J Econ Growth (2015) 20:223–262
DOI 10.1007/s10887-015-9114-3

Patent rights, product market reforms, and innovation

Philippe Aghion[1] · **Peter Howitt**[2] · **Susanne Prantl**[3]

Published online: 27 May 2015

Abstract In this paper, we provide empirical evidence to the effect that strong patent rights may complement competition-increasing product market reforms in fostering innovation. First, we find that the product market reform induced by the large-scale internal market reform of the European Union in 1992 enhanced, on average, innovative investments in manufacturing industries of countries with strong patent rights since the pre-sample period, but not so in industries of countries with weaker patent rights. Second, the positive response to the product market reform is more pronounced in industries where, in general, innovators tend to value patent protection higher than in other industries, except for the manufacture of electrical and optical equipment. The observed complementarity between competition and patent protection 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 a firm that successfully escapes competition by innovating, actually enjoys higher monopoly rents from its technological upgrade.

Keywords Intellectual property rights · Competition · Innovation

JEL Classification O3 · L1 · O4 · L5

Electronic supplementary material The online version of this article (doi:10.1007/s10887-015-9114-3) contains supplementary material, which is available to authorized users.

✉ Philippe Aghion
paghion@fas.harvard.edu

Peter Howitt
peter_howitt@brown.edu

Susanne Prantl
prantl@wiso.uni-koeln.de

1 Harvard University, Cambridge, MA, USA

2 Brown University, Providence, RI, USA

3 University of Cologne, Cologne, Germany

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 innovative activity (Sakakibara and Branstetter 2001; Lerner 2002, 2009; Qian 2007). This led Josh Lerner to stating that “t[T]he 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 that 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 the SMP was implemented 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 in manufacturing industries have widely been documented, for example by Bottasso and Sembenelli (2001), Badinger (2007), and Griffith et al. (2010).

In our empirical analysis, we first compare the innovation responses to the product market reform across two country-industry groups. In our main sample of 13 manufacturing industries in 17 European countries between 1987 and 2003, the first group covers all industries in the countries with strong patent rights. These countries have had patent regimes with strong patent protection since the pre-sample period, 1980 until 1986, and are among the founding states of the European Patent Organization (EPOrg). The second group covers all industries in the countries with weaker patent rights before and during our observation period. The estimation results are in line with the view that product market competition and patent protection can be complementary in inducing innovation: investments in research and development (R&D) respond, on average, positively to the competition-enhancing product market reform in industries of countries with strong patent rights since the pre-sample period, but not so in industries of countries with weaker patent rights.[1] A concern when comparing the reform effects across the two country-industry groups are potential interactions between the competition-increasing product market reform and country-specific factors other than the degree of patent protection. We address this concern by investigating as well whether the responses to the reform vary systematically across the industries within the two country-specific groups. We find that the reform’s positive effect on R&D investments in countries with strong patent rights since the pre-sample period is more pronounced in industries where, in general, innovators tend to value patent protection higher than in other industries,[2] except for the manufacture of electrical and optical equipment.

[1] To quantify the product market reform we use ex ante expectations of experts regarding changes in product market conditions at the country-industry-year level (Buigues et al. 1990). Note as well that we find similar empirical results when using alternative measures of the product market reform, of patent protection and innovative activity (see Sects. 4 and 5).

[2] To identify these industries, we use two alternative measures. First, we classify industries according to the level of the patent intensity in the corresponding United States (US) industry in the pre-sample period. Second, we build on US survey data provided by Cohen et al. (2000).

Empirical results suggesting that product market competition and patent protection can act as complementary inputs to innovation, 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.[3] Thus, patent protection is good for innovation for exactly the same reason that renders competition bad for innovation.[4] However, product market competition and patent protection can become complementary forces in a Schumpeterian growth model with step-by-step innovation. Why? This is because escape competition effects can arise in such a model (Aghion et al. 2001, 2005, 2014), and because better patent protection prolongs the period over which a firm that successfully escapes competition by innovating, actually enjoys higher monopoly rents from its technological upgrade. Hence, product market competition and patent protection can complement each other in inducing innovation.

Our paper relates to several strands of literature. First, it contributes to the literature on competition, innovation and economic growth.[5] Empirical evidence in line with an inverted-U relationship between product market competition and innovation is provided by Aghion et al. (2005) for a panel of industries in the United Kingdom (UK). Using panel data on plants, establishments and firms in the UK, Aghion et al. (2009) report technologically advanced entry of new foreign firms to induce productivity growth and patenting among incumbents in industries close to the technological frontier, but not in those lagging behind. Aghion et al. (2008) show unequal effects of an Indian product market deregulation on industry-level manufacturing output, with more positive effects in Indian states with pro-employer, rather than pro-worker labor market institutions. Focusing on the product market interventions that are part of the SMP, like we do, Bottasso and Sembenelli (2001) and Badinger (2007) show that the intervention reduced mark-ups in manufacturing industries. Griffith et al. (2010) report that the interventions enhanced product market competition which, in turn, led to an increase of R&D expenditures in a panel of manufacturing industries across member countries of the Organisation for Economic Co-operation and Development (OECD).[6] None of these papers addresses how the impact of a competition-increasing product market reform on innovative investments may interact with the strength of patent protection, and this is what we set out to contribute.

---

[3] 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 given that the pre-innovation rent is always equal to zero. Patent protection increases the net innovation rent. This is also the case in Aghion and Howitt (1992) where new innovators leap-frog incumbent firms.

[4] 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 from the early endogenous growth literature, they share the view that product market competition and patent protection are counteracting (or mutually exclusive) forces: namely, whenever one is good for innovation the other is detrimental to innovation.

[5] For related theoretical contributions, see, in particular, Aghion et al. (2001), Acemoglu et al. (2006), Acemoglu (2009), Aghion and Howitt (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).

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

Our work also extends the empirical literature investigating the effects of intellectual property rights (IPRs), as well as IPRs reforms, on the level of innovative activity.[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 patent rights. They find no evidence of positive average reform effects on the R&D spending and innovative output of Japanese firms. Branstetter et al. (2006) report empirical evidence in line with increasing technology transfers within United States (US) multinational firms in response to reforms that strengthen IPRs in the host countries of their affiliates. What these papers do not consider are potential interaction effects between patent law reforms and measures of competition. Qian (2007) reports for a panel of the pharmaceutical industry across OECD countries that introducing national patent protection did, on average, not stimulate pharmaceutical innovation. Moreover, she finds positive coefficients on interactions between patent protection and the country-level Fraser Institute index of economic freedom in equations explaining innovation. The index is a composite which aggregates country-level proxies of freedom to trade, in addition to access to money, regulation of credit, labor or business, legal structure and property rights. To the extent that the composite index may reflect country-level freedom to compete and trade, Qian's finding for the pharmaceutical industry provides a first hint towards the relevance of the complementarity we are interested in. Against this background, our focus is precisely on identifying whether product market competition can complement patent protection in inducing innovation. To that aim, we take advantage of the fact that the major 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 Sect. 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 Sect. 3 and explain the data in Sect. 4. The empirical results are described and discussed in Sect. 5. Section 6 concludes.

2 Competition and patent protection

In this section we use the Schumpeterian growth model with *step-by-step innovation* of Aghion et al. (2001, 2014) to explain why patent protection and product market competition may be complementary in inducing innovation. Therefore, and in contrast to these papers, our focus here is on the combined effect of these two policy instruments on innovation.[8]

2.1 The basic setup

Time is continuous and the economy is populated by a continuum of identical individuals who work either as production workers or researchers. The representative household discounts the future at rate $\rho > 0$, consumes C_t at date t, and has the logarithmic instantaneous utility function $U(C_t) = \ln C_t$. The household's Euler equation is $g_t = r_t - \rho$, where g_t denotes the growth rate of consumption and r_t denotes the interest rate. All costs are in terms of labor

[7] Moser (2005) addresses an important, but different question. She provides empirical evidence suggesting that the existence of patent laws can influence the direction of technological progress. Budish et al. (2015) argue that the structure of the patent system can influence the direction of R&D.

[8] See also Aghion et al. (2013).

units. The household's consumption is equal to the final good production Y_t, that is $C_t = Y_t$, which is also the resource constraint of the economy.

The final good is produced using 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 Eq. (1) implies that in equilibrium final good producers spend the same amount at any time on each basket y_j, and we normalize such that this amount is equal to Y. Thus, a final good producer chooses each y_{Aj} and y_{Bj} to maximize $y_{Aj} + y_{Bj}$ subject to the budget constraint $p_{Aj} y_{Aj} + p_{Bj} y_{Bj} = Y$, and the entire normalized expenditure is devoted to the less expensive of the two goods.

2.2 Technology and innovation

Following Aghion and Howitt (2009), among others, 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 labor. We assume that $A_i = \gamma^{k_i}$ 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 and the unit cost of production is independent of the quantity produced, $c_i = w\gamma^{-k_i}$. A sector j is fully characterized by a pair of integers (k_j, m_j) where k_j is the technology of *the leader* and m_j is the technological gap between the leader and the *follower (or laggard)*.[9]

For simplicity, we assume automatic catch-up such 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 technological par with one another, and (ii) *unleveled* sectors, where the leader lies one step ahead of the follower in the same industry.[10]

To specify the step-by-step innovation technology, we assume that a leader moves one technological step ahead at the rate z by spending the R&D cost $\psi(z) = z^2/2$ in units of labor. The rate z is the innovation rate, or the R&D intensity of the firm. In addition, we assume that a laggard can move one step ahead with probability h by copying the leader's technology at no cost. Thus, $\psi(z) = z^2/2$ is the R&D cost of a laggard moving ahead with probability $z+h$. We follow Acemoglu and Akcigit (2012) in taking h as our inverse measure of patent protection.[11]

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 only on the technological gap, m_j, between the two firms. See below for the case of $m_j \leq 1$.

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

We let z_0 denote the R&D intensity of a neck-and-neck 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 sector is equal to zero ($z_1 = 0$) due to the above assumption of automatic catch-up. The leader in an unleveled sector cannot gain any further advantage by innovating.

2.3 Equilibrium profits and product market competition

Let π_1 denote the normalized equilibrium profit of a leader in an unleveled sector.[12] The laggard in the unleveled sector will be priced out of the market such that

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

Consider now a leveled sector. If the two neck-and-neck 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,[13] each earning a profit equal to $\pi_1/2$.

Accordingly, the two firms in a leveled sector have an incentive to collude.[14] Specifically, we assume that the profit of a neck-and-neck firm is

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

and we parameterize product market competition by Δ, that is, as one minus the fraction of a leader's profits that the leveled firm can attain through collusion. Note that Δ is also the incremental profit of an innovator in a leveled sector, normalized by 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 inverse measure of patent protection, h, and why there might be complementarity between an increase in Δ and a reduction in h in fostering innovation and growth.

2.4 Complementarity

Let V_m denote the normalized steady-state value of currently being a leader in an industry with technological gap m, and V_{-m} the respective value of currently being a laggard. The normalized steady-state wage rate is denoted by $\omega = w/Y$ and the Bellman equations are as follows:[15]

Footnote 11 continued
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 et al. (2012) focus on blocking patents as the share of profits that incumbents are able to extract from entrants, and O'Donoghue and Zweimüller (2004) model the patentability requirement as the minimum quality step size in order for an innovation to be patentable.

[12] It can be shown that $\pi_1 = 1 - \frac{1}{\gamma}$. See, for example, Aghion and Howitt (2009) or Aghion et al. (2014).

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

[14] In an unleveled sector, firms do not collude as the leading firm has no interest in sharing its profit.

[15] Note that all aggregate variables, including firm values, grow at rate g on a balanced growth path, and that all growing variables are normalized by the aggregate output Y. Note also that the left-hand sides of the Bellman equations are originally equal to $rV_s - \dot{V}_s$ with $s = \{-1, 0, 1\}$. To rewrite these, we use (i) that $\dot{V}_s = gV_s$ holds on a balanced growth path and (ii) that the Euler equation is $g = r - \rho$.

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

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

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

where $\bar{z}_0$ denotes the R&D intensity of the competitor in a leveled sector. We focus on a symmetric equilibrium where $\bar{z}_0 = z_0$ and, in Eq. (4), we use $z_1 = 0$ as the leader in an unleveled sector does not invest in R&D in equilibrium.

Equation (2) states that 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 $\bar{z}_0(V_{-1} - V_0)$ 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, according to Eq. (3), 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 $\omega z_{-1}^2/2$. Equation (4) shows that 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, recalling that a leader in an unleveled sector does not invest in R&D in equilibrium.

Using the fact that z_0 maximizes Eq. (2) and z_{-1} maximizes Eq. (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 et al. (1997) the model is closed by a labor market clearing equation that determines ω as a function of the aggregate demand for labor for both production and research. Here, we simplify by ignoring that equation and take the wage rate ω as given, normalizing it at $\omega = 1$.

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

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

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

This system of equations solves recursively for unique positive values of z_0 and z_{-1}. Solving Eq. (7) for z_0, and using the fact that $\pi_1 - \pi_0 = \Delta\pi_1$, we can write the equilibrium R&D intensity z_0 as

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

Differentiating shows that an increase in product market competition Δ increases the equilibrium R&D intensity z_0 of a neck-and-neck firm ($\frac{\partial z_0}{\partial \Delta} > 0$). This is the *escape competition effect*. Moreover, this escape competition effect is decreasing in h, our inverse measure of patent protection: weaker patent protection reduces the magnitude of the escape competition effect ($\frac{\partial z_0}{\partial \Delta \partial h} < 0$). Therefore, patent protection and product market competition are complementary in enhancing innovation incentives in leveled sectors.

Using the equilibrium R&D intensity $z_0(\Delta)$ to rewrite Eq. (8), we can derive the effect of an increase in Δ on the R&D intensity z_{-1} of a laggard. This effect is ambiguous, in general. For a very high discount rate 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, focuses on its short-term net profit flow if it catches up with the leading firm, which decreases in product market competition. This is the *Schumpeterian effect*. However, for low values of ρ, this Schumpeterian 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 leveled sectors and faster or slower growth in currently unleveled sectors. The overall effect on growth will depend upon the discount rate ρ and also the steady-state fraction of leveled versus unleveled sectors in the economy. The steady-state fraction is itself endogenous, depending on the equilibrium R&D intensities in both types of sectors. But for sufficiently small values of ρ it can be shown that the escape and the anticipated escape competition effects will dominate the Schumpeterian effect, so that the overall innovation rate I will satisfy:

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

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

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

It is this possibility of a complementary between patent protection and product market competition which we investigate 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 implemented at a time with significant variation in patent protection across European countries, and it created exogenous variation in product market conditions across industries within countries, across countries and across time.

We proceed in two steps, using panel data for 13 industries in 17 European countries between 1987 and 2003.[16] 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, 1980–1986, and throughout the sample period; (2) all industries in countries with weaker patent rights. We estimate the following equations, as well as related variants:

$$y_{cit} = \beta_1 R_{cit} * G(P_{c,\ ps}^{strong}) + \beta_2 R_{cit} * G(P_{c,\ ps}^{weak}) + \alpha_c + \eta_i + \pi_t + u_{cit} \tag{9}$$

or

$$y_{cit} = \beta_1 R_{cit} * G(P_{c,\ ps}^{strong}) + \beta_2 R_{cit} + \gamma X_{cit} + \alpha_{ct} + \eta_{it} + u_{cit} \tag{10}$$

where the explained variable y_{cit} measures innovation. Our main measure of innovative activity is R&D intensity, defined as R&D expenditures over value added. Countries are indexed by c, industries by i, years by t, and ps indicates the pre-sample period. The main explanatory variable is our measure of the product market reform, denoted by R_{cit}. This

[16] In Sect. 4 and Appendix 2, we explain the data and the construction of the variables.

variable is set to zero in all years before the implementation of the SMP. From 1992 onwards, it takes values between zero and one. A higher value indicates that, ex ante, experts were expecting the competition-increasing reform to change product market conditions for a higher share of the respective country-industry unit than in case of a lower value.

In Eq. (9), we interact the reform measure 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 measure 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. The group indicators are constructed from information on patent law reforms and related regulation. We include the full sets of controls for country fixed effects, α_c, industry fixed effects, η_i, and year fixed effects, π_t, and denote the error term 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 Eq. (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 Eq. (10), we change the model specification by considering as explanatory variables: the interaction between the reform measure and the indicator $G(P^{strong}_{c,\ ps})$, the level term R_{cit}, a vector X_{cit}, and an extended set of fixed effects. The vector X_{cit} captures covariates. Among these are, in particular, a measure of the initial innovative potential of country-industries, as well as a measure of the initial exposure to competition at the level of the EU internal market. We consider country-time fixed effects, α_{ct}, 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-time fixed effects, η_{it}, are used to pick up unobserved factors, like arbitrary drastic innovation, that can induce industry-specific trends over time.

The identification of the coefficient estimates in Eq. (10) relies on using 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 changing the set of fixed effects. In addition, we vary our measures of the product market reform and patent protection. The estimation results are provided in Sect. 5.2.

In the second step of our empirical analysis, we address the concern that reform effect estimates from Eqs. (9) and (10), and the extent to which these differ *across the two considered country-industry groups*, could be influenced by interactions of the reform with country-specific factors other than the degree of patent protection. 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 two country-specific groups*.[17] We single out industries where, in general, innovators tend to consider patent protection as highly relevant, and tend to rely strongly on patenting in appropriating returns to invention. 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, 1980–1986. Second, we build on Cohen et al. (2000) who

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

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.

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

$$y_{cit} = \beta_{11} R_{cit} * G(P^{strong}_{c,\ ps}, I^{>median}_{US,i,\ ps}) + \beta_{12} R_{cit} * G(P^{strong}_{c,\ ps}, I^{\leq median}_{US,i,\ ps}) + \beta_2 R_{cit} + \gamma X_{cit} + \delta G_{ci} + \alpha_{ct} + \eta_{it} + u_{cit} \quad (11)$$

where we estimate the innovation response to the product market reform separately for three country-industry groups. To that aim, Eq. (11) includes the reform measure R_{cit} interacted with $G(P^{strong}_{c,\ ps}, I^{>median}_{US,i,\ ps})$, a dummy variable indicating 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. In addition, R_{cit} enters interacted with $G(P^{strong}_{c,\ ps}, I^{\leq median}_{US,i,\ ps})$ which indicates the complementing group of industries with low patent relevance in countries with strong patent rights. The third reform term is the level term R_{cit}, capturing the average reform effect for all industries in countries with weaker patent rights. To capture time-constant country-industry group effects, we include the vector of the relevant group indicators, G_{ci}.

The coefficients of main interest in Eq. (11) 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}. We provide the estimation results in Sect. 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 Sect. 5.3, we extend our empirical model to allow, among others, for interactions of the product market reform with financial factors that vary across country-industries.

4 Data

For our main sample we combine data from several sources into a panel data set covering 13 industries across 17 European countries between 1987 and 2003. The majority of countries, 11 out of the 17 countries, participated in the European Single Market Program in 1992, as shown in Table 1. 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] Alternative samples are also considered.

Next, we briefly introduce our main variables. Descriptive statistics are provided in Table 8 in Appendix 1, and further information, also on additional variables, can be found in Appendix 2.

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 level panel 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 2.1). We also use measures of real R&D expenditures, that is R&D expenditures in US dollar purchasing power parities at year 2005 prices (in billion).

To capture the initial innovation potential of country-industries we calculate a patent-based measure of the knowledge stock built up per country-industry until 1986, the end of

[18] Industries are classified according to the European NACE classification (version 1993, revision 1).

Table 1 Patent protection per country

	(1)	(2)	(3)	(4)	(5)
	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	4.09	4.34	4.54	4.67
DNK (Denmark)	Early	3.63	3.88	4.54	4.67
ESP (Spain)	Late	2.81	3.56	4.21	4.33
FRA (France)	Early	3.76	3.88	4.54	4.67
GER (Germany)	Early	3.84	3.97	4.17	4.50
GRC (Greece)	Late	2.33	2.87	3.47	3.97
IRL (Ireland)	Late	2.20	2.33	4.14	4.67
ITA (Italy)	Early	3.68	4.01	4.33	4.67
NLD (Netherlands)	Early	3.77	4.22	4.54	4.67
PRT (Portugal)	Late	1.67	1.67	3.35	4.01
UK (United Kingdom)	Early	3.88	4.34	4.54	4.54
European countries outside EU until 1995					
FIN (Finland)	Late	3.31	3.30	4.42	4.54
SWE (Sweden)	Early	3.48	3.88	4.42	4.54
European countries outside EU during sample period (1987–2003)					
CZE (Czech Republic)	Late	n.a.	n.a.	2.96	3.21
HUN (Hungary)	Late	n.a.	n.a.	4.04	4.04
POL (Poland)	Late	n.a.	n.a.	3.46	3.92
SVK (Slovak Republic)	Late	n.a.	n.a.	2.96	2.76
Non-European countries not in main estimation sample					
US (United States)	Early	4.68	4.68	4.88	4.88

Notes In the first panel of this table, we list the 11 countries in the main sample that fell under the product market reform induced by the large-scale, EU-internal market reform in 1992, the EU Single Market Program (SMP). The three lower panels cover the 6 other European countries in the main sample, and the United States. In column 1, we indicate for each listed country whether it adopted strong patent protection early or late in time. Countries with strong patent rights since the pre-sample period, 1980–1986, 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 2–5 provide information on the patent protection index by Ginarte and Park (1997) and Park (2008a, b). The index is available for every fifth year since 1960, takes country-specific values between zero and five, higher values indicate stronger patent protection, and the term 'n.a.' indicates a missing index value

the pre-sample period. To construct the knowledge stock variable we use country-industry-year-specific counts of patents taken out at the US Patent and Trademark Office. These US patent counts are part of the EU KLEMS 2008 database and constructed from the NBER patent database.[19]

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,

[19] See also Appendix 2.1, O'Mahony et al. (2008) and Hall et al. (2001).

Table 2 Patent relevance and product market reform per industry

Industry	(1)	(2)	(3)
	Patent relevance		Product market reform (standard deviation)
	Ranking 1	Ranking 2	
15-16: food, beverages, and tobacco	Low	Low	30.75 (12.01)
17-19: textiles, wearing apparel, and leather	Low	Low	57.27 (12.81)
23: coke, refined petroleum, and nuclear fuel	Medium	High	00.00 (00.00)
24: chemicals including pharmaceuticals	High	High	72.27 (13.11)
25: rubber and plastics	Medium	Medium	46.75 (12.92)
26: other non-metallic mineral products	Medium	Medium	54.55 (16.23)
27: basic metals	Low	Low	07.49 (15.36)
28: fabricated metal products	Medium	Medium	34.09 (17.76)
29: general and special purpose machinery, equipment not elsewhere classified (n.e.c.)	High	High	74.09 (10.20)
30–33: electrical and optical equipment	High	Medium	71.12 (04.89)
34: motor vehicles, trailers, and semi-trailers	Medium	High	69.70 (17.98)
35: other transport equipment	Medium	Medium	46.59 (15.90)
36–37: furniture, jewelery, musical instruments, sports goods, games & toys, recycling, manufacturing n.e.c.	High	Medium	45.45 (09.34)

Notes In column 1 of this table, we provide our main patent relevance measure which ranks each industry based on US patent intensity data during the pre-sample period, 1980 to 1986. In Column 2, we show the alternative measure, building 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. In column 3, we show the main product market reform measure in 1992 for the 13 industries of our main sample, averaged across the 11 countries that fell under the product market reform of the SMP (see Table 1). In 1992, the reform measure (in percent) takes values between zero and 100, with a higher value indicating that, ex ante, experts were expecting a higher share of the respective country-industry unit to be affected by the product market reform than in case of a lower value

as well as related regulation, and focus on a time period with high variation in patent protection across European Countries (see also Appendix 2.3). As shown in column 1 of Table 1, one group of countries in our main sample had strong patent protection already in the pre-sample period, 1980–1986, and also throughout the whole sample period, 1987–2003.

The group covers seven EU member states that implemented the SMP in 1992 (Belgium, Denmark, France, Germany, Italy, Netherlands, United Kingdom) and Sweden which joined the EU in 1995.[20] All other sampled countries form the group with weaker patent protection. Among these are: 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 sample 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.[21] 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 patent regime providing strong patent protection before 1992 (Branstetter et al. 2006; Qian 2007; World Intellectual Property Organization 2012). Our classification is subjective, but consistent with those used in Branstetter et al. (2006), Maskus and Penubarti (1995) or Qian (2007). In addition, we compare our preferred 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 (2008a, b). Columns 2–5 of Table 1 provide the index values for the years 1985, 1990, 1995 and 2000. These values confirm high variation of patent protection across European Countries during our sample period, with international harmonization of patent systems increasing towards the end of the period.

In the second part of the empirical analysis, we estimate the innovation response to the product market reform separately for different patenting-related country-industry groups. In doing so, we start with considering two groups of industries: the group of industries with high patent relevance, compared to the industry with median patent relevance, and the complementing group with low patent relevance. Our main measure of patent relevance ranks each industry i according to the level of the patent intensity in the corresponding US industry in the pre-sample period, 1980–1986.[22] The alternative measure builds on the survey of Cohen et al. (2000) with about 1100 R&D unit or laboratory managers reporting industry-specific shares 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. We use this share data as our alternative measure of patent relevance.

We also consider sets of three instead of two industry groups, respectively with high, low and medium patent relevance at or above the 75th percentile of the chosen relevance measure, below the 25th percentile, and in between. The three-group ranking based on our main measure of patent relevance is shown in column 1 of Table 2; column 2 provides the alternative three-group ranking.

Product market reform

The product market reform which we consider 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

[20] Patent protection is also strong in the United States that we include in one of our alternative samples.

[21] Italy has been a contracting state since 1978, and Denmark since 1990.

[22] We use data on US industries as the US is the technology leader in most industries during the sample period, and not included in our main sample.

and economic growth. Main components of the product market reform 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 reform created exogenous variation in product market conditions across industries within countries, across countries and across time. EU member countries officially implemented the SMP in 1992, a time with significant variation in patent protection across countries (see 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 increased in manufacturing industries in response to the product market reform (Badinger 2007; Bottasso and Sembenelli 2001; Griffith et al. 2010).

For constructing product market reform measures we use a European Commission report by Buigues et al. (1990). The report provides a common list of manufacturing industries that researchers expected ex ante to be affected by the product market reform. Country-specific additions to and removals from the common industry list are also reported (see Appendix 2.4 for details). In the country-industries that were ex ante expected to be affected the initial level of competition was typically low. We can construct reform measures that vary not only across time, but also across industries within SMP countries and across SMP countries, and we exploit that variation for identifying the reform impact from confounding influences. In addition, we can use further variation across countries as non-SMP countries are also part of our main sample.[23]

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.[24] For an *alternative measure of the product market reform* we use employment shares, including those 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 according to the common list. Given that many relevant employment shares are missing, the alternative measure can only be calculated for a smaller sample.

In column 3 of Table 2, we report the main product market reform measure in 1992 for all 13 industries in our data set, averaging across the 11 initial SMP countries in our main sample. The industries that were expected to be affected most are ‘34: motor vehicles, trailers, and semi-trailers’, ‘30–33: electrical and optical equipment’, ‘24: chemicals including pharmaceuticals’, and ‘29: general and special purpose machinery, equipment not elsewhere classified (n.e.c)’. Those that were expected to be affected least are ‘23: coke, refined petroleum, and nuclear fuel’ and ‘27: basic metals’.

23 See Sect. 5.3 for estimation results based on sub-samples without the non-SMP countries.

24 For Swedish or Finnish country-industries in our data set, the main SMP measure is, from 1995 onwards, equal to the ex-ante expected share of the affected industry classes on the common list, and zero otherwise.

Table 3 Baseline models explaining R&D intensity

Explanatory variables	Dependent variable R&D intensity$_{cit}$		
	(1) OLS	(2) OLS	(3) OLS
Product market reform$_{cit}$	0.0324***		0.0341***
	(0.0099)		(0.0100)
Patent protection$_{ct}$		−0.0025	−0.0070
		(0.0061)	(0.0061)
Country effects	Yes	Yes	Yes
Industry effects	Yes	Yes	Yes
Year effects	Yes	Yes	Yes
Observations	2739	2739	2739

Notes In this table, we provide OLS estimates of basic models explaining R&D intensity in our main sample, the unbalanced panel of 2739 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 country c, industry i, and year t. The product market reform measure, *Product market reform*$_{cit}$, equals 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 a higher share of the respective country-industry unit to be affected by the product market reform than in case of a lower value. 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 ***

5 Empirical results

5.1 Baseline results

We start by estimating the average response of innovation to the competition-increasing product market reform which is part of the European Single Market Program, and then estimate the average response to patent protection. This prepares the ground for analyzing the response of innovation to the interaction between the two factors. We report OLS estimation results in Table 3 for the main sample, an unbalanced panel of 2739 observations on 13 manufacturing industries in 17 European countries between 1987 and 2003 (see also Appendix 3). All model specifications include full sets of 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 measure on R&D intensity in column 1 of Table 3.[25] The coefficient estimate indicates that enhancing the reform measure by one standard deviation (0.3077) increases R&D intensity by 0.01 (=0.0324*0.3077).[26] This represents about 21 percent of the mean value of R&D intensity in the estimation sample (0.0470), a reasonable effect size. Such an average effect estimate is consistent with an escape competition effect being relevant, and it fits, among others, with the empirical results of Griffith et al. (2010).

[25] See Table 3 for the definitions of the variables, as well as Sect. 4 and Appendix 2.

[26] See Table 8 in Appendix 1 for the descriptive statistics.

Our second finding is a negative one: patent protection has, on average, no effect on R&D intensity. The coefficient estimate on an indicator that equals one in the years once a country completed its reforms preparing the ground for strong patent protection, and zero otherwise, turns out to be small and not significantly different from zero (see column 2). This result is consistent with previous empirical evidence, in 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 the model specification of column 3. There, we include both linear terms, the one for the competition-increasing product market reform as well as the one for patent protection.

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 hints directly at heterogeneity in the response to the reform, depending on the strength of patent protection. 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 the R&D intensity, the horizontal axes refer to the product market reform measure. 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.[27] 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 Eqs. (9) and (10) in Sect. 3, as well as variants of these. The estimation results in Table 4 indicate a positive effect of the product market reform measure, 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 several alternative model specifications. In column 1, we estimate Eq. (9), including the two interaction terms $R_{cit} * G(Protection\,(P)_{c,\ ps}^{strong})$ and $R_{cit} * G(P_{c,\ ps}^{weak})$ as explanatory variables,[28] as well as full sets of controls for country, industry, and year fixed effects. In column 2, we estimate a version of Eq. (10). In that equation, the coefficient on the interaction term, $R_{cit} * G(Protection\ (P)_{c,\ ps}^{strong})$, indicates how the reform effect for the industries in countries with strong patent rights deviates from the one for country-industries with weaker patent rights. The latter effect is captured by the coefficient on the level term, R_{cit}.[29] We also allow for country-time fixed effects and industry-time fixed effects.[30] In

[27] Each of the 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 measure as the sole explanatory variable.

[28] The group of industries in countries with strong patent protection since the pre-sample period is denoted by G(Protection $(P)_{c,\ ps}^{strong}$); G($P_{c,\ ps}^{weak}$) denotes the corresponding group with weaker patent protection.

[29] The positive reform effect in country-industries with strong patent rights (0.0875+(-0.0102)=0.773) is significantly different from zero (F-test statistic:17.13, p-value: 0.0001).

[30] We consider the full set of interactions between all country dummies and six indicators for time periods, one for the initial two-year period (1987 to 1988) and five for the consecutive three-year periods between 1989 and 2003. We also consider the corresponding set of industry-time interactions.

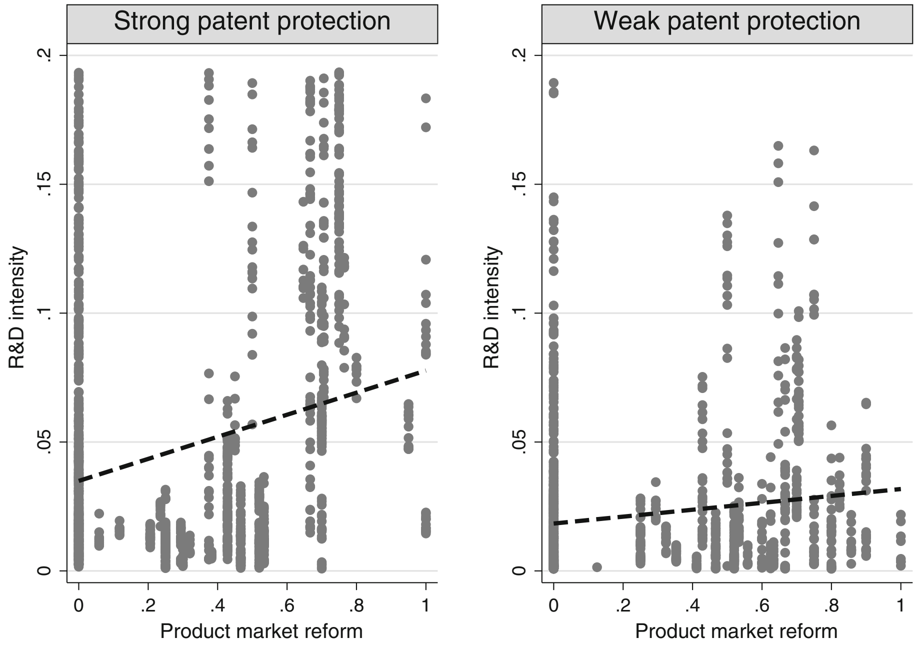

Fig. 1 Patent protection, product market competition and innovation. *Notes* In this figure we show the relation between the competition-increasing product market reform and R&D intensity in countries with strong patent rights since the pre-sample period (*left graph*) and in countries with weaker patent rights (*right graph*). The *horizontal axes* refer to the product market reform measure, the vertical axes to R&D intensity and the circles indicate all 2465 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 the lines represents a linear prediction from a group-specific linear regression of R&D intensity on the product market reform measure as the sole explanatory variable

column 3, we add as explanatory variable the knowledge stock of country-industries in 1986, the last year of the pre-sample period.

Our findings are also robust to the following changes in the way we measure our main explanatory variables. First, we replace our main measure of the product market reform 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.[31] The estimation results are shown in column 4 of Table 4, and the positive effect estimate for industries in countries with strong patent rights is very similar to the one in column 3, that is 0.0806 compared to 0.0788. Second, we replace our preferred pre-sample measure of patent protection by the time-varying Ginarte-Park index (P_{ct}^{GP}). Column 5 provides the respective OLS estimates. As the index is, at least, every fifth year a contemporaneous regressor we also consider that it may be endogenous to innovation, and implement an instrumental variable approach. The excluded instrument is the interaction of our country-specific pre-sample indicator of strong patent rights and the product market reform measure.[32] The second stage estimates on the two product market reform terms in

[31] 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 (see also Sect. 4 and Appendix 2.4).

[32] The coefficient estimate *(s.e.)* on the excluded instrument in the first stage equation is 0.7382*** *(0.1193)*. The test statistic for the F-test on the irrelevance of the excluded instrument takes a value of 38.26 and the null hypothesis is rejected.

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

Explanatory variables	Dependent variable R&D intensity$_{cit}$					
	(1) OLS	(2) OLS	(3) OLS	(4) OLS	(5) OLS	(6) IV
R_{cit}*G(P (Protection)$_{c,\ ps}^{strong}$)	0.0499***	0.0875***	0.0897***	0.0570***		
	(0.0114)	(0.0218)	(0.0229)	(0.0212)		
R_{cit}*G($P_{c,\ ps}^{weak}$)	0.0040					
	(0.0129)					
R_{cit}*Protection^{GP}					0.0430***	0.1215***
					(0.0136)	(0.0357)
R (Product market reform)$_{cit}$		−0.0102	−0.0109	0.0237	−0.1284**	−0.4537***
		(0.0209)	(0.0211)	(0.0145)	(0.0572)	(0.1496)
Knowledge stock$_{ci,1986}$			−0.0012	−0.0002	0.0005	−0.0006
			(0.0036)	(0.0035)	(0.0036)	(0.0035)
Country-time effects	No	Yes	Yes	Yes	Yes	Yes
Industry-time 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						38.265 [1]
Observations	2739	2739	2739	1793	2739	2739

Notes In this table, we provide OLS and IV estimates of R&D intensity models for our main sample, the unbalanced panel of 2739 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 country c, industry i, and year t. In all columns, except column 4, we use the *main product market reform measure*, R_{cit}. It is equal 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 a higher share of the respective country-industry unit to be affected by the product market reform than in case of a lower value. In column 4, we use the *alternative reform measure* (see Sect. 4 for details). *Country groups* are indicated by $G(\cdot)$. The group $G(P_{c,\ ps}^{strong})$ covers the countries where patent protection is strong since the pre-sample period (ps), indicated by $P\ (Protection)_{c,\ ps}^{strong}$; $G(P_{c,\ ps}^{weak})$ denotes the corresponding group with weaker patent protection. The measure $Protection_{ct}^{GP}$ is our alternative measure of patent protection, the Ginarte-Park index. In column 6, we exclude the instrument R_{cit}*G($P_{c,\ ps}^{strong}$). The number of first stage equations is given in brackets at the bottom of column 6. 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 **

column 6 indicate that the reform effect on R&D intensity increases with patent protection, and that it 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.[33]

All our estimation results in Table 4 are in line with the view that the competition-enhancing product market reform is complemented by patent protection in inducing innovation. A

[33] 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 et al. (2007), Kleibergen and Paap (2006), and Stock and Yogo (2005).

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 reform and country-specific factors other than the degree of patent protection.

Accordingly, we turn to investigating whether, in particular, the positive reform effect estimated on *all industries within countries* with strong patent rights varies systematically if we allow for *effect heterogeneity across these industries*. As argued in Sect. 3, we expect the reform effect to be highest in industries of countries with strong patent rights where, in general, innovators tend to consider patent protection as highly relevant, and tend to rely strongly on patenting. We refer to the former industries as industries with higher patent relevance and use the two alternative proxies for patent relevance which we introduced in Sect. 3.

Column 1 of Table 5 provides the estimation results for Eq. (11) in Sect. 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 groups, as well as those in columns 2–4, we use our 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, 1980–1986. Column 1 shows for each of the 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, and that estimate is small and insignificant. Estimating a single 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 of Table 9 in Appendix 1.[34] For the two groups of country-industries with strong patent rights, we find positive reform effects,[35] 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.[36]

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. 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 a high level of patent relevance, as well as in the industries with an intermediate level.[37] We also observe that the responses in these two country-industry groups are stronger than those in other groups.[38] For the group of all industries in countries with

[34] The coefficient estimates on the two sub-groups $G(P^{weak}_{c,\ ps}, I^{>median}_{US,i,\ ps})$ and $G(P^{weak}_{c,\ ps}, I^{\leq median}_{US,i,\ ps})$ are small, not significantly different from zero, and not significantly different from each other (F-test statistic: 0.14, p-value: 0.7122).

[35] The F-test statistic relevant to the country-industry group with strong patent rights and above median patent relevance is 19.26 (p-value: 0.0000). The other F-test statistic is 8.62 (p-value: 0.0037).

[36] The F-test statistic is 4.39 (p-value: 0.0373). The findings for the model specification in column 1 of Table 9 in Appendix 1 indicate as well that the effect estimates for country-industry groups with strong patent rights differ significantly (F-test statistic: 3.85, p-value: 0.0512).

[37] The F-test statistic relevant to the country-industry group with strong patent rights and high patent relevance is 4.19 (p-value: 0.0419). The other relevant F-test statistic is 4.36 (p-value: 0.0381).

[38] The responses are significantly higher than the response in countries with weaker patent rights, reflected by the estimated coefficient on the R_{cit}-term. In addition, the estimates for the industries with high and low patent

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

Explanatory variables	Dependent variable R&D intensity$_{cit}$					
	(1) OLS	(2) OLS	(3) OLS	(4) OLS	(5) OLS	(6) OLS
R_{cit}*G(P (Protection)$^{strong}_{c,\ ps}$, I (Patent relevance)$^{>\ median}_{US,\ i,\ ps}$)	0.1194***		0.1136***		0.0781***	
	(0.0249)		(0.0243)		(0.0210)	
R_{cit}*G($P^{strong}_{c,\ ps}$, $I^{\leq\ median}_{US,\ i,\ ps}$)	0.0705***		0.0615**		0.0508*	
	(0.0240)		(0.0234)		(0.0260)	
R_{cit}*G($P^{strong}_{c,\ ps}$, $I^{high}_{US,\ i,\ ps}$)		0.0614**		0.0748***		0.0549***
		(0.0245)		(0.0244)		(0.0191)
R_{cit}*G($P^{strong}_{c,\ ps}$, $I^{medium}_{US,\ i,\ ps}$)		0.0610**		0.0563**		0.0576
		(0.0262)		(0.0260)		(0.0364)
R_{cit}*G($P^{strong}_{c,\ ps}$, $I^{low}_{US,\ i,\ ps}$)		0.0112		0.0059		0.0026
		(0.0226)		(0.0230)		(0.0233)
R_{cit}*G($P^{strong}_{c,\ ps}$, NACE 30–33$_i$)			−0.0010	−0.0179	−0.0130	−0.0210
			(0.0373)	(0.0366)	(0.0368)	(0.0365)
R (Product market reform)$_{cit}$	−0.0104	−0.0084	−0.0103	−0.0095	−0.0058	−0.0094
	(0.0199)	(0.0190)	(0.0186)	(0.0180)	(0.0186)	(0.0175)
Knowledge stock$_{ci,\ 1986}$	−0.0025	−0.0056	−0.0068	−0.0090*	−0.0083*	−0.0101**
	(0.0036)	(0.0036)	(0.0046)	(0.0046)	(0.0044)	(0.0044)
Controls for the G(·)$_{ci}$-groups	Yes	Yes	Yes	Yes	Yes	Yes
Country-time effects	Yes	Yes	Yes	Yes	Yes	Yes
Industry-time effects	Yes	Yes	Yes	Yes	Yes	Yes
Observations	2739	2739	2739	2739	2739	2739

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 $G(\cdot)$. For the regression in column 1, we assign the industries i in the countries c with strong pre-sample (ps) patent protection ($P\ (Protection)^{strong}_{c,\ ps}$) to two sub-groups: (1) the sub-group of country-industries above the median of the US industry-specific pre-sample patent relevance ($I\ (Patent\ relevance)_{US,\ i,\ ps}$), and (2) the corresponding group with below or at the median patent relevance. 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) is part of the respective industry group with highest patent relevance. In columns 3 to 6, we single it out and use the specific interaction term $R_{cit} * G(P^{strong}_{c,\ ps}, NACE\ 30\text{–}33_i)$ as additional explanatory variable. In columns 1 to 4, we use our main patent relevance measure which ranks each industry i based on US patent intensity data for the pre-sample period, 1980–1986. In columns 5 and 6, we use the alternative ranking, building 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. 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 * weaker patent rights, we estimate again the average reform effect,[39] and we find a small and insignificant estimate. 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 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 industry group in countries with strong patent protection, namely, the group covering the manufacture of electrical and optical equipment (codes 30 to 33 of 1993 NACE, revision 1). Singling that industry out, and excluding it from the other country-industry groups,[40] allows us to relate our work to the empirical literature documenting patenting-related specificities of that industry. Galasso and Schankerman (2015) recently reported that invalidation of a US patent has a significantly positive impact on subsequent citations received by the invalidated patent 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 (Levin et al. 1987; Cohen et al. 2000). Von Graevenitz et al. (2011) provide empirical evidence based on EU patent data, supporting the view that patent thickets are more prevalent in the industry NACE 30–33 than in other industries.[41]

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 one in country-industries with weaker patent rights, reflected by the estimates of the coefficient on the R_{cit}-term. The estimates of the coefficients on the other interaction terms again speak to a complementarity between product market competition 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 patenting-related impediments to cumulative innovation have repeatedly been reported. Expressed otherwise, the 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 purposes like building up patent thickets.

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

Footnote 38 continued
relevance in countries with strong patent rights differ significantly (F-test statistic: 4.03, p-value: 0.0461), as well as those for the industries with intermediate and low patent relevance (F-test statistic: 3.51, p-value: 0.0624).

39 Significant effect variation across industries in countries with weaker patent rights is not apparent in the flexible model specification of column 2 in Table 9 in Appendix 1.

40 In columns 1 and 2, the industry NACE 30–33 is, instead, part of the respective country-industry groups with highest patent relevance.

41 They measure the density of patent thickets in the thirty technology areas covered by the patent system, and the seven technologies where their measure 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 in Von Graevenitz et al. (2011), and see also Hall (2005) and Hall and Ziedonis (2001).

than in other industries, and any such patent may be harder to enforce. 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 are in line with the empirical findings when using the main measure of patent relevance in columns 3 and 4.

In addition to R&D intensity, we also consider alternative measures of innovation. In Table 6, columns 1 to 3, we use real R&D expenditures in order to show that our previous findings do not just reflect value added responding to the product market reform. In columns 4 to 6 we use log-transformed real R&D expenditures. We find positive effects of the competition-increasing product market reform on both these measures in industries of countries where patent rights are strong since the pre-sample period (Table 6, columns 1 and 4). 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. Allowing for effect heterogeneity across industries in countries with strong patent rights, we observe that the reform effects on our measures of real R&D expenditures are more pronounced in industries with high or medium patent relevance, rather than low patent relevance (Table 6, columns 3 to 6). The findings fit with the results for the R&D intensity models in Table 5. Also confirming the results in Table 5, the coefficient estimates on the reform term specific to the industry NACE 30–33 in countries with strong patent rights are insignificant in columns 2 and 3 of Table 6. When we explain log-transformed real R&D expenditures in columns 5 and 6, the estimates are positive, but the estimate in column 5 is similar to the one for the group of industries where patent relevance ranks below the median.[42]

Overall, we provide a large set of empirical results that is suggestive of a complementarity between product market competition and patent protection in inducing innovation. First, we find positive average effects of a competition-enhancing product market reform on R&D intensity, as well as on real R&D expenditures, in industries of countries with strong patent rights since the pre-sample period up to 1986. In industries of countries with weaker patent rights we find no such effects. Second, we observe that these positive effects are more pronounced in industries where, in general, innovators tend to value patent protection higher than in other industries, except for the manufacture of electrical and optical equipment.

5.3 Extensions

Our estimation results in Sect. 5.2 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 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 possibility, 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 reform measure and patenting-related country-industry groups, and we now add interactions between the reform measure and financing-related country-industry groups. To construct the financing-related groups, we first distinguish between countries with initially high and low financial sector development. The separating indicator is set equal to one if private credit use

[42] The relevant F-test statistic is 0.03 (p-value: 0.8606).

Table 6 Models explaining alternative outcome measures

Explanatory variables	Dependent variables					
	Real R&D expenditures$_{cit}$			ln(Real R&D expenditures$_{cit}$)		
	(1) OLS	(2) OLS	(3) OLS	(4) OLS	(5) OLS	(6) OLS
R_{cit}*G(P (Protection)$^{strong}_{c,\ ps}$)	1.0218**			0.4920***		
	(0.4497)			(0.1192)		
R_{cit}*G($P^{strong}_{c,\ ps}$, I (Patent relevance)$^{\geq median}_{US,\ i,\ ps}$)		1.4282***			0.6870***	
		(0.5062)			(0.1383)	
R_{cit}*G($P^{strong}_{c,\ ps}$, $I^{\leq median}_{US,\ i,\ ps}$)		1.0783**			0.4043***	
		(0.5387)			(0.1444)	
R_{cit}*G($P^{strong}_{c,ps}$, $I^{high}_{US,\ i,\ ps}$)			1.3267***			0.5777***
			(0.4814)			(0.1443)
R_{cit}*G($P^{strong}_{c,\ ps}$, $I^{medium}_{US,\ i,\ ps}$)			1.2460*			0.4786***
			(0.6399)			(0.1700)
R_{cit}*G($P^{strong}_{c,\ ps}$, $I^{low}_{US,\ i,\ ps}$)			0.1757			−0.0111
			(0.3177)			(0.1128)
R_{cit}*G($P^{strong}_{c,\ ps}$, NACE 30–33$_i$)		0.9370	0.8605		0.3761**	0.3193*
		(0.6091)	(0.6128)		(0.1610)	(0.1630)
R (Product market reform)$_{cit}$	−0.2200	−0.3392	−0.2968	−0.0388	−0.0563	−0.0512
	(0.3402)	(0.3393)	(0.3556)	(0.0986)	(0.0972)	(0.0994)
Knowledge stock$_{ci,1986}$	0.7421***	0.7421***	0.7206***	0.1888***	0.1765***	0.1679***
	(0.1529)	(0.1606)	(0.1601)	(0.0276)	(0.0276)	(0.0269)
Controls for the G(·)$_{ci}$-groups	No	Yes	Yes	No	Yes	Yes
Country-time effects	Yes	Yes	Yes	Yes	Yes	Yes
Industry-time effects	Yes	Yes	Yes	Yes	Yes	Yes
Observations	2739	2739	2739	2739	2739	2739

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 variable *Real R&D expenditures*$_{cit}$ is defined as R&D expenditures in US dollar purchasing power parities at year 2005 prices (in billion) in country c, industry i, and year t. The measure *ln(real R&D expenditures*$_{cit}$*)* is the log-transformed measure. 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 *

and stock market capitalization between 1980 and 1990, relative to gross domestic product (GDP), rank above the relevant median, and otherwise zero. Second, we group industries according to the pre-sample industry-specific capital needs, proxied by the average capital intensity of production in the corresponding US industries across the years 1980–1986.[43]

In column 1 of Table 7, we extend the model specification of column 3 in Table 5 by adding the interaction between the reform measure and the indicator for industries with above

[43] We use EU KLEMS 2008 data, as well as data from the November 2010 version of the Financial Development and Structure Database. See Beck et al. (2000, 2009, 2010a, b) and Appendix 2.5.

median pre-sample capital needs in countries with initially 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 for the remaining industries in the same group of countries.[44] The coefficient estimates on these financing-related reform terms are positive, and the one specific to industries with above median capital needs in countries with high financial development is significantly different from zero. This result suggests that high development of a country's financial sector can enhance the innovation response to the competition-enhancing product market reform, especially in industries with high capital needs. The pattern of coefficient estimates on the patenting-related reform terms remains, nevertheless, close to the one in column 3 of Table 5, and we find again support for the view that patent protection can complement the competition-increasing product market reform in inducing R&D investments.

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 measure and the indicators for industries with high, low and medium pre-sample capital needs in countries with initially high financial development.[45] We find a similar pattern of coefficient estimates on the patenting-related reform terms as before, that is as in column 4 of Table 5. The coefficient estimates on the financing-related reform terms show a size pattern as in column 1 of Table 7, but the 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 on the initial exposure of country-industries to imports from other EU countries, a proxy of the initial exposure to competition at the level of the EU internal market before the competition-increasing product market reform. To take that issue into account, we extend the model specifications of columns 3 and 4 in Table 5 by adding the interaction of the reform measure with the indicator for those country-industries where the initial EU 15 import penetration is at or above the relevant 75 percentile, $R_{cit} * G(EU\ 15\ import\ penetration^{high}_{ci,\,1988-90})$. The initial EU 15 import penetration is defined as the value of imports from EU 15 member countries to the country-industry *ci* divided by the value of domestic production plus imports from the world minus exports to the world, averaged across the years 1988 to 1990.[46] The coefficient estimates on the trade-related reform term are significantly negative in columns 3 and 4 of Table 7, and the previously reported pattern of coefficient estimates on the patenting-related reform terms holds up.[47]

Finally, we modify the data variation which we use to identify the reform effects of interest, by reducing or extending the estimation sample. So far, we have used data variation within 11 countries that implemented the SMP product market reform in 1992 in combination with

---

[44] Here, as well as in case of all other model extensions that we discuss below, we also add controls for the additionally considered $G(\cdot)_{ci}$-groups.

[45] As industries with high, low and medium pre-sample capital needs, we classify the industries at or above the 75th percentile of the capital needs measure, the ones below the 25th percentile, and the remaining industries.

[46] We use EU KLEMS 2008 data and trade data from the 2010 edition of the OECD STAN Bilateral Trade Database (BTD) for 1988 to 1990, the earliest years for which the BTD 2010 provides the relevant trade data, although not for all country-industries in our main sample (see Appendix 2.6 for details). The group of the EU 15 member states covers the eleven SMP countries in our main sample, Finland, Sweden, and two non-sampled EU 15 member states (Luxembourg, Austria).

[47] This is also the case if we add an additional reform interaction with high initial exposure to imports from all countries worldwide, except the EU 15 countries, or with high exposure to imports from China. When constructing the indicator for high exposure to imports from China, we average across a longer time period, 1988 to 2003, as imports from China were typically low until the mid 1990s (Bloom et al. 2015).

Table 7 Models accounting for alternative explanations

Explanatory variables	Dependent variable R&D intensity$_{cit}$			
	OLS (1)	OLS (2)	OLS (3)	OLS (4)
R_{cit}*G(D (Financial Development)$^{high}_{c,\ 1980-90}$, N (Capital needs)$^{>median}_{US,\ i,\ ps}$)	0.0587**			
	(0.0288)			
R_{cit}*G($D^{high}_{c,\ 1980-90}$, $N^{\leq median}_{US,\ i,\ ps}$)	0.0213			
	(0.0321)			
R_{cit}*G($D^{high}_{c,\ 1980-90}$, $N^{high}_{US,\ i,\ ps}$)		0.0499		
		(0.0319)		
R_{cit}*G($D^{high}_{c,\ 1980-90}$, $N^{medium}_{US,\ i,\ ps}$)		0.0235		
		(0.0274)		
R_{cit}*G($D^{high}_{c,\ 1980-90}$, $N^{low}_{US,\ i,\ ps}$)		−0.0112		
		(0.0585)		
R_{cit}*G(EU 15 import penetration$^{high}_{ci,1988-90}$)			−0.0458*	−0.0490**
			(0.0244)	(0.0237)
R_{cit}*G(P (Protection)$^{strong}_{c,\ ps}$, I (Patent relevance)$^{>median}_{US,\ i,\ ps}$)	0.0942***		0.1219***	
	(0.0264)		(0.0313)	
R_{cit}*G($P^{strong}_{c,\ ps}$, $I^{\leq median}_{US,\ i,\ ps}$)	0.0485*		0.0731**	
	(0.0251)		(0.0317)	
R_{cit}*G($P^{strong}_{c,ps}$, $I^{high}_{US,\ i,ps}$)		0.0671***		0.0834***
		(0.0245)		(0.0299)
R_{cit}*G($P^{strong}_{c,\ ps}$, $I^{medium}_{US,\ i,ps}$)		0.0648**		0.0592*
		(0.0276)		(0.0332)
R_{cit}*G($P^{strong}_{c,\ ps}$, $I^{low}_{US,\ i,ps}$)		0.0168		0.0358
		(0.0236)		(0.0311)
R_{cit}*G($P^{strong}_{c,\ ps}$, NACE 30–33$_i$)	−0.0088	0.0043	−0.0012	−0.0163
	(0.0412)	(0.0430)	(0.0437)	(0.0432)
R (Product market reforms)$_{cit}$	−0.0185	−0.0259	−0.0184	−0.0178
	(0.0209)	(0.0185)	(0.0317)	(0.0316)
Knowledge stock$_{ci,1986}$	Yes	Yes	Yes	Yes
Controls for the G(·)$_{ci}$-groups	Yes	Yes	Yes	Yes
Country-time effects & industry-time effects	Yes	Yes	Yes	Yes
Observations	2739	2739	1947	1947

Notes The OLS estimates of the R&D intensity models in columns 1 and 2 of Table 7 are for the main sample as described in Table 4. The estimates in columns 3 and 4 are for the sub-sample where the relevant trade-related measures are available. The variable *D (Financial Development)*$^{high}_{c,\ 1980-90}$ is coded one for all countries c with high financial sector development between 1980 and 1990, and zero otherwise. We separate between the industries above the median of the capital needs measure, *N (Capital needs)*$^{>median}_{US,\ i,\ ps}$, and the complementing industries. Alternatively, we distinguish between industries at or above the 75th percentile ($N^{high}_{US,\ i,\ ps}$), below the 25th percentile, and intermediate ones. The indicator *EU 15 import penetration*$^{high}_{ci,1988-90}$ is coded one for all industries i in countries c where the initial EU 15 import penetration is at or above the relevant 75th percentile, and zero otherwise. See Tables 4 and 5 for details on the other variables, standard errors, and significance levels variation within six other countries. If instead we use the data for the 11 initial SMP countries only, our main empirical results turn out to be stable (see Table 10 in Appendix 1, 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 9 of the 11 SMP countries in our main sample, excluding the low-income countries Greece and Portugal. In these regressions, the main pattern of results holds up as well (see Table 10 in Appendix 1, 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 30 percent sub-sample which covers the initial SMP countries, but neither Germany which enlarged due to German reunification, nor the years from 1995 onwards, as Finland and Sweden joined the EU, and the SMP, in that year. The empirical findings in column 3 of Table 10 in Appendix 1 are consistent with our main empirical results despite the substantially smaller sample.

Next, we address the issue that the implementation of the SMP in 1992 coincided closely with a setback for the fixed European Exchange Rate Mechanism (ERM) which was introduced in 1979. While already our main model specifications include controls for arbitrary country-specific trends of innovation over time to capture macroeconomic fluctuations, we also re-estimate our main model specifications on a suitably reduced sample. We eliminate the two pivotal countries during the ERM perturbations at the beginning of the 1990s, Germany and UK,[48] and our main empirical findings turn out to remain stable (see Table 11 in Appendix 1, column 1). When we instead extend the estimation sample, again our main results turn out to be robust. First, we add the US, a large non-European country with high innovative potential and, second, we enlarge the sample substantially by adding 6 service industries (Table 11 in Appendix 1, columns 2 and 3).[49]

6 Conclusions

In this paper, we provided empirical evidence to the effect that strong patent rights may complement competition-increasing product market reforms in fostering innovative activity. First, we found that the product market reform induced by the large-scale internal market reform of the European Union (EU) in 1992 enhanced, on average, the R&D investments in manufacturing industries of countries with strong patent rights since the pre-sample period up to 1986, but not in industries of countries with weaker patent rights. Second, the positive response to the product market reform was more pronounced in industries where, in general, innovators tend to value patent protection higher than in other industries, except for the manufacture of electrical and optical equipment.

48 The perturbations 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.

49 Note that the product market reform measure is always equal to zero in the US, as well as in the sampled service industries (electricity and gas and water supply, construction, wholesale and retail trade, transport and storage and communication, financial intermediation, real estate and renting and business activities).

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 a firm that successfully escapes 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 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.

Acknowledgments We are grateful to the Editor, Oded Galor, and the anonymous referees for very valuable and constructive suggestions. We also thank Ufuk Akcigit, Richard Blundell, Rachel Griffith, Bronwyn Hall, Jonathan Haskel, Martin Hellwig, Benjamin Jones, Johannes Münster, Armin Schmutzler, Michelle Sovinsky, John Van Reenen, Georg von Graevenitz, Joachim Winter, seminar participants at the ASSA Annual Meetings in Chicago (ES) and Philadelphia (AEA), Annual Conference of the EPIP Association in Bruxelles, Frankfurt School of Finance and Management, Heinrich-Heine University Duesseldorf, MPI for Research on Collective Goods in Bonn, UNU Merit in Maastricht, University of Cologne, University of Munich (LMU), University of Zurich, and the VfS Annual Conference in Frankfurt.

Appendix 1: Additional tables

See Tables 8, 9, 10, and 11.

Table 8 Definitions of main 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 t	0.0470	0.0735
Real R&D expenditures$_{cit}$	R&D expenditures in US dollar purchasing power parities at year 2005 prices (in billion)	0.5058	1.3412
ln(real R&D expenditures$_{cit}$)	Natural logarithm (1 + R & D expenditures in US dollar purchasing power parities at year 2005 prices (in billion))	0.2549	0.4499
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	0.3052	0.3077
Protection$^{strong}_{c,\ ps}$	1: country c with strong patent rights since the pre-sample period, 1980–1986; 0: otherwise	0.5422	
Protection$^{weak}_{c,\ ps}$	1: country c with weaker patent protection in the pre-sample period and later on; 0: otherwise	0.4578	
Knowledge stock$_{ci,\ 1986}$	Knowledge stock in country-industry ci in 1986 (perpetual inventory method, depreciation rate: 20 %)	0.3712	1.0763
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	0.2294	0.3099
Protection^{GP}	Ginarte-Park patent protection index taking values between 0 to 5 & higher values in country-years ct when patent laws provide stronger IPRs	3.9090	0.7006
Financial development$^{high}_{c,\ 1980-90}$	1: country c with private credit use and stock market capitalization ranking above relevant median during 1980s, relative to gross domestic product (GDP); 0: otherwise	0.4564	
EU 15 import penetration$^{high}_{ci,\ 1988-90}$	1: country-industry ci where import penetration from EU 15 member countries, averaged across 1988 to 1990, is at or above the relevant 75th percentile; 0: otherwise	0.2501	

Notes This table provides definitions of our main variables and non-weighted descriptive statistics. The descriptive statistics for the alternative product market reform measure, R^a_{cit}, are for the sub-sample of 1793 observations (see Table 4), and those for the variable *EU15 import penetration*$^{high}_{ci,\ 1988-90}$ are for the trade-related sub-sample of 1947 observations (see Table 7). In case of all other variables, the descriptive statistics are for the main sample of 2739 observations (see Table 4)

Table 9 Variants to model specifications in Table 5

Explanatory variables	Dependent variable R&D intensity$_{cit}$			
	(1) OLS	(2) OLS	(3) OLS	(4) OLS
R (Product market reforms)$_{cit}$ *G(P (Protection)$^{strong}_{c,\ ps}$, I (Patent relevance)$^{>\ median}_{US,\ i,\ ps}$)	0.1105***			
	(0.0254)			
R$_{cit}$*G(P$^{strong}_{c,\ ps}$, I$^{\leq\ median}_{US,\ i,\ ps}$)	0.0576***			
	(0.0218)			
R$_{cit}$*G(P$^{strong}_{c,\ ps}$, I$^{high}_{US,\ i,\ ps}$)		0.0549**	0.0643**	0.0414**
		(0.0275)	(0.0268)	(0.0199)
R$_{cit}$*G(P$^{strong}_{c,\ ps}$, I$^{medium}_{US,\ i,\ ps}$)		0.0496*	0.0438	0.0486
		(0.0264)	(0.0270)	(0.0368)
R$_{cit}$*G(P$^{strong}_{c,\ ps}$, I$^{low}_{US,\ i,\ ps}$)		0.0055	−0.0020	−0.0042
		(0.0227)	(0.0237)	(0.0246)
R$_{cit}$*G(P$^{strong}_{c,\ ps}$, NACE 30–33$_i$)			−0.0102	−0.0124
			(0.0447)	(0.0450)
R$_{cit}$*G(P$^{weak}_{c,\ ps}$, I$^{>\ median}_{US,\ i,\ ps}$)	−0.0080			
	(0.0212)			
R$_{cit}$*G(P$^{weak}_{c,\ ps}$, I$^{\leq\ median}_{US,\ i,\ ps}$)	−0.0165			
	(0.0255)			
R$_{cit}$*G(P$^{weak}_{c,\ ps}$, I$^{high}_{US,\ i,\ ps}$)		−0.0044	−0.0123	−0.0174
		(0.0226)	(0.0214)	(0.0192)
R$_{cit}$*G(P$^{weak}_{c,\ ps}$, I$^{medium}_{US,\ i,\ ps}$)		−0.0156	−0.0173	−0.0062
		(0.0238)	(0.0235)	(0.0258)
R$_{cit}$*G(P$^{weak}_{c,\ ps}$, I$^{low}_{US,\ i,\ ps}$)		−0.0029	−0.0064	−0.0029
		(0.0202)	(0.0197)	(0.0192)
R$_{cit}$*G(P$^{weak}_{c,\ ps}$, NACE 30–33$_i$)			0.0257	0.0296
			(0.0318)	(0.0312)
Controls for the G(·)$_{ci}$-groups	Yes	Yes	Yes	Yes
Knowledge stock control as in Table 4	Yes	Yes	Yes	Yes
Country-time effects & industry-time effects	Yes	Yes	Yes	Yes
Observations	2739	2739	2739	2739

Notes In this table, we provide OLS estimates of R&D intensity models for the main sample as described in Table 4. In column 1, industries i in countries c with strong pre-sample (ps) patent protection (*P (Protection)*$^{strong}_{c,\ ps}$) are assigned to two sub-groups: (1) country-industries above the median of the US industry-specific pre-sample patent relevance (*I (Patent relevance)*$_{US,\ i,\ ps}$), and (2) country-industries with below or at the median patent relevance. For countries with weak pre-sample patent protection ($P^{weak}_{c,\ ps}$) we proceed analogously. In column 2, we use three industry-specific sub-groups for each protection-specific 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 single it out and use the specific interaction terms $R_{cit} * G(P^{strong}_{c,\ ps}, NACE\ 30\text{–}33_i)$ and $R_{cit} * G(P^{weak}_{c,\ ps}, NACE\ 30\text{–}33_i)$ as additional explanatory variables. In columns 1 to 3, we use our main patent relevance measure, based on US patent data for the pre-sample period 1980–1986. In column 4, we use the alternative measure, based on survey data for 1991 to 1993. See Tables 4 and 5 for details on the other variables, standard errors, and significance levels

Table 10 Identification using alternative data variation: part 1

Explanatory variables	Dependent variable R&D intensity_{cit}		
	(1) OLS	(2) OLS	(3) OLS
Panel A			
R (Product market $\text{reform})_{cit}$	0.0782***	0.0965***	0.0586***
*G(P $(\text{Protection})^{strong}_{c,\ ps}$)	(0.0230)	(0.0347)	(0.0219)
R_{cit}	−0.0115	−0.0629	0.0665*
	(0.0292)	(0.0502)	(0.0369)
Knowledge stock control as in Table 4	Yes	Yes	Yes
Country-time effects & industry-time effects	Yes	Yes	Yes
Observations	2018	1695	822
Panel B			
R_{cit}*G($P^{strong}_{c,\ ps}$, I (Patent $\text{relevance})^{high}_{US,\ i,\ ps}$)	0.0885***	0.1041***	0.0463**
	(0.0286)	(0.0364)	(0.0204)
R_{cit}*G($P^{strong}_{c,\ ps}$, $I^{medium}_{US,\ i,\ ps}$)	0.0553**	0.0673*	0.0587**
	(0.0265)	(0.0355)	(0.0284)
R_{cit}*G($P^{strong}_{c,\ ps}$, $I^{low}_{US,\ i,\ ps}$)	0.0049	0.0262	−0.0072
	(0.0255)	(0.0383)	(0.0291)
R_{cit}*G($P^{strong}_{c,\ ps}$, NACE $30\text{–}33_i$)	−0.0063	0.0277	−0.0387
	(0.0367)	(0.0375)	(0.0356)
R_{cit}	−0.0183	−0.0576	0.0549
	(0.0280)	(0.0499)	(0.0340)
Controls for the $G(\cdot)_{ci}$-groups	Yes	Yes	Yes
Knowledge stock control as in Table 4	Yes	Yes	Yes
Country-time effects & industry-time effects	Yes	Yes	Yes
Observations	2018	1695	822

Notes The R&D-intensity model estimate in panel A of column 1, and the one in panel B, are for the sub-sample covering only the SMP countries from the main sample as described in Table 4. The estimates in column 2 are for the sub-sample of 9 SMP countries in our main sample, excluding the low-income SMP countries Greece and Portugal. For the estimates in column 3 we use the 30 percent sub-sample which covers the initial SMP countries, but neither Germany which enlarged due to German reunification nor the years from 1995 onwards, as Finland and Sweden joined the EU, and the SMP, in that year. See Tables 4 and 5 for details on the variables, standard errors, and significance levels

Table 11 Identification using alternative data variation: part 2

Explanatory variables	Dependent variable R&D intensity$_{cit}$		
	(1) OLS	(2) OLS	(3) OLS
Panel A			
R (Product market reform)$_{cit}$	0.0914***	0.0862***	0.0864***
*G(P (Protection)$_{c,\ ps}^{strong}$)	(0.0223)	(0.0223)	(0.0145)
R$_{cit}$	0.0026	−0.0220	−0.0056
	(0.0184)	(0.0219)	(0.0134)
Knowledge stock control as in Table 4	Yes	Yes	n.a.
Country-time effects & industry-time effects	Yes	Yes	Yes
Observations	2349	2960	3748
Panel B			
R$_{cit}$*G(P$_{c,\ ps}^{strong}$, I (Patent relevance)$_{US,\ i,\ ps}^{high}$)	0.0658**	0.0517**	0.0523***
	(0.0253)	(0.0221)	(0.0198)
R$_{cit}$*G(P$_{c,\ ps}^{strong}$, I$_{US,\ i,\ ps}^{medium}$)	0.0702***	0.0441*	0.0461**
	(0.0251)	(0.0248)	(0.0205)
R$_{cit}$*G(P$_{c,\ ps}^{strong}$, I$_{US,\ i,\ ps}^{low}$)	0.0085	0.0301	0.0063
	(0.0258)	(0.0240)	(0.0120)
R$_{cit}$*G(P$_{c,\ ps}^{strong}$, NACE 30–33$_{i}$)	0.0081	−0.0356	−0.0441
	(0.0393)	(0.0347)	(0.0374)
R$_{cit}$	0.0020	−0.0169	−0.0006
	(0.0158)	(0.0183)	(0.0111)
Controls for the G(·)$_{ci}$-groups	Yes	Yes	Yes
Knowledge stock control as in Table 4	Yes	Yes	n.a.
Country-time effects & industry-time effects	Yes	Yes	Yes
Observations	2349	2960	3748

Notes The R&D-intensity model estimate in panel A of column 1, and the one in panel B, are for the sub-sample that results after eliminating Germany and the UK from the main sample as described in Table 4. The estimates in column 2 are for the extended sample covering the main sample, plus the US. For the estimates in column 3, we add data for 8 service industries to the main sample. We exclude the patent-based knowledge stock from the set of explanatory variables in column 3 as patent data are not available for service industries. See Tables 4 and 5 for details on the variables, standard errors, and significance levels

Appendix 2: Data sources and variables

Appendix 2.1: Research and development expenditures

Our main measure of innovation is *R&D intensity*, that is nominal R&D expenditures as a percentage of nominal value added. For calculating that measure we use country-industry level panel data on nominal research and development expenditures from the OECD Analytical Business Enterprise Research and Development (ANBERD) database (edition 2011).[50]

In addition, we use data on nominal value added from the EU KLEMS database (March 2008 release), adapting the set of national currencies in the EU KLEMS 2008 database to the one of the ANBERD 2011 database.[51] We also use ANBERD 2011 data on *real R&D expenditures* in US dollar purchasing power parities at constant prices of the year 2005 (in billion).

Appendix 2.2: Patenting

For several purposes, we use country-industry-year-specific *US patent counts* constructed by the EU KLEMS consortium.[52] The patent counts are based on the NBER patent data (edition 2002, http://elsa.berkeley.edu/~bhhall/patents.html), specifically on the patents granted by the US Patent and Trademark Office after 1962 and applied for before 2000 (O'Mahony et al. 2008; Hall et al. 2001). Each US patent was assigned to a year according to the application date recorded in the patent document and to a country according to the country of the first inventor. For our main empirical analysis we use the fractional patent counts where each patent is counted in all n OTAF classes it was assigned to with a weight of $1/n$. The patents were assigned to up to 7 OTAF classes per patent and all classes (41 OTAF classes, plus one "other industries" class) were mapped into EU KLEMS 2008 industry classes.[53]

To construct the *knowledge stock built up during the pre-sample period* per country-industry we use the US patent data for the pre-sample period, 1980–1986. Applying the perpetual inventory method, we calculate the knowledge stock as the sum of all pre-sample fractional patent counts (in 1000 patents) that are depreciated to the last year of the pre-sample period with an annual knowledge depreciation rate of 20 percent.

---

[50] The ANBERD database is part of the OECD Structural Analysis (STAN) databases, and we downloaded the ANBERD 2011 edition in its archived version (last updated: January 15, 2013) on January 23, 2015
Footnote 50 continued
from http://dx.doi.org/10.1787/data-00556-en. See also http://www.oecd.org/sti/anberd (accessed: January 23, 2015). As Denmark and Sweden are not covered by the ANBERD 2011 edition, we add the relevant data from the ANBERD 2009 edition. We downloaded the ANBERD 2009 edition on January 7, 2010, and August 19, 2010 from http://dx.doi.org/10.1787/data-00032-en. See also the related book publication (Organisation for Economic Co-operation and Development (OECD) 2009).

[51] The EU KLEMS project was a joint initiative of several academic institutions and national economic policy research institutes, supported from various statistical offices and the OECD, and funded by the European Commission (O'Mahony and Timmer 2009). The initiative provided country-industry level panel data designed to ensure international comparability. We downloaded the EU KLEMS 2008 database on October 15, 2009 from http://www.euklems.net/index.html.

[52] We downloaded the patent data of the EU KLEMS Linked Data (October 2008 Release) on February 2, 2012, from http://www.euklems.net/linked.shtml. See O'Mahony et al. (2008).

[53] The industry classification of the EU KLEMS 2008 patent database (see Table 1.1 of O'Mahony et al. (2008)) fits with the classification of the main EU KLEMS 2008 database, and, thus, the one of our main sample, up to one exception: in case of industry "23: coke, refined petroleum and nuclear fuel" the relevant patent count has to be proxied by the count for the more aggregate industry "23 plus 11: "petroleum and natural gas extraction and refining".

Appendix 2.3: Patent rights

To measure the *strength of patent protection*, that is intellectual property rights (IPRs) as laid down in patent laws,[54] we distinguish between different country groups. To do so, we use information on patent law reforms, as well as related regulation, and data on a time period with high variation of patent protection across European Countries, that is a time period before international harmonization of patent systems started to dominate.[55] The following countries had strong patent protection regimes already in the pre-sample period, 1980–1986, and maintained strong regimes throughout the whole sample period, 1987 to 2003: Belgium, Denmark, France, Germany, Italy, Netherlands, Sweden, and the United Kingdom (plus the United States). The countries with weaker patent protection regimes completed the major patent law reform preparing the ground for a strong patent protection regime in 1992, or later: Czech Republic, Finland, Greece, Hungary, Ireland, Poland, Portugal, Spain, and the Slovak Republic.

All European countries that we classified as having strong patent rights, except for Denmark and Italy, were among the initial contracting states of the European Patent Organisation (EPOrg) in October 1977.[56] All the countries classified as having weaker patent rights joined the EPOrg between October 1986 and March 2004 (European Patent Organization (EPOrg) 2010) and none of these countries completed the reforms preparing the ground for a strong patent protection regime before 1992 (Branstetter et al. 2006; Qian 2007; World Intellectual Property Organization 2012). Our classification is consistent with the groupings in Branstetter et al. (2006) or Qian (2007). It also fits with the patent right index of Maskus and Penubarti (1995) and Rapp and Rozek (1990): the patent laws of all the countries that we classify as countries with strong patent rights were fully conforming to the minimum standards of the US Chamber of Commerce Intellectual Property Task Force in 1984; all other countries lacked fully conforming patent laws in 1984.

For robustness checks, we also use the index of patent protection that was developed by Ginarte and Park (1997), and updated by Park (2008a, b). Walter Park provides the index for more than 100 countries, updating it quinquennially for the years from 1960 onwards.[57] The index takes values between zero and five and higher values indicate patent laws with stronger IPRs. The index coding scheme aggregates information on 1) membership in international treaties (Paris Convention, International Convention for the Protection of New Varieties of Plants, Patent Cooperation Treaty, Budapest Treaty, Agreement on Trade Related Aspects of Intellectual Property Rights), 2) enforcement mechanisms (preliminary injunctions, contributory infringement pleadings, burden of proof reversal), 3) restrictions on patent rights (working requirements, compulsory licensing, revocation of patents), 4) duration of protection and 5) extent of coverage (pharmaceuticals, chemicals, food, surgical products,

54 The strength of patent rights and the strength of other forms of IPRs, in particular copyrights and trademarks, tend to be strongly correlated (Rapp and Rozek 1990).

55 See, among others, Branstetter et al. (2006), Lerner (2000), Maskus (2000), Maskus and Penubarti (1995), Qian (2007), and World Intellectual Property Organization (2012).

56 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.

57 Our calculations are based on the index data that we downloaded on January 18, 2011, from http://www.american.edu/cas/econ/faculty/park.html. The downloaded data coincides with the data published in Table 1 of Park (2008a) in case of all the countries in our Table 1. See also http://nw08.american.edu/~wgp/ (accessed: February 17, 2015).

microorganisms, utility models, software, plant and animal varieties). Relevant in the context of our study is the updated coding scheme as described by Park (2008a); Ginarte and Park (1997) give details on the original coding scheme.

We classify industries according to the extent to which innovators consider the strength of patent rights as relevant, and rely on patenting in appropriating returns to invention. To do so, we form industry groups with different levels of patent relevance. For our *main measure of patent relevance*, we first calculate the nominal patent intensity for US industries in the pre-sample years, 1980–1986, dividing the fractional EU KLEMS patent counts by nominal value added in million US dollars, determine the ranking of US industries based on the intensity variable in each year, and average across the pre-sample years. Then, we generate different sets of industry groups. First, we define the group with high patent relevance as covering the industries at or above the 75th percentile of the average pre-sample US patent intensity ranking. These are the four sampled industries that constitute in all the relevant pre-sample years the industries with the highest patent intensities, reflecting the fact that the ranking is very persistent across these years. The group with low patent relevance covers three industries, two rank below the 25th percentile in all the relevant pre-sample years, and one ranks below in 5 of 7 years. The intermediate group covers all remaining industries. Second, we distinguish between the group of industries with average pre-sample US patent intensity rankings above the median (these 6 industries constitute in all relevant pre-sample years the industries with the highest patent intensities), and the complementing group with rankings below or at the median.

Our *alternative measure of patent relevance* builds on Cohen et al. (2000) who present survey-based evidence on the importance of patenting in appropriating returns to invention from the Carnegie Mellon Survey (CMS) on Industrial R&D in the US manufacturing sector. In the survey, which was conducted in 1994, about 1100 R&D unit or laboratory managers reported, among others, the percentage of their innovations for which patenting had been effective in protecting the firm's "competitive advantage from those innovations" during the prior three years, 1991 to 1993.[58] For 34 manufacturing industries, Tables 1 and 2 in Cohen et al. (2000) provide the mean shares of product and process innovations for which the survey respondents judged patenting to be effective. We aggregate these shares to the level of the 13 industries in our main data set (1993 NACE, revision 1), weighting by the respective numbers of respondents. Then, we generate different sets of industry groups. First, we define the group with high patent relevance as covering the industries at or above the 75th percentile of the share of innovations with effective patent protection, the group with low patent relevance as covering the industries below the 25th percentile, and the intermediate group covering all remaining industries. Second, we distinguish between the group of industries above the median of the share variable, and the complementing group with share values below or at the median.

Appendix 2.4: Product market reform

The product market reform that we consider is part of the large-scale internal market reform of the European Union (EU) in 1992, named the Single Market Program (SMP). The SMP was designed by the European Commission and, thus, a supra-national institutional body. It was meant to bring down internal barriers to the free movement of products and production

[58] Cohen et al. (2000) mention an initial piloting of the questionnaire according to which respondents interpreted the term "competitive advantage from those innovations" as referring to returns realized via commercialization or licensing, not as referring to returns of a more general, less direct or less conventional nature. Note also that the part of the CMS questionnaire regarding appropriation mechanisms builds on the Yale questionnaire (Levin et al. 1987).

factors within the EU in order to foster competition, innovation and economic growth. Recent empirical evidence supports the view that the product market reform increased product market competition in manufacturing industries.[59] The SMP was officially implemented in 1992 in all EU member countries in 1992: Belgium, Denmark, France, Germany, Greece, Ireland, Italy, Netherlands, Portugal, Spain, United Kingdom, and Luxembourg. Eleven of these countries are included in our main sample, and all these had joined the EU much earlier, at the latest in 1986.[60]

For all initial SMP countries, the European Commission report by Buigues et al. (1990) provides a common list of 40 three-digit manufacturing industries that researchers expected ex ante to be affected by the product market reform. Country-specific additions to and removals from the common list are also reported. These additions and removals reflect recommendations of experts, who were asked whether they expected the reform to change the product market conditions in an individual industry in a specific SMP country differently than in the corresponding average industry. In country-industries that were ex ante expected to be affected the initial level of competition was typically low. The information in Buigues et al. (1990) allows for constructing reform measures that vary across industries within countries, across countries and across time. We exploit that fact for identifying the reform impact from confounding influences.

To generate our *main product market reform measure*, R_{cit}, we first link the 40 three-digit industry codes (1970 NACE) that are on the common list of Buigues et al. (1990) to the corresponding 109 four-digit industry codes (1993 NACE, revision 1). Then, we link the 39 three-digit codes (1970 NACE) of the additions to the corresponding 119 four-digit codes (1993 NACE, revision 1). Finally, we aggregate the four-digit industry codes on the common list, as well as the data on country-specific removals and additions of industry codes, to the country-industry level of our data-set:

$$R^{m}_{cit} = \begin{cases} \frac{1}{n_i} \sum_{k \in i} A_{kct} & \text{if } t \geq 1992 \\ 0 & \text{if } t < 1992 \text{ or } \sum_{k \in i} A_{kct} = 0. \end{cases}$$

For each of the 13 manufacturing industries i in each of the 11 SMP countries c in our main sample (see Tables 1 and 2), the main reform measure R_{cit} is set equal to zero in all years t before the implementation of the SMP. From 1992 onwards, it is equal to the share of the four-digit industry classes k per country-industry that were ex ante expected to be affected by the SMP.[61] The dummy variable A_{kct} is coded one from 1992 onwards if a four-digit industry k in country c was ex ante expected to be affected, and zero otherwise. The number of four-digit industry codes per industry i is denoted by n_i. For non-SMP-countries, as well as for service industries, the main reform measure is always equal to zero.

We also apply an *alternative measure of the product market reform*. To construct it, we follow Griffith et al. (2010) in using employment shares, including those that are reported in Buigues et al. (1990), for weighting purposes. First, we link each of the three-digit industry codes (1970 NACE) that are on the common list to the main corresponding industry among the

59 See, for example, Bottasso and Sembenelli (2001), Badinger (2007), or Griffith et al. (2010).

60 For Luxembourg, the twelfth EU member state in 1992, data on R&D expenditures are missing. Germany is part of our main sample in the years after German reunification (from 1991 onwards). Finland and Sweden joined the EU, as well as the SMP, in 1995, and these countries are also covered by our main sample.

61 For country-industries in Sweden or Finland, the main SMP measure is, from 1995 onwards, equal to the share of the 4-digit industry classes that were ex ante expected to be affected according to the common list of Buigues et al. (1990), and zero otherwise.

13 industries (1993 NACE, revision 1) in our main sample and, then, aggregate as follows:[62]

$$R^a_{cit} = \begin{cases} \sum_{j\in i} w_{jic} A_{jt} & \text{if } t \geq 1992 \\ 0 & \text{if } t < 1992 \text{ or } \sum_{j\in i} A_{jt} = 0. \end{cases}$$

For each three-digit industry j in country c, the weight w_{jic} indicates the share that industry j contributes to the employment in industry i in country c, averaged over the years 1985 to 1987. For constructing weight w_{jic}, we divide the employment share w_{jc}, as directly reported by Buigues et al. (1990), by the appropriate employment share w_{ic}. The weight w_{jc} of Buigues et al. (1990) indicates the share of the tree-digit industry j in total manufacturing employment in country c, averaged over the years 1985 to 1987. The weight w_{ic} is constructed from EU KLEMS data and indicates the share of industry i in total manufacturing employment in country c, averaged over the years 1985 to 1987.

In all years t before the implementation of the SMP, the alternative reform measure is set equal to zero. From 1992 onwards, it is equal to the share of the employment-weighted three-digit industry classes per industry i that were ex ante expected to be affected by the SMP. The dummy variable A_{jt} is coded one from 1992 onwards if a three-digit industry j was ex ante expected to be affected according to the common list of Buigues et al. (1990), and zero otherwise.[63]

Appendix 2.5: Financial conditions

The financial variables which we use in Sect. 5.3 are based on data from the EU KLEMS 2008 database and from the November 2010 version of the Financial Development and Structure Database (FDSD) by Beck et al. (2000, 2009, 2010a, b).[64]

First, we measure *financial sector development* at the country-level using data from the Financial Development and Structure Database on stock market capitalization and on the channeling of savings to investors via financial intermediaries, relative to the size of the economy. Our proxy of stock market capitalization is the value of listed shares, relative to gross domestic product (GDP). As values of listed shares are hardly available before 1989, we determine the country ranking based on stock market capitalization for the years 1989 and 1990, and then we average across both years.[65] The channeling of savings to investors via financial intermediaries is captured by the following private credit ratio: claims on the private sector by deposit money banks and other financial institutions, relative to GDP. We use the ratio values between 1980 and 1990 to determine a country ranking per year, and

[62] Note that the employment share data of Buigues et al. (1990) is lacking for all additions to the common list. Therefore, we consider all the industry codes on the common list for the alternative measure, but none of the country-specific changes to the common list. As employment shares are also lacking for several country-industries on the common list, we have to exclude these from the estimation sample. All Swedish and Finnish country-industries are excluded as Buigues et al. (1990) provide no employment share data for these.

[63] Note that the procedure for calculating the employment shares involves using two data sources and two industry classifications. This can lead to the alternative reform measure, R^a_{cit}, taking values that are larger than one, and we eliminate these cases.

[64] We downloaded the November 2010 version of the FDSD on December 28, 2011 from http://econ.worldbank.org/WBSITE/EXTERNAL/EXTDEC/EXTRESEARCH/0,,contentMDK:20696167~pagePK:64214825~piPK:64214943~theSitePK:469382,00.html. See also the permanent ULR: http://go.worldbank.org/X23UD9QUX0 (accessed: February 15, 2015).

[65] Even for these years, we have no data for five countries in our main sample (Czech Republic, Hungary, Ireland, Poland, Slovak Republic).

then we average across all years.[66] Finally, we generate our financial development measure by averaging across both the average stock market and private credit ranking and classify countries with averages above the median rank as having a highly developed financial sector in the time period 1980–1990. These countries are France, Germany, the Netherlands, Spain, Sweden, and the UK. All other countries in our main sample are classified as having a weakly developed financial sector up to 1990.[67]

Second, we classify industries according to their *capital needs*, proxied by the capital intensity of production in the corresponding US industries in the pre-sample period, 1980–1986. To that aim we use the relevant EU-KLEMS 2008 industry-level data on the ratio of capital relative to labor compensation in the pre-sample years, determine the respective industry ranking in each year, average across the pre-sample period, and generate different sets of industry groups. First, we define the group with high US pre-sample capital intensity as covering the industries at or above the 75th percentile of the average pre-sample US capital intensity ranking. The group with low capital intensity covers the industries below the 25th percentile and the intermediate group covers all remaining industries. Second, we distinguish between the group of industries above the median of the average pre-sample US capital intensity ranking, and the complementing group.

Appendix 2.6: Import penetration

For constructing the measures of import penetration which we use in Sect. 5.3, we start by calculating the EU 15 import penetration for industry i in country c in year t,

$$P_{cit}^{EU\ 15} = \frac{M_{cit}^{EU\ 15}}{Q_{cit} + M_{cit} - X_{cit}},$$

where $M_{cit}^{EU\ 15}$ denotes the nominal value of imports from EU 15 member countries, M_{cit} represents the nominal value of imports from all countries worldwide, and X_{cit} represents the nominal value of exports to all countries worldwide. Domestic production is denoted by Q_{cit}. We take data on $M_{cit}^{EU\ 15}$, M_{cit}, and X_{cit}, as well as on all other trade measures mentioned below, from the OECD STAN Bilateral Trade Database (BTD, edition 2010).[68] From the EU KLEMS 2008 database, we take data on Q_{cit}, that is nominal gross output. When calculating the import penetration ratios, we harmonize the set of national currencies in the BTD 2010 database and the EU KLEMS 2008 database.

Then, we average the country-industry-year specific ratios across the years 1988 to 1990 to generate a measure of the initial EU 15 import penetration. The years 1988 to 1990 are the earliest years for which BTD 2010 provides the relevant trade data, although not for all country-industries in our main sample. The group of the EU 15 member states covers the

66 We use the data on all countries in our main sample, except the five countries where data on stock market capitalization is missing.

67 Thus, we classify the five countries where we have no data stock market capitalization and, in parts, no data on the relevant private credit ratio as countries with weakly developed financial sector. This reflects the common view regarding the financial sector development of Ireland during the 1980s, and the fact that the Footnote 67 continued
Czech Republic, Hungary, Poland and the Slovak Republic were planned economies at that time. Note, in addition, that the main estimation results in Table 7, columns 1 and 2, remain stable if we exclude these five countries from the sample.

68 The BTD database is part of the OECD Structural Analysis (STAN) databases, and we downloaded the BTD 2010 edition in its archived version (last updated: October 2011) on February 20, 2015 from http://dx.doi.org/10.1787/data-00028-en. See also http://www.oecd.org/sti/btd (accessed: February 20, 2015).

eleven SMP countries in Table 1, Finland, Sweden, and two non-sampled EU 15 member states (Luxembourg and Austria).

Finally, we set the indicator *EU 15 import penetration*$^{high}_{ci,1988-90}$ equal to one for all industries i in countries c where the initial EU 15 import penetration is at or above the relevant 75th percentile, and zero otherwise.[69]

To generate an indicator for high exposure to imports from all countries worldwide, except the EU 15 countries, we proceed analogously, using $M_{cit}^{World \setminus EU\ 15}$ instead of $M_{cit}^{EU\ 15}$. In case of the indicator for high exposure to imports from China, we average across a longer time period, 1988 to 2003, taking into account that imports from China were typically low until the mid-1990s (Bloom et al. 2015).

Appendix 3: Construction of main estimation sample

Our main estimation sample is an unbalanced panel of 2736 observations on 13 manufacturing industries in 17 countries between 1987 and 2003.

We apply the following standard data cleaning routines. We drop country-industry-year observations with missing values of variables that are relevant to our main regression analysis (see Tables 3, 4, 5 and 6). In addition, we eliminate all observations with absolute growth of more than 200 percent in R&D intensity, or in real R&D expenditures. Finally, we eliminate all country-industries where we observe less than five consecutive years during the time period from 1987 to 2003.[70]

References

Acemoglu, D. (2009). *Introduction to modern economic growth*. Princeton, NJ: Princeton University Press.

Acemoglu, D., Aghion, P., & Zilibotti, F. (2006). Distance to frontier, selection, and economic growth. *Journal of the European Economic Association*, *4*(1), 37–74.

Acemoglu, D., & Akcigit, U. (2012). Intellectual property rights policy, competition and innovation. *Journal of the European Economic Association*, *10*(1), 1–42.

Acemoglu, D., & Linn, J. (2004). Market size in innovation: Theory and evidence from pharmaceutical industry. *Quarterly Journal of Economics*, *119*(3), 1049–1090.

Aghion, P., Akcigit, U., & Howitt, P. (2014). What do we learn from Schumpeterian growth theory? In P. Aghion & S. Durlauf (Eds.), Handbook of economic growth (Vol. 2B, Chap. 1, 1st ed., pp. 515–563). Oxford: Elsevier (North Holland).

Aghion, P., Bloom, N., Blundell, R., Griffith, R., & Howitt, P. (2005). Competition and innovation: An inverted-U relationship. *Quarterly Journal of Economics*, *120*(2), 701–728.

Aghion, P., Blundell, R., Griffith, R., Howitt, P., & Prantl, S. (2009). The effects of entry on incumbent innovation and productivity. *Review of Economics and Statistics*, *91*(1), 20–32.

Aghion, P., Burgess, R., Redding, S. J., & Zilibotti, F. (2008). The unequal effects of liberalization: Evidence from dismantling the License Raj in India. *American Economic Review*, *98*(4), 1397–1412.

Aghion, P., Harris, C., Howitt, P., & Vickers, J. (2001). Competition, imitation and growth with step-by-step innovation. *Review of Economic Studies*, *68*(3), 467–492.

Aghion, P., Harris, C., & Vickers, J. (1997). Competition and growth with step-by-step innovation: An example. *European Economic Review*, *41*(3–5), 771–782.

Aghion, P., & Howitt, P. (1992). A model of growth through creative destruction. *Econometrica*, *60*(2), 323–351.

Aghion, P., & Howitt, P. (2009). *The economics of growth*. Cambridge, MA: MIT Press.

[69] Note that the coefficient estimates on the trade-related terms in Table 7, columns 3 and 4, turn insignificant if we use the alternative indicator, *EU 15 import penetration*$^{>median}_{ci,1988-90}$, which is coded one for all industries i in countries c where the initial EU 15 import penetration is above the relevant median, and zero otherwise.

[70] In case of country-industries with two separate series with at least five observations, we select the earlier one.

Aghion, P., Howitt, P., & Prantl, S. (2013). Revisiting the relationship between competition, patenting, and innovation. In D. Acemoglu, M. Arellano, & E. Dekel (Eds.), Advances in economics and econometrics (Vol. 1 of Econometric Society Monographs (No. 49), Chap. 15, pp. 451–455). Cambridge, MA: Cambridge University Press.

Badinger, H. (2007). Has the EU's Single Market Programme fostered competition? Testing for a decrease in mark-up ratios in EU industries. *Oxford Bulletin of Economics and Statistics*, *69*(4), 497–519.

Baum, C. F., Schaffer, M. E., & Stillman, S. (2007). Enhanced routines for instrumental variables/generalized methods of moments estimation and testing. *Stata Journal*, *7*(4), 465–506.

Beck, T., Demirgüç-Kunt, A., & Levine, R. (2000). A new database on the structure and development of the financial sector. *World Bank Economic Review*, *14*(3), 597–605.

Beck, T., Demirgüç-Kunt, A., & Levine, R. (2009). Financial institutions and markets across countries and over time: Data and analysis. World Bank Policy Research Working Paper 4943.

Beck, T., Demirgüç-Kunt, A., & Levine, R. (2010a). Financial development and structure database (November 2010 version), http://econ.worldbank.org/WBSITE/EXTERNAL/EXTDEC/EXTRESEARCH/0,,contentMDK:20696167~pagePK:64214825~piPK:64214943~theSitePK:469382,00.html, accessed 28 Dec 2011, and http://go.worldbank.org/X23UD9QUX0, accessed 15 Feb 2015.

Beck, T., Demirgüç-Kunt, A., & Levine, R. (2010b). Financial institutions and markets across countries and over time: The updated financial development and structure database. *World Bank Economic Review*, *24*(1), 77–92.

Bloom, N., Draca, M., & Van Reenen, J. (2015). Trade-induced technical change? The impact of Chinese imports on innovation, IT and productivity. Review of Economic Studies (forthcoming).

Boldrin, M., & Levine, D. K. (2008). *Against intellectual monopoly*. Cambridge, MA: Cambridge University Press.

Bottasso, A., & Sembenelli, A. (2001). Market power, productivity and the EU single market program: Evidence from a panel of Italian firms. *European Economic Review*, *45*(1), 167–186.

Branstetter, L. G., Fisman, R., & Foley, C. F. (2006). Do stronger intellectual property rights increase international technology transfer? Empirical evidence from U.S. firm-level panel data. *Quarterly Journal of Economics*, *121*(1), 321–349.

Budish, E., Roin, B. N., & Williams, H. (2015). Do firms underinvest in long-term research? Evidence from cancer clinical trials. American Economic Review (forthcoming).

Buigues, P., Ilzkovitz, F., & Lebrun, J.-F. (1990). *The impact of the internal market by industrial sector: The challenge for the member states*. Commission of the European Communities, European Economy: Social Europe, Special Edition.

Chu, A. C., Cozzi, G., & Galli, S. (2012). Does intellectual monopoly stimulate or stifle innovation? *European Economic Review*, *56*(4), 727–746.

Cohen, W., Nelson, R., & Walsh J. P. (2000). Protecting their intellectual assets: Appropriability conditions and why U.S. manufacturing firms patent (or not). National Bureau of Economic Research (NBER) Working Paper 7552.

Cozzi, G. (2001). Inventing or spying? Implications for growth? *Journal of Economic Growth*, *6*(1), 55–77.

EU KLEMS. (2008). The EU KLEMS Database (March 2008 Release) and EU KLEMS Linked Data (October 2008 Release), see Marcel Timmer, Mary O'Mahony & Bart Van Ark, The EU KLEMS Growth and Productivity Accounts: An Overview, University of Groningen & University of Birmingham, http://www.euklems.net, accessed 15 Oct 2009, and http://www.euklems.net/linked.shtml, accessed 2 Feb 2012.

European Patent Organization (EPOrg). (2010). List of contracting states sorted according to the date of accession (last updated 18 August 2010). http://www.epo.org/about-us/organisation/member-states/date.html, accessed 2 Oct 2012.

Galasso, A., & Schankerman, M. (2015). Patents and cumulative innovation: Causal evidence from the courts. *Quarterly Journal of Economics*, *130*(1), 317–369.

Gilbert, R. (2006). Looking for Mr. Schumpeter: Where are we in the competition-innovation debate? In A. B. Jaffe, J. Lerner & S. Stern (Eds.), Innovation policy and the economy (Vol. 6, Chap. 6, pp. 159–215). Cambridge, MA: MIT Press.

Ginarte, J. C., & Park, W. G. (1997). Determinants of patent rights: A cross-national study. *Research Policy*, *26*(3), 283–301.

Griffith, R., Harrison, R., & Simpson, H. (2010). Product market reform and innovation in the EU. *Scandinavian Journal of Economics*, *112*(2), 389–415.

Guimaraes, P., & Portugal, P. (2010). A simple feasible alternative procedure to estimate models with high-dimensional fixed effects. *Stata Journal*, *10*(4), 628–649.

Hall, B. H. (2005). Exploring the patent explosion. *Journal of Technology Transfer*, *30*(1/2), 35–48.

Hall, B. H., Jaffe, A. B., & Trajtenberg M. (2001). The NBER patent citations data file: lessons, insights and methodological tools. National Bureau of Economic Research (NBER) Working Paper 8498.

Hall, B. H., & Ziedonis, R. H. (2001). The patent paradox revisited: An empirical study of patenting in the U.S. semiconductor industry, 1979–1995. *RAND Journal of Economics*, *32*(1), 101–128.

Kleibergen, F., & Paap, R. (2006). Generalized reduced rank tests using the singular value decomposition. *Journal of Econometrics*, *133*(1), 97–126.

Lerner, J. (2000). 150 years of patent protection. National Bureau of Economic Research (NBER) Working Paper 7478.

Lerner, J. (2002). Patent protection and innovation over 150 years. National Bureau of Economic Research (NBER) Working Paper 8977.

Lerner, J. (2009). The empirical impact of intellectual property rights on innovation: Puzzles and clues. *American Economic Review*, *99*(2), 343–348.

Levin, R. C., Klevorick, A. K., Nelson, R. R., & Winter, S. G. (1987). Appropriating the returns from industrial research and development. *Brookings Papers on Economics Activity*, *3*, 783–820.

Li, C.-W. (2001). On the policy implications of endogenous technological progress. *The Economic Journal*, *111*(471), C164–C179.

Maskus, K. E. (2000). *Intellectual property rights in the global economy*. Washington, DC: Insitute for International Economics.

Maskus, K. E., & Penubarti, M. (1995). How trade-related are intellectual property rights? *Journal of International Economics*, *39*(3–4), 227–248.

Moser, P. (2005). How do patent laws influence innovation? Evidence from nineteenth-century world's fairs. *American Economic Review*, *95*(4), 1214–1236.

O'Donoghue, T., & Zweimüller, J. (2004). Patents in a model of endogenous growth. *Journal of Economic Growth*, *9*(1), 81–123.

O'Mahony, M., Castaldi, C., Los, B., Bartelsman, E., Maimaiti, Y., Peng, F. (2008). EUKLEMS - Linked data: Sources and methods. Mimeo, University of Birmingham, http://www.euklems.net, accessed 18 Feb 2015.

O'Mahony, M., & Timmer, M. P. (2009). Output, input and productivity measures at the industry level: The EU KLEMS database. *The Economic Journal*, *119*(538), F374–F403.

Organisation for Economic Co-operation and Development (OECD). (2009). Research and development expenditure in industry 2009: Analytical business enterprise research and development (ANBERD). Paris: OECD Publishing. doi:10.1787/rd_exp-2009-en-fr, accessed 23 Jan 2015.

Organisation for Economic Co-operation and Development (OECD). (2010). STAN Bilateral Trade Database (BTD, edition 2010, archived version, last updated October 2011), http://dx.doi.org/10.1787/data-00028-en and http://www.oecd.org/sti/btd, accessed 20 Feb 2015.

Organisation for Economic Co-operation and Development (OECD). (2011). STAN R&D Expenditure in Industry (ISIC Rev. 3.1) - Analytical business enterprise research and development (ANBERD) database (edition 2011, archived version, last updated 15 Jan 2013). doi:10.1787/data-00556-en and http://www.oecd.org/sti/anberd, accessed 23 Jan 2015.

Park, W. G. (2008a). International patent protection: 1960–2005. *Research Policy*, *37*(4), 761–766.

Park, W. G. (2008b). Patent protection index. http://www.american.edu/cas/econ/faculty/park.html, accessed 18 Jan 2011, and http://nw08.american.edu/~wgp/, accessed 17 Feb 2015.

Qian, Y. (2007). Do national patent laws stimulate domestic innovation in a global patenting environment? *Review of Economics and Statistics*, *89*(3), 436–453.

Rapp, R. T., & Rozek, R. P. (1990). Benefits and costs of intellectual property protection in developing countries. *Journal of World Trade*, *24*(5), 75–102.

Romer, P. M. (1990). Endogenous technical change. *Journal of Political Economy*, *98*(5), S71–S102.

Sakakibara, M., & Branstetter, L. G. (2001). Do stronger patents induce more innovation? Evidence from the 1988 Japanese patent law reforms. *RAND Journal of Economics*, *32*(1), 77–100.

Schmutzler, A. (2010). Is competition good for innovation? A simple approach to an unresolved question. *Foundations and Trends in Microeconomics*, *5*(6), 355–428.

Scotchmer, S. (2004). *Innovation and incentives*. Cambridge, MA: MIT Press.

Stock, J. H., & Yogo, M. (2005). Testing for weak instruments in linear IV Regressions. In D. W. K. Andrews & J. H. Stock (Eds.), Identification and inference for econometric models: Essays in honor of Thomas J. Rothenberg (pp. 80–108). Cambridge, MA: Cambridge University Press.

Tirole, J. (1988). *The theory of industrial organization*. Cambridge, MA: MIT Press.

Vives, X. (2008). Innovation and competitive pressure. *Journal of Industrial Economics*, *56*(3), 419–469.

Von Graevenitz, G., Wagner, S., & Harhoff, D. (2011). How to measure patent thickets - A novel approach. *Economics Letters*, *111*(1), 6–9.

World Intellectual Property Organization. (2012). WIPO Lex, http://www.wipo.int/wipolex/en/, accessed 15 Mar 2012 and 30 Sept 2014.