Product market regulation, Innovation and Distance to Frontier

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Abstract

This paper tests the relation between product market regulation and innovation conditional to the closeness to the technological frontier on a a panel of 15 industries for 17 OECD countries over the period 1979-2003. A recent literature has focused on a negative impact of regulation growing in intensity with the proximity to the frontier. A simple model of innovation and growth shows that one should not necessarily expect this result. Empirical tests on a variety of specifications show that the schedule linking the impact of product market regulation to the closeness to the technological frontier has a positive slope and that the impact of regulation can be positive when industries are close to the frontier.

1 Introduction

Concerns about the lack of convergence of Europe's productivity level vis-à-vis the US over the past decade have been expressed not only in academic circles but also among policy makers and politicians. As numerous reports have shown (Kok, 2004; Sapir, 2004), Europe seems to be losing ground, not because of an insufficient rate of capital accumulation, but for lack of innovation capability. The so-called Lisbon Strategy, which aims at fostering innovation and productivity, proposes a series of structural reforms for labour, financial and product markets. Regarding the latter, a link between competition and innovation underlies the whole Lisbon Strategy: more

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product market competition should bolster innovation and thus productivity and growth.[1]

According to economic theory, the relation between competition and innovation is ambiguous.[2] For Schumpeter (1934), monopoly profits are rewards to innovators; the appropriability of innovation output is thus a crucial incentive issue. A rise in competition is expected to decrease rents stemming from innovation and thus incentives to innovate. This traditional 'Schumpeterian effect' of competition is featured in numerous innovation-based endogenous growth models, in particular Aghion and Howitt (1992) where innovation effort increases with the Lerner index. On the other hand, competition may encourage innovation. Incumbents may innovate to keep their market power and fend off new entrants, or potential entrants may hope to capture the market position of incumbents by surpassing them with new and better products. In both cases, innovation would be the means for a firm to get the upper hand over its competitors.

Both effects can be introduced in an extension of the Schumpeterian innovation-based endogenous growth model. In Aghion et al. (2005), firms with different productivity levels innovate to decrease their production costs 'step by step': a technological laggard has to catch-up with the technological level of the leader before having the possibility of becoming itself a leader in the industry. The risks for the leader to lose its position are therefore increased when the competitor is only one step away from catching-up. When competitors have comparable productivity levels, i.e. the so-called 'neck and neck' competition, a stronger competition will induce firms to increase their innovative investments in order to acquire a competitive lead over rival firms. This pro-innovation effect of competition is less prominent in industries where the leader has a marked advantage over its competitor.[3]

One would therefore expect economies to behave differently according to the distance to the technological frontier. A recent literature has emphasised that Innovation would matter more than imitation close to the frontier (Acemoglu et al., 2003 & 2006) and the growth- and innovation-enhancing impact of factors such as skilled labour would increase with a country's proximity to the frontier (Vandenbusche et al., 2006). The argument extends to competition and regulation. If product market regulation limits the intensity of competition, this should lead firms to innovate less, and this effect should be all the more important that a country or an industry is close to the technological frontier. Product market regulation could thus possibly boost innovation in laggard industries, but would hinder it in leading sectors.

The aim of this paper is to assess the validity of this argument on two aspects. We

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[1] e.g. the Integrated Guidelines 12 to 16 (European Commission, 2005).

[2] On innovation and competition, see Etro (2007).

[3] The incorporation of both innovation-inducing and innovation-deterring effects of competition into a single model leads to a nonlinear, inverted U-shaped, relation between product market competition and innovation.

propose first a simple modification of the 'distance to frontier' framework and show that the conclusion of an increasingly negative impact of regulation on innovation can be reversed when one enables the leader to innovate, making it more difficult for followers to catch up. This extension is more coherent with existing evidence on leading firms' innovation effort such as documented in the 2008 EU Industrial R&D Investment Scoreboard with the ranking of the world top 50 R&D companies.[4] Also, empirical evidence provided by Crépon and Duguet (1997) shows the existence of a negative externality among R&D competitors in narrowly defined industries.It is also in line with recent developments in the innovation and competition literature: Etro (2007, 2008) shows that for a wide range of models, leaders facing the threat of competition are always aggressive compared to the followers. In a patent race context, Etro (2008) shows that the investment of the leader is higher than the investment of the follower

The paper then tests on industry data the existence of a relationship between product market regulation and innovation conditional on the proximity to the frontier on a sample of OECD countries over the 1979-2003 period using patent data. To the best of our knowledge, this is the first paper testing the impact of regulation on *innovation* at the industry level with a cross-country panel. We show that the schedule linking the impact of regulation on innovation and the proximity to the frontier is upward sloping. Product market regulation may have an innovation-hindering effect far from the frontier, but this effect turns eventually positive as an industry moves closer to the frontier. A comparison of previous industry-level studies with ours show that the upward-sloping schedule seems to be a common pattern (Nicoletti and Scarpetta, 2003).

These results suggest that some channels linking product market regulation to innovation may have been neglected in the 'distance to frontier literature'. Product market deregulation could alter the competitive environment and lead firms to favour the cost-cutting dimension of competition rather than product innovation and quality improvement; it could make firms' economic environment more uncertain and thus discourage them from undertaking risky innovative investment, or shift the focus of innovative activity on incremental modifications with little technological but potentially large economic value rather than more radical improvements.

Our results also contradict the belief in the innovation-boosting effect of product market deregulation for advanced countries such as taken into account in the Lisbon Strategy and hint that deregulation policy cannot be a substitute for active science and technology policies in developed countries.

The paper is organised as follows. The next Section discusses the theoretical argument relating innovation with competition and regulation. A modification of one of the simple baseline model of Aghion et al. (2005)'s hypotheses makes the relation-

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[4] See also Table 1 in Segerstrom (2007).

ship between the innovation-hindering effect of regulation and distance to frontier more complex. Section 3 presents the data and the empirical strategy. Section 4 presents the first estimation results. Section 5 proposes extensions and robustness tests of this model and compares our results with those found in the literature. A brief conclusion proposes some channels through which product market regulation might positively impact innovation.

2 Theoretical Framework

The conclusion that product market regulation would be detrimental to innovation in leading industries/countries is now considered as 'common wisdom' (Aghion and Griffith, 2005). This view may nevertheless neglect mechanisms that could possibly mitigate the conclusions of the 'distance to frontier' literature.

For the sake of simplicity of presentation we remain close to Aghion et al's. (2005) baseline framework and introduce the possibility of leaders being active in innovation in order to show that the validity of the deregulation prescription depends on the extent to which leaders are absent from the R&D contest.[5] We assume that the leader's innovation makes it more difficult for laggards to catch-up. This gives to leaders incentives to innovate and the results is that the pattern of the relationship between competition and innovation depends on the extent to which leaders can influence the innovative process of laggards.[6]

2.1 The baseline setup

We consider Aghion et al.'s (2005) economy composed of a unit mass of identical consumers. Each consumer supplies inelastically one unit of labour and has a logarithmic instantaneous utility function $u(y) = \ln y$ with a constant discount rate r, y being consumption. It is composed of intermediates according to the following production function:

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[5] One may model such incentives in different ways: by supposing asymmetric advantages in Nash-Cournot equilibriums with decreasing returns in R&D technologies (Segestrom, 2007) or by assuming a Stackelberg game in which leaders have a first mover advantage.

[6] The inverted-U pattern has also been empirically criticised by recent contributions. Tingvall and Poldahl (2006) find that, for Swedish firms, the empirical support for the existence of such a pattern depends on the indicator used. While the Herfindal- index gives support to the inverted U-shape, the price cost margin does not allow to fit this pattern. Moreover, the use of time-series estimators reduces considerably the significance of the results. Askenazy, Cahn and Irac (2007), using a panel of French firms, find that the concavity of the curve linking competition and innovation is substantially reduced when the size of the firm is small relative to the cost of innovation. For the authors, this type of firms represents 85% of the sample.

$$\ln y = \int_0^1 \ln x_j dj \tag{1}$$

The market structure is such that there are two duopolists, A and B, in each industry j . Production of an intermediate j at each date is the sum of each duopolist's production: $x_j = x_{Aj} + x_{Bj}$. Because of the logarithmic utility function (1), each intermediate receives the same expenditure share. Spending on each good is normalised to unity: $p_{Aj}x_{Aj} + p_{Bj}x_{Bj} = 1$.

Each intermediate is produced with constant returns to scale using labour as the only input. Denoting k_i the technology level of the duopolistic firm i in industry j, the productivity level of firm i is defined as:

$$A_i = \gamma^{k_i} \qquad i = A, B \tag{2}$$

where γ captures the size of the innovative steps. The baseline model assumes that, in any intermediate industry, the largest gap between the leader and the follower is one technological step because of knowledge externalities. If the leader innovates, the follower immediately climbs one step up the quality ladder so that the relative positions of the two firms is not altered.

At any point in time, there are two types of sectors in this economy: leveled industries where both firms are at the same technological level and unleveled industries where the technological leader is one technology step above its competitor. Thus, three type of firms indexed by $i \in \{-1, 0, 1\}$ exist : a follower ($i = -1$), a firm in a leveled sector ($i = 0$) and a leader ($i = 1$). Depending on innovation firms A and B can find themselves in these different states.

In unleveled industries, the leader applies a limit pricing rule and sets a price equal to the marginal cost of the laggard. The latter makes then zero profit while the leader makes a profit equal to 1 minus its production cost (wages are normalised to 1):

$$\pi_{-1} = 0 \qquad \pi_1 = 1 - \frac{1}{\gamma} \tag{3}$$

In a leveled industry, product market competition is modelled through the degree of collusion ϵ of the two firms. If firms do not collude, Bertrand competion brings profits to zero. At a maximum level of collusion, firms split the leader profits between themselves (one half for each). Thus the model summarises in $\Delta = 1 - \epsilon$ $(0 \leq \epsilon \leq 1/2)$ the degree of competition. Profits in leveled sectors are then given by:

$$\pi_0 = (1 - \Delta)\,\pi_1 \tag{4}$$

Firms can move one technological step ahead at a Poisson hazard rate of n by incurring an R&D cost $\frac{c\,n^2}{2}$. The follower can move one step ahead at a hazard rate h even without spending anything on R&D. One note n_0 the R&D intensity of each firm in leveled industries, n_{-1} that of the follower firm and n_1 that of a leading firm in an unleveled industry. A particular characteristic of the baseline model is that $n_1 = 0$ since the leading firm has no incentive to innovate because of the knowledge externality assumption. It is this feature that we modify in what follows.

2.2 Active leaders

In this new setting, the assumption restricting the maximum sustainable productivity gap to be one step is kept. However, we consider that the leader's R&D effort n_1 makes it more difficult for the follower to innovate and move one step ahead, i.e. it reduces the catch-up probability to $h - \lambda n_1$, with λ a parameter capturing the ability of the leader to influence the R&D difficulty of the follower. One may suppose that the engagement of the leader in a new discovery induces a change in the technological paradigm. Even if the technological difference is still one step, the leader's innovation makes this last step harder to climb for the follower.[7]

The steady state Bellman equations associated to each possible state (leader, leveled or follower) can be expressed as:

$$rV_1 = \pi_1 + (n_{-1} + h - \lambda n_1)(V_0 - V_1) - \frac{cn_1^2}{2} \tag{5}$$

$$rV_{-1} = \pi_{-1} + (n_{-1} + h - \lambda n_1)(V_0 - V_{-1}) - \frac{cn_{-1}^2}{2} \tag{6}$$

$$rV_0 = \pi_0 + n_0 (V_1 - V_0) + \overline{n}_0 (V_{-1} - V_0) - \frac{cn_0^2}{2} \tag{7}$$

Where V_i is the value of each type of firm $i \in \{-1, 0, 1\}$. The R&D effort of the competitor in a leveled sector is denoted by $\overline{n}_0$. In a symmetric Nash equilibrium both R&D intensity are equal. Hence, the baseline model might be interpreted as a particular case in which $\lambda = 0$. Using the maximum principle, first order conditions on the right-hand-side lead to innovating investment decisions:

$$cn_1 = \lambda (V_1 - V_0) \tag{8}$$

$$cn_{-1} = V_0 - V_{-1} \tag{9}$$

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[7] This case is in general excluded in the standard quality ladder framework. However, as Grossman and Helpman (1991) pointed out in its seminal work, leaders might have several reasons to innovate, namely to deter the innovation of their rivals.

$$cn_0 = V_1 - V_0 \tag{10}$$

Recalling that $\pi_0 = (1-\Delta)\,\pi_1$ and solving for n_1 and n_{-1} leads to the reduced system:

$$0 = \Delta\pi_1 - \frac{\rho c n_1}{\lambda} + \frac{c n_1^2}{2}\left(1 - \frac{1}{\lambda^2}\right) \tag{11}$$

$$0 = -\,(1-\Delta)\,\pi_1 - \frac{1}{\lambda^2}\frac{c n_1^2}{2} + \left(\rho + n_1\left[\frac{1}{\lambda} - \lambda\right]\right) c n_{-1} + \frac{c n_{-1}^2}{2} \tag{12}$$

Where $\rho \equiv h + r$. These equations determine the leader R&D effort n_1 and that of the follower n_{-1}, respectively. From (8) and (10) the R&D effort of the leveled firm is inmediately determined $n_0 = \frac{n_1}{\lambda}$. The following propositions characterise the stationary R&D efforts in this jump-stochastic process (proofs are given in appendix).

Proposition 1. *The possibility of two stationary R&D effort of the* ***leader firm*** *depends on λ.*

(a) *For $\lambda < 1$ there is only one relevant stationary strategy for the leader:*

$$n_{1a} = \lambda \frac{\rho c - \sqrt{D_1}}{c\left(\lambda^2 - 1\right)} \tag{13}$$

Where $D_1 \equiv \rho^2 c^2 - 2c\left(\lambda^2 - 1\right)\Delta\pi_1$. For this strategy, competition increases R&D effort.

(b) *For $\lambda > 1$ and $\lambda^2 - 1 < \frac{\rho^2 c}{2\Delta\pi_1}$ there are two relevant stationary strategies for the leader: n_{1a}* and

$$n_{1b} = \lambda \frac{\rho c + \sqrt{D_1}}{c\left(\lambda^2 - 1\right)} \tag{14}$$

For strategy n_{1b}, competition discourages R&D effort.

Proposition 2. *The possibility of two stationary R&D effort of a* ***leveled firm*** *depends on λ.*

(a) *For $\lambda < 1$ there is only one relevant stationary strategy for a leveled firm:*

$$n_{0a} = \frac{\rho c - \sqrt{D_1}}{c\left(\lambda^2 - 1\right)} \tag{15}$$

Where $D_1 \equiv \rho^2 c^2 - 2c\left(\lambda^2 - 1\right)\Delta\pi_1$. *For this strategy competition increases R&D effort.*

(b) *For* $\lambda > 1$ *and* $\lambda^2 - 1 < \frac{\rho^2 c}{2\Delta\pi_1}$ *there are two relevant stationary strategies for a leveled firm:* n_{0a} and

$$n_{0b} = \frac{\rho c + \sqrt{D_1}}{c\left(\lambda^2 - 1\right)} \tag{16}$$

For strategy n_{0b} *competition discourages R&D effort.*

Proposition 3. *For any value of* λ, *competition discourages the stationary R&D effort of the* ***follower firm****. The follower's stationary strategy is given by:*

$$n_{-1} = \frac{\left(-\left(\rho + n_1\left[\frac{1}{\lambda} - \lambda\right]\right)c + \sqrt{D_{-1}}\right)}{c} \tag{17}$$

Where $D_{-1} \equiv \left[\left(\rho + n_1\left[\frac{1}{\lambda} - \lambda\right]\right)c\right]^2 + 2c\left[\left(1 - \Delta\right)\pi_1 + \frac{1}{\lambda^2}\frac{cn_1^2}{2}\right]$.

2.3 Aggregate innovation

The two possible stationary strategies of the leader firm (Proposition 1) will imply two type of equilibrium since n_0 and n_{-1} are functions of n_1. As in the baseline model, the steady state equilibrium is defined in terms of the structure of sectors. If μ_1 is the probability in steady state of being in an unleveled sector, the probability that a sector moves from an unleveled state to a leveled one is then $\mu_1\left(n_{-1} + h - \lambda n_1\right)$. The transition in the opposite direction is made with probability $2\mu_0 n_0$, where μ_0 denotes the steady-state probability of being in a leveled sector. The steady state equilibrium is given by equalising inward- and outward-flows:

$$\mu_1\left(n_{-1} + h - \lambda n_1\right) = 2\mu_0 n_0 \tag{18}$$

Where the condition $\mu_1 + \mu_0 = 1$ must hold . This implies:

$$\mu_1 = \frac{2n_0}{\left[\left(n_{-1} + h - \lambda n_1\right) + 2n_0\right]} \tag{19}$$

$$\mu_0 = 1 - \mu_1 \tag{20}$$

The R&D effort of the leader does not change the structure of the industry, but it contributes to the aggregate flow of innovation, which can be expressed as:

$$I = \mu_1 \left(n_{-1} + h - \lambda n_1 + n_1 \right) + 2\mu_0 n_0 \tag{21}$$

The implication of a positive stationary R&D effort of the leader is that the the steady state proportion of unleveled sectors can be important, because if the leader innovates the follower has a lower probability to catch-up. In this type of sectors, if n_{1b} applies, both leader's and follower's R&D are discouraged by competition. Thus, the aggregate effect of competition can in fact be negative. This is what Figures 1 to 3 show. For the sake of brevity, only numerical simulations are reported. The figures display the aggregate flow of innovation I as function of competition Δ. Figure 1 considers the case of $\lambda < 1$ in which only one stationary strategy n_{1a} is possible. As expected, using a value of λ very close to 0 ($\lambda = 0.001$) the model reproduces the standard results: the effects of competition on innovation are given by an inverted U-shape pattern.

<Figure 1>

When the ability of the leader to influence laggard innovation is important enough ($\lambda > 1$) two equilibriums are possible correponding to the two possible stationary strategies for the leader. Figure 2 and 3 show aggregate innovation when the R&D effort of the leader is n_{1a} and n_{1b}, respectively. We observe that if $\lambda > 1$, when the stationary strategy of the leader is given by n_{1a} the inverted U-shape no longer holds and innovation appears as monotonically increasing with competition. On the other hand, when the leader innovates at the (numerically) higher rate n_{1b} exactly the opposite occurs: competition is uniformly *detrimental* to innovation. As $n_{1b} > n_{1a}$ one might interpret this results as the outcome of fierce rivalry in high technology industries.

<Figure 2>

<Figure 3>

This simple modification of the baseline model shows that the prediction of a boosting effect of competition on innovation in industries that are close to the technological frontier is not the only possible equilibrium. Namely, if leaders have enough influence on the laggard's innovation the outcome of competition can be detrimental for innovation. Since our adaptation of the baseline model modifies its most well known prediction, namely that competition fosters innovation in industries that are close to the technological frontier, we now turn to empirical tests of the robustness of this argument using product market regulation indicators.

3 Data and estimation strategy

3.1 Data

We collected information for 17 OECD countries and 15 manufacturing industries at the 2-digit level ISIC-Rev3 from 1979 to 2003 (see Table A1 in appendix). Original data stems from the STAN database of OECD (henceforth OECD-STAN), the 60-Industry database of the Groningen Growth and Development Centre[8] (henceforth GGDC-Industry) and the Patent Statistic database of EUROSTAT. We focus on manufacturing industry as it better represents the theoretical framework exposed above. One the one hand if fixed costs exists in manufacturing, they are less likely associated to natural monopolies. The regulatory environment then tends to have a more decisive role on market structure. On the other hand, output-based productivity measures are usually seen as better indicators of performance in manufacturing than in services. Thus, while coverage of data is potentially larger in the source datasets, we implement our tests on manufacturing and keep data for industries, countries and period with more reliable and available information. From OECD-STAN we used trade indicators and investment series. Starting from OECD-STAN, the Groningen Growth and Development Centre complete value added information with surveys and their own estimations, checking consistency with national accountings.[9] This GGDC-Industry data is our original source for labour productivity, implicit deflators and hours worked.

3.1.1 Distance to the frontier

Labour productivity (value added per hour worked) is used as the measure of efficiency allowing to identify the technological frontier. The latter is defined as the most productive available technology for each industry and time period. The individual (country-industry couple) having the maximum labour productivity among all countries in a given year is identified as the technological leader for that year. The closeness to the frontier is measured as the percentage of labour productivity

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[8] Groningen Growth and Development Centre, 60-Industry Database, September 2006, http://www.ggdc.net/. This data update information from the O'Mahony and van Ark (2003) dataset for the porject of International Comparisons of Output and Productivity by Industry (ICOP)

[9] GGDC-Indsutry database estimate OECD-STAN missing information going to alternative sources and applying different estimation methods. However, the resulting dispersion is considerably bigger (See GGDC rows in Appendix Table A2). We drop GGDC-Indsutry estimations of industry 30 (office machinery) because of its high dispersion and keep the OECD-STAN values for GGDC-Indsutry outliers when OECD information exists. The global dispersion considerably diminishes (Filtered Data). With this filter we get 6098 observation instead of 4129, with series quite comparable to those available in OECD-STAN.

relative to that of the frontier.[10] We consider a moving average of three year in order to smooth the series.

All nominal series were deflated to 1997 in their national currency. In order to make an international comparison at the industry level, we correct for price differences among countries (cross-section deflation). This is specially important for the value added series a central element of our productivity measure. Use is made of the industry-level purchasing power parities (I-PPPs) provided by Timmer et al. (2007) for 1997. The authors consider a mix between purchasing power parities based on expenditure and production.[11] The consequence is that the identification of the frontier by country-industry couple can be affected by the use of a more precise measure correcting purchasing power differences.

3.1.2 Innovation

As a proxy of innovation we consider patent intensity.[12] This measure aims at controlling for market size effects by relating patenting to labour (hours worked) at the industry level. The results is a continuous aggregated measure of innovation that enables international industry-level comparisons. The indicator of patenting at the industry level is provided by EUROSTAT (Patent Statistic database). In this database the applications at the European Patents Office (EPO) are distributed to industry standard classifications. This is done with the help of a transfer matrix that links technological areas of the International Patent Classification (IPC) to industry classifications through several empirically adjusted steps based on detailed firm-level data and expertise. The methodology of construction of the transfer matrix is fully described in Schmoch et al. (2003).[13]

3.1.3 Regulation

One particular feature of our empirical exercise is that we focus on indicators of regulation. Their use in an international industry-level study presents several advantages. Since they capture *de jure* dimensions of competition, these indicators are more directly linked to policy. For the same reason, they are less suspected of en-

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[10] The distance to frontier is then the inverted ratio.

[11] See Appendix.

[12] Although the model's predictions concern the innovative performance, one may consider R&D investment as alternative measure of technoligical activity. R&D expenditure at the industry level is available from the OECD ANDBERD database. Nevertheless, the data presents many missing values (more than 60% of total observations) and it is only available from 1987 onwards.

[13] The US counterpart of the EPO system is the United States Patents and Trademarked Office (USPTO). The information given by both sources are not directly comparable since the EPO system informs about applications and the USPTO about patent granted. We consider the EPO system as it is more representative for the countries present in our sample.

dogeneity than observed measures of competition during a given short time period. Moreover, they allow to compare different regulatory environments and to exploit the aggregate structure of our data. Three indicators provided by the OECD have been selected to capture the extent of market regulation:

- Knock-on effects of non-manufacturing regulation (henceforth REGIMP): Also detailed in Conway and Nicoletti (2006), this indicator captures how manufacturing is affected by regulatory provisions in: (i) network services, (ii) retail, distribution and business services and (iii) financial sectors. The underlying idea is that these sectors are in constant interaction with manufacturing so that their regulation also constraints the operation of manufacturing firms. REGIMP's calculation is based on input/output matrices defining the use of non-manufacturing sectors as inputs in manufacturing. The main advantage of REGIMP is to provide a time-varying industry-level measure of regulation in line with the panel structure of our sample.

- Regulatory provisions in network sectors (henceforth REGREF): This indicator measures the extent of market regulation in seven network services (telecoms, electricity, gas, post, rail, air passenger transport, and road freight). Similarly than PMR, it is mainly based on qualitative information which is coded into quantitative scores increasing in the expected restriction of competition. It also follows a bottom-up approach to inform of regulation concerning entry, public ownership, vertical integration and market structure. This indicator is available in times series at the national level. Since these network sectors are a key element in national deregulation policies, REGREF should be seen as a proxy of the national evolution of market regulation. Further details can be found in Conway and Nicoletti (2006).

- Product market regulation (henceforth PMR): It is an economy-wide indicator of main inward- and outward-oriented market barriers. While more directly related to product market regulation it is only available for two points in time (1998 and 2003). To maximise sample size these values have been distributed in two periods: before and after 2000. Since PMR is based on a collection of private and governmental practices, this distribution should be in line with the evolution of European market reforms.[14] The PMR indicator we use is a national aggregation of several detailed policy indicators constructed from a set of questions whose answer are codified within a 1-6 scale attributing higher values to practices constraining free market competition. Thanks to a bottom-up approach, these detailed indicators are further aggregated in policy domains

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[14] In our regressions we use several methods purging fixed effects, so that this time-invaryng distribution will have only an impact when the indicator is used in interaction with another variable.

such as state control, barriers to entrepreneurship and barriers to trade and investments. Methodological details of construction are given in Conway et al. (2005).

REGIMP and REGREF have a high level of correlation with PMR, respectively 64% and 78% for 1998 and 2003. Because of their higher time variability, we shall pay special attention to the time-varying indicators REGIMP and REGREF. The panel-data structure of the latter is particularly appealing for estimation efficiency. Appendix Table A6 summarises the main descriptive statistics.

3.1.4 Other explanatory variables

Our regressions also include explanatory variables capturing alternative mechanisms influencing the performance in innovation.

- Technological externalities: Aiming at capturing innovation spillovers, for each country-industry couple and time period we compute the patent intensity performed by the rest of countries in the industry. This proxy of innovation externalities presents then a time-varying industry-level availability consistent with our data structure.

- Import penetration: The import penetration ratio (MPEN) available in OECD-STAN indicators helps to control for foreign competition pressures not captured by our indicators of regulation. Its variability is also compatible with our panel-data structure.

- Labour market protection: We include a measure of employment protection legislation in order to control for potential imperfection affecting the allocation of labour toward more profitable activities. We use the employment protection indicator proposed by Amable et al. (2007) available at country level. This indicator updates the annual employment protection indicator provided by Nickell et al. (2003), by relying on FRDB Social Reforms Database.[15]

- Capital intensity: It is measured as the ratio of capital stock over hours worked. Capital series were constructed using investment series of OECD-STAN and

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[15] The FRDB Social Reforms Database has been developed by the Fondazione Rodolfo Debenedetti (http://www.frdb.org). It collects, on an annual basis, information about social reforms in European countries over the period 1985-2005 in the areas of employment protection legislation. The exact procedure to construct our EPL time series is described in the Appendix of Amable, Demmou and Gatti (2007).

the standard Perpetual Inventory Method (PIM).[16] The inclusion of capital intensity may help to capture complementarities between capital stock and innovation. Its poor availability, however, reduces sample size by more than 50%, mainly due to missing individuals (country-industry). Due to the consequences of this lack of information on selection bias and on the performance of estimation techniques (see below), we will only include this control as a robustness check.

3.2 Estimation Strategy

3.2.1 Dynamic issues

We test the impact of market regulation on innovation using time-series cross-section data at the industry level for OECD countries. A plausible model of the innovation process should exploit this panel structure and allow for a dynamics in which past innovations help to explain current ones. The characteristics of our data imply a non-negligible unobserved heterogeneity among individuals (country-industry) that will be present in both past and current innovation. In such a model, the past realisation of our dependent variable will be endogenous to the fixed effect in the error term. The estimates of the autoregressive coefficient will be upward biased and those yielded by a within-group estimator downward biased (Bond, 2002).

Several strategies can be adopted to face these dynamic concerns. We are particularly interested in the one suggested by Arellano and Bover (1995) and fully developed by Blundell and Bond (1998), usually called system GMM (S-GMM).[17] The main property of S-GMM is to improve efficiency by exploiting initial conditions of the autoregressive process that enable to add the original equations in levels to the transformed model in differences (i.e. the one to has purged the fixed effect). Looking at the number of individuals, it could be argued that S-GMM will not be as suitable as in micro panel studies (small T and large N). While smaller than the number of individuals in usual micro-level data, our number of country-industry couples is around 250 individuals in most of regressions, which is non negligible and namely bigger than the roughly 140 individuals of Arellano and Bond (1992), one

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[16] This method uses the dynamic rule by which current capital stock equals the stock of the preceding period after depreciation plus the current investment. To compute the initial stock, the PIM method supposes that pre-sample investment grows at a constant rate. Under the assumption of steady state this rate equals the one of value added. After applying this result to the dynamic rule, the initial stock becomes a function of initial investment, the global depreciation rate and the steady state growth rate of value added. We proxy the latter with the mean of the sample period and use a depreciation rate of 7.5%.

[17] As previously explained our final measure is an aggregated continuous proxy of innovative performance. We treat then this normalised measure of innovation with methods dealing with continuous variables rather than with counts coming from independant experiments.

of the seminal studies on GMM. More importantly, the inclusion of the equation in levels has two appealing advantages for our empirical exercise. First, it deals with the problem of weak instruments when the series are persistent. Second, it allows to keep the information of variables with a weak variation over time. This is namely the case of our proxies of regulation. Moreover, GMM techniques address endogeneity issues since they allow for predetermined (explained by their past realisations) or endogenous regressors (explained by current and past realisations of other variables and by their own autoregressive process). In our setting, this is particularly important since on the right-hand-side one of our main focus is the interaction term between the closeness to the frontier and market regulation, a terms that is expected to be partially determined by innovation. Thanks to an appropriate set of instruments, S-GMM enables us to tackle this reversal causality issue, common to this type of empirical exercise.

In order to provide further comparable estimates we also report regressions using the within group estimator and the bias correction of Bruno (2005). The idea is to exploit our potential long sample period. As noticed by Bond (2002) the downward bias of the autoregressive coefficient in within group regressions diminishes with the number of periods.[18] Based on Kiviet (1995), Bruno (2005) provide an asymptotic correction of the bias for unbalanced panels for a fixed-effect specification. Although these estimators do not address the endogeneity of regressors, they are useful as alternative robustness tests of our results.

3.2.2 Specification

We focus on three explanatory variables: the closeness to the frontier cl_{it}, product market regulation mr_{it} and their interaction $mr_{it} * cl_{it}$. This interaction term will capture the extent to which market regulation influences the innovative process for a given level of the proximity to the technological frontier. Denoting p_{it} the patenting intesinty of the industry i at time t, the following model is estimated:

$$p_{it} = \alpha\ p_{it-1} + \beta_1\ cl_{it} + \beta_2\ mr_{it} * cl_{it} + \beta_3\ mr_{it} + \delta\ x_{it} + \epsilon_{it} \tag{22}$$

Where x_{it} is a vector of controls. The list includes capital intensity, the externalities arising from innovation in the rest of countries in the industry, year indicators, the ration of import penetration and labour market regulation indicator. We expect an individual time-invaryling fixed component in the error term $\epsilon_{it} = \eta_i + \mu_{it}$.

Aiming at getting further insights about the concavity of the effect of regulation, we include the squared terms of the closeness to the frontier and market regulation:

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[18] The within group estimator substracts the mean to purge the unobserved fixed effect component. Because of the mean transformation, the bias is proportional to 1/T, and so it tends to dissapear as T increases.

$$p_{it} = \alpha p_{it-1} + \beta_1 cl_{it} + \beta_2 mr_{it} * cl_{it} + \beta_3 \; mr_{it} + \beta_7 cl_{it}^2 + \beta_8 mr_{it}^2 + \delta \; x_{it} + \epsilon_{it} \quad (23)$$

This specification is equivalent to consider a translog approximation of a constant elasticity function between both variables. This formulation can be more precise than the reduced form in (22) to capture an eventual complementarity between regulation and proximity to the frontier.

3.2.3 Instruments

One key issue in our instrumenting strategy is the number of instruments since the Hansen test of the exogeneity becomes less rigorous as the number of instruments increases. The usual recommendation is to have less instruments than individuals, a rule that is in line with evidence provided by simulation (see Windmeijer, 2005). This rule for our sample size is somewhat constraining because: (i) the number of instrument is quadratic in time dimension and (ii) S-GMM generates not only a set of instrument for the transformed equation but also for the equation in levels. We overcome this difficulty by using limited lags, by considering only most informative instruments and by collapsing in more restricted regressions the matrix of an instrumenting variable into a vector. The latter strategy is equivalent to sum up independent moment conditions in one equation.[19]

In addition, we pay special attention to the autocorrelation of the error term, a crucial assumption for the validity of instruments. Use is made of the Arellano-Bond test for serial correlation in differences. To ensure the validity of p_{it-2} as instruments, this test check for the autocorrelation between ϵ_{it-1} and ϵ_{it-2} by looking at the correlation between $\Delta\epsilon_{it}$ and $\Delta\epsilon_{it-2}$. As discussed in Bond and Meghir (1994), if p_{it-2} is invalid, earlier lags should be used until to be consistent with the serial autocorrelation of ϵ_{it}. After considering all these issues, S-GMM regressions instrument the lagged dependent variable p_{it-1} with its own lag 3 (i.e. p_{it-4}) or earlier if needed to ensure the consistence with the potential serial autocorrelation of the disturbance.

The set of instruments is also completed by the proximity to the frontier cl_{it} in lag 3 or earlier, the interaction term $mr_{it} * cl_{it}$ in lag 4 or earlier and the proxy of externalities in lag 3 or earlier. Thus we consider all these variables as endogenous regressors. The inclusion of additional controls suspected to be endogeneous leads to the use of further instruments. This is the case of import penetration ratio and the capital intensity. In each case, the main criterion to accept the instrumentation strategy is the Hansen test and its version in difference which allows to test a subset of instruments.[20]

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[19] Examples of this strategy are Calderon et al. (2002) or Beck and Levine (2004)

[20] Blundell and Bond (1998) state the validity of instruments in terms of the stationarity of the

3.2.4 The marginal effect of competition on innovation

Since we have included an interaction term between market regulation and the closeness to technological frontier ($mr_{it} * cl_{it}$), the assessment concerning the expected overall effect of product market competition mr_{it} needs the computation of its marginal effect conditional on specific values of the closeness to the frontier cl_{it}:

$$\frac{\partial E(p_{it}\,|x_{it})}{\partial mr_{it}} = \widehat{\beta}_2 cl_{it} + \widehat{\beta}_3 \tag{24}$$

For the translog version:

$$\frac{\partial E(p_{it}\,|x_{it})}{\partial mr_{it}} = \widehat{\beta}_2 cl_{it} + \widehat{\beta}_3 + 2\widehat{\beta}_8 mr_{it} \tag{25}$$

Similar expressions hold for (**??**) and the lagged version of (23). It is easy to see, for instance, that a negative and significant $\widehat{\beta}_3$ means nothing but that regulation decreases innovation activity *only* for an individual very far from the technological frontier ($cl_{it} = 0$). That is for the unrealistic case of zero labour productivity. Notice that for the augmented version (23), the calculation of the marginal effect of competition depends on the level of competition itself mr_{it} in (25).

As each of these linear combinations is computed using the estimated values of β_2,β_3 and β_8, one still needs to determine their significance, which in turn will depend on the variance of estimates and the value at which cl_{it} is evaluated (Friedrich, 1982; Braumoeller, 2004). Hence, statistically insignificant coefficients may combine to produce statistically significant conditional effects. In our regression we evaluate the marginal effect and its significance for the minimum, one deviation under the mean, the mean, one deviation over the mean and the maximum sample values of cl_{it}. For the translog version we take the mean value of mr_{it}.

4 Results

Table 1 presents results of the tests of the effects of regulation on patenting using two different indicators for regulation: the regulation impact indicator REGIMP (regressions [1] to [3]) and the indicator of regulation in network sectors REGREF ([4] to [6]). Regressions [1], [2], [4] and [6] have a level dependent variable and a lagged dependent variable as a regressor. Regressions [4] and [6] have a difference dependent variable and no lagged dependent variable as a regressor. The inclusion

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initial conditions of the autoregressive process. We verify the risk of unit root of our main time series variables by the means of the Fisher test developed by Maddala and Wu (1999) for panel data. We do not take a risk rejecting the null hypothesis of non stationary for all series using our specification.

of such a specification is made for the sake of comparison. Regressions [1], [3], [4] and [6] are estimated with a standard fixed effect panel data estimator, whereas regressions [2] and [5] use a bias-corrected least square dummy variables dynamic panel data estimator (Kiviet, 1995; Bruno, 2005[21]). For each regression, the lower panel of Table 1 presents the estimated marginal effects of the competition indicator for different levels of the relative productivity level. The first line of the lower panel gives the value of the marginal effect when the relative technological level is at its minimum (min), i.e. when the distance to the frontier is at its maximum. The last lines give the marginal effects and standard errors when the relative productivity level is at the maximum of the sample, i.e. at the technology frontier. Marginal effects coefficients are also presented for the mean value of the relative technological level, the mean value minus one standard deviation and plus one standard deviation. Therefore, reading a column of the lower panel of the Table shows how the marginal effect of competition changes as the distance to the technological frontier decreases and vanishes.

According to the predictions of Aghion et al. (2005), Aghion (2006), one would expect a positive marginal effect of regulation far from the technological frontier (i.e. the predominance of the Schumpeterian effect) and a negative effect close to the frontier (resulting from the predominance of the the 'escape competition' effect), i.e. a downward sloping relationship between the impact of regulation and the closeness to the frontier. However, the results reported in Table 1 show that this conclusion is not valid. All level regressions ([1], [2], [4] and [5]) show a significant positive marginal effect of regulation close to the frontier for both indicators, a significant negative effect of regulation with REGIMP (regressions [1] and [2]) and a non significant effect of regulation with REGREF ([4] and [5]) far from the frontier. The effect of regulation on patenting at the mean is either non significant ([1] and [2]) or significantly positive ([4] and [5]). Therefore, far from obtaining an increasingly negative effect of regulation on innovation as one approaches the technological frontier, one obtains the opposite. Regulation in product markets has a significantly positive effect on innovation as one approaches the technological frontier, the slope of the marginal effect of regulation is positive.

Figure 4 plots the marginal effect of the regulation impact indicator with confidence intervals and the distribution of industries with respect to the distance to the frontier in the background (regression [2]). The positive slope of the schedule indicates that regulation may have a negative effect on innovation when industries are far from the frontier, but this effect becomes gradually positive when the relative productivity level increases. Also, for intermediate values of the distance to the frontier, the marginal effect of regulation is not significant.

Regressions in difference confirm broadly the results obtained with the level de-

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[21] The xtlsdvc procedure under Stata.

pendent variable: a positive effect of regulation as measured with REGIMP (regression [3]) which increases with the closeness to the frontier; a non significant effect of regulation with REGREF. Therefore, there is no evidence supporting the 'common wisdom' about the effect of regulation on innovation.

Table 1. Regulation and Innovation (Within-group and Bruno (2005) regressions)

Panel A. Dependent Variable: Patenting (patents decomposition /hours worked)

	[1] REGIMP (1)	[2] REGIMP (2)	[3] REGIMP (3)	[4] REGREF (1)	[5] REGREF (2)	[6] REGREF (3)
Patenting (t-1)	0.591***	0.685***		0.578***	0.671***	
	(0.021)	(0.013)		(0.021)	(0.014)	
Closeness to frontier	0.298*	0.299**	0.033	-0.162***	-0.169***	-0.000
	(0.153)	(0.118)	(0.167)	(0.039)	(0.046)	(0.039)
Regulation	-0.547*	-0.546**	0.113	-0.207	-0.229*	0.013
	(0.284)	(0.250)	(0.304)	(0.138)	(0.133)	(0.152)
Regulation x Closeness to frontier	0.150**	0.154***	0.014	0.110***	0.106***	0.002
	(0.068)	(0.056)	(0.073)	(0.034)	(0.031)	(0.038)
Externalities	0.243***	0.179***	-0.017	0.247***	0.183***	-0.005
	(0.041)	(0.044)	(0.040)	(0.040)	(0.044)	(0.041)
Year dummies	Yes	Yes	Yes	Yes	Yes	Yes
Number of Obs	5775	5775	5775	5775	5775	5775
Individuals	249	249	249	249	249	249
Estimator	Within	Bruno (2005)	Within	Within	Bruno (2005)	Within

Panel B. Marginal Effect of Regulation

Closeness to frontier	REGIMP (1)	REGIMP (2)	REGIMP (3)	REGREF (1)	REGREF (2)	REGREF (3)
Minimum	-0.344*	-0.337*	0.132	-0.058	-0.086	0.015
	(0.194)	(0.179)	(0.208)	(0.093)	(0.094)	(0.104)
1 Standard deviation below the mean	-0.036	-0.021	0.160*	0.167***	0.131***	0.019
	(0.076)	(0.090)	(0.082)	(0.038)	(0.046)	(0.043)
Mean	0.043	0.061	0.168**	0.224***	0.187***	0.020
	(0.063)	(0.079)	(0.068)	(0.034)	(0.041)	(0.038)
1 Standard deviation over the mean	0.122*	0.142*	0.175**	0.282***	0.243***	0.021
	(0.069)	(0.077)	(0.074)	(0.039)	(0.041)	(0.043)
Maximum	0.144**	0.164**	0.177**	0.298***	0.258***	0.021
	(0.073)	(0.079)	(0.079)	(0.042)	(0.043)	(0.046)

Notes:
- Panel A reports regressions of patenting performance on regulation conditional on the closenness to the frontier
- Panel B reports for each regression the marginal effect of regulation and its significance at different sample values of the closeness
- Standard errors in parentheses. *, ** and *** denote significance at 1%, 5% and 10%, respectively
- Regressions using Bruno's (2005) correction bias use Blundell-Bond initial solution

Table 2. Regulation and Innovation (System GMM regressions)

Panel A. Dependent Variable: Patenting (patents decomposition /hours worked)

	[1] REGIMP (1)	[2] REGIMP (2)	[3] REGREF (1)	[4] REGREF (2)
Patenting (t-1)	0.963***	0.969***	0.959***	0.967***
	(0.009)	(0.006)	(0.009)	(0.007)
Closeness to frontier	0.108***	-0.221	-0.159***	-0.410
	(0.017)	(0.203)	(0.046)	(0.318)
Regulation	-0.191***	-0.669**	-0.386***	-0.118
	(0.028)	(0.306)	(0.136)	(0.112)
Regulation x Closeness to frontier	0.063***	0.125***	0.109***	0.011
	(0.008)	(0.042)	(0.034)	(0.032)
Externalities	0.039***	0.033***	0.039***	0.033***
	(0.010)	(0.007)	(0.010)	(0.009)
Closeness to frontier^2		0.066*		0.053
		(0.039)		(0.046)
Regulation^2		-0.049		0.070***
		(0.045)		(0.025)
Year dummies	Yes	Yes	Yes	Yes
Number of Obs	5775	5775	5775	5775
Hansen p	0.207	0.140	0.111	0.112
Hansen p (instruments for levels)	0.999	0.998	0.995	0.998
AR(2)p	0.000	0.000	0.000	0.000
AR(3)p	0.102	0.102	0.104	0.103
Instruments	237	243	244	249
Individuals	249	249	249	249

Panel B. Marginal Effect of Regulation

Closeness to frontier	REGIMP (1)	REGIMP (2)	REGREF (1)	REGREF (2)
Minimum	-0.107***	-0.296**	-0.238***	0.089
	(0.023)	(0.124)	(0.091)	(0.097)
1 Standard deviation below the mean	0.022	-0.039	-0.014	0.111***
	(0.024)	(0.042)	(0.027)	(0.036)
Mean	0.055**	0.027	0.044***	0.117***
	(0.026)	(0.026)	(0.017)	(0.026)
1 Standard deviation over the mean	0.088***	0.093***	0.102***	0.123***
	(0.028)	(0.024)	(0.022)	(0.024)
Maximum	0.097***	0.111***	0.117***	0.124***
	(0.029)	(0.027)	(0.026)	(0.025)

Notes:
- Panel A reports regressions of patenting performance on regulation conditional on the closenness to the frontier
- Panel B reports for each regression the marginal effect of regulation and its significance at different sample values of the closeness
- Standard errors in parentheses. *, ** and *** denote significance at 1%, 5% and 10%, respectively
- Since disturbances can be autocorrelated of order 1, but not further, the autoregressive variable is instrumented in t-4 (Bond and Meghir, 1994) to ensure valid instruments. The resto of the set of GMM-style instruments is composed of the interaction and externalitites in lag 3 or earlier and the set of IV-style instruments of year dummies.

The use of the S-GMM estimator will allow us to deal not only with the lagged dependent variable bias but also with the potential endogeneity of several of the regressors. One may indeed suppose that the distance to frontier indicator taken into account here is endogenous. Other variables may also be endogenous to the growth process.

Table 2 presents the S-GMM estimations of the effects of regulation on innovation using the same indicators as in the previous Table. Two specifications are tested, one which is identical to the level specification of Table 1, and a translog specification, including quadratic terms for the distance to frontier and the regulation indicators in the regressions. This more flexible function may make it possible to estimate more accurately the effects of regulation. The results of Table 2 confirm those of Table 1. For all specifications, regulation of product markets is found to exert a negative impact on innovation far from the frontier and an increasingly positive effect as the productivity level rises, with a significant positive effect at the mean in most cases. Therefore, the slope of the schedule linking the marginal effect of regulation with the closeness to the frontier is positive (Figures 5 and 6).

Therefore, the results obtained so far allow to depict a clear picture about the marginal effect of regulation according to the proximity to the technological frontier: product market regulation has an increasingly positive impact on innovation as the industry moves closer to the frontier, i.e. the marginal effects of regulation indicators display a positive slope. This result is also broadly confirmed when one uses the less precise PMR indicator (Appendix Table A6). The next Section checks the robustness of these results by considering alternative specifications under system GMM.

<Figures 4 to 6 >

5 Extensions and comparison

5.1 Extended model

The model considered in the preceding Section is now extended with the inclusion of other variables. The regulation indicators considered previously mainly referred to the domestic situation. Competition from foreign firms can be important in some industries. In order to better control for this effect, the import penetration ratio is included in the regressions. Other institutional variables may have an influence too. The literature on competition and innovation refers to labour regulation (Aghion and Griffith, 2005). Labour market flexibility is supposed to favour restructuring and hasten the decline of sunset industries, allowing factors to be transferred to sunrise industries (Saint-Paul, 2002). A measure of employment protection (Amable, Demmou and Gatti, 2007) is included in the extended model. We also control for the influence of the capital-labour ratio. This variable has the drawback of limiting drastically the size of the sample, which is why its inclusion is tested separately. The existence of a possible bias due to the data availability means that results with this variable should be taken with caution. Results for the extended models are presented in Table 3.

Import penetration turns out to have positive coefficients on innovation, but these coefficients are only weakly significant in the regressions using the regulation in services indicator ([3]) or the regulation impact indicator in the regression including the capital-labour ratio ([2]). The labour market legislation (employment protection) variable obtains no significant coefficients whatever the regulation indicator or the model specification. One cannot therefore conclude to the existence of an innovation-hindering effect of employment legislation. Finally, the capital-labour ratio never appears to significantly contribute to innovation.

The extension of the basic model does not alter the broad conclusions regarding the marginal effect of product market regulation. The positively-sloped relationship of the regulation effect with the relative productivity level is maintained (Figure 6), except when one considers the *REGREF* variable with the addition of the foreign competition and employment protection controls (regression [3]). The slope of the relationship linking regulation to distance to frontier turns weakly negative. However, contrary to 'common wisdom', the impact of regulation is always positive whatever the relative level of productivity. Therefore, once again, the common wisdom story receives no empirical support. Estimations with the PMR indicator do not alter this conclusion (Appendix Table A7).

Table 3. Regulation and Innovation (System GMM regressions - Full Control)

Panel A. Dependent Variable: Patenting (patents decomposition /hours worked)

	[1] REGIMP (1)	[2] REGIMP (2)	[3] REGREF (1)	[4] REGREF (2)
Patenting (t-1)	0.978***	0.923***	0.975***	0.869***
	(0.008)	(0.030)	(0.009)	(0.044)
Closeness to frontier	0.148***	1.445**	0.041***	-0.211
	(0.052)	(0.630)	(0.015)	(0.134)
Regulation	-0.117**	-2.737**	0.097	-1.239**
	(0.047)	(1.201)	(0.070)	(0.546)
Regulation x Closeness to frontier	0.062***	0.671**	-0.004	0.218*
	(0.022)	(0.298)	(0.019)	(0.122)
Externalities	0.031***	0.062*	0.031***	0.089**
	(0.008)	(0.036)	(0.009)	(0.045)
Labour market protection	-0.031	0.008	-0.003	-0.065
	(0.022)	(0.060)	(0.014)	(0.168)
Import Penetration	0.018	0.081	0.021*	0.155**
	(0.012)	(0.050)	(0.012)	(0.067)
Capital Intensity		-0.046		0.005
		(0.053)		(0.065)
Year dummies	Yes	Yes	Yes	Yes
Number of Obs	4699	2356	4699	2356
Hansen p	0.151	0.271	0.115	0.466
Hansen p (instruments for levels)	0.588	0.288	0.892	0.333
AR(4)p	0.017	0.910	0.017	0.928
AR(5)p	0.101	0.218	0.099	0.210
Instruments	224	129	224	92
Individuals	232	134	232	134

Panel B. Marginal Effect of Regulation

Closeness to frontier	REGIMP (1)	REGIMP (2)	REGREF (1)	REGREF (2)
Minimum	-0.033	-1.335**	0.091*	-0.782**
	(0.038)	(0.581)	(0.049)	(0.318)
1 Standard deviation below the mean	0.102	-0.246**	0.082**	-0.428**
	(0.063)	(0.117)	(0.035)	(0.193)
Mean	0.131*	0.002	0.080**	-0.347*
	(0.072)	(0.072)	(0.037)	(0.184)
1 Standard deviation over the mean	0.160**	0.251*	0.078*	-0.266
	(0.081)	(0.145)	(0.042)	(0.185)
Maximum	0.169**	0.352*	0.078*	-0.233
	(0.084)	(0.186)	(0.043)	(0.189)

Notes:

- Panel A reports regressions of patenting performance on regulation conditional on the closenness to the frontier
- Panel B reports for each regression the marginal effect of regulation and its significance at different sample values of the closeness
- Standard errors in parentheses. *, ** and *** denote significance at 1%, 5% and 10%, respectively
- Since disturbances can be autocorrelated of order 3, but not further, the autoregressive variable is instrumented in t- 6 or earlier (Bond and Meghir, 1994) to ensure valid instruments. The resto of the set of GMM-style instruments is composed of the interaction term, import pentration and externalitites in lag 4 or earlier and the set of IV-style instruments of year dummies.

5.2 Comparison with previous studies

Our results can be compared to those obtained in the empirical literature linking regulation policy, distance to frontier and TFP growth at the industry level. Nicoletti and Scarpetta (2003) consider a sample of 23 industries for 18 OECD countries over the period 1984-1998. They test a model of TFP growth using OECD's product market regulation indicators both alone and in interaction with an inverse measure of the technology gap variable (the log difference between multifactor productivity of the country-industry and the frontier). Overall, they find statistically significant positive coefficients on the interacted variable, a result they interpreted as a catch-up slowing-down effect of product market regulation. The comparison of our results with those of Nicoletti and Scarpetta's (2003) paper is not an easy task because of differences in the model'specification,[22] sample, dependent variable and estimators. However, if one assumes that the mechanisms by which regulation influences productivity growth are related to innovation, their results on the conditional effect of regulation on TFP are useful to establish a link with our findings. Indeed, the statistically significant positive effect of the interaction term is in line with our results. This finding, stemming from several of their regressions (namely those concerning manufacturing), accounts for a positive slope of the schedule lonking regulation's impact to the closeness to the frontier[23]. Conway et al. (2006) test a similar model of labour productivity with interaction terms between product market regulation indicators and a technology gap measure on a slightly extended sample of OECD countries. They find a significantly positive coefficient on the interacted variables term too. While the authors also interpret their results as a catch-up slowing-down effect of regulation, at the same time their estimates of the interaction term coefficient suggests again an upward-sloping schedule.

It should be stressed that once the differentiated effect of regulation conditional to the productivity gap must be assessed with the magnitude (and significance level) of the marginal effect. What differentiates our results from those found in most of the literature is a careful presentation of such effects. From the results presented in Nicoletti and Scarpetta (2003) or Conway et al. (2006), one can only assess the significance of the impact of regulation at the frontier (i.e. when the log difference of productivity of the industry and that of the leader is zero) with the help of the coefficient for the regulation indicator alone. Though mostly non-significant this coefficient is in general positive. The difference with our results in terms of significance at the very top level of performance probably reflects the method applied and the model tested. While they test a growth model without the lagged dependent variable on the right-hand side (i.e constraining the autoregressive coefficient to be 1) we test a multivariate autoregressive model and address dynamic panel bias issues.

Arnold et al. (2008) test the effect of regulation on firm-level TFP for a sample of selected OECD countries potentially available from 1998-2004. Results highlight a negative significant effect of regulation on productivity in ICT-using sectors. In

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[22] Their specification does not include a lagged dependent variable and considers the growth of the leader as a regressor.

[23] This conditional pattern is actually reflected in the author's claim: "In manufacturing, the productivity gains from liberalization are greater the further a given country is from the technology frontier" (page 1, summary).

both non-ICT and business sectors, regulation fails to produce a statistically significant impact. The negative effect of regulation on ICT-using sectors also shows up when interacted separately with (i) a dummy variable indicating whether the firm has experienced positive catch-up (catch-up firms) in the previous period and (ii) a dummy variable indicating whether the firm is above the median value of productivity in a given country and industry (close-to-frontier firms). The difference between our findings and those suggested by the latter interaction may be related to sample and indicators. First, differences can arise due to the variable capturing the closeness to frontier. While in the present study we have used a continuous variable to measure the proximity to the frontier, the dummy defining close-to-frontier firms focuses on the more productive 50%. The skewness of productivity distributions at the firm-level, with only a small group of firms having high productive levels, is a stylised fact (Bernard and Jensen, 2001; Bernard et al, 2003, Pavcnik, 2002). In this context, the median value may fail to capture the truly most productive firms. Diverging results can also come from the fact that this definition of the technological frontier is national and does not consider the most productive technology available for a given industry at the international level. Secondly, besides the use of firm-level data, the sample also differs in terms of industry definition. While we focus on manufacturing, services are an important part of ICT-using definition in Arnold et al. (2008).[24] On the other hand, the Non-ICT sector considers a broader set of manufacturing industries and, interestingly, regulation has a positive, although non-significant, impact in those regressions.

The lack of evidence for a negative correlation between market regulation and productivity is also present in the work of Inklaar et al. (2007). Using EU KLEMS data on multifactor productivity, their regressions can hardly link significantly regulation and productivity growth for the economy-wide regulation proxy of barriers to entry (a component of PMR) considered alone or in interaction with the productivity gap. Only in post and telecommunication does this regulation indicator present a negative correlation with productivity growth. In the same set of regressions when the interaction term is significant it is also positive.

More indirectly, our results also relate with the work of Griffith, Harrison and Simpson (2006), which measures innovation effort by Business Entreprise R&D expenditure for 12 industries and nine countries over the 1987-2000 period and investigates the effect of the Single Market Programme (SMP). They develop a two-stage methodology firstly relating indicators of product market reforms to profitability and secondly linking the latter with R&D intensity. Results are that the liberalisation process induced by the SMP reforms has positively affected R&D investment. As-

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[24] ICT-using are defined as ISIC rev. 3 21-22 (pulp, paper products); 29 (machinery and equipments); 36-37 (furniture, recycling); 50-52 (wholesales and retail); 65-67 (financial intermediation); 71-74 (renting of machinery and equipments)

suming that R&D intensity and patent intensity are strongly correlated, the main difference with our finding should stem from the indicators of regulation. While we use aggregate indicators of regulation practices with cross-section and time variation, Griffith et al. construct indirect indicators that are used as instruments in the first-stage regressions. These indicators follow a step function which, basically, associates zeros to all years prior to 1992 and the share of each industry that falls into different SMP industry classifications in 1986 (pre-sample year) for the post-1992 years. The intuition is to measure the treatment of the SMP by exploiting its expected intensity. SMP industry classification indicates the type of activity and if prior to SMP the industries were expected to be highly or moderated affected by the reforms. The identification strategy thus depends on (i) whether the share affected to each SMP group only reflects expected intensity of the treatment and on (ii) whether there exists direct mechanisms linking market reforms and R&D directly, and not through profitability. It is difficult to make an assessment regarding the first issue. On the second, however, the authors provide information thanks to reduced form regressions roughly consistent for three of the four SMP groups. Interestingly in two of three R&D reduced-form regression and also in the reported TFP regression the first SMP group, the one related to High-tech public procurement market industries presents a negative significant correlation (i.e; a negative impact of deregulation on R&D and productivity). This particular result can be linked to the lack of support to the negative effect of regulation for industries operating in high technology competition.

Overall, this survey of closely related industry-level evidence leads to the conclusions that the relationship between regulation and innovation remains an open question and that by no means clear-cut results support the common wisdom of a negative link. On the contrary, empirical evidence at the industry level tends to be consistent with an increasing positive slope of the effect of regulation along with the closeness to the frontier that can even end up positive at the top technological level.

6 Conclusion

This paper has critically examined the proposition according to which the impact of product market regulation on innovative performance is increasingly negative as the distance to the technological frontier decreases. According to this proposition, even if regulation may possibly boost innovation for laggard firms or industries, it should represent a major disincentive to innovate as the economy becomes more technologically advanced. Such a conclusion has provided analytical support to deregulation policy recommendations such as found for instance in the Lisbon Agenda. Product market deregulation is expected to be particularly effective in promoting innovation for EU countries, which are close to the technological frontier.

The simple model with which the 'distance to frontier' is established was modified to allow for leading firms' innovation.[25] This modification not only makes the model's features more realistic but also enriches the solution possibilities. Relaxing the innovation constraint on leaders' strategy may lead to question the existence of a negatively-sloped schedule relating the impact of regulation on innovation to the closeness to the frontier.

The 'common wisdom' according to which product market regulation would always be detrimental to innovation neglects several channel through which it could have the opposite effect. Product market regulation may not so much limit competitive pressure, and thus encourage leading firms to be complacent, than set up a specific competitive framework that would make it more difficult for firms to use competitive strategies alternative to product innovation. Regulation on quality standards could push firms to quality improvements and deter them from obtaining a competitive advantage through production cost-lowering changes. In the same spirit, foreign trade regulation could lead firms to abandon cost-cutting supply chain modifications through relocation in favour of high-price competition through quality innovation. Product market regulation could also deter firms from making small-size innovation following a business stealing strategy, in favour of innovations bringing more substantial improvements in technology. In other words, product market regulation may be instrumental in pushing firms to look for a 'high road' type of competition. To study in more depth how product market regulation could affect the forms of competition is a topic for further research.

The existence of a change in the impact of product market regulation on innovation in relation with the distance to the technological frontier was tested on a panel of industries for OECD countries. The estimations show that product market regulation has a positive impact on innovation for industries close to the technological frontier. Moreover, the impact of regulation on innovation is either positive or nil for a wide range of productivity distance, which invalidates the main claims put forward by the 'distance to frontier' literature. These results, though contradicting the dominant belief in the negative effects of regulation on innovation, are compatible with previous theoretical work and micro empirical studies that emphasized the existence of a Schumpeterian effect or even a size effect in innovation.[26] They are also compatible with empirical studies testing the distance to frontier story on industry data. Most works find a positively sloped relationship between the impact of regulation and the proximity to the frontier, and cannot show a negative impact of regulation close to the frontier.

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[25] The link between product market regulation and *de facto* competition is far from trivial. Nevertheless, we focus on that model since it serves as the main theoretical foundation for the applied or policy literature dealing with product market deregulation in developed countries, e.g. Aghion (2006).

[26] See for instance Crépon, Duguet and Kabla (1995), Crépon, Duguet and Mairesse (1998), Crépon and Duguet (1997).

Such results question the relevance of a policy aiming at improving the innovative performance of nations relying mostly on a product market deregulation programme. This is for instance the case for the Lisbon Agenda. In light of this paper's results, deregulation policy cannot be a substitute for science and technology policy.

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7 Appendix:

7.1 Proof of Propositions

Proof Proposition 1. This result relies on whether equation (11) has one or two positive roots. First, we solve the quadratic equation (11). This gives n_{1a} and n_{1b}.

- If $\lambda < 1$ then the coefficient multiplying the squared term in (11) is negative: $\frac{c}{2}\left(1-\frac{1}{\lambda^2}\right) < 0$. Since $\lambda^2 - 1 < 0$ the discriminant D_1 is positive and $\rho c - \sqrt{D_1} < 0$. Hence the polinomial has two roots and its function first increases and then decreases (inverted U-shape). The intercept is positive ($\Delta\pi_1 > 0$), so that only one solution is positive. Because $\rho c - \sqrt{D_1} < 0$ and $\left(\lambda^2 - 1\right) < 0$ the positive root in this case is n_{1a} . One immediatley verifies $\frac{\partial n_{1a}}{\partial \Delta} < 0$ (innovation-inducing effect of competition).

- If $\lambda > 1$ then the coefficient multiplying the squared term in (11) is now positive:$\frac{c}{2}\left(1-\frac{1}{\lambda^2}\right) > 0$. Since the intercept is positve, the curve depicted by (11) intercepts twice the n_1 axis in the positive side for $D_1 > 0$ (i.e. $\lambda^2 - 1 < \frac{\rho^2 c}{2\Delta\pi_1}$). These roots are given by n_{1a} and n_{1b}. One immediatley verifies $\frac{\partial n_{1b}}{\partial \Delta} < 0$ (innovation-deterring effect of competition).■

Proof Proposition 2. This result follows inmediately from Proposition 2 and the first order conditions (8) and (10) by which $n_1 = \lambda n_0$.■

Proof Proposition 3. This proposition stems from the solution of the quadratic equation (12). The coefficient multiplying the squared term in (12) does not depend on λ and is positive :$\frac{c}{2} > 0$. The discriminant D_{-1} is also positive no matter the value adopted by λ. Thus, the polynomial function first decreases and then increases (U-shape). Since its intercept is negative ($-\left(1-\Delta\right)\pi_1 - \frac{1}{\lambda^2}\frac{cn_1^2}{2} < 0$) one solution lies on the negative side of the n_{-1} axis and the other on the positive one. Therefore, only the latter is relevant and is given by (17). It also follows inmediately $\frac{\partial n_{-1}}{\partial \Delta} < 0$.■

7.2 The data

In the following tables descriptive statistics of our data sources are presented. As mentioned in the main texte, one of the main characteristics of our data is the use of specific industry level PPPs provided by Timmer et al. (2007). They propose a mix between expenditure-based PPPs and producer-based PPPs. Expenditure PPPs are computed from ICP index and production PPPs from average producer prices (output values divided by quantities). While the former includes only final goods and must be adjusted for taxes, distribution margins and trade costs, the latter needs to face the problem of matching varieties of goods that may differ in quality and definition among countries. The selected PPPs measure (adjusted-expenditure or production) depends on the specificity of each industry. The authors propose a harmonised dataset of PPPs disaggregated at the industry level for a wide sample of developing countries. Aiming at getting transitive comparable series they also apply the Elteto-Koves-Szulc[27] multilateral weighted aggregation method.

Table A3 shows the average labour productivity of each country for the full sample period and compares the values whether one uses the standard (non-adjusted) expenditure PPPs at the country level or the industry-level PPPs computed by Timmer et al. (2007). Appendix Table A4 presents similar figures by industry (world sample average). If one observes the statistics by country during the full sample period, labour productivity measures seem similar for each type of PPP. However, the variation induced is more prominent when labour productivity is disaggregated at the industry level.

Table A1. List of industries and countries

	Industries	Countries
15-16	Food products, beverages and tobacco	Austria
17-19	Textiles, textile products, leather and footwear	Belgium
17	Textiles	Denmark
18	Wearing apparel, dressing and dyeing of fur	Finland
19	Leather, leather products and footwear	France
20	Wood and products of wood and cork	Germany
21-22	Pulp, paper, paper products, printing and publishing	Greece
24	Chemicals and chemical products	Ireland
25	Rubber and plastics products	Italy
26	Other non-metallic mineral products	Japan
27	Basic metals	Netherland
28	Fabricated metal products, except machinery and equipment	Norway
29	Machinery and equipment, n.e.c.	Portugal
30	Office, accounting and computing machinery	Spain
31	Electrical machinery and apparatus, nec	Sweden
32	Radio, television and communication equipment	UK
33	Medical, precision and optical instruments, watches and clocks	US
34	Motor vehicles, trailers and semi-trailers	

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Table A2. Descriptive statistics of labour productivity for different samples

Sample	Obs.	Mean	Std. Dev.	min	max
OECD-STAN	4129	28.73	19.68	2.82	309.13
GGDC	6345	37.58	216.74	-12.21	12233.91
GGDC (Industry-30)	423	198.4	818.6	-12.21	12233.91
Final Filtered Data	6099	25.73	23.85	0.02	581.73

Notes

- Labour productivity considers industry-level PPPs from Timmer et al. (2007)
- Industry-30 is the ISIC Rev3 Industry 30 (Office, accounting and computing machinery)

Table A3. Labour productivity measures (mean values and coefficients of variation)

	Industry-level PPP		Expenditure PPP	
Country	Mean	Coef. Of Variation	Mean	Coef. Of Variation
Austria	23.19	0.8	25.98	0.6
Belgium	33.27	0.66	32.3	0.71
Denmark	23.44	0.55	23.6	0.46
Finland	26.87	0.73	25.86	0.76
France	28.01	0.99	29.79	0.88
Germany	28.61	0.74	28.19	0.85
Greece	12.24	0.66	13.51	0.68
Ireland	30.35	1.99	32.34	2.03
Italy	29.17	0.63	26.49	0.71
Japan	24.05	1.28	22.54	1.14
Netherland	31.84	0.63	32.86	0.44
Norway	25.42	0.49	26.64	0.45
Portugal	14.03	0.79	15.86	0.7
Spain	25.77	0.49	24.25	0.52
Sweden	27.98	0.58	26.88	0.52
UK	22.74	0.68	25.44	0.62
US	30.86	0.6	30.86	0.6
Total	25.73	0.93	26.07	0.91

Table A4. Labour productivity measures (mean values and coefficients of variation)

	Industry-level PPP		Expenditure PPP	
Industry	Mean	Coef. Of Variation	Mean	Coef. Of Variation
Basic metals	29.21	0.39	28.36	0.38
Chemicals and ch	54.73	0.94	45.16	0.78
Electrical machi	22.93	0.47	25	0.45
Fabricated metal	20.53	0.42	19.5	0.36
Food products, b	24.2	0.44	25.41	0.37
Machinery and eq	23.02	0.36	23.57	0.32
Medical, precisi	19.97	0.5	24.08	0.46
Motor vehicles,	18.92	0.7	26.81	0.47
Office, accounti	29.69	1.49	27.68	1.41
Other non-metall	30.97	0.36	25.28	0.34
Pulp, paper, pap	26.8	0.35	28.27	0.34
Radio, televisio	26.2	1.78	35.74	1.9
Rubber and plast	32.02	0.44	23.26	0.35
Textiles, textil	12.89	0.39	15.64	0.35
Wood and product	16.25	0.43	18.25	0.37
Total	25.73	0.93	26.07	0.91

Table A5. Descriptive statistics

Variable	Obs.	Mean	Std. Dev.	min
Labor productivity	6099	25.73	23.85	0.02
Closeness to the frontier	6099	56.89	24.07	1.93
Patents over hour worked	6345	0.00165	0.00939	0
REGREF	6375	4.19	1.31	1.05
REGIMP	6375	0.13	0.04	0.05
PMR	5760	1.8	0.44	0.92
Capital stock over hours worked	2785	0.05	0.03	0
Labour employment protection	5685	1.23	0.52	0.1
Import penetration	5057	45.28	44.95	0.6

Table A6. Regulation and Innovation (Within-group and Bruno (2005) regressions; Economy-wide indicators)
Panel A. Dependent Variable: Patenting (patents decomposition /hours worked)

	[1] PMR (1)	[2] PMR (2)	[3] PMR (3)
Patenting (t-1)	0.640***	0.734***	
	(0.023)	(0.011)	
Closeness to frontier	-0.081***	-0.087**	0.007
	(0.027)	(0.040)	(0.025)
Regulation	-0.676**	-0.442	0.475
	(0.292)	(0.358)	(0.290)
Regulation x Closeness to frontier	0.150**	0.140**	-0.020
	(0.062)	(0.067)	(0.063)
Externalities	0.226***	0.163***	-0.000
	(0.038)	(0.046)	(0.036)
year dummies	Yes	Yes	Yes
Number of Obs	5438	5438	5438
Individuals	234	234	234
Estimator	Within	Bruno (2005)	Within

Panel B. Marginal Effect of Regulation

Closeness to frontier	PMR (1)	PMR (2)	PMR (3)
Minimum	-0.473**	-0.253	0.448**
	(0.216)	(0.281)	(0.210)
1 Standard deviation below the mea	-0.153	0.046	0.405***
	(0.117)	(0.188)	(0.105)
Mean	-0.080	0.114	0.396***
	(0.105)	(0.176)	(0.093)
1 Standard deviation over the mean	-0.007	0.182	0.386***
	(0.101)	(0.170)	(0.090)
Maximum	0.014	0.202	0.383***
	(0.101)	(0.169)	(0.091)

Notes:
- Panel A reports regressions of patenting performance on regulation conditional on the closenness to the frontier
- Panel B reports for each regression the marginal effect of regulation and its significance at different sample values of the
- Standard errors in parentheses. *, ** and *** denote significance at 1%, 5% and 10%, respectively
- Regressions using Bruno's (2005) correction bias use Blundell-Bond initial solution

Table A7. Regulation and Innovation (System-GMM regressions; Economy-wide indicators)

Panel A. Dependent Variable: Patenting (patents decomposition /hours worked)

	[1]	[2]	[3]	[4]
	PMR (1)	PMR (2)	PMR (3)	PMR (4)
Patenting (t-1)	0.942***	0.923***	0.923***	0.924***
	(0.026)	(0.029)	(0.027)	(0.034)
Closeness to frontier	-0.057	0.702*	-0.151**	0.051
	(0.037)	(0.400)	(0.070)	(0.111)
Regulation	-0.983**	-1.086*	-1.981***	0.150
	(0.452)	(0.568)	(0.736)	(0.865)
Regulation x Closeness to frontier	0.250**	0.288**	0.480***	0.077
	(0.111)	(0.128)	(0.172)	(0.169)
Externalities	0.083**	0.091**	0.075***	0.038
	(0.040)	(0.039)	(0.026)	(0.034)
Closeness to frontier²		-0.109*		
		(0.059)		
Regulation²		-0.079		
		(0.058)		
Import Penetration			0.055	0.157**
			(0.036)	(0.068)
Labour market protection			0.030	-0.130
			(0.021)	(0.099)
Capital Intensity				0.122
				(0.080)
Year dummies	Yes	Yes	Yes	Yes
Number of Obs	5438	5438	4699	2356
Hansen p	0.113	0.154	0.156	0.198
Hansen p (instruments for levels)	0.866	0.985	0.988	0.185
AR(2)p	0.036	0.035	0.076	0.041
AR(3)p	0.030	0.030	0.015	0.917
Instruments	219	230	226	87
Individuals	234	234	232	134

Panel B. Marginal Effect of Regulation

Closeness to frontier	PMR (1)	PMR (2)	PMR (3)	PMR (4)
Minimum	(0.303)	(0.393)	(0.505)	(0.541)
	-0.110	-0.167	-0.286**	0.437
1 Standard deviation below the mean	(0.073)	(0.131)	(0.141)	(0.335)
	0.012	-0.027	-0.062	0.465
Mean	(0.034)	(0.082)	(0.080)	(0.303)
	0.134**	0.113*	0.162**	0.494*
1 Standard deviation over the mean	(0.053)	(0.063)	(0.077)	(0.283)
	0.169**	0.154**	0.228**	0.506*
Maximum	(0.066)	(0.068)	(0.090)	(0.278)
	0	0	0	0

Notes:

- Panel A reports regressions of patenting performance on regulation conditional on the closenness to the frontier
- Panel B reports for each regression the marginal effect of regulation and its significance at different sample values of the closeness

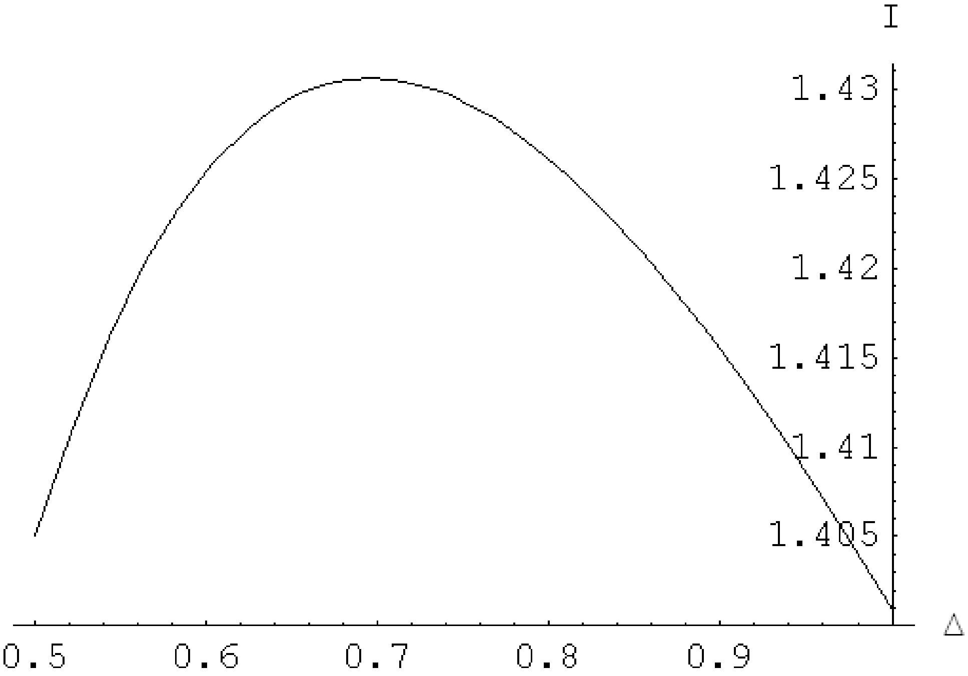


Figure 1. The effect of competition (Δ) on aggregate flow of innovation (I) using n_{1a}

$h = 0.5,\ r = 0,\ c = 0.5,\ \pi 1 = 0.8, \lambda = 0.001$

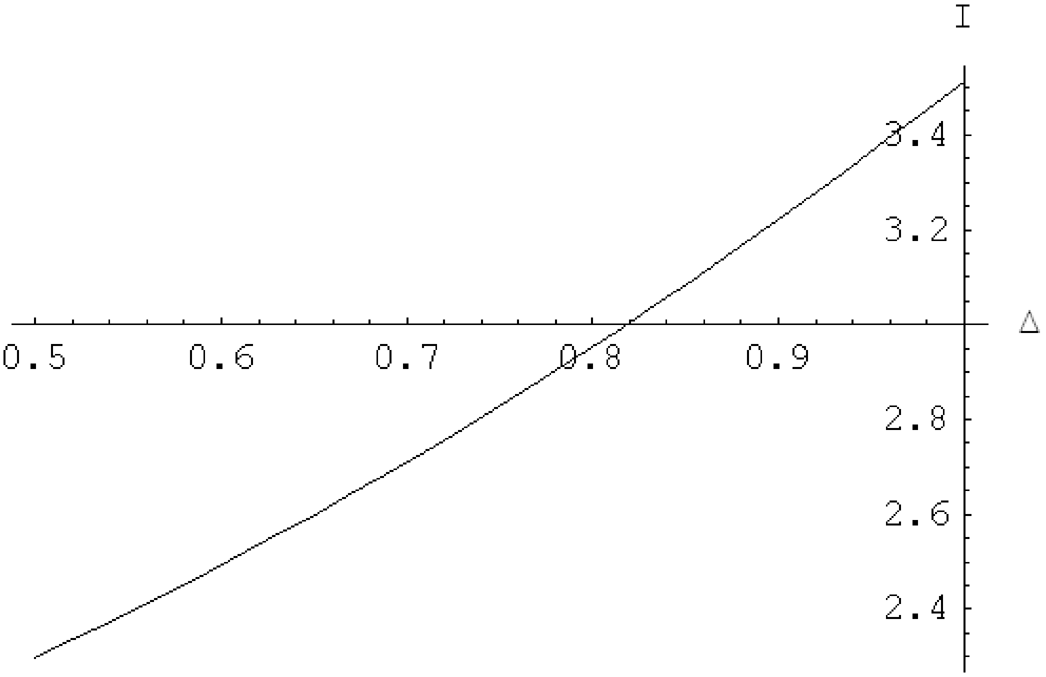


Figure 2. The effect of competition (Δ) on aggregate flow of innovation (I) using n_{1a}

$h = 0.5; r = 0; c = 0.5; \pi 1 = 0.8; \lambda = 1.01$

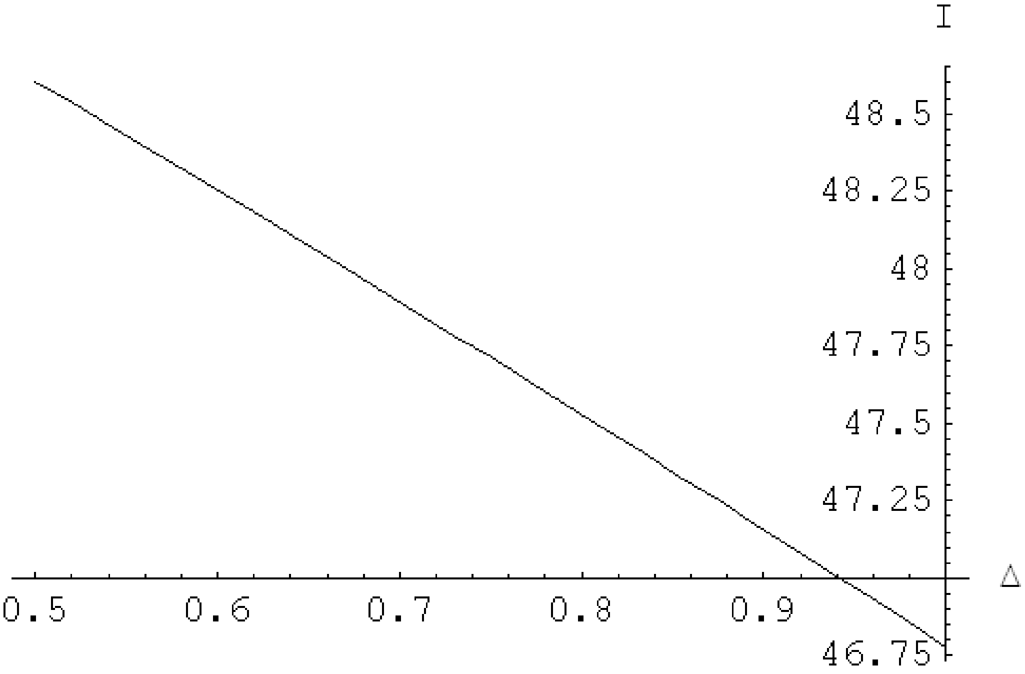
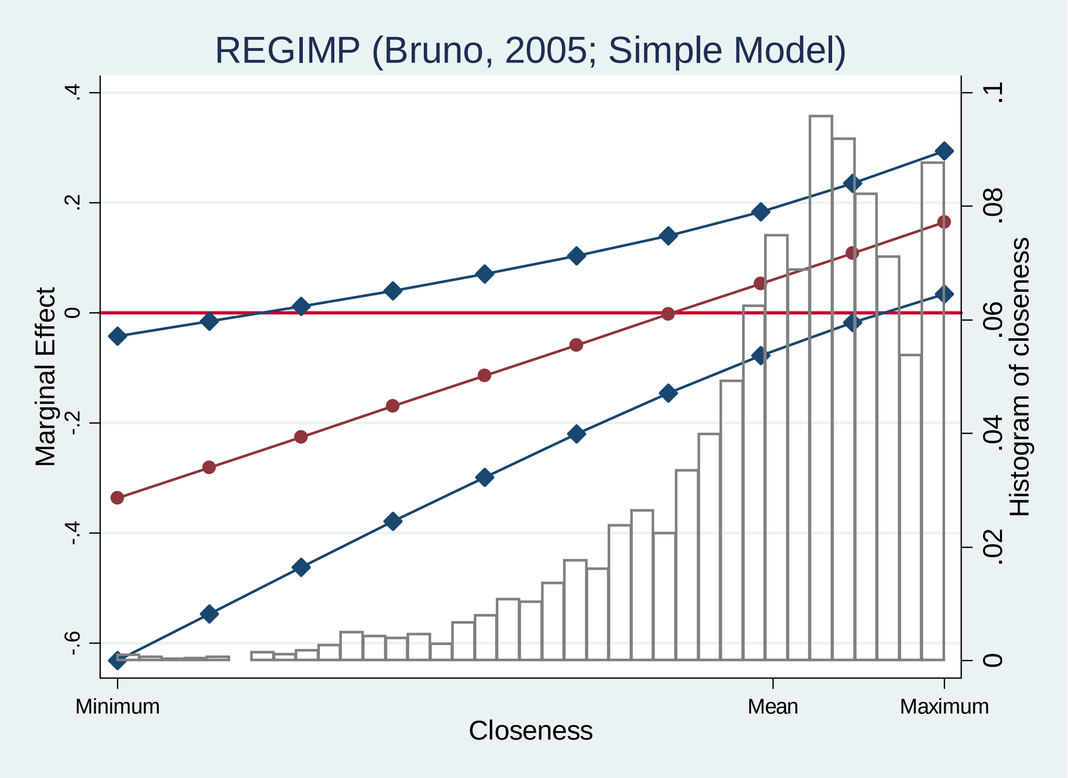
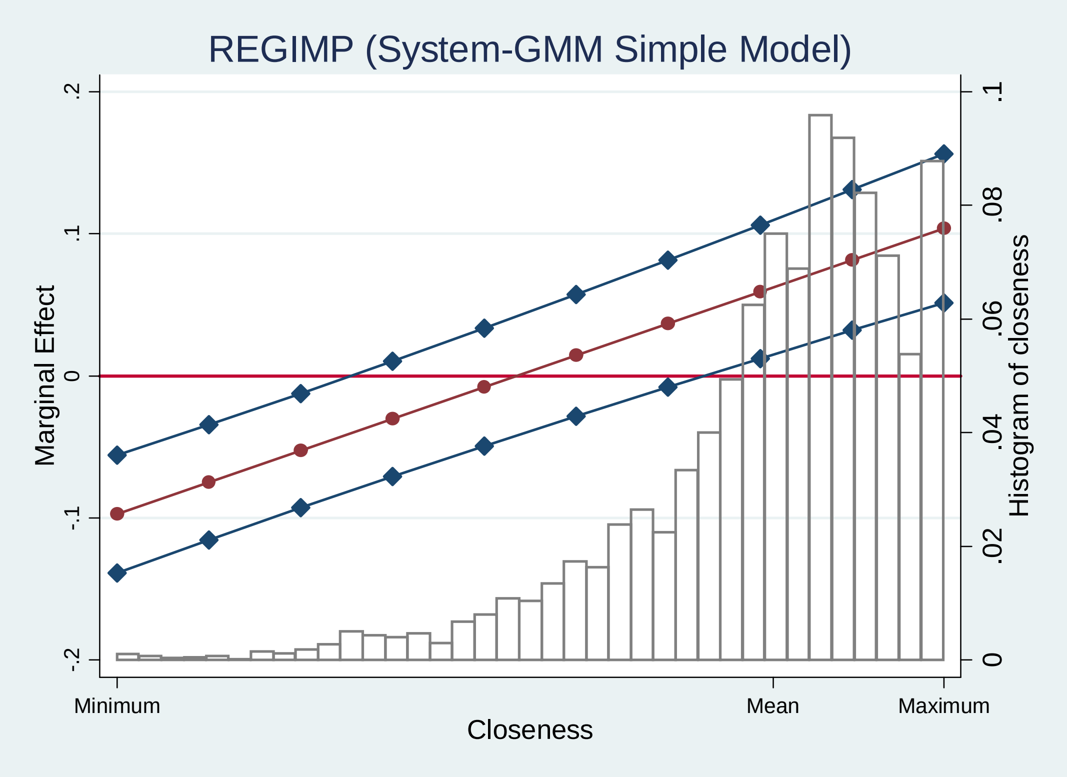
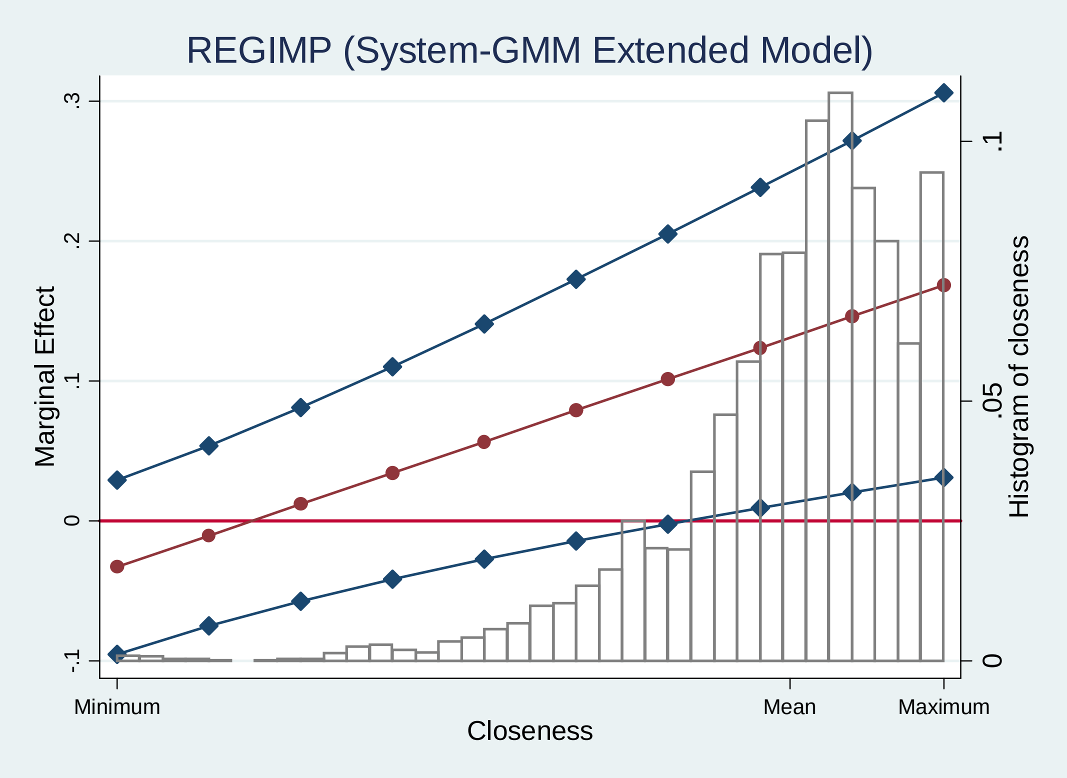


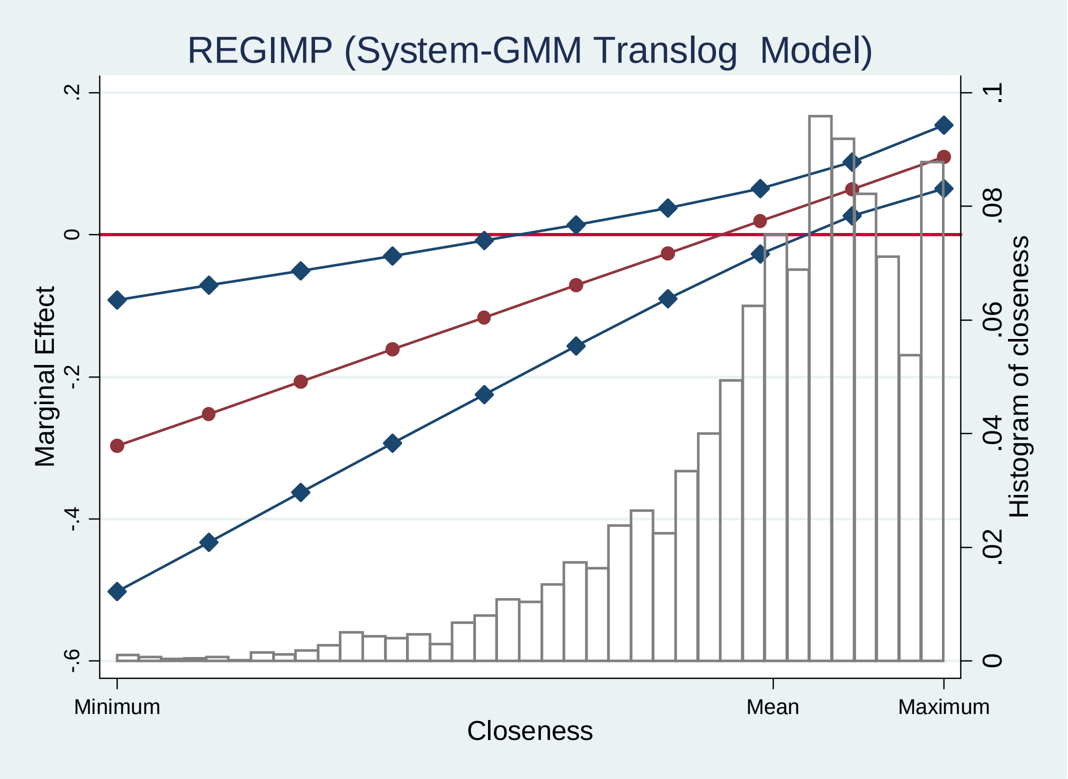
Figure 3. The effect of competition (Δ) on aggregate flow of innovation (I) using n_{1b}

$h = 0.5; r = 0; c = 0.5; \pi 1 = 0.8; \lambda = 1.01$


REGIMP (Bruno, 2005; Simple Model)
Marginal Effect
.4
.2
0
-.2
-.4
-.6
Histogram of closeness
.1
.08
.06
.04
.02
0
Minimum
Mean
Maximum
Closeness


REGIMP (System-GMM Simple Model)
Marginal Effect
.2
.1
0
-.1
-.2
Histogram of closeness
.1
.08
.06
.04
.02
0
Minimum
Mean
Maximum
Closeness


REGIMP (System-GMM Extended Model)
Marginal Effect
-.1
0
.1
.2
.3
Histogram of closeness
0
.05
.1
Minimum
Mean
Maximum
Closeness


REGIMP (System-GMM Translog Model)
Marginal Effect
.2
0
-.2
-.4
-.6
Histogram of closeness
.1
.08
.06
.04
.02
0
Minimum
Mean
Maximum
Closeness