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Patent Rights, Product Market Reforms, and Innovation

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Abstract

In this paper, we provide empirical evidence to the effect that strong patent rights may complement competition-increasing product market reforms in inducing innovation. First, we find that the product market reform induced by the large-scale internal market reform of the European Union in 1992 enhanced innovation in industries of countries where patent rights are strong, but not in industries of countries where patent rights are weak. Second, the positive innovation response to the product market reform is more pronounced in industries in which innovators rely more on patenting than in other industries. The observed complementarity between patent protection and product market competition can be rationalized using a Schumpeterian growth model with step-by-step innovation. In such a model, better patent protection prolongs the period over which the firm escaping competition by innovating, actually enjoys higher monopoly rents from its technological upgrade.

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1 Introduction

Over the past two decades, the effects of regulatory changes that strengthen patent protection have been investigated in numerous empirical studies, with hardly any study reporting evidence of a positive average effect on the level of innovation (Sakakibara and Branstetter, 2001, Lerner, 2002 and 2009, or Qian, 2007, among others). This led Josh Lerner to stating that "the lack of a positive impact of strengthening of patent protection on innovation is a puzzling result. It runs (..) against our intuition as economists that incentives affect behavior (...)." (see Lerner, 2009, p. 347).

In this paper, we set out to study whether patent protection can foster innovation when being complemented by product market competition. More specifically, we investigate how innovation responses to a competition-increasing product market reform depend upon the strength of patent rights. The product market reform we consider was part of the large-scale internal market reform of the European Union (EU) in 1992, named the Single Market Program (SMP). The European Commission designed this policy initiative to enhance competition, innovation and economic growth and implemented it at a time with significant variation in patent protection across European Countries. The product market reform created exogenous variation in product market conditions across industries within countries, across countries and across time. Positive average effects of the reform on product market competition have been widely documented (Badinger, 2007, Bottasso and Sembenelli 2001, and Griffith, Harrison and Simpson 2010, among others).

In our empirical analysis, we first compare the innovation responses to the product market reform across two country groups. The first group covers the countries with strong patent rights in our main sample of 13 manufacturing industries in 17 European countries between 1987 and 2003. These countries have had strong intellectual property rights (IPR) regimes since the pre-sample period, 1980 until 1986, and are among the founder states of the European Patent Organization (EPOrg). The second group covers the countries with weaker patent rights before and during our observation period. The estimation results indicate that innovation responds positively to the competition-enhancing product market reform in industries that are located in countries with strong patent rights, but not so in industries of countries with weaker patent rights.[1] These findings in turn are consistent with the view that patent protection and product market competition may be complementary in inducing innovation. A concern when comparing these effects of the reform on innovation across the two country groups are potential interactions between the product market reform and country-specific factors other than the degree of patent protection. We address this concern by investigating whether the reform's effects vary systematically across different industry groups within the country groups. We find that the reform's effect on innovative activity in countries with strong patent rights is more pronounced in industries where innovators are generally more prone to rely on patenting and are likely to value strong patent protection more than in other industries,[2] except for one industry where patent thickets and other patent-related impediments to cumulative innovation are most likely to be prevalent (electrical, medical and optical equipment, including computing machinery, radio, television, and (tele)communication equipment, NACE 30-33).

Empirical results suggesting that patent protection and product market competition can act as complementary inputs to innovation and growth, are at odds with what early endogenous growth models would predict (e.g., Romer, 1990, and Aghion and Howitt, 1992). In these models patent protection fosters innovation and growth as it enhances the rents from innovation, whereas product market competition deters innovation and growth by reducing these rents. Thus, patent protection is good for innovation for exactly the same reason that renders competition bad for innovation.[3] However, patent protection and product market

[1] To measure the intensity of the product market reform we use ex ante expectations of experts regarding changes in product market conditions at the country-industry-year level (Buigues, Ilzkovitz and Lebrun, 1990). We find similar results when using alternative measures of the product market reform intensity, of patent protection and innovation (see Sections 4 and 5).

[2] To identify these industries in which patent relevance is high in general we use two alternative measures. First, we classify industries according to the level of the patent intensity in the corresponding US industry in the pre-sample period. Second, we build on US survey data provided by Cohen, Nelson and Walsh (2000).

[3] More recently, Boldrin and Levine (2008) have argued that patent protection is detrimental to innovation because it blocks product market competition whereas competition is good for innovation because it allows the greatest scope to those who can develop new ideas. Even though Boldrin and Levine (2008) depart here

competition can become complementary forces in a Schumpeterian growth model with step-by-step innovation. Why? Because in such a model a positive fraction of sectors involve neck-and-neck firms, that is, firms that compete on an equal technological footing. Each firm's incentive to innovate depends on the difference between its post-innovation rent and its pre-innovation rent, and this difference - the net innovation rent - is in turn affected by both, product market competition and patent protection. More specifically, in a neck-and-neck sector where firms make positive profits even if they do not innovate, tougher product market competition will reduce this pre-innovation rent. It may also lower the post-innovation rents but to a lower extent. Thus, overall, product market competition will increase the net innovation rents in a neck-and-neck sector: this we refer to as the escape competition effect in Aghion, Harris, Howitt and Vickers (2001) and Aghion, Bloom, Blundell, Griffith and Howitt (2005). On the other hand, stronger patent protection will enhance post-innovation rents to a larger extent than pre-innovation rents, especially when the latter are bogged down by competition. Hence, product market competition and patent protection can complement each other in inducing innovation.[4]

Our paper relates to several strands of literature. First, it contributes to the literature on competition and growth.[5] Aghion et al. (2005) report empirical evidence of an inverted-U relationship between product market competition and innovation for a panel of industries in the United Kingdom (U.K.). Aghion, Blundell, Griffith, Howitt and Prantl (2009) use panel data on plants, establishments and firms to show that escape-entry effects on the productivity growth and patenting of incumbents in the U.K. vary with the technological development

from the early endogenous growth literature, they share the view that patent protection and competition are counteracting (or mutually exclusive) forces: namely, whenever one is good for innovation the other is detrimental to innovation. See also our discussion in Aghion, Howitt and Prantl (2013b).

[4]In Romer (1990) where innovations are made by outsiders who create a new variety, product market competition reduces the post-innovation rent from innovation, which is equal to the net innovation rent, and patent protection increases that rent. This is also the case in Aghion and Howitt (1992) where new innovators leap-frog incumbent firms.

[5]See, in particular, Aghion et al. (2001), Aghion et al. (2005), Acemoglu, Aghion and Zilibotti (2006), Aghion and Howitt (2009), Acemoglu (2009), and Acemoglu and Akcigit (2012). With regard to the related theoretical literature in industrial organization, we refer the reader, among others, to Tirole (1988), Scotchmer (2004), Gilbert (2006), Vives (2008), and Schmutzler (2010, 2012).

at the industry-level. Aghion, Burgess, Redding and Zilibotti (2008) study how the effects of an Indian product market deregulation on industry output vary across Indian states with different labor market institutions. Focusing on the SMP, like we do,[6] Bottasso and Sembenelli (2001) and Badinger (2007) show that this product market intervention reduced mark-ups in manufacturing industries. Griffith et al. (2010) report that the SMP enhanced product market competition which, in turn, led to an increase in R&D expenditures, using panel data for manufacturing industries in OECD countries. None of these papers, however, examines how the impact of the competition-increasing product market reform on innovation may interact with the strength of patent protection.

Our work also contributes to the empirical literature on the effects of intellectual property rights (IPR), as well as IPR reforms, on the level of innovation.[7] Sakakibara and Branstetter (2001) investigate consequences of the Japanese patent law reform in 1988. The reform introduced the option of multiple, (in)dependent claims per patent and, thus, broadened the scope of Japanese patents. They find no evidence of positive average reform effects on R&D spending or innovative output of Japanese firms. Branstetter, Fisman and Foley (2006) investigate how the extent of technology transfers within United States (U.S.) multinational firms responds to IPR reforms in their affiliates' host countries. What these papers do not consider are potential interaction effects between the patent law reform and product market competition. Qian (2007) uses country-level panel data for the pharmaceutical industry in OECD countries to show that introducing national patent protection does, on average, not stimulate pharmaceutical innovation. In addition, she finds positive, often statistically significant coefficients on interactions between patent protection and the country-level Fraser Institute index of economic freedom.[8] To the extent that this index can reflect country-level

[6] In Aghion et al. (2005, 2009), the SMP provides the excluded instruments that are used in instrumental variable and control function models explaining innovation or productivity growth.

[7] Moser (2005) addresses an important, but different question. She provides empirical evidence suggesting that the existence of patent laws influences the direction of technological progress, as well as the pattern of comparative advantages across countries.

[8] This index is a composite measure which aggregates country-level proxies of the size of government, access to money, regulation of credit, labor and business, legal structure and property rights, and freedom to trade.

freedom to compete and trade, Qian's finding for the pharmaceutical industry provides a first hint towards the complementarity we are interested in. Against this background, we focus on identifying interaction effects between product market competition and patent protection, exploiting the fact that the SMP product market reform created exogenous variation in product market conditions across industries within countries, across countries, and across time.

The remainder of the paper is organized as follows. In Section 2, we use a simple Schumpeterian growth model to explain why product market competition and patent protection can be complementary in fostering innovation. We present the empirical approach in Section 3 and explain the data in Section 4. The empirical results are described and discussed in Section 5. Section 6 concludes.

2 Why can patent protection and product market competition be complementary?

In this section we use the simple Schumpeterian growth model with *step-by-step innovation* of Aghion et al. (2001), Aghion et al. (2005), or Aghion, Akcigit and Howitt (2014) to explain why patent protection and product market competition may be complementary in inducing innovation. The novelty with respect to the papers above is that here we focus on the combined effect of these two policy instruments on innovation.

2.1 Basic setup

Time is continuous and the economy is populated by a continuum of individuals. The representative household consumes C_t at date t, has logarithmic instantaneous utility $U(C_t) = \ln C_t$, discounts the future at rate $\rho > 0$, has inelastic labor supply, and holds a balanced portfolio of the shares of all firms. The economy is closed, all costs are in terms of labor units, and the household's consumption is equal to the total output of the final good, that is $C_t = Y_t$. The Euler equation is $g_t = r_t - \rho$ with g denoting the growth rate of consumption, and thus output, and r denoting the interest rate.

The unique final good is produced under perfect competition from a continuum of intermediate inputs, according to the logarithmic production function:

$$\ln Y_t = \int_0^1 \ln y_{jt} dj. \tag{1}$$

We introduce competition by assuming that each sector j is *duopolistic* with respect to production and research activities. We denote the two duopolists in sector j as A_j and B_j and assume that y_j is the sum of the intermediate goods produced by the two duopolists in sector j, that is $y_j = y_{Aj} + y_{Bj}$. The logarithmic structure of the production function in equation (1) implies that final good producers spend the same amount on each basket y_j in equilibrium at any time, and we choose the numeraire so that this amount is normalized to one. Thus, a final good producer chooses each y_{Aj} and y_{Bj} to maximize $y_{Aj} + y_{Bj}$ subject to the budget constraint $p_{Aj}y_{Aj} + p_{Bj}y_{Bj} = 1$ where p_{Aj} and p_{Bj} are the intermediate good prices. The entire unit expenditure will be devoted to the least expensive of the two intermediate goods.

2.2 Technology and innovation

Following Aghion and Howitt (2009), we assume that each firm takes the wage rate as given and produces using labor as the only input according to the following linear production function,

$$y_{it} = A_{it} l_{it} \text{ with } i \in \{A, B\}$$

and l_{jt} denoting employed labor. Assume $A_i = \gamma^{k_i}$ where k_i is the technology level of duopoly firm i in sector j and $\gamma > 1$ is the parameter that measures the size of a leading-edge innovation. Equivalently, it takes γ^{-k_i} units of labor for firm i to produce one unit of output. Thus, the unit cost of production is simply $c_i = w\gamma^{-k_i}$, which is independent of the quantity produced. Thus, a sector j is fully characterized by a pair of integers (k_j, m_j) where k_j is the technology of *the leader* who lies one step ahead of its competitor (the *laggard* or *follower firm)* and m_j is the technological gap between the leader and the laggard.[9]

[9]The above logarithmic final good technology together with the linear production cost structure for intermediate goods implies that the equilibrium profit flows of the leader and the follower in sector j depend

For simplicity, we assume that neither firm can get more than one technological level ahead of the other, that is $m_j \leq 1$. Thus, at any point in time, there will be two kinds of intermediate sectors in the economy: (*i*) *leveled* or *neck-and-neck* sectors, where both firms are at the same technological level, and (*ii*) *unleveled* sectors, where the leader lies one step ahead of the laggard.[10]

Now, we specify the step-by-step innovation technology. We assume that a leader moves one technological step ahead at a rate z by spending the R&D cost $\psi(z) = z^2/2$ in units of labor. We call z the innovation rate or R&D intensity of the firm. We assume that a laggard can move one step ahead with probability h, even if it spends nothing on R&D, by copying the leader's technology. Accordingly, $z^2/2$ is the R&D cost of a follower firm moving ahead with probability $z + h$. As in Aghion et al. (2001), Aghion et al (2005), or Acemoglu and Akcigit (2012), h measures the ease of imitation, and as Acemoglu and Akcigit (2012) we use it as an inverse measure of patent protection.[11]

We let z_0 denote the R&D intensity of a firm in a leveled sector, and z_{-1} the R&D intensity of a laggard in an unleveled sector. The R&D intensity of the leader in an unleveled industry, denoted by z_1, is equal to zero ($z_1 = 0$) due to the above assumption of automatic catch-up.

2.3 Equilibrium profits and product market competition

As shown in Aghion and Howitt (2009), the equilibrium profit of a leader in an unleveled sector is

$$\pi_1 = 1 - \frac{1}{\gamma}$$

only on the technological gap m_j between the two firms (see below for the case where $m_j \leq 1$).

[10] Aghion et al. (2001) and Acemoglu and Akcigit (2012) analyze the more general case where there is no limit to how far ahead the leader can get.

[11] As patent systems usually feature multiple policy instruments, the patent literature has developed alternative modeling approaches. Among others, Cozzi (2001) models intellectual appropriability as the probability that inventors are able to prevent their innovations from being stolen by imitators, Li (2001) models patent breadth as the market power of firms in a quality-ladder model, Chu, Cozzi and Galli (2012) focus on blocking patents as the share of profits that incumbents are able to extract from entrants and O'Donoghue and Zweimuller (2004) model the patentability requirement as the minimum quality step size in order for an innovation to be patentable.

and the laggard will be priced out of the market such that

$$\pi_{-1} = 0.$$

Consider now a leveled (neck-and-neck) sector. If the two firms engaged in open price competition with no collusion, the equilibrium price would fall to the unit cost of each firm, resulting in zero profit. If, instead, the two firms colluded so effectively as to maximize their joint profits and shared the proceeds, then they would together act like the leader in an unleveled sector,[12] each earning a profit equal to $\pi_1/2$.

Accordingly, the two firms in a leveled sector have an incentive to collude and we model the degree of product market competition inversely by the degree to which the firms are able to collude, denoting it by Δ.[13] Specifically, we assume that the profit of a neck-and-neck firm is

$$\pi_0 = (1 - \Delta)\,\pi_1 \text{ with } 1/2 \leq \Delta \leq 1.$$

Note that Δ is also the incremental profit of an innovator in a leveled sector, normalized by a leader's profit π_1.

We next analyze how the equilibrium R&D intensities z_0 and z_{-1} of neck-and-neck firms and laggards, respectively, and consequently the aggregate innovation rate, vary with our measure of product market competition Δ and the measure of patent protection and why there might be complementarity between an increase in Δ and a reduction in h in fostering innovation and growth.

2.4 Patent protection and product market competition

Let V_m (resp. V_{-m}) denote the normalized steady-state value of currently being a leader (resp. a laggard) in an industry with technological gap m, and let $\omega = w/Y$ denote the

[12] Here we assume that any third firm could compete using the previous best technology, just like a laggard in an unleveled sector.

[13] In an unleveled sector, firms do not collude as the leader has no interest in sharing her profit.

normalized steady-state wage rate. We have the following Bellman equations:[14]

$$\rho V_0 = \max_{z_0} \left\{ \pi_0 + \overline{z}_0 (V_{-1} - V_0) + z_0 (V_1 - V_0) - \omega z_0^2/2 \right\} \tag{2}$$

$$\rho V_{-1} = \max_{z_{-1}} \left\{ \pi_{-1} + (z_{-1} + h)(V_0 - V_{-1}) - \omega z_{-1}^2/2 \right\} \tag{3}$$

$$\rho V_1 = \pi_1 + (z_{-1} + h)(V_0 - V_1) \tag{4}$$

where $\overline{z}_0$ denotes the R&D intensity of the competitor in a neck-and-neck industry. In (4), we used $z_1 = 0$ as the leader in an unleveled sector does not invest in R&D in equilibrium. Note also that we focus on a symmetric equilibrium in Markov strategies where $\overline{z}_0 = z_0$.

The growth-adjusted annuity value ρV_0 of currently being neck-and-neck is equal to the current profit flow π_0 plus the expected capital gain $z_0(V_1 - V_0)$ of acquiring a lead over the rival by innovating plus the expected capital loss $\overline{z}_0(V_{-1} - V_0)$ if the rival innovates and thereby becomes the leader, minus the R&D cost $\omega z_0^2/2$. The annuity value ρV_{-1} of currently being a laggard in an unleveled industry is equal to the current profit flow π_{-1} plus the expected capital gain $(z_{-1} + h)(V_0 - V_{-1})$ of catching up with the leader, minus the R&D cost $\omega z_{-1}^2/2$. Finally, the annuity value ρV_1 of being a leader in an unleveled industry is equal to the current profit flow π_1 plus the expected capital loss $(z_{-1} + h)(V_0 - V_1)$ if the leader is being caught up by the laggard.

Given that z_0 maximizes (2) and z_{-1} maximizes (3), we have the first-order conditions:

$$\omega z_0 = V_1 - V_0 \tag{5}$$

$$\omega z_{-1} = V_0 - V_{-1}. \tag{6}$$

In Aghion, Harris and Vickers (1997) the model is closed by a labor market clearing equation that determines ω as a function of the aggregate demand for R&D plus the aggregate demand for manufacturing labor. Here, we ignore that equation for simplicity and take the wage rate ω as given, normalizing it at $\omega = 1$.

[14] Here we use (i) that the left-hand-side is equal to $rV_0 - \dot{V}_0$; (ii) that $\dot{V}_0 = gV_0$ holds on a balanced growth path; and (iii) that the Euler equation is $g = r - \rho$.

Using (5) and (6) to eliminate the V's from the system of equations (2)-(4), we end up with the system of the following two equations in the unknown R&D intensities z_0 and z_{-1}:

$$z_0^2/2 + (\rho + h)z_0 - (\pi_1 - \pi_0) = 0 \qquad (7)$$

$$z_{-1}^2/2 + (\rho + z_0 + h)z_{-1} - (\pi_0 - \pi_{-1}) - z_0^2/2 = 0 \qquad (8)$$

These equations solve recursively for unique positive values of z_0 and z_{-1}, and in particular we get

$$z_0 = \frac{2\Delta\pi_1}{\rho + h + \sqrt{(\rho + h)^2 + 2\Delta\pi_1}}.$$

We first get the result that an increase in Δ increases the innovation intensity z_0 of a neck-and-neck firm. This is the *escape competition effect.* Moreover, this effect is decreasing with h as $\frac{\partial z_0}{\partial\Delta\partial h} < 0$. In other words, weaker patent protection reduces the magnitude of the escape competition effect. Hence, patent protection and product market competition are complementary in enhancing innovation incentives in neck-and-neck firm.

Plugging $z_0(\Delta)$ into (8), we can then look at the effect of an increase in competition Δ on the innovation intensity z_{-1} of a laggard. This effect is ambiguous in general: in particular, for very high ρ, the effect is negative, since then z_{-1} varies like

$$\pi_0 - \pi_{-1} = (1 - \Delta)\pi_1.$$

In this case the laggard is very impatient and thus looks at its short-term net profit flow if it catches up with the leader, which in turn decreases when competition increases. This is the *Schumpeterian effect.* However, for low values of ρ, this effect is counteracted by an *anticipated escape competition effect.*

Overall, an increase in product market competition will have an ambiguous effect on aggregate innovation and growth. It induces more intense innovation and faster productivity growth in currently neck-an-neck sectors and faster or slower growth in currently unleveled sectors. The overall effect on growth will depend upon ρ and also the (steady-state) fraction of leveled versus unleveled sectors. This steady-state fraction is itself endogenous, since it depends on equilibrium R&D intensities in both types of sectors. But what we can show is that in the case where ρ is sufficiently small, the escape competition and anticipated escape competition effects will dominate the Schumpeterian effect, so that the overall innovation rate I will satisfy:

$$\frac{\partial I}{\partial \Delta} > 0.$$

But in addition, and this is the new prediction we put forward in this section:

$$\frac{\partial^2 I}{\partial \Delta \partial h} < 0.$$

It is this possibility of a complementary effect of patent protection and product market competition which we proceed to test in the following sections.

3 Empirical modeling

Our empirical approach is designed to identify heterogeneity in the effect of a competition-increasing product market reform on innovation, depending on the strength of patent rights. The product market reform we focus on was part of the large-scale internal market reform of the European Union (EU) in 1992, named the Single Market Program (SMP). The reform was designed by the European Commission to enhance competition, innovation and economic growth. The effects of the reform on product market conditions were ex ante expected to vary across industries, countries and time, and the reform was repeatedly reported to reduce mark-ups and to increase product market competition (see Section 4 and Appendix B for details).

We proceed in two steps, using panel data for 13 industries in 17 European countries between 1987 and 2003. In the first step, we compare the effect of the product market reform on innovation across two country-industry groups: 1) all industries in countries with strong patent rights in the pre-sample period, 1980 to 1986, and throughout the sample period; 2) all industries in countries with weaker patent rights (see also Section 4 and Appendix B).

We estimate the following equation, as well as related variants:

$$y_{cit} = \beta_1 R_{cit} * G(P^{strong}_{c,\,ps}) + \beta_2 R_{cit} * G(P^{weak}_{c,\,ps}) + \gamma X_{cit} + \alpha_{ct} + \eta_{it} + u_{cit}, \tag{9}$$

where the explained variable y_{cit} measures innovation. Our main measure of innovation is R&D intensity, defined as R&D expenditures over value added. In addition, we use real R&D expenditures and a count of patents. Countries are indexed by c, industries by i, time by t, and ps indicates the pre-sample period. The main explanatory variable R_{cit} measures the intensity of the product market reform. This variable is set to zero in all years before the implementation of the SMP. From 1992 onwards, it takes values between zero and one, with a higher value indicating that, ex ante, experts were expecting the respective country-industry unit to be affected more by the SMP than other country-industries. We interact the reform intensity with $G(P^{strong}_{c,\,ps})$, a time-invariant indicator for all industries in the country group where patent rights are strong since the pre-sample period. We also interact the reform intensity with $G(P^{weak}_{c,\,ps})$, the corresponding indicator for all industries in the country group with weaker patent rights since the pre-sample period. These indicators are constructed from information on patent law reforms and related regulation.

Country-year fixed effects, α_{ct}, are included to capture unobserved factors which may trigger country-specific trends of innovation over time. Macroeconomic fluctuations induced by changes to the European Exchange Rate Mechanism at the beginning of the 1990s are among such factors. Industry-year fixed effects, η_{it}, are used to pick up unobserved factors, like arbitrary drastic innovation, that can induce industry-specific trends over time. The vector X_{cit} captures further covariates. These include, in particular, a measure of the initial innovative potential of country-industries, as well as measures of their initial capital intensity or initial exposure to competition at the level of the EU internal market. The error term is denoted by u_{cit}. We cluster standard errors at the country-industry level to allow for unrestricted correlation between annual observations within the same country-industry.

Our main interest in equation (9) is on the coefficients of the two product market reform terms, β_1 and β_2. If patent protection is to reinforce the positive effect of a competition-increasing product market reform on innovation, then the estimate of β_1 should be positive and larger than the one of β_2. In the preferred variant of the model specification in equation (9), the coefficients β_1 and β_2 are identified from data variation across country-industries and across time within country-industries. We also identify the coefficients of interest from alternative sources of data variation, for example, by varying the set of fixed effects. In addition, we use alternative measures of the product market reform and of the patenting-related variables. The estimation results are provided in Section 5.2.

In the second step of our empirical analysis, we address the concern that the estimates of β_1 and β_2, and the extent to which these differ *across the two country-industry groups in equation (9)*, could be influenced by interactions of the reform with country-specific factors other than the patent protection regime.[15] Modifying our initial identification strategy, we study as well whether the response of innovation to the product market reform *varies systematically across the industries within these country-industry groups*.[16] We single out industries where, in general, innovators tend to rely strongly on patenting and, thus, should value patent protection highly. In line with our main theoretical prediction, innovation in these industries in countries with strong patent rights should respond more positively to a competition-increasing reform than innovation in other industries. We refer to the former industries as industries with higher patent relevance, denote patent relevance by $I_{US,i,ps}$ and proxy it in two alternative ways. First, we classify each industry i according to the level of the patent intensity in the corresponding US industry in the pre-sample period, 1980 to 1986. Second, we build on Cohen, Nelson and Walsh (2000) who use survey responses of R&D unit or laboratory managers to classify US industries according to the importance of patenting in appropriating returns to invention in the years 1991 to 1993 (see also Section 4 and Appendix B).

[15] This concern may be relevant despite the variation of the reform intensity across industries within countries, not only across countries and across time, and despite the control for country-year fixed effects.

[16] See Sakakibara and Branstetter (2001) and Branstetter et al. (2006), among others, for similar approaches.

We consider the following estimation equation, as well as related variants:

$$
\begin{aligned}
y_{cit} = {} & \beta_{11} R_{cit} * G(P_{c,\,ps}^{strong}, I_{US,\,i,\,ps}^{>median}) + \beta_{12} R_{cit} * G(P_{c,\,ps}^{strong}, I_{US,\,i,\,ps}^{\leq median}) \\
& + \beta_{21} R_{cit} * G(P_{c,\,ps}^{weak}, I_{US,\,i,\,ps}^{>median}) + \beta_{22} R_{cit} * G(P_{c,\,ps}^{weak}, I_{US,\,i,\,ps}^{\leq median}) \\
& + \gamma X_{cit} + \delta G_{ci} + \alpha_{ct} + \eta_{it} + u_{cit},
\end{aligned} \tag{8}
$$

where we estimate the innovation response to the product market reform separately for four country-industry groups. The dummy variable $G(P_{c,\,ps}^{strong}, I_{US,\,i,\,ps}^{>median})$ indicates the group of industries with high patent relevance in countries with strong patent rights. This group covers the industries where innovators rely strongly on patenting, and where therefore patent protection should be more relevant, compared to the industry with median patent relevance. The dummy variable $G(P_{c,\,ps}^{strong}, I_{US,\,i,\,ps}^{\leq median})$ indicates the complementing group of industries with low patent relevance in countries with strong patent rights. For countries with weaker patent rights we proceed analogously, constructing the indicators $G(P_{c,\,ps}^{weak}, I_{US,\,i,\,ps}^{>median})$ and $G(P_{c,\,ps}^{weak}, I_{US,\,i,\,ps}^{\leq median})$. To capture fixed country-industry group effects, we include the vector of the group indicators, G_{ci}.

The coefficients of main interest in equation (8) are β_{11} and β_{12}. If patent protection is to enhance the positive effect of a competition-increasing product market reform on innovation, and the more so in industries where patent protection is more relevant, then the estimate of β_{11} should be positive and larger than that of β_{12}. In addition, the coefficient estimates for industries in countries with strong patent rights, β_{11} and β_{12}, should be larger than the corresponding estimates for industries in countries with weaker patent rights, β_{21} and β_{22}, and the difference $\beta_{11} - \beta_{12}$ should be larger than $\beta_{21} - \beta_{22}$. We provide the estimation results in Section 5.2, along with the results for model specifications where the reform effect is allowed to vary more flexibly along the distribution of the patent relevance measure, $I_{US,\,i,\,ps}$.

In the final part of our empirical analysis, we extend our model specification to allow for interactions of the product market reform with country- and industry-specific financial factors, among others.

4 Data

For our main sample we combine data from several sources into a panel dataset covering 13 industries across 17 European countries between 1987 and 2003. The majority of countries, 11 out of the 17 countries for which we have the relevant data, participated in the European Single Market Program in 1992, as shown in Table 1.[17] The other six European countries include Finland and Sweden that joined the EU, and the SMP, in 1995. Among the 13 industries are nine two-digit industries and four more aggregate industries, all in manufacturing (see Table 2).[18] In section 5.3, we also use alternative samples.

Next, we briefly introduce our main variables. Descriptive statistics are provided in Table A-1, further details, also on additional variables, are provided in Appendix B.

Innovation

Our main measure of innovation is R&D intensity, defined as nominal R&D expenditures over nominal value added. To construct this variable, we use country-industry-year level data on research and development expenditures for the business enterprise sector from the OECD ANBERD database, edition 2011, and data on value added from the EU KLEMS database, edition 2008 (see also Appendix B.1). We also use real R&D expenditures, that is R&D expenditures in US dollar purchasing power parities at year 2000 prices (in billion), and a count of patents taken out per country-industry-year at the US Patent and Trademark Office. The count of patents is part of the EU KLEMS 2008 database and constructed from the NBER patent database with patents granted by the US Patent and Trademark Office (see also Appendix B.2 and Hall, Jaffe and Trajtenberg, 2001).[19]

We capture the initial innovation potential of country-industries by a continuous measure of the patent-based knowledge stock built up until 1986, the end of the pre-sample period.

[17] All of these 11 countries had entered the European Union much earlier, at the latest in 1986. For the twelfth EU member state in 1992, Luxembourg, data on R&D expenditures are missing. Germany is part of our main estimation sample from 1991 onwards, these being the years after German reunification.

[18] We grouped up to four two-digit industries together if the underlying raw data required us to do so. Industries are classified according to the European NACE classification (version 1993, revision 1).

[19] Using data on US patents is advantageous in our context as low-value inventions are less likely to be patented abroad.

Patent rights

To capture the strength of patent protection, we separate between countries with strong patent rights and those with weaker patent rights. To do so, we use data on patent law reforms, as well as related regulation, and focus on a time period with significant variation in patent protection across European Countries (see also Appendix B.3). One group of countries in our dataset had strong patent protection already in the pre-sample period, 1980 to 1986, and also throughout the whole sample period, 1987 to 2003. The group covers seven EU member states that implemented the SMP in 1992 (Belgium, Denmark, France, Germany, Italy, Netherlands, United Kingdom), Sweden which joined the EU in 1995, and the United States in an extended estimation sample. All other sampled countries form the group with weaker patent protection. Among these are: 1) four EU member states that implemented the SMP in 1992 (Greece, Ireland, Portugal, Spain), Finland which joined the EU in 1995, and four European countries outside the EU during our observation period (Czech Republic, Hungary, Poland, Slovak Republic).

All European countries in our group with strong patent rights, except for Denmark and Italy, were among the states that set up the European Patent Organisation (EPOrg) in October 1977.[20] The countries in our group with weaker patent rights joined the EPOrg between October 1986 and March 2004 (EPOrg, 2010) and none of these countries completed the required reforms for a strong patent protection regime before 1992 (Branstetter et al. 2006, Qian 2007, and World Intellectual Property Organization 2012, among others). Our classification is consistent with those used in Branstetter et al. (2006), Maskus and Penubarti (1995) or Qian (2007). In addition, we compare our time-invariant, pre-sample patent protection measure to the time-varying index of patent protection that was developed by Ginarte and Park (1997), and updated by Park (2008). The index is available for every fifth year

[20] Italy has been a contracting state since 1978, and Denmark since 1990. The EPOrg is the intergovernmental organization that was created for granting patents in Europe under the European Patent Convention of 1973; the European Patent Office (EPO) acts as the executive body and the first patent applications were filed in 1978. A European patent is a set of essentially independent patents with national enforcement, national revocation, and central revocation or narrowing via two alternative unified, post-grant procedures.

between 1960 and 2005, it takes country-specific values between zero and five, with higher values indicating patent laws with stronger IPR. In 1985, the countries with strong patent rights have Ginarte-Park index values of about 3.5 or more, and the average is 3.9.[21] In 2000, the index values of these countries are at least 4.5. All countries with weaker patent rights have much lower index values (below 2.8) in 1985, except for Finland or countries with missing index values. The average is 2.5. In 2000 only two such countries, Ireland and Finland, scored above 4.5. Overall, the index change over time and the index values for 2000 reflect that strong international harmonization of patent systems has been reached at the end of our observation period.

In the second part of the empirical analysis, when estimating the innovation response to the product market reform separately for different patenting-related country-industry groups, we start with two group of industries. First, we single out the industries with high patent relevance where, in general, innovators tend to rely more on patenting, and where therefore patent protection should be more relevant, compared to an industry with median patent relevance. Second, we form the complementing industry group with low patent relevance.

To construct the industry groups we need a measure of patent relevance, $I_{US,i,\,ps}$.[22] Our main proxy ranks each industry i according to the level of the patent intensity in the corresponding US industry in the pre-sample period, 1980 to 1986. The alternative measure builds on Cohen, Nelson and Walsh (2000) who use survey data to classify US industries according to the importance of patenting in appropriating returns to invention. In the survey, about 1,100 R&D unit or laboratory managers reported per manufacturing industry the share of their product and process innovations in the years 1991 to 1993 for which patenting had been effective in protecting returns to invention, realized via commercialization or licensing.

In more flexible model specifications, we consider alternative sets of three instead of two industry groups, respectively with high, low and medium patent relevance at or above the

[21] Columns 3 to 6 in Table 1 indicate the Ginarte-Park index values for the sampled countries in 1985, 1990, 1995 and 2000.

[22] Both these measures are based on data for U.S. industries as the U.S. is the technology leader in most industries and it is not included in our main sample.

75th percentile of the chosen relevance measure, below the 25th percentile, and in between. The three-group ranking based on the pre-sample US patent intensity data is shown in column 3 of Table 2 for each sampled industry. Column 4 provides the ranking building on the survey data of Cohen, Nelsen and Walsh (2000).[23]

Product market reform

The considered product market reform is part of the large-scale internal market reform of the European Union (EU) in 1992, named the Single Market Program (SMP). With the SMP, the EU aimed at bringing down internal barriers to the free movement of products and production factors within the EU in order to foster competition, innovation and economic growth. Main components include changes to national legislation meant to harmonize technical product standards within the EU; removals of national requirements and other non-tariff barriers that enable firms to segment the internal market and limit competition; and the reduction of public sector discrimination in favor of national firms, for example due to mandatory EU-wide tendering for high-value procurement. Designed by the European Commission, and therefore a supra-national institutional body, the product market reform was officially implemented by EU member countries in 1992, a time with significant variation in patent protection across countries (see also Table 1). All the 11 initital SMP countries in our main sample had entered the EU much earlier, at the latest in 1986. Previous empirical studies support the view that product market competition has increased in response to the product market reform, and often so from initially low levels of competition(e.g., see Badinger 2007, Bottasso and Sembenelli 2001 or Griffith et al. 2010).

For constructing product market reform measures we use the European Commission report by Buigues et al. (1990) which provides a common list of manufacturing industries that were ex ante expected to be affected by the product market reform. Country-specific additions to and removals from the common industry list are also reported.[24] The information

[23] See Appendix B.3 for details.

[24] These additions and removals reflect recommendations of experts, who were asked whether they expected the reform to change the product market conditions in a specific country-industry differently than in the corresponding average industry.

in Buigues et al. (1990) allows us to construct reform measures that vary not only across time, but also across industries and SMP countries. This data variation is useful for identifying the reform impact from confounding influences. Further data variation is also available as our main data set covers non-SMP countries as well, not only SMP countries.

To generate our *main measure of the product market reform* we aggregate the information from the common list of Buigues et al. (1990), as well as the country-specific additions and removals. For each of the 13 industries in each of the SMP countries in our data set, the measure is set equal to zero in all years before the implementation of the product market reform. From 1992 onwards, it is equal to the share of the non-weighted four-digit industry classes per country-industry that were ex ante expected to be affected by the product market reform.[25] For an *alternative measure of the product market reform* we use the employment shares that are reported in Buigues et al. (1990) to calculate the share of the employment-weighted three-digit industry classes per country-industry that were expected to be affected.[26] Given that many relevant employment shares are missing, the alternative measure can only be calculated for a smaller sample, not including Sweden and Finland (see Appendix B.4 for details). Our main findings are, however, robust towards using the alternative measure (see Section 5).

In column 5 of Table 2, we report the product market reform intensity in 1992 for all 13 industries in our data set, averaging the main reform measure across the 11 initial SMP countries in our main sample. The industries that were expected to be affected least are 'coke, refined petroleum, and nuclear fuel (23)', 'basic metals (27)', and 'food, beverages, and tobacco (15/16)'. Those that were expected to be affected most are 'motor vehicles, trailers, and semi-trailers (34)', 'electrical and optical equipment (30-33)', 'chemicals including pharmaceuticals (24)', and 'general and special purpose machinery (29)'.

[25] For country-industries in Sweden or Finland, the main SMP measure is, from 1995 onwards, equal to the ex-ante expected share of the affected industry classes on the common list of Buigues et al. (1990) per country-industry, and zero otherwise.

[26] See Griffith et al. (2010) for a similar approach.

5 Empirical results

5.1 Baseline results

We start by separately estimating the average effect of the competition-increasing product market reform which is part of the European Single Market Program and the average effect of patent protection on innovation. This prepares the ground for analyzing innovation effects of the interaction between the two factors. We report OLS estimation results in Table 3 for the main sample, an unbalanced panel of 2,761 observations on 13 manufacturing industries in 17 European countries between 1987 and 2003. All model specifications include country, industry and year indicators to capture country, industry and year effects. Standard errors are robust and clustered at the country-industry level to allow for unrestricted correlation between annual observations within the same country-industry.

Our first finding is that of a positive average effect of the product market reform intensity on R&D intensity in column 1 of Table 3.[27] The coefficient estimate indicates that enhancing the reform intensity by one standard deviation (0.3076) increases R&D intensity by 0.0108 (=0.0352*0.3076).[28] This represents about 23 percent of the mean value of R&D intensity in the estimation sample (0.0464), a reasonable effect size. Such an average effect estimate is consistent with an escape competition effect and it fits with the empirical results of Griffith et al. (2010).[29]

Our second finding is a negative one: we find no effect of patent protection on R&D intensity. In column 2, we show the coefficient estimate on a time-varying indicator which equals one in the years once a country completed its reforms preparing the ground for a strong patent protection regime, and zero otherwise. The estimate is small, positive and not significantly different from zero.[30] This is consistent with previous empirical evidence, in

[27] See Section 4 for the definitions of the variables.

[28] See Appendix Table A-1 for the descriptive statistics.

[29] Griffith et al. (2010) use data on a similar set of industries in a different set of countries (Belgium, Canada, Denmark, Finland, France, Netherlands, United Kingdom, United States).

[30] Using the patent protection index provided by Ginarte and Park (1997) and Park (2008) yields a very similar coefficient estimate.

particular by Sakakibara and Branstetter (2001) for the manufacturing sector in Japan or by Qian (2007) for the pharmaceutical industry in OECD countries.

Both these findings remain robust in a model specification where we include both terms, the linear term for the competition-increasing product market reform as well as the linear term for patent protection (see column 3).

5.2 Main results

Our main focus in this paper is on the response of innovation to the interplay between the competition-enhancing product market reform and patent protection. As shown in Figure 1, our raw data directly hints at heterogeneity in the response to the reform, depending on the strength of patent rights. The left-hand graph refers to industries in countries with strong patent rights since the pre-sample period up to 1986, the right-hand graph refers to industries in countries with weaker patent rights. The vertical axes indicate R&D intensity, the horizontal axes indicate the product market reform intensity. Circles represent all the country-industry-year data points between the fifth and the ninety-fifth percentile of the R&D intensity distribution in the main sample. The regression line for industries in countries with strong patent rights has a more positive slope than the corresponding line for industries in countries with weaker patent rights.[31] Overall, the raw data pattern is consistent with the view that innovation responds more strongly to the competition-enhancing reform if patent rights are stronger.

Next, we estimate equation (9) of Section 3. The estimation results in Table 4 indicate a positive effect of the product market reform intensity, R_{cit}, on R&D intensity for industries in countries with strong patent rights since the pre-sample period. For industries in countries with weaker patent rights we find no such effect. These findings are stable across the following variants of the estimation equation: a) the one in column 1 of Table 4 with two interaction terms, $R_{cit}* \ G(P\ (Protection)^{strong}_{c,\ ps})$ and $R_{cit}* \ G(P^{weak}_{c,\ ps})$, as well as controls for

[31] Each of these regression lines is specific to the country-industry group used in the respective graph, indicating a linear prediction from the group-specific linear regression of R&D intensity on the product market reform intensity as the sole explanatory variable.

country, industry, and year fixed effects; b) the one in column 2 with the interaction term $R_{cit}*$ $G(Protection\ (P)_c^{strong})$, the level term R_{cit}, controls for country-year fixed effects and for industry-year fixed effects;[32] c) and, finally, the one in column 3 where we added the knowledge stock of country-industries in 1986 as explanatory variable.

Our findings are also robust to various changes in the way we measure our main explanatory variables. First, we replace our main measure of the product market reform intensity by the alternative measure which, from 1992 onwards, is equal to the share of *employment-weighted three-digit* industry classes per country-industry that were ex ante expected to be affected by the reform.[33] The estimation results are shown in column 4 of Table 4, and they are very similar to those in column 3. Second, we replace our preferred time-invariant, pre-sample measure of patent protection by the time-varying, contemporaneous Ginarte-Park index (P_{ct}^{GP}). Column 5 of Table 4 provides the respective OLS estimates. As the contemporaneous index may reflect regulatory changes that are endogenous to innovation during our sample period, we also implement an instrumental variable approach. Our excluded instrument is the interaction of the country-specific pre-sample indicator of strong patent rights and the product market reform intensity.[34] The second stage estimates on the two product market reform terms in column 6 indicate that the reform effect on R&D intensity increases with patent protection and is positive for all index values above 3.7. About 65% of all sample observations in 1992 have larger index values than 3.7 and in later years the percentage is even higher.[35]

All our estimation results in Table 4 are in line with the view that the competition-

[32]The coefficient on the interaction term, $R_{cit}*$ $G(P_{c,\ ps}^{strong})$, indicates now how the reform effect for the industries in countries with strong patent rights deviates from the reform effect for the industries in countries with weaker patent rights. The latter is captured by the coefficient on the level term, R_{cit}.

[33]For the main measure we use instead the share of the *unweighted four-digit* industry classes per country-industry that were expected to be affected by the reform. The alternative measure is available for a smaller sample than the main measure.

[34]The coefficient estimate *(s.e.)* on the excluded instrument in the first stage equation is 0.7336*** *(0.1254)*. The test statistic for the F-test on the irrelevance of the excluded instrument takes a value of 34.24 and we reject the null hypothesis.

[35]The weak identification test is not indicating a weak instrument problem. See the Kleibergen-Paap Wald statistic at the bottom of column 6 in Table 4, Baum, Schaffer, and Stillman, 2007, Kleibergen and Paap, 2006, and Stock and Yogo, 2005.

enhancing product market reform is complemented by patent protection in inducing innovation. A potential concern with these results is that the estimates of the product market reform effect for industries in countries with strong patent rights, and their deviation from the estimates for industries in countries with weaker patent rights, could be influenced by interactions between the product market reform and country-specific factors other than the patent protection regime. This concern may be relevant despite the variation of the reform intensity across industries within countries, not only across countries and across time, and despite the control for country-year fixed effects.

Accordingly, we turn to investigating whether, in particular, the positive reform effect which *refers to all industries within countries* with strong patent rights *varies systematically across industries*. As argued in Section 3, we expect that effect to be stronger in industries where innovators rely more on patenting and where, therefore, patent protection should be valued more than in other industries. We refer to these industries as industries with higher patent relevance and use the two alternative proxies for patent relevance introduced in Section 3.

Column 1 of Table 5 provides the estimation results for a variant of equation (8) in Section 3, allowing for different innovation responses to the competition-increasing product market reform across three country-industry groups. The first group, $G(P^{strong}_{c,\,ps}, I^{>median}_{US,\,i,\,ps})$, covers the industries with above median patent relevance in countries with strong patent rights, and the second group, $G(P^{strong}_{c,\,ps}, I^{\leq median}_{US,\,i,\,ps})$, complements with the remaining industries in the same group of countries. To form these country-industry groups, as well as those in columns 2 to 4, we use the main measure of patent relevance, ranking each industry i according to the level of the patent intensity in the corresponding US industry in the pre-sample period, 1980 to 1986. Column 1 shows for each of these two groups a significantly higher reform effect on R&D intensity than for the third group, covering all industries in countries with weaker patent rights. The reform effect for the third group is reflected by the estimate of the coefficient on the R_{cit}-term.[36] In addition, we find positive reform effects in both groups of countries with strong patent rights[37] and, most importantly, we find a higher reform effect for the group with above median patent relevance than for the one with lower patent relevance.[38]

In column 2, we consider a model specification which allows for differential reform effects on R&D intensity across three industry groups in countries with strong patent rights, respectively with a level of patent relevance at or above the 75th percentile of the relevance measure, below the 25th percentile, and in between.[39] We find, in countries with strong patent rights, a positive effect of the competition-increasing product market reform on R&D intensity in the industries with high level of patent relevance, as well as in the industries with an intermediate level. We also observe that the responses in these two country-industry groups are stronger than those in other groups.[40] For the group of all industries in countries with weaker patent rights, we estimate again the average reform effect and find a small and insignificant estimate.[41] Summing up, we find further evidence that is in line with complementarity between the competition-increasing product market reform and patent protection: R&D intensity responds more strongly to the reform in country-industries where patent rights are strong since the pre-sample period until 1986 and where patent relevance takes high or

[36] Estimating the average reform effect for all industries in countries with weaker patent rights is appropriate according to the results for the more flexible model specification in column 1 in Appendix Table A-3. The coefficient estimates on the two relevant groups, $G(P_{c,\,ps}^{weak}, I_{US,\,i,\,ps}^{>median})$ and $G(P_{c,\,ps}^{weak}, I_{US,\,i,\,ps}^{\leq median})$ in equation (8), lead to coefficient estimates which are small, insignificant, and not significantly different from each other. The F-test statistic for the null hypothesis "N_0: $\beta_{21} - \beta_{22} = 0$" is 0.22 (p-value: 0.6402).

[37] The F-test statistic relevant to the country-industry group with strong patent rights and above median patent relevance is 17.93 (p-value: 0.0000). The other relevant F-test statistic is 8.85 (p-value: 0.0033).

[38] The F-test statistic for the test of the null hypothesis, "N_0: $\beta_{11} - \beta_{12} = 0$" using the notation in equation (8), is 4.33 (p-value: 0.0387). The findings for the model specification in Column 1 in Appendix Table A-3 shows as well that the effect estimates for country-industry groups with strong patent rights differ significantly more than those for country-industry groups with weaker patent rights. This is in line with our discussion in Section 3. The F-test statistic for the test of the null hypothesis "N_0: $(\beta_{11} - \beta_{12}) - (\beta_{21} - \beta_{22}) = 0$" is 3.10 (p-value: 0.0796).

[39] The industry "Chemicals incl. Pharmaceuticals", ranking at the 75th percentile, is included in the high patent relevance group. Note that this was not the case in the working paper version of our paper (see Aghion, Howitt and Prantl, 2013a).

[40] The reform effect estimates for the industries with high and low patent relevance in countries with strong patent rights differ significantly according to F-test results (p-value: 0.0240), and those for the industries with intermediate and low patent relevance differ at the 10%-significance level (p-value: 0.0546).

[41] Significant effect variation across industries in countries with weaker patent rights is not apparent in a more flexible model specification (see column 2 in Appendix Table A-3).

medium values, rather than low values.

From column 3 onwards, we use model specifications with an additional product market reform term that is specific to one single industry in countries with strong patent protection, namely, the industry covering electrical, medical and optical equipment, including computing machinery, radio, television, and (tele)communication equipment (codes 30 to 33 of 1993 NACE, revision 1).[42] Separating that industry out allows us to relate our work to the empirical literature documenting patenting-related specificities of that industry. Galasso and Schankerman (2013) recently reported that invalidations of US patents have a significantly positive impact on subsequent patent citations in technology fields related to industry NACE 30-33 (electrical equipment and electronics, computers and communications, and medical instruments incl. biotechnology), but not in other examined fields. They state that the relevance of invalidation for subsequent citations is suggestive of patent rights blocking follow-on innovation in these fields which are classified as complex technology fields (see Levin, Klevorick, Nelson and Winter, 1987, and Cohen et al., 2000). Using EU patent data, Von Graevenitz, Wagner and Harhoff (2011) provide empirical support for the view that patent thickets are more prevalent in the industry NACE 30-33 than in other industries.[43]

For the extended model specifications, for example in columns 3 and 4, we find small and insignificant estimates of the coefficient on the product market reform term specific to the industry NACE 30-33 in countries with strong patent rights. Accordingly, the respective reform effect is not significantly different from the reform effect in industries in countries

[42] Here, we follow a very helpful suggestion of one of our referees and single that industry out, excluding it from the other country-industry groups. In Columns 1 and 2, the industry NACE 30-33 is, instead, part of the respective country-industry groups with highest patent relevance.

[43] They measure the density of patent thickets in the thirty technology areas covered by the patent system, and the seven technologies where their measures, the mean triple number, scores highest can all be linked to the industry NACE 30-33 in our data: audiovisual technology, telecommunications, semiconductors, information technology, optics, electrical machinery and electrical energy, engines, pumps and turbines (see Table 1, von Graevenitz et al., 2011). The mean triple number is a technology-specific count of potential blocking relationships among firms which is identified from patent citations, specifically X and Y references in search reports of the European Patent Office. Type X or Y references refer to prior art documents, which call the novelty or the inventive step of a patent claim into question. A triple is defined as a set of patent links where three firms mutually hold patents limiting new patents of each other according to X or Y references. See also von Graevenitz et al. (2013), as well as Hall (2005) and Hall and Ziedonis (2001).

with weaker patent rights, reflected by the estimates of the coefficient on the R_{cit}-term. The estimates on the coefficients of the other interaction terms again speak to a complementarity between the competition-increasing product market reform and patent protection in increasing R&D intensity. These results indicate that our main findings do not relate to the particular industry NACE 30-33 for which it has repeatedly been reported that phenomena like patent thickets and other patent-related impediments to cumulative innovation have been prevalent during our observation period. Expressed otherwise, our main findings are not driven by that industry where incumbent firms may be particularly prone to increase their R&D expenditures after the competition-increasing product market reform for the purpose of rent-seeking activities, like building up patent thickets via strategic patenting.

In columns 5 and 6, we use our alternative patent relevance measure to address the following concern regarding our main measure based on pre-sample US patent intensity: firms in an industry characterized by high product complexity and cumulative innovation may have to take out many more patents to protect the technology in a single product or process, and any such patent may be harder to enforce, than in other industries. For constructing the alternative measure we build on Cohen et al. (2000) who use survey responses of R&D unit or laboratory managers to classify US industries according to the importance of patenting in appropriating returns to invention in the years 1991 to 1993. The estimates that we show in columns 5 and 6, as well as all the relevant test results, are in line with the empirical findings when using our main measure of patent relevance.

Overall, we provide a large set of empirical results that is suggestive of a complementarity between the strength of patent rights and the competition-enhancing product market reform in inducing innovation. First, we find a positive average reform effect on R&D intensity in industries of countries with strong patent rights since the pre-sample period up to 1986, not in industries of countries with weaker patent rights. Second, we observe that this positive effect is more pronounced in industries where patenting is more important for innovators than in other industries, except for the industry where patent thickets and other patenting-related impediments to cumulative innovation are most likely to be prevalent.

5.3 Extensions

In addition to R&D intensity, we also consider alternative measures of innovation. First, we explain real R&D expenditures in order to show that our previous findings do not just reflect value added responding to the product market reform (Table 6, columns 1, 2 and 3). Second, we explain the number of patents (Table 6, columns 4, 5 and 6).[44] We find a positive effect of the competition-increasing product market reform on real R&D expenditures, as well as on the number of patents, in industries located in countries where patent rights are strong since the pre-sample period (Table 6, columns 1 and 4).[45] In country-industries with weaker patent rights we observe no such effects. These results are in line with the findings for the R&D intensity models in Table 4. As in the R&D intensity models in column 3 of Table 5, we observe, in countries with strong patent rights, that the increase of real R&D expenditures in response to the product market reform is more pronounced in industries with high or medium rather than low patent relevance (Table 6, column 3), and the results are qualitatively similar in column 2 of Table 5.[46] Our main empirical findings are also stable in patent count models (Table 6, columns 5 and 6).

A lingering concern with our estimation results so far, is that these might be influenced by different mechanisms causing similar heterogeneity in the effects of the competition-increasing product market reform across countries, as well as across industries. In particular, the reform may increase innovation more in industries of countries with initially more developed financial sectors than in industries of other countries given that firms need to finance

[44] The patent count models are estimated on a smaller sample with the a shorter time horizon 1987 to 1999, namely the period for which patent data are available to us. As including country-year fixed effects and industry-year fixed effects is straightforward then, we estimate linear probability models (Wooldridge, 2010).

[45] The F-test statistic relevant to the R&D expenditure model is 4.69 (p-value: 0.0316) and the one relevant to the patent model is 3.13 (p-value: 0.0783).

[46] In column 2 of Table 5 the difference between the positive effects for the two country-industry groups specific to countries with strong patent rights is not statistically significant. Note also that the results in columns 2 and 3 of Table 5 are robust when using model specifications with a control for real value added, that is, value added in US dollar puchasing power parities at year 2000 prices. In addition, the results are also stable if we use the extended sets of explanatory variables as in Columns 3 to 6 of Table 5.

their innovative investments. And the relevance of high financial sector development might be disproportionately larger in those industries where capital needs tend, in general, to be higher than in other industries.

To account for this concern, we extend the two model specifications of columns 3 and 4 in Table 5. These include the so far most flexible sets of interactions between the competition-increasing product market reform intensity and patenting-related country-industry groups, and we now add interactions between the reform intensity and financing-related country-industry groups. To construct the financing-related groups, we first separate between countries with high and low financial sector development. The distinguishing indicator is set equal to one if private credit use and stock market capitalization during the 1980s, relative to gross domestic product (GDP), rank above the relevant sample median, and otherwise zero.[47] Second, we group industries according to the industry-specific capital needs, proxied by a measure of capital intensity in the corresponding US industries in the pre-sample period between 1980 and 1986.[48] We first divide industries into two groups: the group of industries above the median level of the capital needs measure, and the complementing group of industries below the median. Alternatively, we divide industries into three groups: the group with high capital needs covering the industries at or above the 75th percentile of the capital needs measure, the group of industries below the 25th percentile, and the group of all intermediate industries.

In column 1 of Table 7, we extend the model specification corresponding to column 3 in Table 5 by adding the interaction term between the reform intensity and the indicator for industries with above median capital needs in countries with high development of the financial sector, $R_{cit} * G(D\,(Financial\ development\,)^{high}_{c,\,1980-90},\, N\,(Capital\,needs)^{>median}_{US,\,i,\,ps})$, and by also adding the complementing interaction term. The coefficient estimates on these financing-related reform terms are positive, and the one specific to industries with above median capital

[47] The data is taken from the November 2010 version of the Financial Development and Structure Database (Beck, Demirgüc-Kunt and Levine, 2000 and 2010b). See Appendix B for details.

[48] The proxy is based on data from the EU KLEMS database. See Appendix B for details.

needs in countries with high financial development is significantly different from zero (p-value: 0.0513). These results are in line with the view that high development of a country's financial sector enhances the innovation response to the competition-enhancing product market reform, especially in industries with high capital needs. In line with our previous main findings, the response of R&D intensity to the reform is positive in the country-industry group with strong patent rights and above median patent relevance, excluding the industry NACE 30-33, and the effect for that group is higher than the effects for the other patenting-related country-industry groups.[49]

In column 2 of Table 7, we extend the model specification of column 4 in Table 5 by adding three interactions: namely, the interactions between the reform intensity and the indicators for industries with high, medium or low capital needs in countries with high financial development. Again, we find, for countries with strong patent rights, that R&D intensity responds more positively to the competition-enhancing product market reform in industries with high or medium patent relevance, excluding the industry NACE 30-33, than in industries with low patent relevance.[50] The coefficient estimates on the financing-related interaction terms show a size pattern which is in line with the findings in column 1 of Table 7, but these estimates, as well as the differences between them, are not significant at conventional levels of statistical significance.

The innovation response to the competition-increasing product market reform may also depend in a different way upon financing-related initial conditions of country-industries. To take that possibility into account, we extend the two model specifications of columns 3 and 4 of Table 5 as follows. First, we add a measure of the pre-sample capital intensity per country-industry, $Capital\ intensity_{ci,\ ps}$. Second, we add the interaction of the reform intensity with

[49] It is significantly higher than the positive effect for the country-industry group with lower patent relevance (F-test statistic: 3.28, p-value: 0.07) or the one specific to the industry NACE 30-33 (F-test statistic: 5.74, p-value: 0.02), and it is significantly higher than the effect for countries with weaker patent rights, reflected by the coefficient on the R_{cit}-term.

[50] The F-test statistic relevant to the comparison involving the country-industry group with strong patent rights and high patent relevance is 4.02 (p-value: 0.0462). The other relevant F-test statistic is 3.29 (p-value: 0.0711).

the indicator for those country-industries where the pre-sample capital intensity is above the sample median, $R_{cit} * G(Capital\ intensity^{>median}_{ci,\ ps})$. The coefficient estimates on both these terms turn out to remain insignificant in columns 3 and 4 of Table 7.

To consider that the innovation response to the competition-increasing product market reform may depend on the initial exposure of country-industries to trade within the EU, and, thus, to initial competition at the level of the EU-internal market, we add two further terms in columns 3 and 4 of Table 7. The first one is the ratio of the value of exports and imports involving EU 15 member countries as trading partners relative to the value of domestic production output per country-industry in 1988, $EU\text{-}internal\ trade\ exposure_{ci,\ 1988}$.[51] The second one is the interaction of the reform intensity with the indicator for those country-industries where the initial EU-internal trade exposure is above the sample median, $R_{cit} * G(EU\text{-}internal\ trade\ exposure^{>median}_{ci,\ 1988})$. While the coefficient estimates on the level term remain insignificant, those on the interaction term are significantly negative at the 10-percent significance level. The latter finding is in line with the view that country-industries which were more exposed to trade within the EU before the reform, and, thus, to competition at the level of the EU internal market, have been more likely to be in an unleveled state where Schumpeterian effects can arise. Most importantly, adding the four financing- and trade-related terms in columns 3 and 4 of Table 7 does not challenge our main empirical findings.

Finally, we modify the data variation which we use to identify the effects of the competition-increasing product market reform on innovation, by reducing or extending the estimation sample. So far, we have mainly used data variation *within* 11 countries that implemented the SMP product market reform in 1992 in combination with variation *between* these countries and six other countries. If instead we use the data for the 11 initial SMP countries only,

[51] We use trade data from the October 2011 version of the OECD STAN Bilateral Trade Database (BTD) for 1988 as this is the earliest year for which we have the relevant trade data, although not for all country-industries in our main sample (see also Appendix B.6). The group of the EU 15 member states covers the eleven SMP countries in Table 1, Finland and Sweden, all of which are in our main sample. The two non-sampled EU 15 member states are Luxembourg and Austria.

our main empirical results turn out to be stable (see Appendix Table A-4, column 1, panels A and B). Accordingly, our main empirical findings hinge neither on including or excluding the Nordic countries (Finland, Sweden), nor the former planned economies (Czech Republic, Hungary, Poland, Slovak Republic). As a further concern may arise in relation to lower-income SMP countries, we re-estimate our main model specifications on those initial SMP countries in our sample that are not in the lowest tercile of the real per capita GDP sample distribution, which excludes Greece and Portugal. In these regressions, our main empirical findings hold up as well (see Appendix Table A-4, column 2). While the focus of the SMP as implemented in 1992 was on increasing competition, as well as innovation and economic growth, within the EU internal market, market size expansions followed subsequently. As increases in market size can have direct effects on innovation (see Acemoglu and Linn, 2004, among others), we re-estimate our main model specifications on the sample where expansion-related effects are least likely to be relevant. This is the sub-sample, covering the initial SMP countries in our main sample, but neither Germany which enlarged due to German reunification nor Belgium for which we have no data before 1992, and covering only the years before 1995, as Finland and Sweden joined the EU, and the SMP, in that year. The coefficient estimates in column 3 of Appendix Table A-4, as well as the relevant F-test results, are consistent with our main empirical findings despite the substantially smaller sample.

Next, we address the issue that the implementation of the SMP in 1992 coincided closely with changes of the fixed European Exchange Rate Mechanism (ERM) which was introduced in 1979. The ERM perturbations at the beginning of the 1990s related to the ERM entry of the UK in October 1990, the German currency effectively serving as the base currency of the ERM, the German Bundesbank tightening monetary policy in response to German reunification which succeeded the unexpected fall of the Berlin Wall in November 1989, and the ERM exit of the UK in September 1992. If we eliminate the two pivotal countries, Germany and UK, from the estimation sample, our main empirical findings remain stable (see Appendix Table A-5, column 1).[52] When we instead extend the estimation sample, again our main results remain stable. First, we add the US, a large non-European country with high innovative potential and, second, we enlarge the sample substantially by adding 8 service industries (Table A-5, columns 2 and 3).[53] Finally, the main findings are stable when re-estimating on the 47 samples that result if we exclude individual industries, countries or years one by one.

6 Conclusions

In this paper, we provided empirical evidence to the effect that strong patent rights may complement competition-increasing product market reforms in inducing innovation. First, we found that the product market reform induced by the large-scale internal market reform of the European Union (EU) in 1992 enhanced innovation in industries that are located in countries where patent rights are strong, but not in industries of countries where patent rights are weak. Second, the positive innovation response to the product market reform was more pronounced in industries in which innovators rely more on patenting than in other industries, except for one industry where patent thickets and other patent-related impediments to cumulative innovation are most likely to exist (electrical, medical and optical equipment, including computing machinery, radio, television, and (tele)communication equipment, NACE 30-33).

The complementarity between patent protection and product market competition can be rationalized using a Schumpeterian growth model with step-by-step innovation in which product market competition encourages firms to innovate in order to escape competition. In such a model, better patent protection prolongs the period over which the firm escaping competition by innovating, actually enjoys higher monopoly rents from its technological upgrade.

Our analysis has implications for the long-standing policy debate on the need for and

[52] Note that our main model specifications already include controls for arbitrary country-specific trends of innovation over time.

[53] Note that the product market reform intensity is always equal to zero in the US, as well as in service industries.

the design of patent systems. Complementarity of patent protection with competition in product markets, as well as with competition-enhancing product market interventions, should be taken into account when assessing the effects of patent policies. More generally, our work provides support for the importance of interaction effects between different types of institutions and policies in the growth process.

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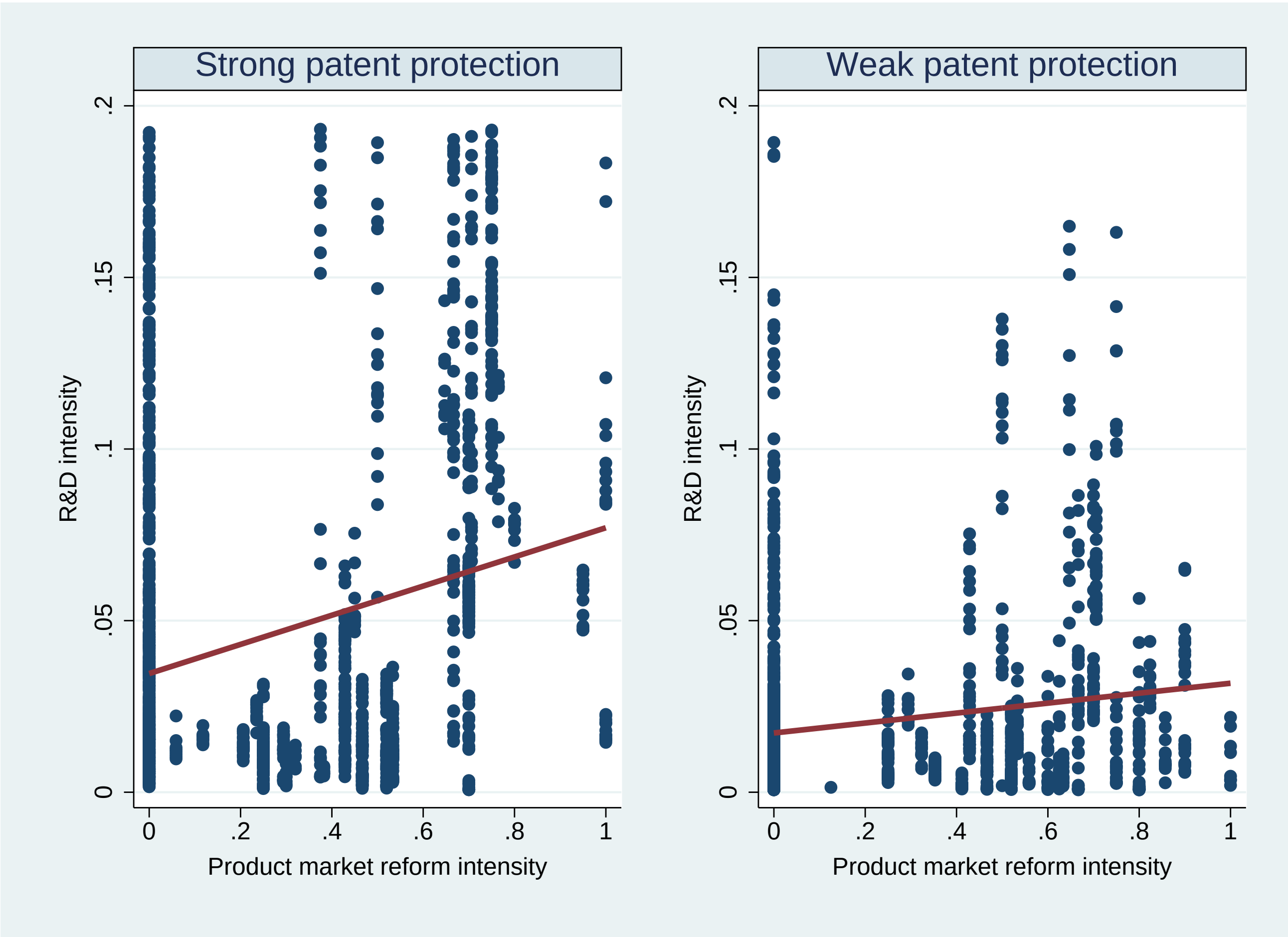
Figures and Tables

Figure 1: Patent rights, product market reforms and innovation
- A first look at the raw data -



Notes: In this figure we show the relation between the competition-increasing product market reform and innovation in countries with strong patent protection since the pre-sample period (left graph) and in countries with weaker patent protection (right graph). The horizontal axes refer to our measure of product market reform intensity, the vertical axes to R&D intensity and the circles indicate all 2,483 country-industry-year data points between the fifth and the ninety-fifth percentile of the R&D intensity distribution in our main sample on 13 manufacturing industries in 17 European countries between 1987 and 2003. Each of these lines represents a linear prediction from a country group-specific linear regression of R&D intensity on product market reform intensity as the sole explanatory variable.

Table 1: Patent protection per country

	Adoption of strong patent protection	Patent protection index			
		1985	1990	1995	2000
EU member states with SMP product market reform in 1992					
BEL (Belgium)	early	4.0917	4.3417	4.5417	4.6667
DNK (Denmark)	early	3.6333	3.8833	4.5417	4.6667
FRA (France)	early	3.7583	3.8833	4.5417	4.6667
GER (Germany)	early	3.8417	3.9667	4.1667	4.5000
GRC (Greece)	late	2.3250	2.8667	3.4667	3.9667
IRL (Ireland)	late	2.2000	2.3250	4.1417	4.6667
ITA (Italy)	early	3.6833	4.0083	4.3333	4.6667
NLD (Netherlands)	early	3.7667	4.2167	4.5417	4.6667
PRT (Portugal)	late	1.6657	1.6657	3.3490	4.0050
ESP (Spain)	late	2.8080	3.5583	4.2083	4.3333
UK (United Kingdom)	early	3.8833	4.3417	4.5417	4.5417
European countries outside EU until 1995					
FIN (Finland)	late	3.3083	3.3083	4.4167	4.5417
SWE (Sweden)	early	3.4833	3.8833	4.4167	4.5417
European countries outside EU during observation period					
CZE (Czech Republic)	late	n.a.	n.a.	2.9583	3.2083
HUN (Hungary)	late	n.a.	n.a.	4.0417	4.0417
POL (Poland)	late	n.a.	n.a.	3.4583	3.9167
SVK (Slovak Republic)	late	n.a.	n.a.	2.9583	2.7583
Non-European countries (not in main estimation sample)					
US (United States)	early	4.6750	4.6750	4.8750	4.8750

Notes: In column 2, we indicate whether a sampled country adopted strong patent protection early or late in time, distinguishing between countries that fell under the large-scale, EU-internal product market reform, the EU Single Market Program (SMP), and those that didn't. Countries with strong patent rights since the pre-sample period, 1980 to 1986, are classified as early adopters. Countries with weaker patent rights are late adopters, completing their reforms relevant to a strong patent protection regime in 1992, or even later. For comparison, columns 3 to 6 provide information on the patent protection index by Park (2008) and Ginarte and Park (1997); it takes values between zero and five and higher values indicate stronger patent protection. The term 'n.a.' indicates a missing index value.

Table 2: Patent relevance and product market reform per industry

Industry	Patent relevance		Product market reform
	Ranking 1 rank (group)	Ranking 2 rank (group)	Share in 1992 (s.e.)
15-16: food, beverages, and tobacco	low	low	0.3075 (0.1201)
17-19: textiles, leather, and footwear	low	low	0.5727 (0.1281)
23: coke, refined petroleum, and nuclear fuel	medium	high	0.0000 (0.0000)
24: chemicals including pharmaceuticals	high	high	0.7227 (0.1311)
25: rubber and plastics	medium	medium	0.4675 (0.1292)
26: other non-metallic mineral products	medium	medium	0.5455 (0.1623)
27: basic metals	low	low	0.0749 (0.1536)
28: fabricated metal products	medium	medium	0.3409 (0.1776)
29: general & special purpose machinery n.e.c., engines, turbines & domestic appliances n.e.c., machine tools, weapons	high	high	0.7409 (0.1020)
30-33: electrical, medical & optical equipment incl. computing machinery, radio, television and (tele)communication equipment	high	medium	0.7112 (0.0489)
34: motor vehicles, trailers, and semi-trailers	medium	high	0.6970 (0.1798)
35: other transport equipment	medium	medium	0.4659 (0.1590)
36-37: furniture, jewelery, games & toys, sports goods, recycling	high	medium	0.4545 (0.0934)

Notes: In column 2 of this table, we provide the industry-specific patent relevance ranking based on the US patent intensity data for the pre-sample period, 1980 to 1986, and in column 3 the ranking based on Cohen, Nelson and Walsh (2000). In column 4, we show the product market reform intensity in 1992 in the sampled 13 two-digit industries, averaged across the 11 countries that fell under the product market reform of the SMP (see Table 1). The measure is set to zero in all years before the implementation of the reform, from 1992 onwards it takes a positive value in country-industries that were ex ante expected to be affected by the reform, otherwise zero. Country-industries with higher values were expected to be affected more than others.

Table 3: Baseline models explaining R&D intensity

	Dependent variable: R&D intensity$_{cit}$		
	OLS	OLS	OLS
	(1)	(2)	(3)
Explanatory Variables:			
Product market reform$_{cit}$	0.0352***		0.0356***
	(0.0099)		(0.0099)
Patent protection$_{ct}$		0.0003	0.0027
		(0.0062)	(0.0061)
Country effects	Yes	Yes	Yes
Industry effects	Yes	Yes	Yes
Year effects	Yes	Yes	Yes
Observations	2,761	2,761	2,761

Notes: In this table we provide OLS estimates of basic models explaining R&D intensity in our main sample, the unbalanced panel of 2,761 observations on 13 manufacturing industries in 17 European countries between 1987 and 2003.
R&D intensity$_{cit}$ is defined as R&D expenditures over value added. The product market reform intensity, *Product market reform*$_{cit}$, equals zero in all years before the implementation of the SMP, from 1992 onwards it takes positive values up to 1 with higher values for country-industries that were ex ante expected to be affected more by the SMP than others. The measure *Patent protection*$_{ct}$ is coded one in the years once a country completed its reforms preparing the ground for a strong patent protection regime, and zero otherwise.
Standard errors in parentheses are robust and clustered to allow for unrestricted correlation between annual observations within country-industries. Statistical significance at the 1% level is indicated by ***.

Table 4: Main models explaining R&D intensity: Part 1

	Dependent variable: R&D intensity$_{cit}$					
	OLS	OLS	OLS	OLS	OLS	IV
Explanatory Variables:	(1)	(2)	(3)	(4)	(5)	(6)
R_{cit}*G(P (Protection)$^{strong}_{c,\ ps}$)	0.0525***	0.0870***	0.0885***	0.0807***		
	(0.0115)	(0.0229)	(0.0241)	(0.0202)		
R_{cit}*G($P^{weak}_{c,\ ps}$)	0.0074					
	(0.0125)					
R_{cit}*Protection$^{Ginarte/Park}_{ct}$					0.0482***	0.1206***
					(0.0162)	(0.0344)
R (Product market reform)$_{cit}$		-0.0060	-0.0065	0.0070	-0.1466**	-0.4467***
		(0.0219)	(0.0220)	(0.0170)	(0.0676)	(0.1437)
Knowledge stock$_{ci,1986}$			-0.0008	0.0012	0.0008	-0.0002
			(0.0037)	(0.0045)	(0.0037)	(0.0033)
Country-year effects	No	Yes	Yes	Yes	Yes	Yes
Industry-year effects	No	Yes	Yes	Yes	Yes	Yes
Country effects	Yes	No	No	No	No	No
Industry effects	Yes	No	No	No	No	No
Year effects	Yes	No	No	No	No	No
Weak identification test: Kleibergen-Paap rk Wald F Statistic						34,236 [1]
Observations	2,761	2,761	2,761	1,992	2,761	2,761

Notes: In this table we provide OLS and IV estimates of R&D intensity models for our main sample, the unbalanced panel of 2,761 observations on 13 manufacturing industries in 17 European countries between 1987 and 2003.
R&D intensity$_{cit}$ is defined as R&D expenditures over value added. In all columns except for column 4, we measure the product market intensity, R_{cit}, using our *main reform measure*. It is equal to zero in all years before the implementation of the SMP, from 1992 onwards it takes positive values up to 1 with higher values for country-industries that were ex ante expected to be affected more by the SMP than others. In column 4, we use the *alternative reform measure* (see Section 4 for details).
Country groups are indicated by G(·). The group G($P^{strong}_{c,\ ps}$) covers the countries where patent protection is strong since the pre-sample period, indicated by $P\ (Protection)^{strong}_{c,\ ps}$. The group G($P^{weak}_{c,\ ps}$) complements. The measure $Protection^{GP}_{ct}$ is the patent protection index of Ginarte and Park (1997) and Park (2008). In column 5, we exclude the instrument R_{cit}*G($P^{strong}_{c,\ ps}$). The number of first stage equations is given in brackets at the bottom of column 5.
The variable *Knowledge stock*$_{ci,1986}$ is the patent-based knowledge stock per country-industry in 1986.
Standard errors in parentheses are robust and clustered to allow for unrestricted correlation between annual observations within country-industries. Statistical significance at the 1% and 5% level is indicated by *** and **.

Table 5: Main models explaining R&D intensity: Part 2

	Dependent variable: R&D intensity$_{cit}$					
	OLS	OLS	OLS	OLS	OLS	OLS
	(1)	(2)	(3)	(4)	(5)	(6)
Explanatory Variables:						
R_{cit}*G(P (Protection)$^{strong}_{c,\ ps}$,	0.1205***		0.1124***		0.0755***	
I (Patent relevance)$^{\geq\ median}_{US,\ i,\ ps}$)	(0.0267)		(0.0258)		(0.0218)	
R_{cit}*G($P^{strong}_{c,\ ps}$, $I^{\leq\ median}_{US,\ i,\ ps}$)	0.0682***		0.0597**		0.0495*	
	(0.0250)		(0.0245)		(0.0276)	
R_{cit}*G($P^{strong}_{c,\ ps}$, $I^{high}_{US,\ i,\ ps}$)		0.0623**		0.0742***		0.0527***
		(0.0261)		(0.0259)		(0.0198)
R_{cit}*G($P^{strong}_{c,\ ps}$, $I^{medium}_{US,\ i,\ ps}$)		0.0590**		0.0550**		0.0559
		(0.0270)		(0.0269)		(0.0387)
R_{cit}*G($P^{strong}_{c,\ ps}$, $I^{low}_{US,\ i,\ ps}$)		0.0081		0.0034		-0.0005
		(0.0237)		(0.0244)		(0.0247)
R_{cit}*G($P^{strong}_{c,\ ps}$, NACE 30-33$_i$)			0.0029	-0.0137	-0.0092	-0.0171
			(0.0393)	(0.0384)	(0.0386)	(0.0383)
R (Product market reform)$_{cit}$	-0.0060	-0.0045	-0.0073	-0.0069	-0.0029	-0.0068
	(0.0208)	(0.0198)	(0.0196)	(0.0188)	(0.0195)	(0.0184)
Knowledge stock$_{ci,\ 1986}$	-0.0022	-0.0052	-0.0068	-0.0090*	-0.0083*	-0.0102**
	(0.0038)	(0.0038)	(0.0049)	(0.0049)	(0.0047)	(0.0047)
Controls for all G(*)$_{ci}$-groups	Yes	Yes	Yes	Yes	Yes	Yes
Country-year effects	Yes	Yes	Yes	Yes	Yes	Yes
Industry-year effects	Yes	Yes	Yes	Yes	Yes	Yes
Observations	2,761	2,761	2,761	2,761	2,761	2,761

Notes: In this table we provide OLS estimates of R&D intensity models for the main sample as described in Table 4).
Country-industry groups are indicated by G(·). In Column 1, we divide all industries in the country group with strong pre-sample patent protection (*P (Protection)*$^{strong}_{c,\ ps}$) into the industry-specific sub-group with above median patent relevance (*I (Patent relevance)*$_{US,\ i,\ ps}$), and the complementing group. In Column 2 we use three industry-specific groups for countries with strong patent protection, distinguishing between high, medium and low patent relevance. In Columns 1 and 2, the industry NACE 30-33 (electrical and optical equipment including computing machinery, radio, television and (tele)communication equipment) is part of the respective industry group with highest patent relevance. In columns 3 to 6, we exclude it from these groups and include, instead, the specific interaction term R_{cit}*G($P^{strong}_{c,\ ps}$, *NACE 30-33*$_i$).
In Columns 1 to 4, we use our main patent relevance measure which ranks each industry i based on US patent intensity data during the pre-sample period, 1980 to 1986. In Columns 5 and 6, we use the alternative measure, building on Cohen, Nelson and Walsh (2000) who use survey responses of R&D unit or laboratory managers to classify US industries according to the importance of patenting in appropriating returns to invention in the years 1991 to 1993.
All other variables are defined as in Table 4. Standard errors in parentheses are robust and clustered to allow for unrestricted correlation between annual observations within country-industries. Statistical significance at the 1%, 5% and 10% level is indicated by ***, ** and *.

Table 6: Models explaining alternative outcome variables

	Dependent variables:					
	Real R&D expenditures$_{cit}$			Number of patents$_{cit}$		
	OLS	OLS	OLS	OLS	OLS	OLS
Explanatory Variables:	(1)	(2)	(3)	(4)	(5)	(6)
R_{cit}*G(P (Protection)$^{strong}_{c,\ ps}$)	0.9503**			0.0592*		
	(0.4061)			(0.0320)		
R_{cit}*G($P^{strong}_{c,\ ps}$, I (Patent relevance)$^{\geq\ median}_{US,\ i,\ ps}$)		1.4065***			0.1245***	
		(0.4411)			(0.0473)	
R_{cit}*G($P^{strong}_{c,\ ps}$, $I^{<\ median}_{US,\ i,\ ps}$)		1.0305**			0.0032	
		(0.4902)			(0.0208)	
R_{cit}*G($P^{strong}_{c,ps}$, $I^{high}_{US,\ i,\ ps}$)			1.1586***			0.1063**
			(0.4181)			(0.0455)
R_{cit}*G($P^{strong}_{c,\ ps}$, $I^{medium}_{US,\ i,\ ps}$)			1.1377**			0.0034
			(0.5761)			(0.0214)
R_{cit}*G($P^{strong}_{c,\ ps}$, $I^{low}_{US,\ i,\ ps}$)			0.1963			-0.0189
			(0.2806)			(0.0189)
R (Product market reform)$_{cit}$	-0.1711	-0.2725	-0.2290	0.0048	0.0086	0.0092
	(0.3002)	(0.3033)	(0.3178)	(0.0245)	(0.0245)	(0.0242)
Knowledge stock$_{ci,1986}$	0.6337***	0.6587***	0.6340***	0.2711***	0.2671***	0.2658***
	(0.1370)	(0.1423)	(0.1433)	(0.0155)	(0.0163)	(0.0164)
Controls for all G(*)$_{ci}$-groups	No	Yes	Yes	No	Yes	Yes
Country-year effects	Yes	Yes	Yes	Yes	Yes	Yes
Industry-year effects	Yes	Yes	Yes	Yes	Yes	Yes
Observation period	87-03	87-03	87-03	87-99	87-99	87-99
Observations	2,761	2,761	2,761	2,031	2,031	2,031

Notes: In this table we provide OLS estimates of models explaining real R&D expenditures for the main sample as described in Table 4. The OLS estimates of models explaining the number of patents are for the sub-sample of all 2,031 observations for the years 1987 to 1999.
The variable *Real R&D expenditures*$_{cit}$ is defined as R&D expenditures in US dollar purchasing power parities at year 2000 prices (in billion). The measure *number of patents*$_{cit}$ is a fractional count of patents taken out per country-industry-year at the US Patent and Trademark Office.
All other variables are defined as in Tables 4 and 5. Standard errors in parentheses are robust and clustered to allow for unrestricted correlation between annual observations within country-industries. Statistical significance at the 1%, 5% and 10% level is indicated by ***, ** and *.

Table 7: Models accounting for alternative explanations

	Dependent variable: R&D intensity$_{cit}$			
	OLS	OLS	OLS	OLS
Explanatory Variables:	(1)	(2)	(3)	(4)
R_{cit}*G(D (Financial Development)$^{high}_{c,\,80-90}$, N (Capital needs)$^{\geq median}_{US,\,i,\,ps}$)	0.0598*			
	(0.0305)			
R_{cit}*G($D^{high}_{c,\,80-90}$, $N^{\leq median}_{US,\,i,\,ps}$)	0.0236			
	(0.0342)			
R_{cit}*G($D^{high}_{c,\,80-90}$, $N^{high}_{US,\,i,\,ps}$)		0.0512		
		(0.0340)		
R_{cit}*G($D^{high}_{c,\,80-90}$, $N^{medium}_{US,\,i,\,ps}$)		0.0223		
		(0.0289)		
R_{cit}*G($D^{high}_{c,\,80-90}$, $N^{low}_{US,\,i,\,ps}$)		-0.0088		
		(0.0616)		
R_{cit}*G(Capital intensity$^{\geq median}_{ci,\,ps}$)			-0.0277	-0.0296
			(0.0202)	(0.0192)
R_{cit}*G(EU-internal trade exposure$^{\geq median}_{ci,\,1988}$)			-0.0427*	-0.0391*
			(0.0243)	(0.0232)
R_{cit}*G(P (Protection)$^{strong}_{c,\,ps}$, I (Patent relevance)$^{\geq median}_{US,\,i,\,ps}$)	0.0923***		0.1203***	
	(0.0281)		(0.0376)	
R_{cit}*G($P^{strong}_{c,\,ps}$, $I^{\leq median}_{US,\,i,\,ps}$)	0.0468*		0.0662*	
	(0.0264)		(0.0392)	
R_{cit}*G($P^{strong}_{c,ps}$, $I^{high}_{US,\,i,ps}$)		0.0674**		0.0888**
		(0.0261)		(0.0357)
R_{cit}*G($P^{strong}_{c,\,ps}$, $I^{medium}_{US,\,i,ps}$)		0.0642**		0.0523
		(0.0286)		(0.0411)
R_{cit}*G($P^{strong}_{c,\,ps}$, $I^{low}_{US,\,i,ps}$)		0.0146		0.0142
		(0.0249)		(0.0390)
R_{cit}*G($P^{strong}_{c,\,ps}$, NACE 30-33$_i$)	-0.0054	0.0060	0.0108	-0.0001
	(0.0435)	(0.0453)	(0.0524)	(0.0507)
R (Product market reforms)$_{cit}$	-0.0161	-0.0237	0.0047	-0.0050
	(0.0220)	(0.0195)	(0.0424)	(0.0400)
Capital intensity$_{ci,ps}$	No	No	Yes	Yes
EU-internal trade exposure$_{ci,1988}$	No	No	Yes	Yes
Knowledge stock$_{ci,1986}$ (as in Table 5)	Yes	Yes	Yes	Yes
Controls for all G(*)$_{ci}$-groups	Yes	Yes	Yes	Yes
Country-year effects and industry-year effects	Yes	Yes	Yes	Yes
Observations	2,325	2,325	1,725	1,725

Note: The OLS estimates of the R&D intensity models are for the sub-samples of the main sample in Table 4 where the relevant financial and trade-related measures are available. Country-industry groups are indicated by G(·). The variable *D (Financial Development)*$^{high}_{c,\,1980-90}$ is coded one for all industries in countries with high financial sector development, and we separate between the industries above the median of the capital needs measure, *N (Capital needs)*$^{\geq med.}_{US,\,i,\,ps}$, and the complementing ones. Alternatively, we distinguish between industries at or above the 75th percentile ($N^{high}_{US,\,i,\,ps}$), below the 25th percentile, and intermediate ones. In columns 3 and 4, we include 1) the pre-sample capital intensity per country-industry, *Capital intensity*$_{ci,\,ps}$, 2) the interaction of R_{cit} with the indicator for country-industries above the relevant median, R_{cit}**G(Capital intensity*$^{\geq median}_{ci,\,ps}$*)*, 3) the ratio of EU 15 exports and imports relative to domestic production output per country-industry in 1988, *EU-internal trade exposure*$_{ci,1988}$, and 4) the interaction of R_{cit} with the indicator for country-industries above the relevant median, R_{cit}**G(EU-internal trade exposure*$^{\geq median}_{ci,1988}$*)*. All other variables, the standard errors in parentheses, and significance levels are as in Tables 4 and 5.

Appendix A: Additional Tables

Table A-1: Definitions of variables and descriptive statistics

Variable	Definition	Mean/ share	Standard deviation
R&D intensity$_{cit}$	nominal R&D expenditures divided by nominal value added in country c, industry i and year y	0.0464	0.0734
Real R&D expenditures$_{cit}$	R & D expenditures in US dollar purchasing power parities at year 2000 prices (in billion)	0.4443	1.1583
Number of patents$_{cit}$	fractional count of patents taken out in 1000 in US Patent Office	0.1036	0.3012
Product market reform$_{cit}$ *(main measure R^m_{cit})*	share of non-weighted 4-digit classes in country-industry ci that are ex ante expected to be affected by the product market reform from 1992 onwards; 0: otherwise	0.3027	0.3076
Protection$^{strong}_{c,\, ps}$	1: country c with strong patent rights since the pre-sample period, 1980 to 1986 0: otherwise	0.5389	
Protection$^{weak}_{c,\, ps}$	1: country c with weaker patent protection in the pre-sample period and later on, 0: otherwise	0.4611	
Knowledge stock$_{ci,\, 1986}$	knowledge stock in country-industry ci in 1986 (perpetual inventory method, depreciation rate: 20 %)	0.3684	1.0725
Patent intensity$_{US,\, i,\, 1982}$	number of patents divided by nominal value added in million US dollar in US-industry i in year 1982	0.0496	0.0376
Product market reform$_{cit}$ *(alternative measure R^a_{cit})*	share of employment-weighted 3-digit classes in country–industry ci that are ex ante expected to be affected by the reform from 1992 onwards; 0: otherwise	0.2741	0.4062
Protection$^{Ginarte/Park}_{ct}$	patent protection index (Park, 2008, Ginarte & Park, 1997) taking values 0 to 5 & higher values in country--years ct with patent laws providing stronger IPR	3.9029	0.7067
Financial development$_{c,\, ps}$	1: country c with private credit use and stock market capitalization during the 1980s, relative to gross domestic product (GDP), above the relevant sample median distribution, 0: otherwise	0.4524	
Capital needs$_{US,\, i,\, ps}$	capital intensity in US-industry i in the pre-sample period	0.4452	0.3533
EU internal trade exposure$_{ci,\, 1988}$	ratio of export plus import values involving EU 15 member countries as trading partners relative to domestic production output value per country-industry in 1988		

Notes: This table provides non-weighted descriptive statistics for our main sample, an unbalanced panel of 2,761 observations on 13 manufacturing industries in 17 European countries between 1987 and 2003, except for the variable *EU internal trade exposure*$_{ci,\, 1988}$ which is reported for the sub-sample of 1,725 observations as used in columns 3 and 4 of Table 7.

Appendix (possibly online publication)

Table A-2: US patent intensity and patent effectiveness per industry

Industry	US patent intensity (1982, nominal)	Patent effectiveness (Cohen, Nelson and Walsh, 2000)
15-16: food, beverages, and tobacco	0.0037	17.33
17-19: textiles, leather, and footwear	0.0055	22.61
23: coke, refined petroleum, and nuclear fuel	0.3222	35.00
24: chemicals including pharmaceuticals	0.0799	33.73
25: rubber and plastics	0.0673	26.29
26: other non-metallic mineral products	0.0329	24.34
27: basic metals	0.0141	21.41
28: fabricated metal products	0.0545	31.16
29: general & special purpose machinery n.e.c., engines, turbines & domestic appliances n.e.c., machine tools, weapons	0.0846	34.36
30-33: electrical, medical & optical equipment incl. computing machinery, radio, television and (tele)communication equipment	0.1052	28.45
34: motor vehicles, trailers, and semi-trailers	0.0232	33.30
35: other transport equipment	0.0154	27.21
36-37: furniture, jewelery, games & toys, sports goods, recycling	0.1242	28.77

Notes: In column 2 of this table, we show for each sampled industry the nominal US patent intensity in 1982, one exemplary year of the pre-sample period 1980 to 1986. In column 3, we show the share of product and process innovations in the years 1991 to 1993 for which R&D unit and laboratory managers judged patenting to be effective in protecting returns to invention, realized via commercialization or licensing (Cohen, Nelson and Walsh, 2000).

Appendix (possibly online publication)

Table A-3: Variants to model specifications in Table 5

Explanatory Variables:	Dependent variable: R&D intensity$_{cit}$ OLS (1)	OLS (2)	OLS (3)	OLS (4)
R (Product market reforms)$_{cit}$ *G(P (Protection)$^{strong}_{c,\ ps}$, I (Patent relevance)$^{>\ med.}_{US,\ i,\ ps}$)	0.1163***			
	(0.0274)			
R$_{cit}$*G(P$^{strong}_{c,\ ps}$, I$^{\leq\ median}_{US,\ i,\ ps}$)	0.0591**			
	(0.0228)			
R$_{cit}$*G(P$^{strong}_{c,\ ps}$, I$^{high}_{US,\ i,\ ps}$)		0.0603**	0.0646**	0.0415**
		(0.0290)	(0.0285)	(0.0208)
R$_{cit}$*G(P$^{strong}_{c,\ ps}$, I$^{medium}_{US,\ i,\ ps}$)		0.0521*	0.0460	0.0489
		(0.0275)	(0.0282)	(0.0392)
R$_{cit}$*G(P$^{strong}_{c,\ ps}$, I$^{low}_{US,\ i,\ ps}$)		0.0021	-0.0051	-0.0079
		(0.0240)	(0.0254)	(0.0264)
R$_{cit}$*G(P$^{strong}_{c,\ ps}$, NACE 30-33$_i$)			-0.0007	-0.0036
			(0.0446)	(0.0450)
R$_{cit}$*G(P$^{weak}_{c,\ ps}$, I$^{>\ median}_{US,\ i,\ ps}$)	-0.0028			
	(0.0220)			
R$_{cit}$*G(P$^{weak}_{c,\ ps}$, I$^{\leq\ median}_{US,\ i,\ ps}$)	-0.0140			
	(0.0265)			
R$_{cit}$*G(P$^{weak}_{c,\ ps}$, I$^{high}_{US,\ i,\ ps}$)		0.0001	-0.0144	-0.0161
		(0.0234)	(0.0228)	(0.0203)
R$_{cit}$*G(P$^{weak}_{c,\ ps}$, I$^{medium}_{US,\ i,\ ps}$)		-0.0111	-0.0128	-0.0067
		(0.0245)	(0.0242)	(0.0275)
R$_{cit}$*G(P$^{weak}_{c,\ ps}$, I$^{low}_{US,\ i,\ ps}$)		-0.0079	-0.0108	-0.0077
		(0.0218)	0.213	(0.0209)
R$_{cit}$*G(P$^{weak}_{c,\ ps}$, NACE 30-33$_i$)			0.0389	-0.0417
			(0.0278)	(0.0270)
Knowledge stock$_{ci,1986}$	-0.0022	-0.0053	-0.0091*	-0.0103**
	(0.0037)	(0.0038)	(0.0049)	(0.0047)
Controls for G(*)$_{ci}$-groups	Yes	Yes	Yes	Yes
Country-year effects	Yes	Yes	Yes	Yes
Industry-year effects	Yes	Yes	Yes	Yes
Observations	2,761	2,761	2,761	2,761

Notes: In this table we provide OLS estimates of R&D intensity models for the main sample as described in Table 4. Country-industry groups are indicated by G(·). In Columns 3 and 4, *G(P (Protection)*$^{strong}_{c,\ ps}$*, NACE 30-33*$_i$ singles out the industry covering electrical and optical equipment incl. computing machinery, radio, television and (tele)communication equipment in countries with strong patent protection. In Column 1, we divide all industries in the country group with strong pre-sample patent protection ($P^{strong}_{c,\ ps}$), as well as those in the country group with weaker protection ($P^{weak}_{c,\ ps}$), into the industry-specific sub-group with below or at median patent relevance and the sub-group with above median patent relevance (*I (Patent relevance)*$_{US,\ i,ps}$). In Column 2 we use three industry-specific groups for each country group, distinguishing between high, medium and low patent relevance. In Columns 1 and 2, the industry NACE 30-33 is part of the respective industry group with highest patent relevance. In columns 3 and 4, we exclude it from these groups. We use our main patent relevance measure in Columns 1 to 3 and we use the alternative measure in Column 4. All other variables are defined as in Table 4. Standard errors in parentheses are robust and clustered to allow for unrestricted correlation between annual observations within country-industries. Statistical significance at the 1%, 5% and 10% level is indicated by ***, ** and *.

Appendix (possibly online publication)

Table A-4: Identification using alternative sources of data variation: Part 1

	Dependent variable: R&D intensity$_{cit}$		
	Sample *including...*		
	...SMP-countries only	...SMP-countries, except Greece & Portugal	...SMP countries, except Germany and Belgium, in years before 1995
Panel A	OLS	OLS	OLS
	(1)	(2)	(3)
Explanatory Variables:			
R (Product market reforms)$_{cit}$	0.0775***	0.0959**	0.0651**
*G(P (Protection)$^{strong}_{c,\ ps}$)	(0.0244)	(0.0375)	(0.0251)
R$_{cit}$	-0.0109	-0.0625	0.0631
	(0.0312)	(0.0542)	(0.0425)
Knowledge stock control as in Table 4	Yes	Yes	Yes
Country-year effects	Yes	Yes	Yes
Industry-year effects	Yes	Yes	Yes
Observations	2,025	1,698	896
Panel B	OLS	OLS	OLS
	(4)	(5)	(6)
Explanatory Variables:			
R$_{cit}$*G(P$^{strong}_{c,\ ps}$, I$^{high}_{US,\ i,\ ps}$)	0.0745**	0.0905**	0.0313
	(0.0299)	(0.0385)	(0.0235)
R$_{cit}$*G(P$^{strong}_{c,\ ps}$, I$^{medium}_{US,\ i,\ ps}$)	0.0559**	0.0666*	0.0771***
	(0.0278)	(0.0387)	(0.0289)
R$_{cit}$*G(P$^{strong}_{c,\ ps}$, I$^{low}_{US,\ i,\ ps}$)	0.0106	0.0284	0.0030
	(0.0265)	(0.0411)	(0.0336)
R$_{cit}$	-0.0148	-0.0511	0.0514
	(0.0299)	(0.0550)	(0.0387)
Controls for the G(*)$_{ci}$-groups	Yes	Yes	Yes
Knowledge stock control as in Table 4	Yes	Yes	Yes
Country-year effects	Yes	Yes	Yes
Industry-year effects	Yes	Yes	Yes
Observations	2,025	1,698	896

Notes: The R&D-intensity model estimates in panel A of column 1, as well as those for panel B, are for the sub-sample, resulting after eliminating all non-SMP countries from the main sample, as used in Table 4. The estimates in column 2 are for the sub-sample of SMP countries that are not in the lowest tercile of the real per capita GDP sample distribution, excluding Greece and Portugal. For the estimates in column 3 we use the 30 percent sub-sample of our main sample, covering only EU member countries that implemented the SMP in 1992, but neither Germany which enlarged due to German reunification nor Belgium for which we have no data before 1992, and using only observations for years before 1995, when Finland and Sweden joined the EU, and the SMP.
All explanatory variables are defined as in Tables 4 and 5. Standard errors in parentheses are robust and clustered to allow for unrestricted correlation between annual observations within country-industries. Statistical significance at the 1% and 5% level is indicated by *** and **.

Table A-5: Identification using alternative sources of data variation: Part 2

	Dependent variable: R&D intensity$_{cit}$		
	Main sample...		
	...without Germany and UK	...plus the United States	...plus service industries
Panel A	OLS	OLS	OLS
	(1)	(2)	(3)
Explanatory Variables:			
R (Product market reforms)$_{cit}$	0.0894***	0.0857***	0.0878***
*G(P (Protection)$^{strong}_{c,\, ps}$)	(0.0236)	(0.0233)	(0.01233)
R$_{cit}$	0.0073	-0.0180	0.0020
	(0.0192)	(0.0228)	(0.0133)
Knowledge stock control as in Table 4	Yes	Yes	n.a.
Country-year effects	Yes	Yes	Yes
Industry-year effects	Yes	Yes	Yes
Observations	2,371	2,982	4,030
Panel B	OLS	OLS	OLS
	(4)	(5)	(6)
Explanatory Variables:			
R$_{cit}$*G(P$^{strong}_{c,\, ps}$, I (Patent relevance)$^{high}_{US,\, i,\, ps}$)	0.0640**	0.0583**	0.0529**
	(0.0275)	(0.0248)	(0.0233)
R$_{cit}$*G(P$^{strong}_{c,\, ps}$, I$^{medium}_{US,\, i,\, ps}$)	0.0717***	0.0451*	0.0786***
	(0.0270)	(0.0261)	(0.0213)
R$_{cit}$*G(P$^{strong}_{c,\, ps}$, I$^{low}_{US,\, i,\, ps}$)	0.0108	0.0276	0.0101
	(0.0261)	(0.0253)	(0.0150)
R$_{cit}$	0.0084	-0.0122	0.0024
	(0.0180)	(0.0200)	(0.0124)
Controls for the G(*)$_{ci}$-groups	Yes	Yes	Yes
Knowledge stock control as in Table 4	Yes	Yes	n.a.
Country-year effects	Yes	Yes	Yes
Industry-year effects	Yes	Yes	Yes
Observations	2,371	2,982	4,030

Notes: The R&D-intensity model estimates in panel A of column 1, as well as those in panel B, are for the sub-sample, resulting after eliminating Germany and the UK from the main sample, as used in Table 4. The estimates in column 2 are for the extended sample covering all countries in the main sample, plus the US. For the estimates in column 3 we add data for 8 service industries to the main sample. As patent data are not available for service industries, the model specifications in column 3 lack the patent-based knowledge stock control variable.

All explanatory variables are defined as in Tables 4 and 5. Standard errors in parentheses are robust and clustered to allow for unrestricted correlation between annual observations within country-industries. Statistical significance at the 1% and 5% level is indicated by *** and **.