumbent becomes an innovative permanent leader firm or a non-innovative monopolist that can delay to some extent its date of replacement. Hence, the value of the incumbent leader can be discomposed into both situations:

$$v_L(j_\omega) = \left\{ \begin{array}{ll} \frac{\pi_L - c(\theta_{j_\omega},\psi)}{r+\ell_o\Lambda_o(\theta_{j_\omega})} & \text{if } \cos^\xi \theta_{j_\omega} > \left[1-\gamma^{-[\sigma-1]}\right] \\ \frac{\pi_L - c(\theta_{j_\omega},\psi)}{r} & \text{if } \cos^\xi \theta_{j_\omega} \leq \left[1-\gamma^{-[\sigma-1]}\right] \end{array} \right\} \quad (20)$$

Note that before the leader takes the decision of bias, outsiders can potentially carry out research efforts and the free entry condition holds. Thus, the rationale of the decision of bias starts by considering the first case in (20). Since at this stage no technological advantage has been induced, the leader firm is not credible for the moment. The value is given by (13) for $\ell_L = 0$. Here, the leader firm waits until a new successful innovator replace it. But it can still do better. For a given value of outsider's R&D effort ℓ_o , the discounted expected value of the leader will increase with the technical bias θ_{j_ω}. A higher R&D difficulty means a lower probability of replacement and then a higher expected monopolist life. This decision of bias implies a cost of $c(\theta_{j_\omega},\psi)$ units of labour which is increasing in ψ, the regulation parameter. Thus, the leader will choose a value of θ_{j_ω}as high as possible, depending on regulation ψ . For a certain "low" level of regulation, this bias can be high enough to ensure the credibility condition as equality. In that case the economy jumps to a permanent monopolist framework.

Let us now derive this rationale analytically. Define $I_{oL} \equiv \ell_o\Lambda_L$ as the potential menace of outsiders, that is the probability of outsiders' innovative success in the absence of any bias ($\theta_{j_\omega} = 0$) (i.e. the same R&D productivity as the leader). We can then rewrite the bellman equation of the leader firm as

$$rv_L(j_\omega) = \pi_L - I_{oL}\cos^\xi \theta_{j_\omega} v_L(j_\omega) - c(\theta_{j_\omega},\psi) \quad (21)$$

Proposition 3 *For a constant potential outsider menace I_{oL}, the optimal choice of θ_{j_ω}, is constant. Its value is given by*

$$\cos\theta = \left[\frac{\psi f}{\xi I_{oL}}\right]^{\frac{1}{\psi}} \quad (22)$$

Proof. By the maximum principle, the choice of θ_{j_ω},is determined by the first order condition of the RHS of (21). To do so, we use $c(\theta_{j_\omega},\psi)$ as defined by (9). Recall also that the free entry condition in the precedent R&D race (the one that the incumbent has won) states: $v_L(j_\omega) = \frac{1}{\Lambda_o(j_\omega,\theta_{j_\omega-1})} = \frac{1}{\Lambda_L(j_\omega)\cos^\xi \theta_{j_\omega-1}}$ where $\Lambda_o(j_\omega,\theta_{j_\omega-1})$ and $\Lambda_L(j_\omega)$ are the outsiders and the leader R&D productivity in the preceding R&D race, respectively. After applying this, first order condition can be written as $\cos\theta_{j_\omega} = \cos^{\frac{\xi}{\xi+\psi}}\theta_{j_\omega-1}\left[\frac{\psi f}{\xi I_{0L}}\right]^{\frac{1}{\xi+\psi}}$. Define now $q \equiv \left(\frac{\psi f}{\xi I_{0L}}\right)^{\frac{1}{\xi+\psi}}; \beta \equiv \frac{\xi}{\xi+\psi} < 1; a_{j_\omega} \equiv \cos\theta_{j_\omega}$. The sequence of a_{j_ω} can be expressed as $a_{j_\omega} = q^{z(j_\omega)}$ where $z(j_\omega) = \sum_{j=1}^{j_\omega}\beta^j$ is itself a geometric sequence that converges towards $\frac{1}{1-\beta}$. Thus, for a high enough level of j_ω, one has $a = q^{\frac{1}{1-\beta}}$. Putting back the definitions of a, q and β gives directly (22). ■

As expected $\cos\theta$ decreases with I_{oL}. A higher potential menace of replacement implies a higher defensive strategy. Recalling that $I_o = I_{oL}\cos^{\xi}\theta$, the probability of outsiders to succeed in innovation is then:

$$I_o = I_{oL}^{\frac{\psi-\xi}{\psi}}\left[\frac{\psi f}{\xi}\right]^{\frac{\xi}{\psi}} \tag{23}$$

Note that in the extreme case of $\psi \to \infty$, the outsiders'probability of innovation converges toward its potential $I_o \to I_{oL}$. Hence, a high level of regulation may (asymptotically) eliminate the bias ($\cos\theta \to 1$).

In particular, ψ can determine whether the credibility condition holds. Indeed, note that for agiven value of I_{oL} regulation reduces the bias: $\frac{\partial\cos\theta}{\partial\psi} > 0$. [6] If ψ is particularly low, the technological bias implies that the R&D advantage of the leader firm relative to that of outsiders $\left(\frac{1}{\cos\theta}\right)$ can be high enough to allow it a credible commitment. In this case, the second part of the discontinuous function of the leader value (20) applies. The leader now enjoys permanent profits as an innovative monopolist. Since $\frac{\partial c(\theta_{j_\omega},\psi)}{\partial\theta_{j_\omega}} > 0$, a value of $\cos^{\xi}\theta_{j_\omega}$lower than $\left[1-\gamma^{-[\sigma-1]}\right]$ will only reduce $v_L(j_\omega)$. Therefore, the leader does not need further R&D advantages beyond the credibility point. As a consequence the optimal choice will be given by

$$\cos^{\xi}\theta = \left[1-\gamma^{-[\sigma-1]}\right] \tag{24}$$

Equation (24), however, is not sufficient to analyse the regulation threshold alowing to separate both cases of (20). Actually $\cos\theta$ depends on the outsiders' potential menace. The latter needs to be computed at the steady state equilibrium.

Finally, it should be stressed that the reaction of zero R&D effort of outsiders is a direct consequence of the linear R&D technology. With decreasing returns in the R&D technology, one has both players active in R&D races (see Segerstrom, 2007). For the simplicity of the exposition we have adopted linear technologies.

2.5 Global accounting and steady state equilibrium

To sum up, the discontinuity of (20) implies two cases depending on the fulfillment of the credibility condition, which in turn depend on ψ. In the first case, outsiders do all R&D and the leader waits for its replacement (Schumpeterian replacement case). In the second situation, the leader may become the only innovator and enjoys permanent

[6] Taking I_{oL} as given, $\frac{\partial\cos\theta}{\partial\psi} = \cos\theta\left[\frac{1-\log\left[\cos^{\psi}\theta\right]}{\psi^2}\right] > 0$ since $\log\left[\cos^{\psi}\theta\right] < 0$.

profits (permanent monopolist case). In this subsection we analyse the steady state macro equilibrium for each case.

The macro equilibrium for a continuum Schumpetrian replacement is given by the labour market clearing and the free entry condition. In a situation with a permanent monopolist, the free entry condition no longer holds. Instead, the steady state equilibrium condition arises from the interest rate (18) allowing a positive and finite amount of research.

2.5.1 The Schumpeterian replacement case

Labour market clearing needs the addition of labour used in research $L_r = \int_0^1 \ell_o (j_\omega + 1)\, d\omega$, manufacturing $L_y = \int_0^1 L \;\; d(j_\omega + 1)\, d\omega$ and defensive activities related to technological bias $L_f = \int_0^1 c(\theta,\psi) \;\; d\omega$. We focus on the symmetric steady state equilibrium in which expenditure E and outsiders innovative potential I_{0L} are constant. As a consequence, θ and I_0 are also constant. Using the probability of outsiders' innovative success (8), $I_{0L} = \ell_o \Lambda_L = \frac{I_o}{\cos^{\xi}(\theta)}$ and the definition the average quality Q and $\delta(j_\omega + 1)$, the demand for labour in research activities is given by:

$$L_r = \frac{I_{oL}\gamma^{\sigma-1}}{h} Q \tag{25}$$

After including consumers' demand $d(j_\omega + 1)$ (2), labour required for manufacturing is:

$$L_y = L\frac{E}{p}$$

To obtain the labour demand for defensive activities, we use the definition of $c(\theta,\psi)$ written in (9) and the average quality Q. This leads to[7]:

$$L_f = \frac{f}{h\cos^{\psi}\theta} Q$$

We can now state the full employment condition clearing the labour market. This requires $L = L_y + L_r + L_f$, which is equivalent to:

$$1 = \frac{E}{p} + \frac{I_{oL}\gamma^{\sigma-1}}{h}\frac{Q}{L} + \frac{f}{h\cos^{\psi}\theta}\frac{Q}{L} \tag{26}$$

Recall that $\cos^{\xi}\theta$ is stable when I_{oL} is stable. Thus, in a equilibrium in which I_{oL} and E are constant $x \equiv \frac{Q}{L}$ must also be constant. As mentioned, prices and the rest of exogenous parameters do not depend on time. Thus, like in the standard schumpeterian model without scale effects and exogenous rate of growth, the average quality and the population must grow at the same rate:

[7]Because industries are symmetric in probabilities, $\cos^{\psi}\theta$ (which depends on I_{0L}) can be considered as a constant inside integrals.

$$\frac{\overset{\bullet}{Q}}{Q} = \frac{\overset{\bullet}{L}}{L} = n \tag{27}$$

The rate of growth of Q is obtained in the usual way. Using the law of large numbers, the variation of average quality can be computed by adding the expected technological jump of each industry: $\overset{\bullet}{Q} = \int_0^1 I_o \left[\delta\left(j_\omega + 1\right) - \delta\left(j_\omega\right)\right] d\omega$. By applying the definition of Q one obtains:

$$\frac{\overset{\bullet}{Q}}{Q} = I_o \left[\gamma^{\sigma-1} - 1\right]$$

In steady state, condition (27) must hold. Thus, the innovation rate in steady state has the usual form:

$$I_o = \frac{n}{\left[\gamma^{\sigma-1} - 1\right]} \tag{28}$$

The growth of the average quality Q implies an steady-state utility growth of $\frac{\overset{\bullet}{u}(t)}{u(t)} = \frac{n}{\sigma-1}$. This is the standard result obtained after putting demands (2) into the instantaneous utility (1) taking logs and differencing.

Back to our particular setup, the steady-state rate I_o and equation (23) imply the following innovative potential of outsiders in steady state

$$I_{oL} = \left[\frac{n}{\left[\gamma^{\sigma-1} - 1\right]\left[\frac{\psi f}{\xi}\right]^{\frac{\xi}{\psi}}}\right]^{\frac{\psi}{\psi-\xi}} \tag{29}$$

The steady-state bias in the Schumpeterian replacement case is obtained by putting (29) into (22):

$$\cos^{\xi}\theta = \left[\frac{\left[\gamma^{\sigma-1} - 1\right]\psi f}{\xi n}\right]^{\frac{\xi}{\psi-\xi}} \tag{30}$$

Again, here in steady state equilibrium, as $\psi \to \infty$ the bias decreases ($\cos^{\xi}\theta \to 1$). Thus regulation limits the possibilities of bias in steady state. As Figure 2 shows, upon a certain level of ψ the economy can jump from the Schumpeterian equilibrium to the permanent monopolist one. The following proposition expose this.

Proposition 4 *For $\psi > \xi$ there exists a unique level of regulation $\overline{\psi}$ defining the threshold between the Schumpeterian replacement and the permanent monopolistic cases involved in the value of the leader firm (20).*

Proof. The value $\overline{\psi}$ defined above is the one solving $\cos^{\xi}\theta = \left[1 - \gamma^{-[\sigma-1]}\right]$. Denote $\Omega(\psi) \equiv \cos^{\xi}\theta = \left[\frac{\left[\gamma^{\sigma-1}-1\right]\psi f}{\xi n}\right]^{\frac{\xi}{\psi-\xi}}$ and $\Psi \equiv \left[1 - \gamma^{-[\sigma-1]}\right]$. To prove proposition 4, we need to show that $\Omega(\psi)$ intercepts Ψ once for $\cos\theta \in \left]0;1\right]$. We show first that Ω is an increasing function of ψ. Taking partial derivates gives:

$\frac{\partial\Omega(\psi)}{\partial\psi} = \frac{-\xi}{\psi[\xi-\psi]^2}\left[\frac{[\gamma^{\sigma-1}-1]\psi f}{\xi n}\right]^{\frac{\xi}{\xi-\psi}}\left[\xi-\psi+\psi\ln\left[\frac{[\gamma^{\sigma-1}-1]\psi f}{\xi n}\right]\right]$. Since $\cos^{\xi}\theta = \left[\frac{[\gamma^{\sigma-1}-1]\psi f}{\xi n}\right]^{\frac{\xi}{\psi-\xi}} \in]0;1]$ and $\psi > \xi$, the sign of the term in the brakets at the right-hand end is negative. Thus $\frac{\partial\Omega(\psi)}{\partial\psi} > 0$,which means that $\Omega(\psi)$ is a monotonically increasing function of ψ. On the other hand, the term Ψ does not vary along with ψ. Furthermore, for $\gamma > 0$ and $\sigma > 1$ (the standard parameter) we verify $\Psi < 1$. Hence, for relevant values of $\cos\theta$ there exists a unique intercept for Ω and Ψ. Figure 2 illustrate this proof.■

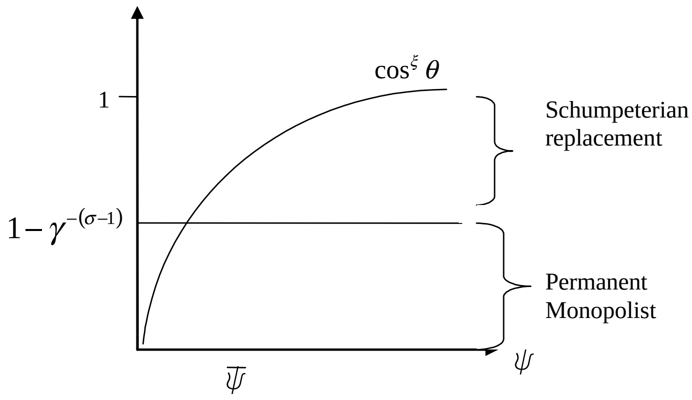


Figure 2.

We can analyse the role of regulation in steady-state by studying the share of labour allocated to research $s_r \equiv \frac{L_r}{L}$. This can be obtained from a system of two equations (the free entry condition (11) and (b) the labour market clearing (26)) with two unknowns: $x \equiv \frac{Q}{L}$ and E . For the free entry condition, the firm value is the one of the replacement case in (20). Both equations must be evaluated at the steady state values of I_{oL} and $\cos\theta$. In addition, for a constant value of expenditure E, equation (6) must be verified and then $r = \rho$. Solving this system for x and using L_r as expressed by (25) one obtains:

$$s_r = \frac{1}{\Gamma_{rep} + \frac{\xi p}{\gamma^{\sigma-1}[p-1]\psi}} \tag{31}$$

Where $\Gamma_{rep} \equiv 1 + \frac{[1-\gamma^{-[\sigma-1]}]\rho}{[p-1]n} + \frac{1}{\gamma^{\sigma-1}[p-1]}$. The following proposition can now be stated.

Proposition 5 *In the Schumpeterian equilibirum, regulatory provisions ψ increase the labour share allocated to R&D s_r and their effect is all the more important that the size of innovation γ is bigger.*

Proof. By simple inspection of (31) one verifies that s_r is increasing in ψ . Analytically, using price setting $p = \gamma$ and (31) we evaluate the effect of ψ on s_r as $\frac{\partial s_r}{\partial\psi} = \frac{n^2[\gamma-1]\gamma^{2+\sigma}\xi}{[\gamma^{\sigma}\psi[n[\gamma-1]+\rho]+\gamma[n[\gamma\xi+\psi]-\rho\psi]]^2} > 0$. To understand the effect of the size of innovation note that the multiplicative factor of ψ in (31) is $\gamma^{\sigma-1}\left[1-\frac{1}{\gamma}\right]$, which is increasing in γ. Although crossed derivates can be computed, for the sake of presentation we show numerical simulations. Figure 3 plots $\frac{\partial s_r}{\partial \psi}$ for different values of γ. The shape of the curve does not change for a large set of parameters values provided that $\gamma < \frac{\sigma}{\sigma-1}$ and $n < \rho$ (the standard intertemporal assumption)[8].■

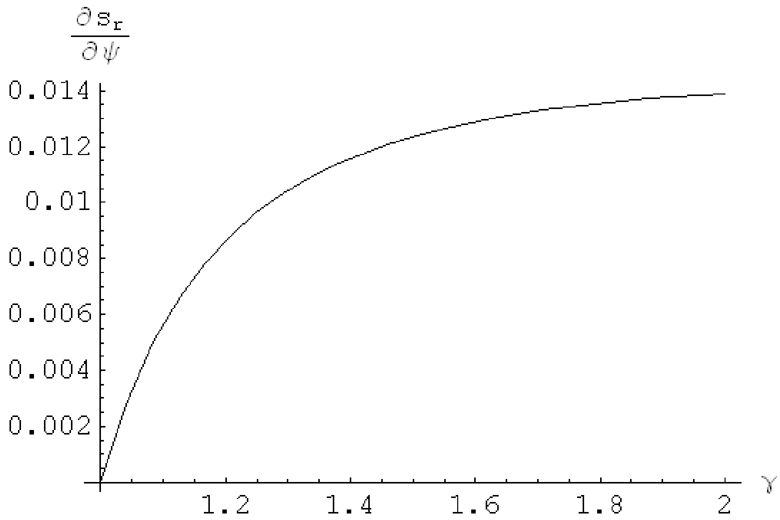


Figure 3. $\xi = 0.5, n = 2\%, \sigma = 2, \rho = 5\%, \psi = 2$

At the steady state Schumpeterian equilibrium, which namely verifies the free entry condition, the aggregate of R&D investment decisions is computed, of course, once costs have been taken into account. Thus the dissuasive effect of the technological bias appears. Since R&D becomes harder, at equilibrium, less firms will be willing to enter the R&D race. The aggregate labour allocated to R&D then decreases.

The size of innovation affects the monopolistic setting price and also influences the difficulty of R&D races because it affects the cumulative cost of climbing the quality-ladder. Concerning setting prices, the size of innovation acts as an increasing factor of the monopolist markup. This is a Schumpeterian incentive to R&D captured by the multiplicative term $\frac{p}{p-1} = 1-\frac{1}{\gamma}$. This monopolistic incentive modulate the R&D incentives coming from the reduction of bias. As Figure 3 shows, the effect of regulation is (postively) conditioned by the size of innovation.

2.5.2 The permanent monopolist equilibrium

In this equilibrium some minor adaptations for labour market clearing must be considered. First, the monopolist allocate labour to research without being affected by the bias. Its probability of innovative success is then $I_L = \ell_L \Lambda_L$. Second, the optimal choice of bias is now given by $\cos^{\xi}\theta = \left[1-\gamma^{-[\sigma-1]}\right]$. The condition $L = L_y + L_r + L_f$ is thus stated as:

$$1 = \frac{E}{p} + \frac{I_L \gamma^{\sigma-1}}{h}\frac{Q}{L} + \frac{f}{h\left[1-\gamma^{-[\sigma-1]}\right]^{\frac{\psi}{\xi}}}\frac{Q}{L} \tag{32}$$

[8]Numerical simulation are available upon request.

As before, if expenditure and innovation rates are constant, we require $\frac{\dot{Q}}{Q} = \frac{\dot{L}}{L} = n$. Thus the steady-state rate of innovation remains the same: $I_L = \frac{n}{[\gamma^{\sigma-1}-1]}$. Moreover, since E is constant, consumption growth is still given by $\frac{\dot{u}(t)}{u(t)} = \frac{n}{\sigma-1}$.

To compute the steady-state expenditure, we can not use the free entry condition. In the case of permanent rent, none outside the market is willing to participate in the R&D race. Instead, what equilibrates the economy is the interest rate (18). Putting this expression in the optimal path of expenditure (6) implies:

$$E = \frac{\rho x}{\left[1-\gamma^{-[\sigma-1]}\right] h} \frac{p}{p-1} \tag{33}$$

The steady-state share of labour allocated to R&D $s_{rm} = \frac{L_r}{L}$ for the permanent monopolistic case can be obtaiend by substituting E, as defined by (33), into labour market clearing (32) for I_L at the steady state. This yields:

$$s_{rm} = \frac{1}{\left[\Gamma_{per} + \frac{f}{n\left[1-\gamma^{-(\sigma-1)}\right]^{\frac{\psi}{\xi}-1}}\right]} \tag{34}$$

Where $\Gamma_{per} \equiv 1 + \frac{\rho}{n[p-1]}$.

Proposition 6 *In the permanent monopolist equilibrium, the level of regulation ψ reduces the share of labour allocated to R&D.*

Proof. $\frac{\partial s_{rm}}{\partial \psi} = \frac{f\left[1-\gamma^{-(\sigma-1)}\right]^{1-\frac{\psi}{\xi}} \ln\left[1-\gamma^{-(\sigma-1)}\right]}{n\xi\left[1+\frac{f}{n}\left[1-\gamma^{-(\sigma-1)}\right]^{1-\frac{\psi}{\xi}}+\frac{\rho}{n[\gamma-1]}\right]} < 0$ since $0 < 1-\gamma^{-(\sigma-1)} < 1$.Thus, s_{rm} is decreasing in ψ.■

Because of the discontinuity of the leader firm value, the optimal steady-state bias induced by the leader does not vary along with regulation. Indeed, the monopolist will not go beyond the level given by $\cos^{\xi}\theta = \left[1-\gamma^{-[\sigma-1]}\right]$. If regulation increases, but not enough to ensure a continous monopolistic replacement, its effect translates into more labour required for defensive strategies. Since in this region $\left(\psi < \overline{\psi}\right)$ the decision of labour allocated to defensive purposes does not consider its cost, it merely implies less labour to R&D. In this equilibrium, the modulation made by the size of innovation on the effect of regulatiob is less clear. By simple inspection one notes that it depends on particular values of $\frac{\psi}{\xi}$. For the parameter values of Figure 3, the effect of γ on $\frac{\partial s_{rm}}{\partial \psi}$ depicts a relationship as illustrated in Figure 4.

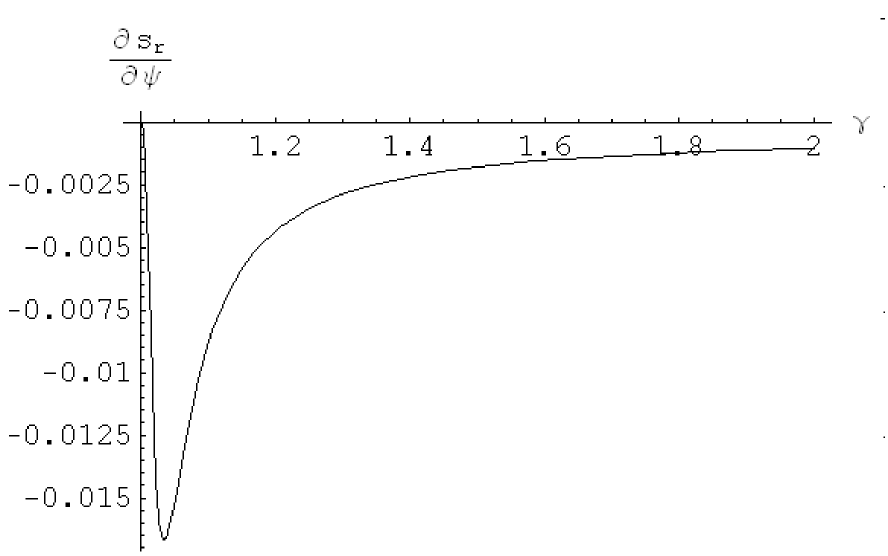


Table 4.

3 Evidence

3.1 Empirical Strategy

Our aim is to identify the effect of regulation on R&D effort at the industry level. Following the model, the role of regulation depends on its level. If regulation is high enough, the continuous Schumpeterian replacement equilibrium arises and regulatory provisions do have an incitative effect on R&D. On the contrary, if regulation is low enough to allow the credibility of the leader commitment, the permanent equilibrium arises and regulatory provisions have a negative effect on R&D effort.

Since data on outsiders R&D is not available we cannot empirically differenciate between both situations. Moreover, as explained above, the outcome of zero R&D effort comes from the choice of a linear technology in R&D, the standard assumption. In practice, monopolists are replaced, even if very later. Indeed, as we are dealing with quality improvements within manufacturing, we should expect a value of σ and γ leading to a low level of $\left[1-\gamma^{-[\sigma-1]}\right]$ and, therefore, a high level of bias θ required to ensure leader credibility. Thus, one may assume the "truly" permanent monopolistic case as an extreme possibility and suppose that sooner or later monopolists are replaced.

Consequently, we should be mainly concerned with the Schumpeterian equilibrium. We then expect a positive effect of regulation on R&D effort, which is more likely to be observed for higher sizes of innovation. Data availability is also constraining in this respect. We suppose that high technology manufacturing (HT) industries make bigger innovative steps. In the sample, these industries are defined as 30-33 ISIC Rev-3 industries. This includes the information and communication technologies (ICT industries) and the manufacturing of medical precision and optical instruments. Results remain similar if one includes industries 29 (machinery and equipment) and motor vehicles (34), industries using intensively ICT technologies.

Therefore, one should expect that, for these industries, innovation especially allows for additional possibilities of monopolistic markups. If this is true, R&D incentives induced by regulation should be higher in HT industries relative to the rest. Let y_{it} be the measure of aggregate R&D effort (labour share in the model) of industry i at time t. We proxy R&D effort with the R&D intensity of the industry measured as the R&D expenditure over value added. Denoting R_{it} the regulation proxy and HT the dummy variable identifying HT industries, our regressions have the following specification:

$$y_{it} = \alpha_1 \; R_{it} + \alpha_2 \; R_{it} \times HT + \alpha_3 \; HT + \alpha_5 x_{it} + \epsilon_{it} \tag{35}$$

Where $\epsilon_{it} = \eta_i + \mu_{it}$, x_{it} is a vector of controls. All variables are in natural logs (except HT). The marginal effect of regulation can be computed as

$$\frac{\partial E\left[y_{it}/HT\right]}{\partial R_{it}} = \alpha_1 \; + \alpha_2 \; HT$$

If $HT = 0$ then the marginal effect is α_1 and reflects the effect of regulation on non-HT industries. When $HT = 1$ the marginal effect is $\alpha_1 \; + \alpha_2$. This means that α_1 is also the effect of regulation which is common to HT and non-HT industries. Thus, α_2 is the effect of regulation on R&D intensity in HT industries *relative* to non-HT ones.

Our model predicts a positive effect of regulation on R&D intensity that increases with the size of innovation. Hence, we expect a positive and significant estimate $\widehat{\alpha}_2$. In other words, if an R&D-boosting effect of regulation can be expected by our theoretical argumetns, it is more likely to be observed in the specificity of high technology industries. In *absolute* terms, the over all effect of regulation on R&D intensity in HT industries will be given by $\widehat{\alpha}_1 \; + \widehat{\alpha}_2$. While the significance of $\widehat{\alpha}_2$ can be ridden directly from the regressions, for $\widehat{\alpha}_1 \; + \widehat{\alpha}_2$ we need to compute the joint significance (See Friedrich, 1982; Braumoeller, 2004; Mullahy, 1999): $\frac{\widehat{\alpha}_1 + \widehat{\alpha}_2}{\sqrt{\widehat{\sigma}_{\widehat{\alpha}_1\widehat{\alpha}_1} + \widehat{\sigma}_{\widehat{\alpha}_2\widehat{\alpha}_2} + 2\widehat{\sigma}_{\widehat{\alpha}_1\widehat{\alpha}_2}}}$, where $\widehat{\sigma}_{ab}$ is the sample covariance between a and b.

Since individuals units are manufacturing industries in different countries we expect a fixed component in the error term. The bias produced by this unobserved time-invariant heterogeneity can be eliminated by the Within Group estimator, at the cost of losing the information provided by $\widehat{\alpha}_3$. The Within Group estimator transforms the model by subtracting the sample period mean of each variable for each individual. This allows to eliminate η_i, but also all time-invariant variables such as HT. As our focus of interest is mainly $\widehat{\alpha}_2$ and $\widehat{\alpha}_1 + \widehat{\alpha}_2$ we adopt this strategy.[9]

Among controls x_{it} in (35) we consider (i) the lag of the closeness relative to the technological frontier (measured as the labour productivity of the country-industry couple relative to the highest one in the world in the same industry at the corresponding period); (ii) a capital intensity ratio; (iii) innovation spill-overs proxied by the innovative activity

[9] Further insights about HT can be learned by using the fixed effect vector decomposition (FEVD) developed by Plümper and Troeger (2007). It consists of three stages. First, a fixed model effect is estimated in order to measure η_i. The second stage correlates this measure with time-invariant variables, those that are eliminated in the usual fixed effect strategy. This step then decompose η_i into a part explained by time-invariant variables and an unexplainable one. The third stage re-estimates the model by OLS and includes the unexplainable error term accounted in the second step. This final step also controls for collinearity between time-varying and time-invariant variables and it adjusts the degrees of freedom. Results (not reported in this version) do not change when we use this methodology.

performed by the rest of the world in the same industry; (iv) financial deepness proxied by the ratio of total asset investment of institutional investors over GDP; and (v) the dependant variable in the previous period.

The control included in (v) implies a dynamic model since it includes the past realisation of the dependant variable on the left-hand-side of (35). Because of the presence of an unknown fixed effect in the error term, the lagged value of the dependant variable will be endogenous to the error term. Among different solutions proposed in the literature, a commonly suggested estimator is System-GMM (Arellano and Bover, 1995; Blundell and Bond, 1998). Intuitively, GMM-based methods exploit the exogeneity of lagged regressors (moment conditions) which is used as information in the search for identification. Basically, what System-GMM does is to include not only the moment conditions provided by the transformed equation (that purge the fixed effect) but also those implied by the equation in levels (not transformed), which is instrumented by lagged differences. This provide a better fit when series are persistent since in that case past differences tends to be better instruments than past values. However, GMM estimators are basically constructed for micro panel data containing a large number of individual for a short sample period. In our industry panel (time-series cross-section data), we have a small number of individuals. In addition, the availability of data for the model including all controls reduces considerably the sample size. This might be very constraining for instrumenting strategies. Namely, the test of exogeneity of instruments are weakened when the number of instruments are large relative to the number of individuals.

On the other hand, a simple OLS estimation will neglect η_i and yield upward biased estimates of the autoregressive coefficient. The within-group estimator will partially address this problem since it purges the fixed effect by subtracting the mean. In this transformation y_{it-1} becomes $\overline{y}_{it-1} = y_{it-1} - \frac{1}{T}\sum_{t=2..T} y_{it-1}$. A similar transformation applies to the error term. A downward bias is expected because the y_{it-1} term present in $\overline{y}_{it-1}$ will correlate negatively with the $-\frac{1}{T}\epsilon_{it-1}$ term of the transformed error term. However, as it has been noted by Bond (2002) and Benavente et al. (2005), this should be less problematic when the number of periods T increases (the correlation is reduced by T). As we have potentially 15 years, we will keep within-group estimates and avoid the problems of instrumenting with a small number of individuals.

3.2 Data

We use the dataset constructed by Amable, Demmou and Ledezma (2007). It contains information for 17 manufacturing industries across 17 OECD countries. Transversal deflation uses the industry-level PPA for 1997 of Timmer, Ympa and van Ark (2006). R&D series are provided by the OECD STAN dataset. The sample period is given by the R&D data availability (1987-2003).

Regulation indicators are also provided by the OECD. We consider the economy-wide indicators of product market regulation PMR, a collection of inward and and outward-oriented market barriers. An important component of PMR that we shall consider in regressions is the size of the public enterprise sector (PMR-Public). This proxy can allow to capture different ways to conduct R&D between public and private actors and also the regulatory environment in R&D activities. Indicators of regulation in times-series at the country level are also available for non-manufacturing sectors (telecoms, electricity, gas, post, rail, air passenger transport, and road freight). This information is summarised in the REGREF indicator provided by the OECD. The corresponding effect of these regulatory provisions on manufacturing activities is also computed by the OECD. These manufacturing "knock-on" effects of regulation is a useful proxy of regulation at the industry level available in the form of panel data. The methodology in the construction of these regulation indicators are fully detailed in Conway and Nicoletti (2006) and Conway et al. (2006). The interpretation of these indicators is discussed in the analysis of results.

3.3 Results

Results of Within Group regressions are presented in Tables 1 to Table 4 for each regulation proxy. All regressions consider Huber-White corrected standard errors. Columns display a progressive inclusion of the explanatory variables. We start with the basic model considering regulation and R&D spillovers (column [1]). We then allow for a differentiated effect of regulation depending on the size of innovation,which is captured by the interaction between regulation and the dummy variable HT (column [2]). In line with recent works on innovation (Aghion et al. [2005]), the model in column [3] includes the proximity to the technological frontier. We use the lag of this variable in order to avoid (at least in part) reverse causality caveats. In column [4] we add the capital labour ratio and the financial deepness proxy. Finally, in column [5] we test a dynamic model including the lagged value of R&D intensity and the rest of controls. All models considers year dummies and individual fixed effects. Further, in the bottom part of each table we include the assessment of the overall effect of regulation on R&D intensity in HT industries. This is computed as the marginal effect $\widehat{\alpha}_1 + \widehat{\alpha}_2$ (equation 35) and its significance.

Table 1 shows the results corresponding to the regulation proxy REGREF related to regulatory provisions in non-manufacturing sectors (telecoms, electricity, gas, post, rail, air passenger transport, and road freight). Manufacturing industries are intermediate inputs of these seven services and also use it in their business process. In this sense, manufacturing production can be seen as subject to their regulation. In a more indirect way, this indicator also allows to capture the regulatory environment of an economy. Following this indicator, in our sample average, Greece and Italy appear as the most regulated countries. UK and US on the contrary are in the opposite extreme.

In the basic model of column [1], regulation has a positive and significative impact on R&D intensity. As expected, international R&D spillovers (R&D intensity of the rest of the world in the same industry), have a positive and significant effect in column [1]. The same is true for the rest of regressions. The model in column [2] yields a positive and significant coefficient of the interaction between regulation and the dummy variable HT. Thus, relative to the rest of industries, the effect of regulation is higher in HT manufacturing. Confirming the model's prediction this interaction term is positive and significant in all specifications. On the other hand, regulation fails to account for a significant effect in non-HT industries (the estimated elasticity of REGREF alone).

The marginal effect, computed in the bottom part of Table 1, considers both (a) the effect of regulation that is common for HT and non-HT industries ($\widehat{\alpha}_1$ in equation 35) and (b) the additional incentives of HT industries to carry out R&D when regulation is increased ($\widehat{\alpha}_2$ in equation 35). This marginal effect of regulation on R&D intensity in HT industries is mostly positive and significant. Only in the model with full controls the minimum level of significance is not attained.

Capital labour ratio and financial assets over GDP have a positive and significant estimated elasticity in column [4]. When the lag of the dependent variable is included (column [5]), their effect is no longer significant. On the contrary, the closeness to frontier is only significant in the latter model (at 10%) and its sign is negative. Theoretically it can not be discarded a negative sign since in advanced technological states R&D costs are higher. The change of sign and significance in this estimate, however, calls for further analysis since a correlation is expected with the lagged dependant variable. On the other hand, R&D spillovers and the interaction term are still significant in this autoregressive specification.

Dependent variable: R&D intensity (R&D/VA) - **Within Group** estimator
Regulation proxy: Regulatory Provisions in Services (REGREF)

	[1]	[2]	[3]	[4]	[5]
R&D Spillovers	0.146***	0.205***	0.226***	0.364***	0.199***
	(0.047)	(0.042)	(0.039)	(0.066)	(0.071)
REGREF	0.264***	0.047	0.011	-0.384***	-0.182**
	(0.082)	(0.070)	(0.066)	(0.105)	(0.085)
REGREF x HT		0.663***	0.705***	0.817***	0.286***
		(0.094)	(0.089)	(0.123)	(0.107)
Closeness to Frontier (t-1)			0.087	0.030	-0.073*
			(0.058)	(0.057)	(0.042)
K/L				0.160**	-0.015
				(0.079)	(0.061)
Financial Assets				0.131*	0.073
				(0.077)	(0.070)
R&D/VA (t-1)					0.601***
					(0.045)
_cons	-3.023***	-2.761***	-3.003***	-2.109***	-0.645
	(0.220)	(0.195)	(0.320)	(0.551)	(0.524)
REGREF on HT industries (marginal effect)		0.709***	0.716***	0.433***	0.104
		(0.119)	(0.114)	(0.147)	(0.127)
year dummies	Yes	Yes	Yes	Yes	Yes
Number of Obs	2756	2756	2743	1110	1012
Number of groups	189	189	189	98	98

Note: Huber-White corrected standard errors in parentheses
All variables in natural logs, except HT (dummy)

Table 1.

The so called "knock-on" effect of non-manufacturing regulation on manufacturing activities are captured by the regulation proxy REGIMP. This policy indicator is constructed accordingly to the "use" of non-manufacturing sectors in manufacturing. It gives then a measure of the regulatory constraints on the input side of production. The advantage is that it is available in time-series cross-section data. Results are presented in Table 2. As before, the impact of R&D spillover on R&D intensity is significant in all specifications. Further, in non-HT industries regulation does not account for a significant effect on R&D intensity. This time this is observed in all columns. However, once the interaction is considered, one observes the positive effect of regulation on R&D intensity in HT industries. This is true in relative and absolute terms. For both the interaction term and the overall marginal effect of regulation on HT manufacturing, the estimated coefficients are positive and significant in all specification, even for the autoregressive model.

The sign of the rest of controls are similar than before, but their significance changes. Financial deepness fails to yield a significant effect. This time, neither does the closeness to frontier in column [5]. On the contrary, its positive sign in column [3] is significant.

Dependent variable: R&D intensity (R&D/VA) - **Within Group** estimator
Regulation proxy: "Knock on" effect of non-manufacturing regulation (REGIMP)

	[1]	[2]	[3]	[4]	[5]
R&D Spillovers	0.159***	0.204***	0.225***	0.342***	0.184**
	(0.048)	(0.044)	(0.041)	(0.069)	(0.072)
REGIMP	-0.026	-0.175	-0.179	-0.300	-0.004
	(0.129)	(0.125)	(0.125)	(0.221)	(0.195)
REGIMP x HT		1.533***	1.720***	1.558***	0.593**
		(0.260)	(0.231)	(0.288)	(0.238)
Closeness to Frontier (t-1)			0.105*	0.043	-0.068
			(0.060)	(0.057)	(0.042)
K/L				0.161**	-0.013
				(0.082)	(0.062)
Financial Assets/ GDP				0.115	0.079
				(0.084)	(0.077)
R&D/VA (t-1)					0.610***
					(0.045)
_cons	-2.618***	-1.892***	-2.166***	-2.868***	-0.692
	(0.287)	(0.323)	(0.361)	(0.566)	(0.525)
REGIMP on HT industries (marginal effect)		1.358***	1.541***	1.258***	0.589**
		(0.291)	(0.256)	(0.337)	(0.292)
year dummies	Yes	Yes	Yes	Yes	Yes
Number of Obs	2756	2756	2743	1110	1012
Number of groups	189	189	189	98	98

Note: Huber-White corrected standard errors in parentheses
All variables in natural logs, except HT (dummy)

Table 2

Results are slightly different for the product market regulation proxy (PMR). PMR is an aggregate of economy-wide indicators aiming at capture market barriers. It does not vary in every period. We dispose of two surveys (2 points in time) distributed in the sample. This is probably the main reason for some changes in the estimations. Table 3 presents the results. Now the effect of regulation in the simple model (column [1]) appear to be negative and significant. This is also true for the effect of regulation in non-HT technologies in column [2] and [3], but the significance is not attained when further controls are included (column [4] and [5]). Interestingly, a positive and significant interaction between regulation and HT industries still shows up in these regressions, at the exception of the full control model with autoregressive dependent variable. While the result of additional R&D incentives induced by regulation in HT industries still holds, the addition of the positive and the negative part of regulation consequences yields a non significant overall marginal effect of regulation on HT industries.

Again a change of sign and significance is observed for the closeness to frontier. In general, the level of significance of the controls in these PMR regressions does not allow further conclusions.

Dependent variable: R&D intensity (R&D/VA) - **Within Group** estimator **Regulation proxy**: Economy-wide product market regumation (PMR)					
	[1]	[2]	[3]	[4]	[5]
R&D Spillovers	0.152***	0.192***	0.217***	0.331***	0.170**
	(0.048)	(0.046)	(0.043)	(0.070)	(0.073)
PMR	-0.782***	-0.933***	-0.908***	-0.262	-0.009
	(0.240)	(0.244)	(0.235)	(0.332)	(0.257)
PMR x HT		0.675***	0.788***	0.641***	0.037
		(0.171)	(0.143)	(0.188)	(0.161)
Closeness to Frontier (t-1)			0.067	0.036	-0.071*
			(0.060)	(0.058)	(0.042)
K/L				0.133	-0.030
				(0.086)	(0.062)
Financial Assets/ GDP				0.079	0.062
				(0.084)	(0.076)
R&D/VA (t-1)					0.621***
					(0.045)
_cons	-2.117***	-1.998***	-2.221***	-2.475***	-0.797
	(0.223)	(0.217)	(0.313)	(0.640)	(0.567)
PMR on HT industries (marginal effect)		-0.258	-0.120	0.379	0.029
		(0.255)	(0.227)	(0.355)	(0.252)
year dummies	Yes	Yes	Yes	Yes	Yes
Number of Obs	2756	2756	2743	1110	1012
Number of groups	189	189	189	98	98
Note: Huber-White corrected standard errors in parentheses					
All variables in natural logs, except HT (dummy)					

Table 3.

Among market barriers summarised in PMR, one important indicators is the size of public sector enterprise (PMR-Public). One should expect that a higher and active scope of the state in manufacturing impose higher regulation, namely in the production of new varieties. Table 4 shows the results considering PMR-Public. The effect of regulation in the simple model is again positive and significant (column [1]). Similarly, once the interaction is considered the effect of PMR Public alone (the impact of regulation on R&D inn non-HT industries) is non significant. Concerning our estimates of interest, we observe again that the interaction variable has a positive and significant coefficient in almost all specifications. In column [4] (full set of controls), however, the significance is ensured only at 10% and in column [5] (full set of control and autoregressive dependant variable) it is not attained. The overall marginal effect of regulation on HT industries is positive and significant as before. The estimates related to the rest of controls are similar than in PMR regressions. Only the closeness to the frontier is significant in the autoregressive model.

Dependent variable: R&D intensity (R&D/VA) - **Within Group** estimator
Regulation proxy: Size of Public Sector Entrprise (PMR Public)

	[1]	[2]	[3]	[4]	[5]
R&D Spillovers	0.155***	0.190***	0.217***	0.318***	0.166**
	(0.054)	(0.052)	(0.049)	(0.071)	(0.073)
PMR Public	0.555**	0.147	0.193	0.371	0.162
	(0.250)	(0.250)	(0.245)	(0.321)	(0.215)
PMR Public x HT		1.566***	2.011***	0.818*	-0.076
		(0.551)	(0.470)	(0.418)	(0.332)
Closeness to Frontier (t-1)			0.086	0.044	-0.070*
			(0.064)	(0.058)	(0.041)
K/L				0.113	-0.037
				(0.085)	(0.062)
Financial Assets/ GDP				0.107	0.066
				(0.079)	(0.070)
R&D/VA (t-1)					0.622***
					(0.045)
_cons	-3.751***	-3.657***	-4.093***	-3.395***	-1.002*
	(0.327)	(0.310)	(0.427)	(0.662)	(0.549)
PMR Public on HT industries (marginal effect)		1.713***	2.204***	1.189***	0.086
		(0.531)	(0.469)	(0.396)	(0.313)
year dummies	Yes	Yes	Yes	Yes	Yes
Number of Obs	2548	2548	2535	1110	1012
Number of groups	176	176	176	98	98

Note: Huber-White corrected standard errors in parentheses
All variables in natural logs, except HT (dummy)

Table 4.

Overall, these results confirm the main model prediction regarding the Schumpetrian equilibrium. As regulation increase, the dissuasive effect of defensive strategies of the leaders can be reduced. As a consequence, R&D incentives are higher, but the final effect regulation is always modulated by the size of innovation since it shapes monopolist incentives. This prediction implies that the positive effect of regulation should empirically be found when the size of innovation is higher. This is what the interaction term confirm for almost all regressions and indicators of regulation. Finally, it should be stressed that further work is needed concerning the dynamic regressions. The reduced size of the sample has compelled us to abandon a GMM strategy. A detailed examination of available instruments should be carry out. The aim of this task should be to find a reduced and powerful set of instruments allowing to control for the (reduced) risk of downward bias in the autoregressive coefficient, without weaking the tests of exogeneity of instruments. However, note that for the time varying regulation proxies (REGREF and REGIMP), the interaction term still yields a positive and significant coefficient in the dynamic specification. This is important because these indicators are more pertinent to perform panel data regressions.

One may argue that our time-series cross-section data structure implies intra-group correlation. Thus, we run all regressions using clustered Huber-White correction of standard errors. Results are presented in Tables 5 to 8 in the Appendix. Concerning the interaction term, most of the previous results are preserved. Namely, for the time varying indicators REGREF and REGIMP, the sign of the estimate is positive and significant in all regressions, even for the autoregressive model. The significance of the overall marginal effect of regulation on R&D in HT industries is reduced for the static model with the full set of controls and the autoregressive one. As before, the lack of significance of this estimate still appears in PMR regressions. However, the marginal effect still remain positive and significant in most of regressions.

Finally, as an additional robustness check we redefine the HT dummy variable to incorporate other activities using intensively ICT industries as suppliers. We namely include industries 29 (machinery and equipment) and motor vehicles (34). We show the results in Tables 9 to 12 in the Appendix. Here again the main argument of the model is confirmed: the coefficient of the interaction term is still positive and significant for most of specifications and indicators.

4 Conclusion

We have shown in a simple model of innovation by quality the consequences of defensive innovation strategies on R&D effort and market structure. Among available strategies, defensive reactions may render R&D more costly and reduce the incentives to innovate. Institutions constraining this set of strategies and reducing its deterring effects may increase the resources devoted to innovation and also the number of active R&D race participants. The evolution of R&D expenditure and indicators of market regulation in OECD industries confirms these results. Despite data limitation and the simple framework of the model, the core message seems clear: manufacturing defensives reactions, hard to enforce and more or less limited by market regulation, rise the question about the role of market institutions steering rivalry externalities.

5 Appendix

5.1 Robustness check 1: clustered corrected standard errors

Dependent variable: R&D intensity (R&D/VA) - **Within Group** estimator
Regulation proxy: Regulatory Provisions in Services (REGREF)

	[1]	[2]	[3]	[4]	[5]
R&D Spillovers	0.146*	0.205***	0.226***	0.364***	0.199***
	(0.079)	(0.071)	(0.062)	(0.104)	(0.054)
REGREF	0.264	0.047	0.011	-0.384*	-0.182
	(0.198)	(0.147)	(0.139)	(0.205)	(0.118)
REGREF x HT		0.663***	0.705***	0.817***	0.286**
		(0.231)	(0.226)	(0.221)	(0.123)
Closeness to Frontier (t-1)			0.087	0.030	-0.073
			(0.130)	(0.106)	(0.058)
K/L				0.160	-0.015
				(0.144)	(0.078)
Financial Assets				0.131	0.073
				(0.127)	(0.071)
R&D/VA (t-1)					0.601***
					(0.044)
_cons	-3.023***	-2.761***	-3.003***	-2.109**	-0.645
	(0.425)	(0.359)	(0.645)	(1.021)	(0.613)
REGREF on HT industries (marginal effect)		0.709**	0.716**	0.433	0.104
		(0.301)	(0.290)	(0.264)	(0.147)
year dummies	Yes	Yes	Yes	Yes	Yes
Number of Obs	2756	2756	2743	1110	1012
Number of groups	189	189	189	98	98

Note: Clustered Huber-White corrected standard errors in parentheses
* p<0.10, ** p<0.05, *** p<0.01; All variables in natural logs, except HT (dummy)

Table 5.

Dependent variable: R&D intensity (R&D/VA) - **Within Group** estimator
Regulation proxy: "Knock on" effect of non-manufacturing regulation (REGIMP)

	[1]	[2]	[3]	[4]	[5]
R&D Spillovers	0.159*	0.204***	0.225***	0.342***	0.184***
	(0.081)	(0.073)	(0.064)	(0.108)	(0.056)
REGIMP	-0.026	-0.175	-0.179	-0.300	-0.004
	(0.257)	(0.255)	(0.257)	(0.369)	(0.232)
REGIMP x HT		1.533***	1.720***	1.558***	0.593**
		(0.588)	(0.560)	(0.574)	(0.293)
Closeness to Frontier (t-1)			0.105	0.043	-0.068
			(0.138)	(0.102)	(0.055)
K/L				0.161	-0.013
				(0.147)	(0.076)
Financial Assets/ GDP				0.115	0.079
				(0.135)	(0.075)
R&D/VA (t-1)					0.610***
					(0.045)
_cons	-2.618***	-1.892***	-2.166***	-2.868**	-0.692
	(0.537)	(0.635)	(0.737)	(1.109)	(0.683)
REGIMP on HT industries (marginal effect)		1.358**	1.541***	1.258*	0.589*
		(0.629)	(0.589)	(0.643)	(0.327)
year dummies	Yes	Yes	Yes	Yes	Yes
Number of Obs	2756	2756	2743	1110	1012
Number of groups	189	189	189	98	98

Note: Clustered Huber-White corrected standard errors in parentheses
* p<0.10, ** p<0.05, *** p<0.01; All variables in natural logs, except HT (dummy)

Table 6.

Dependent variable: R&D intensity (R&D/VA) - **Within Group** estimator
Regulation proxy: Economy-wide product market regumation (PMR)

	[1]	[2]	[3]	[4]	[5]
R&D Spillovers	0.152*	0.192**	0.217***	0.331***	0.170***
	(0.081)	(0.075)	(0.066)	(0.107)	(0.057)
PMR	-0.782*	-0.933**	-0.908**	-0.262	-0.009
	(0.415)	(0.430)	(0.408)	(0.400)	(0.289)
PMR x HT		0.675**	0.788***	0.641***	0.037
		(0.310)	(0.266)	(0.244)	(0.130)
Closeness to Frontier (t-1)			0.067	0.036	-0.071
			(0.139)	(0.101)	(0.052)
K/L				0.133	-0.030
				(0.156)	(0.080)
Financial Assets/ GDP				0.079	0.062
				(0.135)	(0.077)
R&D/VA (t-1)					0.621***
					(0.045)
_cons	-2.117***	-1.998***	-2.221***	-2.475**	-0.797
	(0.416)	(0.396)	(0.596)	(1.004)	(0.626)
PMR on HT industries (marginal effect)		-0.258	-0.120	0.379	0.029
		(0.423)	(0.377)	(0.438)	(0.260)
year dummies	Yes	Yes	Yes	Yes	Yes
Number of Obs	2756	2756	2743	1110	1012
Number of groups	189	189	189	98	98

Note: Clustered Huber-White corrected standard errors in parentheses
* p<0.10, ** p<0.05, *** p<0.01; All variables in natural logs, except HT (dummy)

Table 7.

Dependent variable: R&D intensity (R&D/VA) - **Within Group** estimator
Regulation proxy: Size of Public Sector Entrprise (PMR Public)

	[1]	[2]	[3]	[4]	[5]
R&D Spillovers	0.155*	0.190**	0.217***	0.318***	0.166***
	(0.090)	(0.085)	(0.076)	(0.110)	(0.057)
PMR Public	0.555	0.147	0.193	0.371	0.162
	(0.381)	(0.400)	(0.395)	(0.450)	(0.231)
PMR Public x HT		1.566	2.011**	0.818	-0.076
		(0.971)	(0.849)	(0.565)	(0.283)
Closeness to Frontier (t-1)			0.086	0.044	-0.070
			(0.150)	(0.101)	(0.052)
K/L				0.113	-0.037
				(0.155)	(0.078)
Financial Assets/ GDP				0.107	0.066
				(0.134)	(0.071)
R&D/VA (t-1)					0.622***
					(0.045)
_cons	-3.751***	-3.657***	-4.093***	-3.395***	-1.002*
	(0.531)	(0.496)	(0.814)	(1.046)	(0.594)
PMR Public on HT industries (marginal effect)		1.713*	2.204***	1.189**	0.086
		(0.892)	(0.823)	(0.513)	(0.227)
year dummies	Yes	Yes	Yes	Yes	Yes
Number of Obs	2548	2548	2535	1110	1012
Number of groups	176	176	176	98	98

Note: Clustered Huber-White corrected standard errors in parentheses
* p<0.10, ** p<0.05, *** p<0.01; All variables in natural logs, except HT (dummy)

Table 8.

5.2 Robustness check 2: high technology definition

Dependent variable: R&D intensity (R&D/VA) - **Within Group** estimator
Regulation proxy: Regulatory Provisions in Services (REGREF)

	[1]	[2]	[3]	[4]	[5]
R&D Spillovers	0.146***	0.201***	0.233***	0.362***	0.184**
	(0.047)	(0.046)	(0.043)	(0.072)	(0.077)
REGREF	0.264***	0.046	-0.008	-0.355***	-0.164*
	(0.082)	(0.073)	(0.068)	(0.107)	(0.086)
REGREF x HT2		0.449***	0.505***	0.254**	0.045
		(0.072)	(0.076)	(0.107)	(0.077)
Closeness to Frontier (t-1)			0.125**	0.071	-0.066
			(0.063)	(0.060)	(0.043)
K/L				0.124	-0.031
				(0.084)	(0.062)
Financial Assets				0.106	0.061
				(0.079)	(0.070)
R&D/VA (t-1)					0.617***
					(0.045)
_cons	-3.023***	-2.786***	-3.140***	-2.330***	-0.659
	(0.220)	(0.209)	(0.342)	(0.574)	(0.527)
REGREF on HT2 industries (marginal effect)		0.495***	0.497***	-0.101	-0.119
		(0.101)	(0.099)	(0.152)	(0.103)
year dummies	Yes	Yes	Yes	Yes	Yes
Number of Obs	2756	2756	2743	1110	1012
Number of groups	189	189	189	98	98

Note: Huber-White corrected standard errors in parentheses
All variables in natural logs, except HT2 (dummy)

Table 9

Dependent variable: R&D intensity (R&D/VA) - **Within Group** estimator
Regulation proxy: "Knock on" effect of non-manufacturing regulation (REGIMP)

	[1]	[2]	[3]	[4]	[5]
R&D Spillovers	0.159***	0.200***	0.231***	0.352***	0.183**
	(0.048)	(0.047)	(0.044)	(0.072)	(0.076)
REGIMP	-0.026	-0.203	-0.230*	-0.215	0.032
	(0.129)	(0.129)	(0.130)	(0.220)	(0.197)
REGIMP x HT2		0.969***	1.153***	0.681***	0.231
		(0.184)	(0.187)	(0.231)	(0.176)
Closeness to Frontier (t-1)			0.133**	0.076	-0.057
			(0.065)	(0.060)	(0.043)
K/L				0.133	-0.025
				(0.085)	(0.062)
Financial Assets/ GDP				0.107	0.074
				(0.085)	(0.077)
R&D/VA (t-1)					0.619***
					(0.045)
_cons	-2.618***	-1.990***	-2.332***	-2.807***	-0.633
	(0.287)	(0.322)	(0.361)	(0.563)	(0.524)
REGIMP on HT2 industries (marginal effect)		0.766***	0.922***	0.466	0.262
		(0.210)	(0.201)	(0.293)	(0.240)
year dummies	Yes	Yes	Yes	Yes	Yes
Number of Obs	2756	2756	2743	1110	1012
Number of groups	189	189	189	98	98

Note: Huber-White corrected standard errors in parentheses
All variables in natural logs, except HT2 (dummy)

Table 10.

Dependent variable: R&D intensity (R&D/VA) - **Within Group** estimator
Regulation proxy: Economy-wide product market regumation (PMR)

	[1]	[2]	[3]	[4]	[5]
R&D Spillovers	0.152***	0.182***	0.210***	0.325***	0.171**
	(0.048)	(0.047)	(0.045)	(0.071)	(0.075)
PMR	-0.782***	-0.958***	-0.945***	-0.284	-0.017
	(0.240)	(0.252)	(0.244)	(0.349)	(0.264)
PMR x HT2		0.476***	0.577***	0.311**	0.046
		(0.127)	(0.122)	(0.144)	(0.112)
Closeness to Frontier (t-1)			0.089	0.062	-0.068
			(0.063)	(0.059)	(0.041)
K/L				0.130	-0.029
				(0.087)	(0.062)
Financial Assets/ GDP				0.079	0.062
				(0.084)	(0.076)
R&D/VA (t-1)					0.621***
					(0.045)
_cons	-2.117***	-2.028***	-2.331***	-2.613***	-0.803
	(0.223)	(0.223)	(0.324)	(0.643)	(0.565)
PMR on HT2 industries (marginal effect)		-0.482**	-0.368*	0.026	0.029
		(0.236)	(0.218)	(0.304)	(0.233)
year dummies	Yes	Yes	Yes	Yes	Yes
Number of Obs	2756	2756	2743	1110	1012
Number of groups	189	189	189	98	98

Note: Huber-White corrected standard errors in parentheses
All variables in natural logs, except HT2 (dummy)

Table 11.

Dependent variable: R&D intensity (R&D/VA) - Within Group estimator Regulation proxy: Size of Public Sector Entrprise (PMR Public)	[1]	[2]	[3]	[4]	[5]
R&D Spillovers	0.155***	0.179***	0.210***	0.307***	0.164**
	(0.054)	(0.054)	(0.051)	(0.072)	(0.074)
PMR Public	0.555**	0.142	0.158	0.481	0.196
	(0.250)	(0.277)	(0.275)	(0.359)	(0.238)
PMR Public x HT2		1.005**	1.335***	0.176	-0.134
		(0.409)	(0.382)	(0.383)	(0.277)
Closeness to Frontier (t-1)			0.105	0.050	-0.073*
			(0.068)	(0.059)	(0.041)
K/L				0.102	-0.037
				(0.086)	(0.063)
Financial Assets/ GDP				0.110	0.066
				(0.079)	(0.070)
R&D/VA (t-1)					0.622***
					(0.045)
_cons	-3.751***	-3.681***	-4.176***	-3.556***	-1.005*
	(0.327)	(0.319)	(0.443)	(0.658)	(0.552)
PMR Public on HT2 industries (marginal effect)		1.147***	1.493***	0.657**	0.062
		(0.373)	(0.352)	(0.324)	(0.240)
year dummies	Yes	Yes	Yes	Yes	Yes
Number of Obs	2548	2548	2535	1110	1012
Number of groups	176	176	176	98	98
Note: Huber-White corrected standard errors in parentheses					
All variables in natural logs, except HT2 (dummy)					

Table 12.

5.3 Descriptive Statistics

Variable	Obs	Mean	Std. Dev.
R&D / Added Value	2852	0,104	0,527
PMR	5760	1,801	0,437
REGREF	6375	4,193	1,312
PMR Public	6375	3,015	1,280
REGIMP	6375	0,132	0,037
Closeness to Frontier	6043	56,946	23,458
K/L (hours)	2785	0,046	0,031
Financial Assets/GDP	4440	66,915	50,330

Table 13

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