Product market regulation and innovation efficiency*

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Abstract

We study the role of upstream product market regulation (PMR) in innovation efficiency. By estimating a knowledge production function for a large sample of OECD industries through a stochastic frontier analysis, we find that service regulation remarkably reduces R&D efficiency in the manufacturing sector. These results are robust to controlling for the institutional setting of the technology, the labour and the financial market, as well as to various forms of heterogeneity such as, for instance, non-linearities in the effect of PMR. The marginal impact of upstream regulation is higher in less regulated economies indicating that large improvements in R&D efficiency cannot be achieved at the earlier stages of deregulation. We quantify total gains in R&D efficiency and patenting that could be obtained by late reforming countries by liberalizing the product market.

Keywords: R&D, knowledge production, efficiency, product market regulation
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1 Introduction

In the OECD area, differentials in productivity growth rates have been widening since the early 1990s (Nicoletti and Scarpetta, 2003). Most of this gap derives from service industries, where the regulatory framework is found to be severally detrimental for TFP growth, especially in Europe (Inklaar et al., 2008). This form of regulation generates sizeable negative effects on firm productivity even outside the tertiary sector, because of the intense intermediate transactions between producers and users of service inputs (Bourlés et al., 2012). One important channel through which service (upstream) regulation influences productivity in manufacturing (downstream) industries is by influencing the outcome of research (Amable et al., 2009). Despite the relevant contribution provided by such pioneering studies, it still remains unexplained *how* imperfections in regulated intermediate input markets reverberate on manufacturing innovation. The object of the present paper is to identify one possible *mechanism* of transmission.

We postulate that upstream product market regulation (PMR) changes the ability of downstream industries (and firms) to efficiently manage R&D resources and carry out the complex set of innovation tasks. When intermediate input markets work imperfectly – due to administrative barriers, licensing, etc. – innovating firms are constrained in factor allocation, and cannot focus on their core activities due to the difficulty to outsource marginal tasks. Moreover, upstream regulation concurs to erecting entry barriers in downstream markets, changing the competitive pressure and incentives to innovate. Because of these factors, innovating firms may reach sub-optimal levels of R&D efficiency, falling below the frontier of knowledge production.

We study the role of the regulatory setting of the upstream product markets by estimating a knowledge production function through a stochastic frontier analysis (SFA). In contrast to most existing works that exploit only one dimension of data variation (industry or country), we use a fully comprehensive dataset covering fifteen manufacturing industries in ten OECD economies between 1990 and 2002. As widely documented in the literature, this was a period of intense pro-competition initiatives, rapid technological advancements but profoundly diverging patterns in productivity growth. In identifying the regulation impact on R&D efficiency, we control for the institutional setting governing the functioning of the technology, the labour and the financial market, as well as several forms of heterogeneity such as, for instance, non-linearities in the effect of PMR along its distribution.

Our results provide robust evidence that upstream regulation remarkably reduces efficiency levels in manufacturing innovation. The marginal unit impact of PMR is larger in less regulated economies. It suggests that sizeable improvements in R&D efficiency cannot be expected at the initial stages of deregulation and that market liberalization takes time to produce widespread effects within the economy. We also find that the negative relationship between marginal impact and level of regulation strengthened during the 1990s when product market reforms were launched by most OECD economies. Overall, potential gains from deregulation are larger for those countries characterised by more restrictive administrative barriers to competition.

This paper makes an important contribution to three key literatures. First, it contributes to the growing body of studies on the linkages between institutions and innovation (Nelson, 2008), by specifically exploring one dimension of the regulatory setting (upstream product market regulation) and identifying one channel of transmission (R&D efficiency). Second, it broadens understanding of the growth effects of competition policies. Earlier studies have looked at the effect of regulation on investment (Alesina et al., 2005), occupational outcomes (Griffith et al., 2007, Fiori et al., 2012), workforce training (Bassanini and Brunello, 2011), export performance (Barone and Cingano, 2011), inflation dynamics (Correa-López et al., 2013), productivity growth and convergence to the frontier (Buccirossi et al., 2012, Bourlés et al., 2012). Third, relying upon recent developments in stochastic frontier analysis, we extend the literature seeking to identify the key factors underlying productivity growth (Kneller and Stevens, 2006, Henry et al., 2009) R&D and patenting (Wang, 2007, Fu and Yang, 2009, Cullmann et al., 2012).

The remainder of the paper is the following. Section 2 surveys the literature on the nexus between product market regulation and innovation. Section 3 defines the analytical framework, discusses the econometric methodology and then presents data. Section 4 reports both descriptive statistics and the econometric evidence. Section 5 discusses the results and, finally, Section 6 concludes.

2 Product market regulation and innovation

Theoretical background

The most recent Schumpeterian growth theories mainly describe the relationship between product market regulation, competition and innovation as non-linear. This is the outcome of a race between two opposite forces (Aghion et al., 2013a). The first one is the *pure competition effect* of the old Schumpeterian tradition, which interprets ex-ante monopoly rents as a pre-requisite to innovate. The second one reflects the *escaping-competition effect*, which predicts that firms innovate to outstrip competitors and earn ex-post monopoly rents. The former force prevails in 'unlevelled' markets where incumbents dominate, the latter where firms are technologically contiguous and there is 'neck-to-neck' competition. In levelled markets, if firms do not collude, competition raises the share of market profits going to the innovator; in unlevelled markets, competitive pressure reduces incumbent's profitability. On the aggregate, there emerges an inverted U-shaped relationship between competition and innovation which depends on the fraction of sectors that are in leveled state (*composition effect*), and regulation should discourage innovation the closer a firm to the frontier, but not far from it.

This general theoretical framework can yield a large array of results. Amable et al. (2009) hypothesize that the leader's R&D effort raises the difficulty for the follower to innovate and move one step ahead along the product quality ladder. Under this condition, the relationship between competition and innovation may be U-shaped and the effect of competition (regulation) on innovation be harmful closer to (far from) the frontier. Bourlés et al. (2012) adapts the mainstream Schumpeterian growth framework to allow for the knock-on effects of product market regulation, i.e. how regulation in upstream industries influences the economic performance of downstream firms and industries using regulated intermediate factors such as service inputs.[1] Because of barriers to entry, licensing, etc., downstream firms access to such inputs at higher prices or lower quality than in a market without frictions. These unfavourable conditions inhibit firms from outsourcing marginal tasks, properly allocating factor inputs and efficiently managing their core activities. In this model, imperfect competition in upstream sectors makes the search for intermediate input suppliers time-consuming and costly for new

[1] Bourlés et al. (2012, working paper version) builds upon the model originally developed by Lopez (2010) which consists in an extension of Aghion et al. (1997).

downstream firms. These costs provide market power to upstream suppliers, creating a gap between the intermediate input price and the marginal cost of producing the input. This represents a barrier to entry in downstream markets reducing both the number of active producers and incentives of these firms to improve efficiency. When there is an increase in the competitive pressure of upstream markets, the bargaining power of these suppliers fall, as well as the expected cost for a downstream firm to find a supplier. On the other hand, stronger competition downstream increases incentives to efficiency improvements by reducing profits in such leveled industries, i.e. by increasing the gap between pre- and post-innovation rents. As a net impact between the pure competition and the escaping-competition effects, this model predicts that upstream regulation (competition) reduces (increases) incentives to efficiency and productivity improvements downstream. In the following, our empirical analysis relies upon this growth framework to assess the effect of service regulation on R&D efficiency of the manufacturing sector.

Empirical evidence

The prediction that the relationship between competition and innovation follows an inverted-U pattern has been supported by Aghion et al. (2005), whereas Aghion et al. (2009) document that more intense competition enhances innovation in frontier firms, but discourages it in non-frontier firms. Evidence departing from this pattern has recently been provided, for the US case, by Correa and Ornaghi (2013) where competition is extensively found to favour the achievement of better innovation and productivity outcomes. Griffith et al. (2010) assess the direct effects of own-industry regulation on innovation output. Exploiting information on the EU Single Market Programme's (SMP) reforms of the 1990s, these authors illustrate that the fall in the administrative barriers to competition lowered firm profitability, raising incentives to carry out R&D: firms innovated more and, as a result, reaped larger productivity benefits.[2]

Attention has recently been paid to the empirical assessment of the knock-on effects exerted by product market regulation in service industries. Although such anti-competitive laws pertain the tertiary sector, their effects spread diffusely throughout the economy with the intense inter-industry

[2]Aghion et al. (2013b) document that the EU SMP reforms raised innovation in countries characterized by strong patent rights, but not elsewhere; this effect was more relevant in industries relying on patenting as main tool of innovation.

(input-output) transactions of intermediate inputs (Conway et al., 2006). Imperfections in intermediate input markets have been acknowledged to slow productivity growth at various level of data aggregation and this effect strengthened during the 1990s with the deepening of globalization and ICT diffusion (Arnold et al., 2011, Bourlés et al., 2012). However, it remains less explored how the institutional setting of the intermediate input markets reverberates on R&D of the manufacturing sector. Amable et al. (2009) show that upstream (service) regulation has a negative impact on patenting for countries far from the frontier, whilst this effect is positive for technology leaders. Consistently, Sanyal and Ghosh (2013) find that patenting in the field of electrical technology declined after the deregulation in the US electricity market during the 1990s. Blind (2012) finds that PMR is unrelated to patenting when more dimensions of regulation policies are considered (competition legislation, price control, environmental laws). Conversely, Barbosa and Faria (2011) show that the probability to innovate is significantly lower in presence of a stricter regulation in upstream product markets, even when controlling for other institutional factors.

3 Analytical framework

3.1 Econometric strategy

We study the impact of upstream PMR on innovation efficiency of OECD manufacturing industries by applying a SFA to a knowledge production function (KPF). Innovation output (I) is assumed to depend on research input (R), within-industry international knowledge spillovers (K), human capital (H), and financial input (F):

$$I_{ij,t} \quad = \quad A \cdot \mathbf{Z}^{\theta} = AR_{ij,t}^{\gamma_1} K_{ij,t}^{\gamma_2} H_{ij,t}^{\gamma_3} F_{ij,t}^{\gamma_4}. \tag{1}$$

i denotes industries, j countries, t time. A is an exogenous productivity parameter of R&D. $\mathbf{Z}$ is a factor aggregating function, θ a vector of factor elasticities. Eq. (1) is a variant of the knowledge production function devised by Ang (2011). In the econometric specification, we hypothesize that industries differ for the efficiency in factor usage:

$$I_{ij,t} = A \cdot \mathbf{Z}^{\theta} \cdot e^{\alpha_{ij} + \tau_t} \cdot e^{v_{ij,t} - u_{ij,t}}. \tag{2}$$

In natural logs, it is reworded as:

$$\ln I_{ij,t} = \alpha + \theta \cdot \ln \mathbf{Z} + \alpha_{ij} + \tau_t + v_{ij,t} - u_{ij,t}. \tag{3}$$

Eq. (3) includes a set of fixed effects for each industry-country pair to account for unobserved time-invariant heterogeneity (α_{ij}), and a group of year dummies to capture the impact of temporary common shocks (τ_t). To determine the knowledge production 'frontier', defined as the maximum attainable output by a given level of inputs, the stochastic component is modeled with a two-part error structure (Aigner et al., 1977; Meeusen and van den Broeck, 1977). $v_{ij,t}$ is a normally distributed disturbance capturing random departures from the predicted-by-the-model output (due to unobserved observation-specific random shocks, measurement errors, etc.). $u_{ij,t}$ is a half-normally distributed term aimed to capture deviations from the frontier induced by a sub-optimal usage of innovation inputs, namely R&D inefficiency.[3]

To assess how product market regulation (PMR) affects innovation efficiency, we adopt the one-step estimator devised by Wang and Schmidt (2002) and Schmidt (2011). It consists in specifying the parameters of the inefficiency term as a function of a vector of determinants, and estimating them jointly with the parameters of the KPF.[4] Assuming

$$v_{ij,t} \sim N(0, \sigma_v) \qquad u_{ij,t} \sim N^+(0, \sigma_{u_{ij,t}}), \tag{4}$$

the (in)efficiency equation can be expressed (in logs) as a function of an industry-specific measure of upstream product market regulation (to be described in detail below):

$$\ln \sigma^2_{u_{ij,t}} = \rho_0 + \rho_1 \cdot PMR_{ij,t} + \rho' \mathbf{W} + \eta_i \cdot t + \mu_j \cdot t. \tag{5}$$

$\mathbf{W}$ is a vector of institutional controls, available at the country level, used

[3]Unreported sensitivity results indicate that (in)efficiency estimates are robust to alternative distributions (i.e., the exponential). Thus, the distributional choice is dictated only by computational tractability (Greene, 2008, p.180).

[4]This procedure outperforms the two-step methodology mostly used in earlier works. The latter consists of first estimating inefficiency scores from a baseline function (such as for instance our KPF), and then regressing these values on a set of additional explanatory variables (product market regulation). The two-step procedure has been shown to yield biased estimates of the (in)efficiency parameters in presence of omitted variables in the first-step estimation.

to avoid spurious correlation between PMR and innovation efficiency that may be induced by competition policies pursued in the other markets of the economy (technology, labour and finance). η_i's are industry-specific time trends capturing changes in structural characteristics of innovation enabled by the exogenous component of technical progress. μ_j's denote country-specific time trends controlling for the evolution of the general institutional setting; if omitted, this may be confounded with the deregulation wave in the product markets started in the early 1990s. The coefficient ρ_1 is the key parameter of the analysis as identifying the impact of service regulation on the (in)efficiency of knowledge generating activities conducted by manufacturing industries.

Some properties of the empirical model are worthy to point out. First, as discussed above, to get consistent estimates, the determinants of the KPF are estimated jointly with the inefficiency parameters (ρ, η_i, μ_j) by means of maximum likelihood. Second, the model is heteroskedastic in $u_{ij,t}$, as the variance of this term depends on the level of upstream regulation in each industry-country pair (i and j); this condition is crucial to obtain unbiased efficiency scores.[5] Third, by allowing for individual heterogeneity (α_{ij}) and time-varying (in)efficiency ($u_{ij,t}$), the model circumvents the distortion in the KPF parameters potentially related to the correlation between industry-country fixed effects and innovation inputs. If uncontrolled, this 'pure' heterogeneity would affect the overall residuals ($\epsilon_{ij,t} = v_{ij,t} - u_{ij,t}$), leading to an incorrect statement of technical (in)efficiency. The specification used in this paper is known as the 'true' fixed-effects model (Greene, 2005a, and 2005b). In this respect, our work extends previous research in the field. For instance, Fu and Yang (2009) disentangle patenting at the economy-wide level into the effects of innovation capacity and efficiency, allowing for country fixed-effects within the (in)efficiency equation but no deterministic element within the frontier. Comparable works, using a similar specification without fixed effects but focused on output production efficiency, are Kneller and Stevens (2006) and Henry et al. (2009).

[5] See Kumbhakar and Lovell (2000, pp. 272-3), Caudill and Ford (1993) and Caudill et al. (1995).

3.2 Data

We use data for fifteen manufacturing industries observed between 1990 and 2002 in ten OECD countries.[6]

3.2.1 Determinants of knowledge production

We measure innovation output, $I_{ij,t}$, with the number of patent applications at the US Patent and Trademark Office (USPTO). Patent counts are distinguished by application year, industry and nationality of the assignee.[7] Research input, $R_{ij,t}$, is measured by R&D capital. This variable is obtained from research expenses' data applying the perpetual inventory method and a geometrical depreciation rate of 15%. As a proxy for the within-industry international knowledge spillovers, we use the un-weighted sum across countries of the industry patent stock. It reflects the idea that, when an innovation is patented, the underlying knowledge is disclosed and disseminates without any specific conduit (Bottazzi and Peri, 2007).

Human capital and financial input are defined as an exponential function of the labour share of high-skilled workers and the relative availability of financial funds, respectively (hs and fd). These variables are expressed in percentage terms and enter linearly the econometric specification, being our KPF estimated in logs. In essence, human capital is defined in a Mincherian way and, similarly to Mason et al. (2012), its level is benchmarked to the weight of low- and medium-skilled workers in the industry, $H = exp(hs_{ij,t})$. This variable should capture the contribution of total labour quality, and not only that of R&D employees, to patenting (source: EU KLEMS 2008). Following the literature on the role of financial factors for R&D (Maskus et al., 2012, Brown et al., 2012), we define fd as an interaction between an

[6] Details are provided in the Web Appendix. Industry list: Food, beverage and tobacco; Chemicals; Pharmaceuticals; Rubber and plastics; Other non-metallic minerals; Basic metals; Fabricated metal products; Machinery; Office machinery; Electrical eq. and apparatus; Communication eq.; Medical and scientific instruments; Motor vehicles; Other transport eq.; Other manufacturing. Country list: Australia, Canada, Germany, France, Great Britain, Italy, Japan, The Netherlands, Sweden, US.

[7] Although patent data mainly account for the output of formal innovation, they present some important advantages. First, using applications at the USPTO, we work with a standardized measure of innovation output that reduces measurement errors, as all innovators are subjected to the same IPR law. Second, we cover the portion of innovations with higher quality as firms demand patent protection in the US –the world-wide leading technology market– only for their most valuable ideas.

industry measure of external finance dependence (benchmarked to the US average values of the 1980s) and a country-specific, time-varying indicator of financial development. Financial dependence is defined by the share of external funds on total capital expenditure (Von Furstenberg and Von Kalckreut, 2006). Financial development is alternatively approximated by the ratio to GDP of bank credit, private bond market capitalization and stock market capitalization (Beck and Demirgü-Kunt, 2009). As pioneered by Rajan and Zingales (1998), a lower degree of financial development is particularly harmful for those industries mostly relying on external funds to finance innovation and other risky activities (Ang, 2011). fd is designed to capture cross-sector heterogeneity in the impact of financial input, $F_{ij,t} = exp(fd_{ij,t})$.

3.2.2 Determinants of innovation efficiency

As a proxy for PMR, we use the index of the regulation impact from OECD Product Market Regulation dataset (Conway and Nicoletti, 2006). This indicator measures how anti-competitive legislation in the tertiary sector reverberates on downstream sectors using services as factor inputs. It quantifies anti-competitive regulation in non-manufacturing industries (energy, transport and communications, retail and professional services) projecting its effect on downstream industries on the basis of the coefficients of service input requirements from Input-Output tables. Anti-competitive practices in service industries include: entry regulation, the extent of public ownership, vertical integration and the market structure.

To consistently identify the effect of upstream regulation on R&D efficiency we control for a large set of confounding factors. We account for the institutional setting governing the functioning of the labor, the technology and the financial market. All these control variables are available at the country level, reinforcing our choice of including country- and industry-specific trends within the (in)efficiency term in order to collect unobserved time-varying heterogeneity.

The strand of studies on the relationship between labor market institutions and innovation is quite extensive. The impact of the regulatory framework does differ in accordance with the time/country coverage of the analyses, as well as with the institutional profile of the labor market under assessment (Menezes-Filho and Van Reenen, 2003). We consider the strictness of employment protection legislation, distinguishing between the regulation pertaining the dismissal of regular workers and legislation on temporary contracts (Venn, 2009). Griffith and Macartney (2013) find that the former is associated with a higher level of patenting in firms engaged in incremental innovation, as it favours the accumulation of firm-specific human capital. By contrast, more stringent regulation on temporary workers is harmful for patenting in turbulent technology markets, where innovation is radical and firms need to rapidly adjust workforce skills to the new state of technological knowledge.

We also account for the possibility that the capacity to efficiently use R&D resources is affected by the legal regime of intellectual property rights (IPR) protection. More specifically, we include a measure of IPR protection relative to the US levels (Ginarte and Park, 1997). This country has been historically acknowledged for the strongest system to enforce innovation and, in our study, is the reference technology market where non-US innovating firms apply for. According to our view, firms that benefit from a domestic IPR framework closer to the US standards are likely to better manage R&D, as knowing the administrative procedure to route patenting, enforce property rights, and license innovation. Samaniego (2013) provides evidence that IPR enforcement increases innovation spending in high-tech industries by influencing both the market entry and exit.

The potential impact of financial regulation is examined by a measure of the extent to which each country has been reforming the financial markets, such as for instance by reducing state control or barriers to intermediation operations (Abiad et al., 2008). Ang (2011) finds that financial liberalization is negatively related to patenting as it reduce savings, triggers financial instability and leads to a disproportionate expansion of the financial sector that crowds out high-tech industries.

4 Results

4.1 Descriptive analysis

Table 1 shows the average value at the country level of the variables entering the KPF and the institutional factors potentially explaining R&D inefficiency. To increase data comparability, in this section we scale patent and R&D variables on the number of employees to account for the industry size.

In terms of innovation output, US and Japan are the leading countries.

Table 1: Determinants of KPF and R&D efficiency: average values 1990-2002

	KPF					(In)efficiency				
	I (p.e.)	R (p.e.)	K (p.e.)	H (hs %)	F (fd %)	PMR (%)	IPRP (rel. %)	EPL Reg.	EPL Temp.	FIN Ref.
AU	2.3	16.3	3011.8	13.2	1.1	7.6	81.5	1.3	0.9	91.6
CA	2.6	25.4	841.2	18.7	1.3	7.0	87.2	1.3	0.3	97.1
DE	1.9	33.0	190.2	13.7	1.4	10.4	91.8	2.7	2.8	88.3
FR	2.4	72.5	445.2	14.8	1.1	10.2	87.8	2.4	3.6	94.1
GB	1.2	40.6	310.2	14.9	1.8	8.7	93.0	1.0	0.3	97.4
IT	0.7	26.1	493.8	4.6	0.9	15.9	90.7	1.8	4.7	79.1
JP	4.8	37.4	72.7	24.1	2.7	11.6	90.9	1.9	1.5	79.5
NL	4.0	57.8	1936.8	8.3	1.3	6.9	93.5	3.1	2.1	94.9
SE	3.2	46.5	2266.2	14.6	0.7	6.5	89.8	2.9	2.5	94.5
US	6.7	58.7	27.2	34.5	0.8	5.7	100.0	0.2	0.3	94.1
Mean	3.0	41.4	959.5	16.1	1.3	9.1	90.6	1.8	1.9	91.1

[a] I= Patents; R=R&D stock; K=Technology spillovers; H=Human capital (hs=labour share of high skilled reported); F=Financial factor (fd=relative financial development reported). p.e.= variables expressed per thousand employee. PMR=upstream product market regulation. $IPRP$= IPRs protection (relative to the US). $EPL\ Reg$= employment protection legislation on regular contracts. $EPL\ Temp$= employment protection legislation on temporary contracts. $FIN\ Ref$=Financial reforms.

Smaller European economies such as Sweden and the Netherlands rank relatively well, while the UK and Italy lag behind. Looking at the innovation effort, as measured by R&D stock, France is ahead, ranking much better than for patents per employee. Australia and Canada are characterized by a relatively low value of research capital per worker. As expected, smaller countries display higher values of the technology spillover variable. The United States stand out for the labour share of high-skilled workers, whereas Japan for the extent of the financial input.

Turning to the determinants of R&D inefficiency, the largest EU countries (Italy, France, and Germany) and Japan denote the heaviest anti-competitive regulation in services; conversely, the US and Sweden fall in the upper tail of the distribution. The UK exhibits levels of IPRs protection relatively close to the US and, on the financial ground, it was the country that more intensively liberalised the market between 1990 and 2002. As for employment protection, the Netherlands emerge for the most restrictive discipline on regular contracts, Italy on temporary contracts.

Overall, our descriptive statistics indicate that, in terms of input/output combination, there is a wide range of possibilities in conducting innovation, as those countries that lead for patenting not necessarily invested more in research inputs (and viceversa). This may be due to a different degree of R&D efficiency.

4.2 Estimation results

Table 2 shows the baseline estimates for Eqs. (3) and (5). At first, we look at how R&D stock, taken alone, contributes to patenting (cols. 1-2). Then, we consider all inputs of the knowledge production function (cols. 3a-3c). In these regressions, PMR is treated as the sole determinant of innovation efficiency, whilst the last estimates of the table account for the full set of institutional factors (cols. 4a-4c). As described above, financial input is given by industry financial dependence alternatively multiplied by the value of bank credit, private bond market capitalisation and stock market capitalisation over GDP.

In cols. (1)-(2) the cumulative value of R&D has a positive and significant effect on patenting (around 0.25-0.27). The positive coefficient for ρ_1 implies that PMR raises the variance of the inefficiency distribution (0.19); in other words, more stringent regulation in service industries is associated with a lower efficiency in the knowledge generating activities conducted by manufacturing (downstream) industries.[8]

In regressions (2a) through (2c), we consider the extended knowledge frontier. Here, the R&D elasticity is somewhat smaller but still stands in the range of values found in earlier studies (see for example Fu and Yang, 2009, Ang and Madsen, 2011). Among the other innovation inputs, international technology spillovers are found to play a crucial role in the creation of new technological knowledge. As documented in the literature (Bottazzi and Peri, 2007; Mancusi, 2008), the impact of this variable exceeds returns to internal R&D and, as we show below, this holds in particular for laggard countries. Also, we detect a positive effect of financial input on patenting, which is statistically more robust when financial development is measured by the ratio to GDP of bank credit and stock market capitalisation. This is consistent with the studies claiming that financial factors raise the ability to innovate (Maskus et al., 2012; Ang, 2011; Ang and Madsen, 2012). Conversely, there is no evidence that the labour quality exerts an effect on innovation output

[8]It should be borne in mind that the parameters estimated in the inefficiency equation cannot be interpreted as marginal effects (Wang, 2002; Liu and Myers, 2009). This issue will be addressed in Section 5.

Table 2: Maximum-likelihood estimation of the KPF with inefficiency equation, baseline specification

Specification		Coef.	(1)	(2)	(3a)	(3b)	(3c)	(4a)	(4b)	(4c)
KPF, dependent variable: $I_{ij,t}$										
R&D stock	R	γ_1	0.245***	0.273***	0.122***	0.122***	0.141***	0.102***	0.099***	0.125***
			(0.028)	(0.024)	(0.024)	(0.024)	(0.024)	(0.024)	(0.024)	(0.024)
Spillovers	K	γ_2			0.788***	0.775***	0.770***	0.839***	0.845***	0.847***
					(0.056)	(0.056)	(0.055)	(0.055)	(0.055)	(0.054)
Labor quality	H	γ_3			-0.001	-0.001	-0.001	0.001	0.001	0.002
					(0.002)	(0.002)	(0.002)	(0.002)	(0.002)	(0.002)
Finance: Fin. dependence × Bank credit/GDP	F	γ_4			0.029***			0.021**		
					(0.010)			(0.010)		
Finance: Fin. dependence × Private bond capitalization/GDP	F	γ_5				0.031			0.067*	
						(0.035)			(0.035)	
Finance: Fin. dependence × Stock market capitalization/GDP	F	γ_6					0.051***			0.071***
							(0.012)			(0.013)
Inefficiency equation, dependent variable: $ln(\sigma^2_{u_{ij,t}})$										
Product market regulation	PMR	ρ_1		0.186***	0.213***	0.222***	0.223***	0.175***	0.186***	0.176***
				(0.052)	(0.046)	(0.047)	(0.046)	(0.051)	(0.052)	(0.053)
IPR protection (relative to US)	IPRP	ρ_2						-0.086***	-0.095***	-0.104***
								(0.015)	(0.016)	(0.017)
Employment protection (regulars)	EPLR	ρ_3						-0.526	-0.731	-0.851*
								(0.508)	(0.511)	(0.507)
Employment protection (temporary)	EPLT	ρ_4						0.338***	0.369***	0.427***
								(0.087)	(0.088)	(0.089)
Financial reforms	FINR	ρ_5						0.023***	0.027***	0.022**
								(0.008)	(0.009)	(0.009)
Constant		ρ_0	-2.152***	261.344***	56.779	63.764*	48.309	-117.764**	-140.929***	-206.467***
			(0.193)	(40.909)	(36.294)	(37.729)	(37.784)	(49.873)	(54.106)	(56.683)
$ln(\sigma^2_v)$										
Constant		ν_0	-3.166***	-4.335***	-5.063***	-4.967***	-4.996***	-5.039***	-4.905***	-4.943***
			(0.167)	(0.109)	(0.214)	(0.195)	(0.195)	(0.234)	(0.203)	(0.209)
Industry/country dummies		α_{ij}	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Year dummies		τ_t	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Industry trends		$t \cdot \eta_i$	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Country trends		$t \cdot \mu_j$	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Log-likelihood			-333	222	316	312	321	345	345	359
Observations			1950	1950	1950	1950	1950	1950	1950	1950

[a] Industry/country FE, year dummies in the KPF, industry- and country-trends in the (in)efficiency equation omitted to save space. The complete table available from the authors upon request.

at the industry level. This result follows the analysis carried out by Venturini (2012) on the US manufacturing sector. It would suggest that only the human capital of researchers – accounted for by the wages paid to these workers and therefore included in R&D statistics – is significant to patent. In this second group of regressions, the effect of PMR on the variance of the inefficiency distribution is slightly larger (0.22).

In order to assess the robustness of the regulation impact, we introduce the full set of institutional controls into Eq. (5). These estimates are reported in regressions (4a)-(4c) and largely confirm our previous evidence: the coefficient of PMR is positive and significant, ranging from 0.18 to 0.20.

Looking at the control variables, it should first be noted that IPRs protection has a negative coefficient; it means that a well defined set of rules on the technology market helps firms organize at best the entire array of research tasks (access to finance, R&D operation, innovation licensing, etc.).[9]

Employment protection legislation denotes a strongly heterogeneous impact. Indeed, whereas the legal discipline on regular contracts does not have a robust effect, protection for temporary workers remarkably enhances R&D inefficiency. The latter is fully consistent with the effect found by Griffith and Macartney (2013) on radical innovation of multinational enterprises. Below, it is shown that these findings hide large cross-country disparities.

It also emerges that R&D efficiency is lower in those economies where financial liberalisation is more pronounced. This finding is in accordance with Ang (2011) who detects a negative impact of financial reform on patenting. From this perspective, our work identifies one possible channel through which this effect transits, i.e. R&D efficiency. There are some reasons that can motivate this finding. First, changes in the sources (and the extent) of funding may force firms to re-organize R&D activities, and this implies sustaining large adjustment costs. Second, the higher financial instability induced by financial reforms in the short run may increase inefficiencies in firm operations. Third, knowledge generating activities may be crowded out by the disproportionate expansion of the financial sector resulting from liberalization, as this distorts the allocation of highly skilled workers away from the

[9]The relationship between IPR stringency and innovation remains a debated issue (Boldrin and Levine, 2013) and, sometimes, it is depicted as an inverted-U shape, e.g. stronger IPR protection increases innovation only in the short run (Furukawa, 2010). Furthermore, the strength of patent protection may interplay with the policies pursued in other markets, for instance enhancing the positive impact of product market liberalization on R&D and patenting (Aghion et al., 2013b).

research sector.[10]

A crucial step before proceeding with the analysis is to assess the validity of the assumptions underlying our econometric model. This is done by conducting some generalized likelihood-ratio tests on the estimated parameters (Table 3). As a first check, we examine whether inefficiency is really contained in the data; to this aim, the baseline knowledge production 'frontier' (col. 1, Table 2) is tested against the 'average' knowledge production, which instead implies $u_{ij,t} = 0$ for all ij, t. The LR test for the hypothesis that σ_u=0, shown in the first row of Table 3, indicates that the variance of the inefficiency term is indeed statistically different from 0 (χ^2=20.6). Moreover, we evaluate whether both the set of industry/countries fixed effects and time dummies are significant in the KPF ($\alpha_{ij} = 0$ or $\tau_t = 0$); as shown by the statistic tests reported in the next two rows, the hypothesis that these groups of deterministic elements are equal to zero can be strongly rejected. Finally, we assess the significance of the parameters in the inefficiency equation, using regression (4a) as our best specification given that it is more conservative concerning the impact of financial input. Either when we consider all the covariates together or PMR taken alone, the null hypothesis is refuted, proving that R&D (in)efficiency depends on the institutional factors under assessment. These findings also confirm that our model is heteroskedastic.[11]

Table 3: Generalized LR tests on parameters of the frontier model

Null Hypothesis	Specification	Conditions	χ^2 statistics	Critical values (5%)
No inefficiency	1	σ_u=0	20.56	2.71[a]
No Industry/country dummies	1	α_{ij}=0	5318.54	178.48
No Year dummies	1	τ_t=0	704.95	21.02
No heteroskedasticity in $u_{ij,t} = 0$	(4a)	$\rho_{k\neq 0}$=0	970.55	42.55
No PMR effect upon $u_{ij,t} = 0$	(4a)	ρ_1=0	12.01	3.84

[a] This test is at the boundary of parameter space (σ_u); the critical value comes from Kodde and Palm (1986).

[10]In cols. (4a)-(4c), we find that returns to R&D are slightly lower in the KPF, whilst the spillover variable and financial input have a larger effect. In terms of coefficient size, the impact of the ratio to GDP of private bond market capitalisation dominates over the other proxies for financial development.

[11]Unreported LR tests indicate that industry- and country-specific time trends included into the inefficiency term are always different from zero. It confirms that, to consistently estimate the effect of upstream regulation, it is crucial to control for the deterministic evolution of this variable over time. In accordance with Fiori et al. (2012), when time trends are omitted PMR turns out to be insignificant.

Table 4: Maximum-likelihood estimation of the KPF with inefficiency equation: robustness checks

Specification			(1)	(2)	(3)	(4)	(5)	(6)
KPF, dependent variable: $I_{ij,t}$			Asset tangibility	Industry structure	Export structure	R&D input	Quality adj. patents	1-year lagged regressors
R&D stock	R	γ_1	0.102***	0.097***	0.110***		0.061**	0.103***
			(0.024)	(0.024)	(0.024)		(0.024)	(0.031)
R&D expenses	R	γ_1				0.052***		
						(0.017)		
Spillovers	K	γ_2	0.839***	0.856***	0.828***	0.751***	0.807***	0.768***
			(0.055)	(0.055)	(0.054)	(0.043)	(0.048)	(0.071)
Labor quality	H	γ_3	0.001	0.002	0.001	0.001	0.002	-0.001
			(0.002)	(0.002)	(0.002)	(0.002)	(0.002)	(0.002)
Finance: industry indicator × Bank credit/GDP	F	γ_4	0.032*	0.021**	0.021**	0.017	0.003	0.004
			(0.019)	(0.010)	(0.010)	(0.011)	(0.011)	(0.011)
Employment share	INDSH	γ_5		0.024***				
				(0.008)				
Export composition	EXPINT	γ_5			-0.003**			
					(0.001)			
Inefficiency equation, dependent variable: $ln(\sigma^2_{u_{ij,t}})$								
Product market regulation	PMR	ρ_1	0.177***	0.180***	0.198***	0.188***	0.188***	0.188***
			(0.051)	(0.051)	(0.053)	(0.063)	(0.057)	(0.051)
IPR protection (relative to US)	IPRP	ρ_2	-0.087***	-0.088***	-0.099***	-0.133***	-0.115***	-0.090***
			(0.015)	(0.015)	(0.017)	(0.019)	(0.017)	(0.017)
Employment protection (regulars)	EPLR	ρ_3	-0.552	-0.582	-0.695	-0.833	-0.855	-0.823
			(0.511)	(0.510)	(0.514)	(0.547)	(0.520)	(0.512)
Employment protection (temporary)	EPLT	ρ_4	0.342***	0.353***	0.362***	0.421***	0.306***	0.314***
			(0.088)	(0.088)	(0.089)	(0.101)	(0.090)	(0.089)
Financial reforms	FINR	ρ_5	0.024***	0.023***	0.027***	0.038***	0.034***	0.033***
			(0.009)	(0.009)	(0.009)	(0.010)	(0.009)	(0.009)
Constant		ρ_0	-120.178**	-137.504***	-146.561***	-148.628***	-196.995***	-123.700**
			(50.762)	(50.898)	(54.754)	(54.766)	(49.008)	(49.434)
$ln(\sigma^2_v)$								
Constant		ν_0	-5.003***	-5.007***	-4.898***	-4.171***	-4.557***	-5.557***
			(0.224)	(0.223)	(0.203)	(0.064)	(0.092)	(0.422)
Industry/country dummies		α_{ij}	Yes	Yes	Yes	Yes	Yes	Yes
Year dummies		τ_t	Yes	Yes	Yes	Yes	Yes	Yes
Industry trends		$t \cdot \eta_i$	Yes	Yes	Yes	Yes	Yes	Yes
Country trends		$t \cdot \mu_j$	Yes	Yes	Yes	Yes	Yes	Yes
Log-likelihood			344	350	348	321	270	333
Observations			1950	1950	1950	1950	1950	1800

[a] Industry/country FE, year dummies in the KPF, industry- and country-trends in the (in)efficiency equation omitted to save space. Full results available from the authors upon request. Cols. (2)-(6) use industry financial dependence. Col. (2) includes the industry share of total employment, col. (3) the US share of industry exports. Col. (4) relies on R&D expenses as research input. Col. (5) considers patent counts multiplied by the number of cites received, adjusted for truncation. Col. (6) is based on one-year lagged values of the KPF explanatory variables.

Table 5: Maximum-likelihood estimation of the KPF with inefficiency equation, different samples of countries

				NO US			Only EU countries	
Specification	Variable	Coef.	(1a)	(1b)	(1c)	(2a)	(2b)	(2c)
KPF, dependent variable: $I_{ij,t}$								
R&D stock	R	γ_1	0.101***	0.085***	0.121***	0.089***	0.083***	0.088***
			(0.028)	(0.025)	(0.025)	(0.027)	(0.027)	(0.028)
Spillovers	K	γ_2	0.654***	0.841***	0.847***	0.999***	1.007***	1.009***
			(0.050)	(0.059)	(0.058)	(0.055)	(0.054)	(0.056)
Labor quality	H	γ_3	-0.006*	-0.007**	-0.005	-0.008*	-0.005	-0.009**
			(0.004)	(0.003)	(0.003)	(0.004)	(0.004)	(0.004)
Finance: Fin. dependence × Bank credit/GDP	F	γ_4	0.024**			0.043***		
			(0.010)			(0.011)		
Finance: Fin. dependence × Private bond capitalization/GDP	F	γ_4		0.101**			0.238***	
				(0.046)			(0.048)	
Finance: Fin. dependence × Stock market capitalization/GDP	F	γ_4			0.077***			0.003
					(0.016)			(0.024)
Inefficiency equation, dependent variable: $ln(\sigma^2_{u_{ij,t}})$								
Product market regulation	PMR	ρ_1	0.215***	0.228***	0.204***	0.140**	0.110	0.142**
			(0.063)	(0.052)	(0.063)	(0.070)	(0.071)	(0.072)
IPR protection (relative to US)	IPRP	ρ_2	-0.131***	-0.120***	-0.119***	-0.083*	-0.102**	-0.093**
			(0.019)	(0.016)	(0.016)	(0.043)	(0.043)	(0.046)
Employment protection (regulars)	EPLR	ρ_3	-0.506	-0.685	-0.700	12.747***	13.056***	11.952***
			(0.555)	(0.501)	(0.485)	(1.765)	(1.734)	(1.997)
Employment protection (temporary)	EPLT	ρ_4	0.360***	0.317***	0.354***	0.085	0.049	0.142
			(0.103)	(0.087)	(0.085)	(0.124)	(0.124)	(0.126)
Financial reforms	FINR	ρ_5	0.034***	0.025***	0.016*	0.040***	0.042***	0.046***
			(0.010)	(0.009)	(0.009)	(0.011)	(0.011)	(0.011)
Constant		ρ_0	-126.059**	-234.403***	-282.878***	-37.235	-30.136	-72.377
			(57.898)	(51.344)	(49.434)	(63.981)	(64.408)	(67.214)
$ln(\sigma^2_v)$								
Constant		ν_0	-4.164***	-4.991***	-5.321***	-4.672***	-4.647***	-4.571***
			(0.083)	(0.215)	(0.268)	(0.185)	(0.172)	(0.190)
Industry/country dummies		α_{ij}	Yes	Yes	Yes	Yes	Yes	Yes
Year dummies		τ_t	Yes	Yes	Yes	Yes	Yes	Yes
Industry trends		$t \cdot \eta_i$	Yes	Yes	Yes	Yes	Yes	Yes
Country trends		$t \cdot \mu_j$	Yes	Yes	Yes	Yes	Yes	Yes
Log-likelihood			200	219	228	190	195	183
Observations			1755	1755	1755	1170	1170	1170

[a] Industry/country FE, year dummies in the KPF, industry- and country-trends in the (in)efficiency equation omitted to save space. The complete table available from authors upon request.

4.3 Sensitivity analysis

Now we perform some robustness checks to verify whether the regulation impact changes when allowing for a larger set of innovation inputs within the KPF, or with the composition of the country sample (Table 4 and 5).

In Table 4, we first use a proxy for financial input based on the degree of asset tangibility, in place of external finance dependence, multiplied by the bank credit-GDP ratio. As argued by Maskus et al. (2012), the firm need of external funds is likely to be ultimately determined by capital structure; therefore, asset tangibility could better capture industry heterogeneity in using financial input.[12] In fact, in col. (1) this factor has a slightly higher coefficient than in our previous estimates; nevertheless, the effect of all the other explanatory variables of the KPF, as well as the one of the inefficiency determinants, remains unchanged. Then, we introduce a time-varying control for the industrial structure of each country, defined as the sector share on total employment. The rationale is that the larger the industry, and its growth over time, the higher patenting. This expectation is confirmed by regression (2). In col. (3), we account for heterogeneity in trade specialization. The propensity to patent in the US might indeed reflect the extent to which a country sells its products on this market. This issue is controlled for by including the share of industry exports towards the US.[13] Surprisingly, this variable has a negative impact which, however, is not economically relevant; it may be explained with the use of both of country/industry fixed effects and our proxy for trade specialisation within the same specification. The sensitivity analysis proceeds considering R&D expenses, expressed in real terms, as a measure of research input. As expected this variable has a smaller coefficient than R&D stock (col. 4). It should also be noted that, in this regression, financial input is not significant. A similar finding emerges in the two subsequent regressions (cols. 5 and 6). The former considers patent counts weighted with the number of cites received to qualitatively adjust our measures of innovation output and technology spillover (see Hall et al., 2001, 2005); the latter uses one-year lagged values of all the explanatory variables

[12] Asset tangibility is given by the average share of structure, transport and non-ICT equipment on total capital expenditure, observed on the US industries during the 1980s. The high correlation between the measures of financial input based on external finance dependence and asset tangibility inhibits the inclusion of both variables within the same specification.

[13] For the US, we consider the cross-country average value of import shares.

to allow for possible delays in their effect on patenting. Overall, this group of robustness checks strongly confirms the solidity of our regression framework in assessing the effect of upstream regulation on R&D efficiency, as the coefficient of our key explanatory variable remains stable across specifications. It is worth recalling that the regression approach adopted in this work (SFA) does not allow to directly control for reverse causality between innovation efficiency and PMR; however, in our framework, the endogenity issue is softened by the long time lag existing between the design and the implementation of the changes in competition legislation.

Table 5 examines the sensitivity of the results to the composition of country sample; in such checks, we use the full set of financial development indicators. As a first step, we exclude the US to control for the possible home bias associated with the usage of USPTO data to measure innovative output. Indeed, one may be concerned that our results are driven by the patenting performance of American industries, as well as by the product market policies pursued in this country. Estimates reported in cols. (1a)-(1c) clearly exclude this possibility. As expected, the regulation impact is moderately stronger than in our prior findings (0.21-0.24). On the other hand, in knowledge production, the effect of technology spillovers is larger whilst returns to R&D are lower; this confirms the primary role played by the pool of external knowledge for patenting of the laggard countries.

As discussed above (Nicoletti and Scarpetta, 2003; Inklaar et al., 2008), there is large consensus that the EU has been struggling in terms of productivity performance because of an institutional architecture of the markets less conducive to economic growth. Hence, it is legitimate to ask to what extent such a detrimental effect is channelled by innovation activities; for this reason we re-estimate the model considering only the EU member states (Table 5, cols. 2a-2c). Interestingly, it emerges that the impact of product market regulation on R&D efficiency is smaller than found above, and is even insignificant when private bond capitalization over GDP is used as a proxy for financial development (col. 2b). In Europe, research efficiency is severely depressed by the legal discipline of regular contracts; conversely, the protection for temporary workers does not exert any statistically significant impact. These findings somehow conform to Bassanini et al. (2009) where it is documented that technological catch-up with the productivity frontier is negatively influenced only by the former type of employment protection.[14]

[14]We also inspect whether there is heterogeneity in the impact of PMR according to the

5 Discussion

This section discusses the results of the econometric analysis and the associated policy implications. As a first step, we compute the mean efficiency scores for each industry/country pair from our benchmark specification (col. 4a, Table 2). In Figure 1, we report the country average scores evaluated at three reference years.[15] It should be observed that, despite the econometric model includes a number of country-specific deterministic elements, well-defined nationwide patterns emerge in efficiency performance. In our sample, there are three outstanding economies: the US, Japan and Germany. On average, efficiency scores increased over time in most economies, but fell in France and the UK. The Netherlands and Sweden rapidly improved their performance during the 1990s, probably as a result of the increasing specialisation in (some) high-tech productions. Interestingly, Italy ranks relatively well in efficiency terms, albeit being a laggard either for innovative output or research effort. Table 6 details average efficiency scores by country and industry. The US broadly outstrip the other economies in technologically advanced industries, such as office machinery, electrical equipment, communication eq. and other transport eq., but not in pharmaceuticals where Germany is leading. On the contrary, cross-country differentials appear narrower in less technologically advance productions.

Next, we calculate the marginal effect of upstream regulation with a view to raising the economic interpretation of the econometric results. In doing so, we track how the unit impact of PMR changes along its distribution in

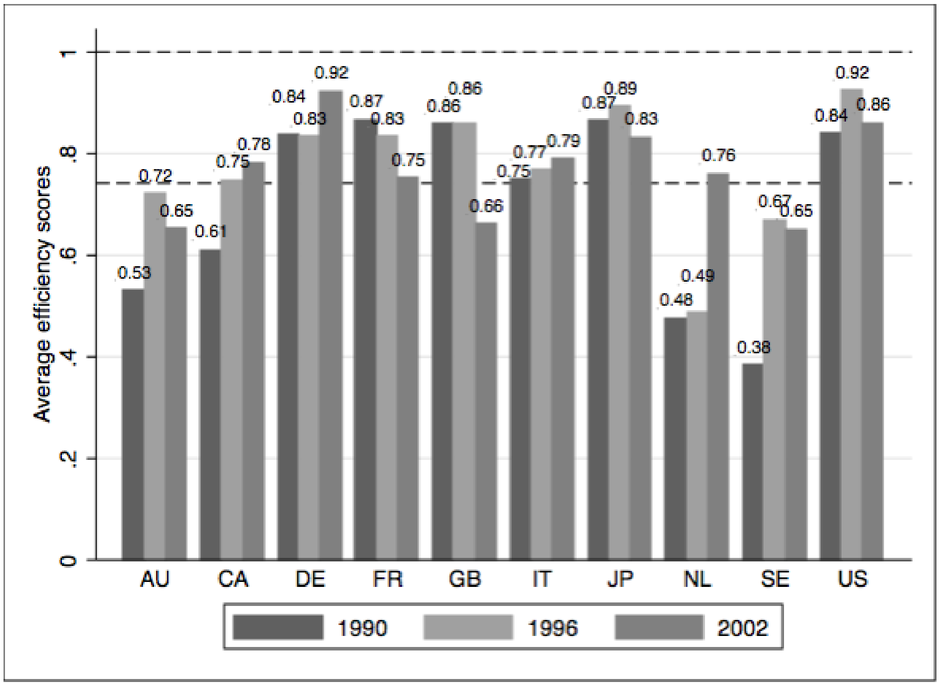
technological base of the industry production. There is evidence that high-tech sectors are less influenced by PMR; however, this finding is quite sensitive to the criterion followed to group industries.

[15]Efficiency scores are calculated for each country j on an annual base as: $\sum_i TE_{ij,t}/I$, where $TE_{ij,t} = exp(-\widehat{u}_{ij,t})$. In turn, inefficiency scores have been obtained through the conditional (to the overall residual) mean estimator, corrected for heteroskedasticity, developed by Jondrow et al. (1982):

$$\widehat{u}_{ij,t} = E\left(u_{ij,t}|\epsilon_{ij,t}\right) = \frac{\sigma_v \sigma_{u_{ij,t}}}{\sigma_{ij,t}} \left[\frac{\phi\left(\frac{\epsilon_{ij,t}\lambda_{ij,t}}{\sigma}\right)}{1-\Phi\left(\frac{\epsilon_{ij,t}\lambda_{ij,t}}{\sigma_{ij,t}}\right)} - \left(\frac{\epsilon_{ij,t}\lambda_{ij,t}}{\sigma_{ij,t}}\right)\right],$$

where $\sigma_{ij,t} = \sqrt{\sigma_v^2 + \sigma_{u_{ij,t}}^2}$, $\lambda_{ij,t} = \sigma_{u_{ij,t}}/\sigma_v$, and $\phi(\cdot)$ and $\Phi(\cdot)$ denote, respectively, the density function and the cumulative function of the standard normal distribution. Estimates of $\epsilon_{ij,t}$ are directly recoverable from eq. (3): $\widehat{\epsilon}_{ij,t} = I_{ij,t} - \widehat{\alpha} - \widehat{\theta} \ln Z_{ij,t} - \widehat{\alpha}_{ij} - \widehat{\tau}_t$.

Figure 1: Average technical efficiency by country, selected years



order to verify whether there are non-linearities in the effect of this variable.[16] The mean partial effect amounts to 0.028. It implies that an unit *decrease* in regulation is associated with a 2.8% *increase* (reduction) in R&D efficiency (inefficiency) and, through this channel, in patenting. This value is comparable in size to the effect of PMR on the employment rate (0.3-0.4%), investment (1%), and convergence rates towards the productivity frontier (6-12%) found in earlier studies.[17] Intuitively, using the sample average value as benchmark, our evidence indicates that if upstream regulation halved (from 9 to 4.5%), R&D efficiency would increase by 13%, and the number of patents would approximately rise from 3 to 3.5 per thousand employee.

[16]Following Wang (2002) and Liu and Myers (2009), marginal effects are defined as:

$$\frac{\partial \left[E\left(u_{ij,t} | \ln Z_{ij,t}, PMR_{ij,t}, \mathbf{W} \right) \right]}{\partial PMR_{ij,t}}.$$

[17]See respectively Fiori et al. (2012), Alesina et al. (2005), Bourlés et al. (2012).

Table 6: Efficiency scores by country and industry: averages

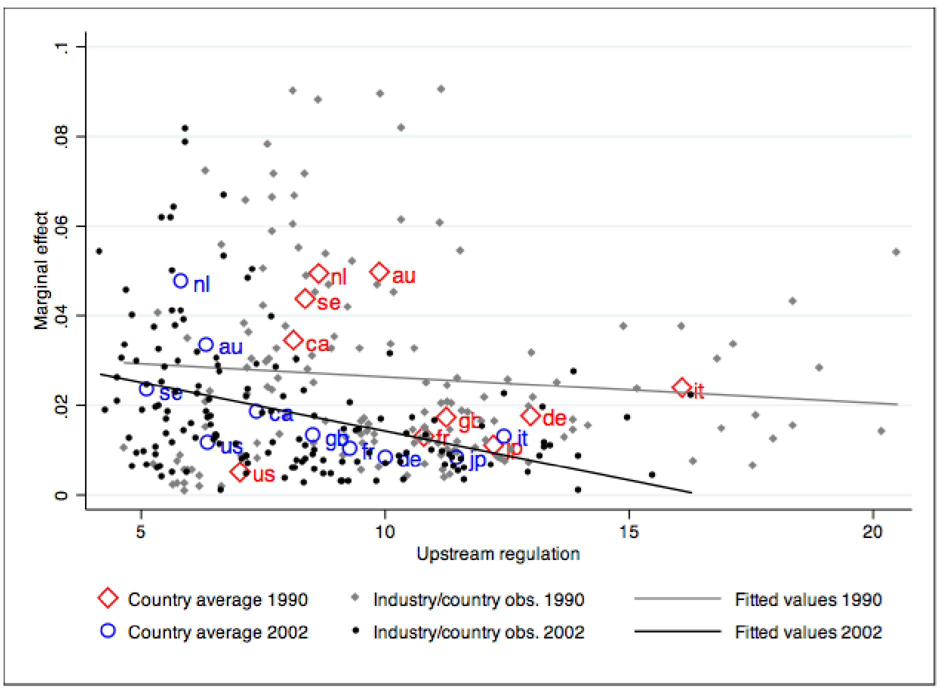
Industry \ Country	AU	CA	DE	FR	GB	IT	JP	NL	SE	US	TOTAL
Food, beverage and tobacco	0.59	0.73	0.78	0.69	0.60	0.70	0.80	0.49	0.58	0.85	0.68
Chemicals	0.67	0.84	0.94	0.92	0.90	0.84	0.93	0.76	0.79	0.94	0.85
Pharmaceuticals	0.61	0.64	0.86	0.76	0.73	0.67	0.77	0.67	0.60	0.80	0.71
Rubber and plastics	0.69	0.84	0.92	0.89	0.88	0.76	0.92	0.70	0.67	0.92	0.82
Other non-metallic minerals	0.70	0.80	0.87	0.86	0.82	0.78	0.91	0.68	0.68	0.91	0.80
Basic metals	0.64	0.83	0.88	0.81	0.76	0.64	0.89	0.57	0.61	0.90	0.75
Fabricated metal products	0.58	0.75	0.88	0.80	0.82	0.75	0.89	0.52	0.69	0.91	0.76
Machinery	0.84	0.92	0.96	0.94	0.94	0.91	0.96	0.81	0.84	0.96	0.91
Office machinery	0.41	0.57	0.79	0.80	0.73	0.71	0.79	0.39	0.51	0.82	0.65
Electrical equipment and apparatus	0.52	0.79	0.81	0.84	0.81	0.75	0.82	0.31	0.67	0.87	0.72
Communication equipment	0.60	0.56	0.77	0.81	0.76	0.74	0.86	0.43	0.51	0.87	0.69
Medical and scientific instruments	0.75	0.83	0.91	0.88	0.89	0.85	0.91	0.51	0.74	0.93	0.82
Motor vehicles	0.70	0.67	0.82	0.86	0.80	0.73	0.87	0.61	0.67	0.90	0.76
Other transport equipment	0.67	0.57	0.79	0.78	0.73	0.55	0.76	0.43	0.59	0.88	0.67
Other manufacturing	0.73	0.83	0.92	0.84	0.85	0.78	0.89	0.65	0.67	0.92	0.81
TOTAL	0.65	0.74	0.86	0.83	0.80	0.74	0.86	0.57	0.65	0.89	0.76

Figure 2 plots the partial effect observed on each industry/country pair against the PMR distribution, as well as the corresponding linear interpolations, at the beginning and at the end of the sample period (denoted in grey and black, respectively). The graph also reports the average marginal impact at the country level (marked by red diamonds and blue circles). Overall, Figure 2 illustrates that the effect of regulation on inefficiency is positive along the *entire* distribution of PMR. Though, the highest unit impact is not found for the most regulated countries (Italy, Japan and Germany), but for the economies more prone to market competition such as the Netherlands. In other words, anti-competitive legislation is more harmful for innovation efficiency when the level of regulation is low. It means that product market reform programmes are unlikely to produce sizeable effects at the earlier stages of deregulation. These results are in line with Alesina et al. (2005) who find that the positive effect of deregulation on investment is inversely related to the starting level of anti-competitive barriers. Consistently with this pattern, Figure 2 shows that the negative relationship between marginal impact and level of regulation strengthened during the 1990s as OECD economies started opening their product markets (the slope of the interpolation line increases). The partial impact of PMR was largely heterogeneous among countries at the beginning of the 1990s, but in the subsequent decade it converged both in terms of levels and dispersion.[18]

[18]The negative relationship between level and marginal impact of regulation is weaker at the extreme tails of the distribution (below the 10th and above the 90th percentile). This

Our results indicate that for late reformers, although the *unit* benefits from deregulation are relatively modest, *total* gains may be substantial. For instance, if Italy reduced service regulation to the US levels (i.e. a ten points reduction), it could obtain a 16% increase in R&D efficiency and patenting (total gains = unit impact × change in regulation levels). This value largely exceeds the benefits that could be obtained from convergence towards to the US standards by a low regulated country such as Canada (3.7%=2.8% × 1.3).

Figure 2: Marginal effect of PMR on inefficiency



finding mainly reflects the performance of Italy and the US which denote relatively similar unit impacts, but two profoundly different institutional settings. For these countries, the marginal effect of PMR is estimated around 1.6 and 1.9%, respectively.

6 Concluding remarks

As R&D-based endogenous growth theories influentially state, knowledge creation is one of the crucial forces to expand at a stable rate in the global economy. However, the ability to efficiently manage R&D resources, and therefore to achieve better growth performances, cannot be taken for granted.

There is widespread evidence indicating that barriers to competition hamper the market entry and the arrival of new innovations. Thus far, less explored has been the issue of how the regulation in the upstream product markets reverberates on downstream innovation. This paper has filled this lack undertaking a stochastic frontier analysis on the knowledge production function of a large sample of OECD industries, investigating whether regulation in the service sector influences efficiency levels in innovation activities conducted by the manufacturing industries.

Our econometric analysis clearly shows that PMR depresses R&D efficiency downstream. This finding is robust to controlling for a large array of institutional factors such as IPR protection, employment protection legislation and financial regulation. There is evidence of some heterogeneity in the regulation impact across countries, as this effect is moderately weaker among the EU member states. In the post-estimation analysis, we have computed the marginal effect of PMR and verified whether its unit impact changes with the stringency of the regulatory setting. We have seen that the detrimental effect of this institutional factor is stronger in less regulated economies. The negative relationship between unit impact and level of regulation strengthened during the 1990s when product market reforms were launched by most OECD economies. These findings have important implications for policy-making as suggesting that significant improvements in R&D efficiency, patenting, and more generally innovation outcomes, cannot be achieved in a relatively short-term horizon, or at the beginning of the deregulation programmes. Market liberalization takes time to produce widespread effects within the economy. In absolute terms, gains from deregulation are however more relevant for those countries starting from a more restrictive setting to competition.

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