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R&D, Patenting and Growth: The Role of Public Policy

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ABSTRACT/RÉSUMÉ

R&D, patenting and growth: the role of public policy

This paper uses panel regression techniques to assess the policy determinants of private sector innovative activity – proxied by R&D expenditure and the number of new patents – across 19 OECD countries. The relationship between innovation indicators and multifactor productivity (MFP) growth is also examined with a particular focus on the role of public policies in influencing the returns to new knowledge. The results establish an empirical link between R&D and patenting, as well as between these measures of innovation intensity and MFP growth. Innovation-specific policies such as R&D tax incentives, direct government support and patent rights are found to be successful in encouraging the innovative activities associated with higher productivity growth. However, direct empirical evidence of the positive effects of these policies on productivity is less forthcoming. A pervasive theme from the analysis is the importance of coupling policies aimed at encouraging innovation or technological adoption with well designed framework policies that allow knowledge spillovers to proliferate. In particular, the settings of framework policies relating to product market regulation, openness to trade and debtor protection in bankruptcy provisions are found to be important for the diffusion of new technologies.

JEL classification codes: L20; O30; O40.
Keywords: Intangible assets; innovation; productivity growth; public policy.

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R&D, brevets et croissance : le rôle des politiques publiques

Ce document utilise des techniques de régression en panel pour évaluer les déterminants politiques de l'activité d'innovation du secteur privé – représentée par les dépenses de R & D et le nombre de brevet - à travers 19 pays de l'OCDE. La relation entre les indicateurs de l'innovation et la croissance de la productivité multifactorielle (PMF) est également analysée avec une attention particulière sur le rôle des politiques publiques pour influencer les rendements de nouvelles connaissances. Les résultats établissent un lien empirique entre la R & D et les brevets, ainsi qu'entre ces mesures de l'intensité de l'innovation et la croissance de la PMF. Des politiques spécifiques d'innovation telles que des incitations fiscales pour la R & D, le soutien direct de l'État et les droits de brevet sont avérées efficaces pour encourager les activités innovantes associées à une plus forte croissance de la productivité. Toutefois, les preuves empiriques directes des effets positifs de ces politiques sur la productivité sont plus rares. Un thème récurrent de l'analyse est l'importance du couplage des politiques visant à encourager l'innovation ou l'adoption technologique avec des politiques-cadres bien conçues qui permettent une plus large diffusion des connaissances. En particulier, les paramètres des politiques-cadres relatives à la réglementation des marchés de produits, l'ouverture au commerce et à la protection du débiteur dans les dispositions de la faillite sont jugés importants pour la diffusion des nouvelles technologies.

Classification JEL : L50 ; 030 ; 040.
Mots clefs : Les immobilisations incorporelles ; l'innovation ; croissance de la productivité multifactorielle ; politiques publiques.

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R&D, PATENTING AND GROWTH: THE ROLE OF PUBLIC POLICY

By Ben Westmore[1]

1. Introduction

1.1 Context and purpose

1. Beginning with the work of Solow (1956), the importance of innovation as a driver of long-term economic growth has long been recognised. Such activity may be characterised by increasing returns to scale as innovation by one entity can produce externalities, in the form of knowledge spillovers, that benefit follow-on innovators. The fact that these spillovers are often non-rival and non-excludable results in the social rate of return to many innovative activities exceeding the private rate of return (Arrow, 1962). As a consequence, private firms tend to under-invest in innovation, potentially motivating public policy intervention to boost innovative activity to more socially optimal levels.

2. This paper investigates the influence of public policies on private sector innovation and the returns to new knowledge. The analysis uses country-level data to assess: *i)* the policy determinants of business research and development (R&D); *ii)* the policy determinants of the number of new patents; and *iii)* the link between innovative activity and multifactor productivity (MFP). One benefit of studying innovation at the aggregate instead of the sectoral or firm level is that the spillover effects between firms, industries and countries that are associated with innovation are better identified (Guellec and Van Pottelsberghe, 2003). Spillovers are critical in determining the degree to which new technologies, production processes and organisational methods translate into economy-wide productivity gains, and public policies may play a role in shaping this process. Nevertheless, a possible downside to an aggregate-level study is that the estimated relationships may be more sensitive to changes in sectoral specialisation patterns and less informative about the channels through which policies influence innovation and productivity growth than analysis based on more disaggregated data.

3. This study is conducted over three separate panels of 19 countries[2] from the mid-1980s to 2008 and is an update and extension of earlier OECD work by Jaumotte and Pain (2005a). A number of key findings emerge from the analysis:

- Both business and non-business R&D have a positive influence on patenting activity. In turn, business R&D and the stock of patents are positively associated with MFP growth. There is some evidence that innovative activity has a larger effect on MFP growth when the share of business researchers in total employment is high, reflecting the importance of absorptive capacity for the proliferation of knowledge spillovers.

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1 Ben Westmore (ben.westmore@oecd.org) is a member of the Economics Department of the OECD. This paper is part of the Working Party No.1 project on "Knowledge-based capital, innovation and resource allocation" conducted jointly with the Science, Technology and Industry Directorate. Without implication, the author would like to thank several OECD colleagues; Dan Andrews, Jørgen Elmeskov, Giuseppe Nicoletti, Chiara Criscuolo and Carlo Menon, for valuable comments and suggestions, Catherine Chapuis for technical assistance and Irene Sinha for editorial support. The views expressed in this paper are those of the author and do not necessarily reflect those of the OECD and its member countries.

2 Countries included are Australia, Austria, Belgium, Canada, Denmark, Finland, France, Germany, Ireland, Italy, Japan, Netherlands, Norway, Portugal, Spain, Sweden, Switzerland, United Kingdom and the United States of America.

- More generous innovation-specific policies are found to encourage private sector innovative activity, though empirical evidence regarding the direct impact of such policies on MFP growth is less forthcoming. In particular;
    - R&D tax incentives are positively associated with recorded private sector R&D spending. However, this does not hold in countries that frequently reverse policy settings, suggesting that a predictable policy environment may be important for the efficacy of such measures.
    - In contrast with some earlier studies, direct government support for private R&D is found to be positively associated with business R&D spending. This finding relies on data from the post-2000 period, raising the possibility that the design of such policies has improved through time.
- Framework policies that promote competition have a pervasive influence on incentives to innovate and the returns to new ideas. For example:
    - Pro-competition reforms to product market regulation are associated with an increase in the number of patents. There is also some, albeit weaker, evidence that such reforms encourage higher business R&D spending.
    - Strengthening patent rights is more likely to encourage patenting activity when regulatory barriers to firm entry are low.
    - Domestic patenting activity appears to benefit from access to foreign R&D, but only when combined with low barriers to firm entry. Such an environment mitigates the opportunity for incumbent firms with monopoly rights over existing technologies to resist the adoption of innovations from abroad. This idea aligns with the finding that countries are slower to converge to the productivity frontier when product market regulation is strict.
    - Less stringent product market regulation is associated with higher MFP growth. This may reflect easier implementation and commercialisation of new ideas in more competitive markets.
    - Provided that domestic barriers to firm entry are low, countries with greater geographical proximity to technological leader countries exhibit stronger MFP growth.
- Other framework policies relating to trade and bankruptcy laws may also be important for the diffusion of innovations from abroad. In particular:
    - Firms with access to a greater quantity of foreign R&D undertake less domestic R&D, suggesting a degree of substitutability between the two sources of innovation.
    - Countries behind the productivity frontier tend to converge more rapidly the more open they are to trade.
    - Convergence is faster in countries with bankruptcy regimes that are less punishing to debtors. This is consistent with firm level evidence suggesting that low exit costs make it less likely that resources are tied up in inefficient firms (Andrews and Cingano, 2012).

1.2 Roadmap

4. The next section examines the existing evidence of the links between innovation and productivity growth, outlining a framework for thinking about the relationship between the variables of interest and the influence of public policies. Section 3 describes three empirical models that seek to explore the links between a range of potentially relevant policy variables and the key outcome variables relating to business R&D, the number of new patents per capita and multifactor productivity growth respectively. Section 4 describes the data used for the analysis and Section 5 presents the econometric results. Section 6 summarises the findings and offers some concluding thoughts.

2. Innovation and public policies in OECD countries: existing evidence

2.1 The relationship between innovation and productivity growth

5. A large volume of literature has found that the majority of income differences in developed economies cannot be explained by the stock of labour and tangible capital resources (Caselli, 2005). The residual is ascribed to differences in productivity that depend on countries' ability to accumulate intangible assets, not least through the process of innovation and its diffusion. For each of the 19 OECD countries in the sample, Figure 1 plots the evolution of a measure of MFP that accounts for the capital stock and employment adjusted for human capital (Panel A), along with the business R&D stock to GDP (Panel B) and the stock of triadic patent families (Panel C).[3] Before proceeding, it is important to recognise that such measures of MFP are prone to measurement error as they are derived as the residual once the other (imperfectly measured) production factors are taken into account. That said, common patterns in measured productivity have recently been exhibited across the countries in the sample, with average MFP growth generally slowing since 2000 relative to the previous decade.[4]

6. Empirical studies tend to find a positive link between business R&D and measures of innovative outputs such as new patents (see Danguy *et. al.,* 2009 for a review) and more importantly, productivity growth (see Nadiri, 1993 or Hall *et. al.,* 2009 for a review).[5] Examining trends in these variables indicates that in Belgium, Canada, Ireland and the United States, a slowing in the pace of productivity growth since 2000 has occurred at the same time as weaker growth in the stock of business R&D (to GDP) and patents. Nevertheless, movements in productivity growth in a number of countries do not seem to accord with trends in R&D and patents. Certainly, recent declines in productivity in many regions are difficult to reconcile with increases in the stock of business R&D and patents over the period.[6] Taken together, these trends suggest that while it is important to gain a better understanding of the policy determinants of business R&D and patenting activity, it is also necessary to investigate the factors that may influence the degree to which such innovative activity is reflected in movements in measured productivity growth.

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3 A triadic patent family is a series of patents for the one invention filed at the European Patent Office and the Japan Patent Office, and granted at the United States Patent and Trademark Office. These are generally high value patents less affected by patenting propensity than other measures (de Rasenfosse & van Pottelsberghe, 2008).

4 This is the case in 17 of the 19 countries even if the post-2007 financial crisis period is excluded from the calculation.

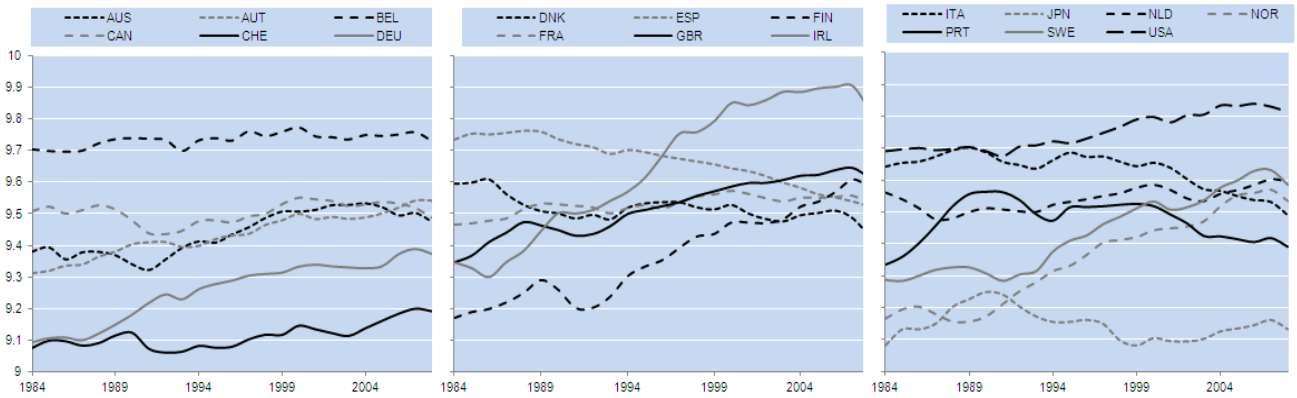
5 Innovation is the result of a range of activities including R&D, informal learning by doing, non-R&D knowledge-building expenditures as well as the registration and commercialisation of new ideas. While R&D expenditure and the number of new patents are the most suitable proxies for innovation when making comparisons across time and countries, they do not capture the full range of such activity and can be affected by factors outside the innovation process. For example, a patent does not reflect the quality of new ideas and can be lodged for strategic purposes such as earning licensing revenue, for increasing the chance of attracting capital or as a negotiation tool with competitors and collaborators (Danguy *et.al*., 2009).

6 This seeming inconsistency may also have to do with the fact that the knowledge-based capital thought to underlie innovation comprises a broader range of assets than just R&D and patents.

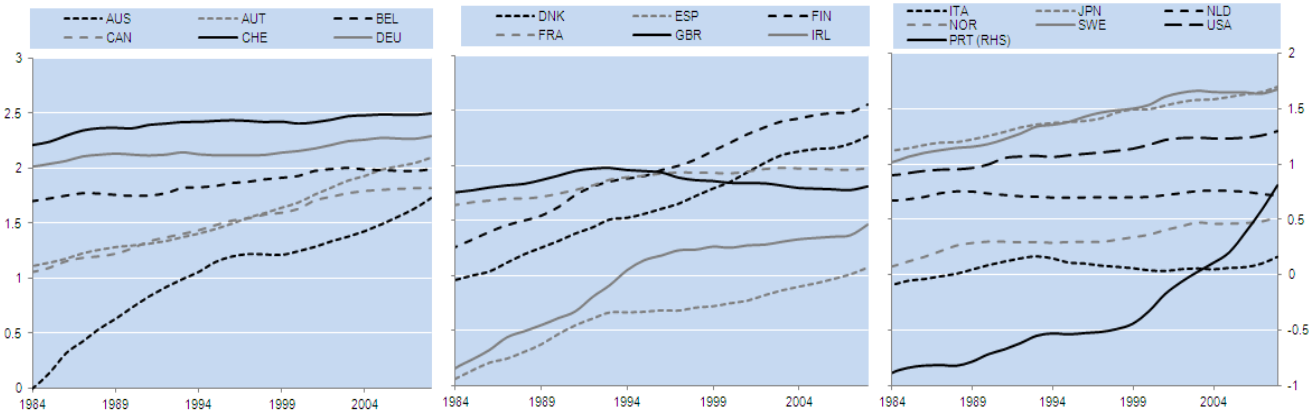
Figure 1. Cross country differences in MFP, the business R&D stock to GDP and the patent stock

1984-2008, log scale

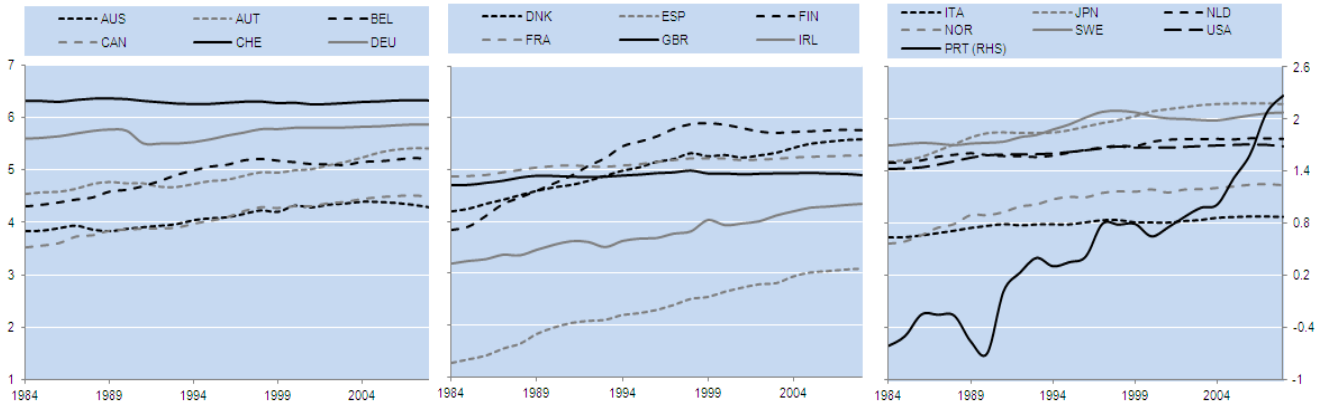
Panel A: Multifactor Productivity



Panel B: Business R&D stock to GDP (%)



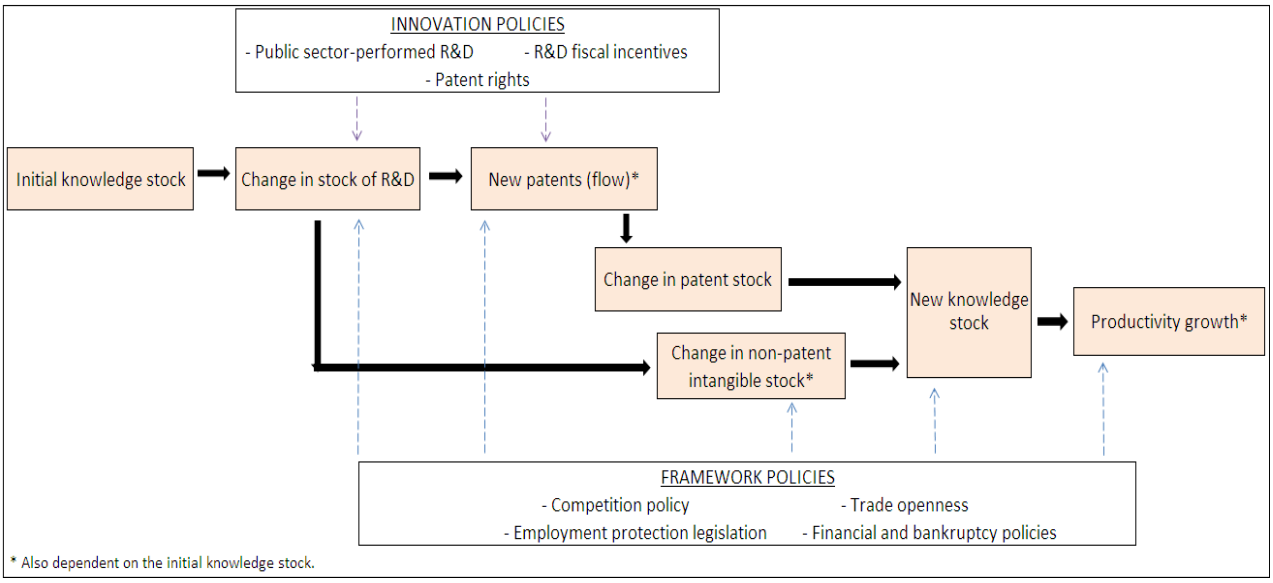
Panel C: Patent stock per capita



Source: The stock of R&D and patents per capita are author's calculations based on data from OECD *Science and Technology Indicators*. MFP data are taken from Johansson and Murtin (2012) and, along with the business R&D stock to GDP, are calculated from data in constant 2005 PPP USD terms. Panel C shows signs of a possible data break in Germany around the time of the country's reunification. However, unreported regressions controlling for this break confirm that the estimation results reported in Section 5 are robust to this feature of the data.

7. The innovation process is complex and varies greatly across industries and technologies. With this in mind, Figure 2 portrays a general – albeit heavily stylised – framework that maps the linkages between government policies, measures of innovation and productivity growth.

Figure 2 – A stylised depiction of the private sector innovation process



Note: Non-R&D expenditures and informal innovation at the workplace level are also methods for augmenting the existing knowledge stock and driving productivity growth not illustrated here.

8. From an initial knowledge state that is drawn-upon throughout the innovation process, firms invest in R&D in the conviction that growth in the stock of such activity improves the probability of innovative success – which can be imperfectly proxied by the number of new patents.[7] The non-rivalrous nature of knowledge means that it is possible for novel ideas generated from R&D to be used by other innovative entities at no additional cost, enabling increasing returns to R&D in terms of the number of new patents. Likewise, a subsequent rise in the stock of patented ideas can benefit multiple follow-on innovators as a condition of being conferred patent rights is that the patent holder publicly discloses technical information regarding the underlying innovation. As made explicit in Figure 2, R&D may also contribute to increasing the stock of technological advances that are not patented. In the case of non-patent intangibles, firms can use other methods of appropriating returns such as secrecy, barriers to entry and long lead times.

9. New ideas – patented or not – are absorbed into the knowledge stock and can contribute to higher productivity as they are utilised to produce a higher volume of output for the same volume of inputs.[8] The effect on productivity is the focus of Figure 2 and the analysis that follows, but it should be acknowledged that, in the short to medium term, the gains from innovation could come in the form of higher firm profits as innovations may lower input costs or allow firms to raise finished good prices without increasing the volume of output. The magnitude of the effect on productivity is likely to be influenced by the quality and

7 The estimated relationship between R&D and patenting tends to be weaker in studies utilising within-firm or industry level data (Czarnitzki et.al., 2008; Hausman et.al., 1984) than in a number of cross-country panel studies (de Rassenfosse and van Pottelsberghe, 2009; Falk, 2004b; Jaumotte and Pain, 2005a; Sanyal and Jaffe, 2005). This may reflect the presence of spillovers to R&D that are better captured at higher levels of data aggregation.

8 The amount of R&D may also influence the ability of firms to absorb new knowledge (*i.e.* Griffith *et. al.,* 2004) and hence the productivity effects.

execution of new ideas as well as the size of the spillovers that exist. Each stage of the innovation process will be influenced by government policies (the dashed arrows in Figure 2) relating specifically to innovation as well as economy-wide framework policies, which are now discussed in turn.

2.2 Innovation policies

10. Innovation-specific policies strengthen business incentives to innovate, counteracting the private under-investment in such activity. A number of such policies are targeted to particular types of firms or industries, and hence, may be best analysed using event studies or data at a highly disaggregated level. The analysis in this paper focuses on a few larger scale innovation policies for which relatively reliable cross-country data exist and that are suspected to directly influence the dependent variables of interest.

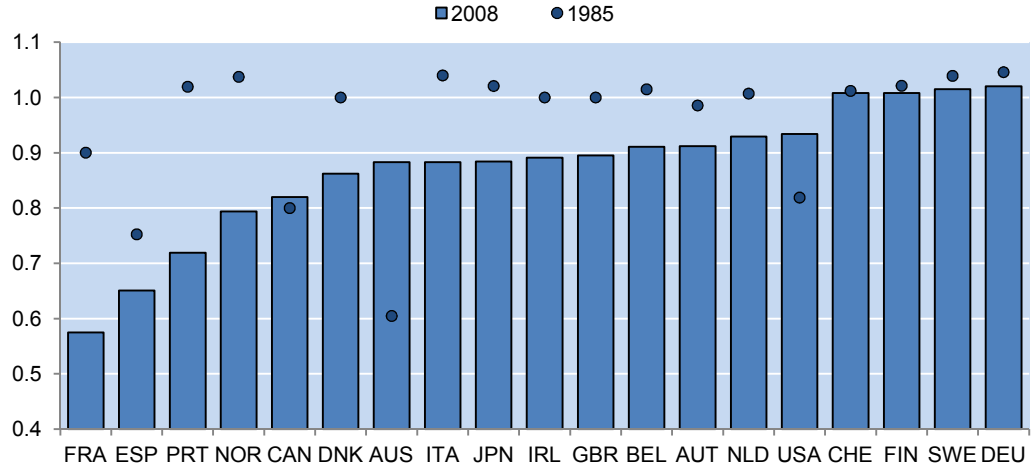
2.2.1 R&D tax incentives

11. Tax incentives for R&D can take various forms but are market-based instruments that leave firms to decide which R&D activities to fund. Either expenditure-based schemes (*i.e.* R&D tax credits, tax allowances and payroll withholding tax credits for R&D wages), or income-based schemes (*i.e.* taxing income derived from knowledge-based capital at a preferential rate), can be implemented. The overall generosity of R&D tax incentives can be summarised by the B-index (Warda, 2001), which represents the required rate of pre-tax return to justify $1 of R&D outlay taking account of both R&D tax incentives and the corporate income tax rate. Consequently, an increase in R&D tax incentives is reflected by a decline in the B-index.

12. A comparison of the level of the B-index for the sampled countries in 1985 and 2008 highlights that R&D tax incentives in most countries have become more generous in recent years, but important cross-country differences remain (Figure 3).

Figure 3. R&D tax incentives

The B-index at 1985 and 2008



Source: OECD

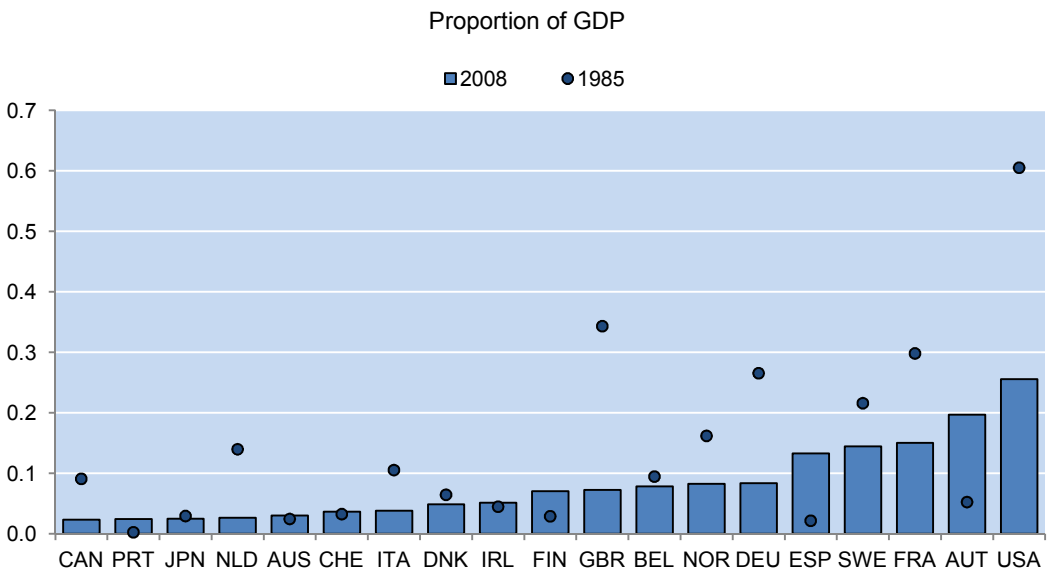
13. The majority of existing cross-country studies find that tax incentives are effective in explaining the evolution of business R&D with a long-run elasticity around unity: on average, one dollar of tax incentive eventually induces one dollar of recorded private R&D spending (Hall and Van Reenen, 2000). This may vary with the design of the incentive, with incremental tax credits (i.e. R&D expenditures are

only eligible if they exceed some baseline amount) sometimes found to be more effective in inducing business R&D spending than general – volume-based – tax credits (i.e. all R&D expenditures are eligible; Lokshin & Mohnen, 2009). Regardless, the implications for economic welfare are unclear since the introduction of an R&D tax incentive raises administrative and compliance costs as well as the need for financing through distortionary taxation (see Box 1).

2.2.2 Government financed business R&D

14. Direct government funding of private R&D can come in a number of different guises (*e.g.* grants, loans, loan guarantees etc.) and can vary significantly in the way it is administered. Taking all such instruments together indicates that while there is significant cross-country variation in the ratio of government financed business R&D to GDP, direct funding has generally become less supportive of R&D over the past few decades (Figure 4). This contrasts with the trend in the generosity of R&D tax incentives and reflects a growing acknowledgment that although, in principle, direct funding schemes allow governments to select R&D activities with the highest marginal social returns, in practice, identifying such projects can be complicated by information asymmetries and decisions may be influenced by rent-seeking entities.

Figure 4. Government financed business R&D



Source: OECD

15. The tendency for governments to move away from direct support has been reinforced by a body of empirical research that remains inconclusive as to whether such schemes encourage additional private R&D (David *et al.*, 2000). Instead, it may be that firms substitute public R&D funds for their own or that subsidies feed into higher wages rather than a greater volume of R&D (Goolsbee, 1998; Jaumotte and Pain, 2005a).

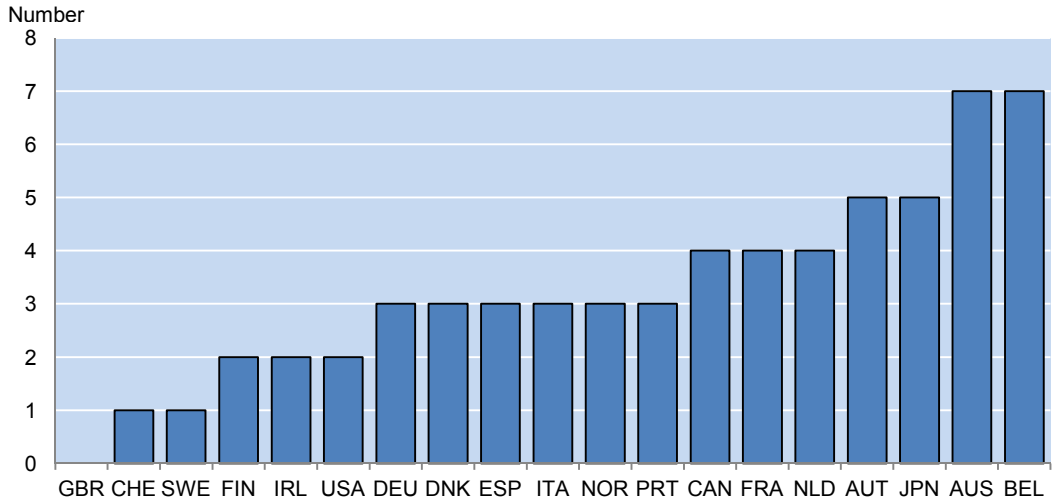
16. Whether government assistance is provided through tax incentives or direct funding, there is some evidence that the effect of such R&D policies can be undermined if they are particularly "unstable" - proxied by the standard deviation of policy variables (Guellec and Van Pottelsberghe, 2003). Cost certainty is important for many R&D projects given that they often have a multi-year horizon and the investment decision is difficult to reverse once the project is commenced (Pindyck, 1992). It may be, however, that unstable but predictable policy movements still allow private firms to confidently plan and implement

R&D projects. As such, a better proxy for policy instability may be a measure of the frequency with which policy has reversed course, rather than simply an indicator of the dispersion of policy from its mean over a given period.

17. Measuring the unpredictability of R&D tax policy as the number of instances in which the B-index immediately reversed course over the 1981-2008 period highlights significant dispersion across the countries in the sample (Figure 5).[9] Moreover, a simple regression between this variable and the within country standard deviation of the B-index suggests that the two measures are not statistically related to one another.

Figure 5. Cumulative "reversals" in R&D tax policy

1982-2008



Source: Authors calculations based on data from the OECD *Science, Technology and Industry Outlook*

2.2.3 Government performed research

18. Empirical studies occasionally find that public research induces further private sector R&D (Falk, 2004a), but there is also evidence that such funding can displace private investment (Guellec and Van Pottelsberghe, 2003). In general, evidence that public R&D is a substitute for private R&D is most commonly found in studies at lower levels of aggregation (David *et al.,* 2000). While history provides numerous instances of government research being at the root of revolutionary commercial technologies, the lags can be long and unpredictable and thus difficult to identify empirically (Sheehan and Wyckoff, 2003). A common example is the internet revolution of the past few decades, which evolved from government investments that were made as far back as the 1960s.

2.2.4 Patent Protection

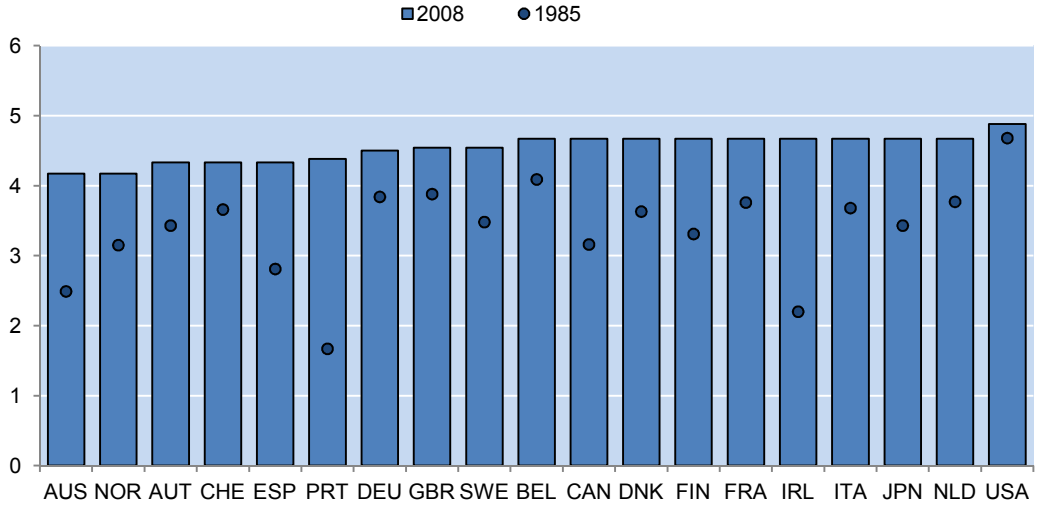
19. Patent rights temporarily grant the holder the ability to limit others from using an invention in exchange for the innovation being made public. In strengthening such rights, a delicate balance exists between granting firms some market power to incentivise innovation on the one hand, and ensuring that the competitive forces that prevent abuses and also motivate ongoing innovation and diffusion of ideas are not

[9] The tax policy reversals variable is calculated by tallying the number of times that a country implements more generous R&D tax policy immediately after implementing less generous policy or vice versa over the sample period.

stifled on the other. For many years there was a general tendency for countries to increase the amount of protection given to patent holders (Figure 6). However, in the past decade or so, most OECD countries have maintained a relatively stable intellectual property rights (IPR) regime. One consequence of this for empirical analysis is that it may be difficult to identify a causal effect of patent rights (Falk, 2004b).

Figure 6. Patent rights

Ginarte-Park Index of Patent Protection



Source: Park (2008)

2.3 Framework policies

20. Framework policies that promote domestic and international competition (Conway *et. al.,* 2006, Coe and Helpman, 1995) and adaptable labour markets (Bassanini *et. al.*, 2009) have been identified as important for fostering productivity growth. A channel through which this may occur is via the effect on the innovation process. In particular, framework policies may influence the ability and incentive of firms to undertake innovative activity, attract resources to commercialise new ideas, scale back outdated activities and processes and to take advantage of knowledge spillovers from earlier innovations.

2.3.1 Policy affecting competition

21. The relationship between competition and private sector innovation is likely to vary depending on the particular attributes of the firm or market. While some models advocate competition on the basis that firms with high market power may be disinclined to pursue innovation that may displace existing rents (Arrow, 1962; Reinganum, 1983), early Schumpeterian growth models (Aghion and Howitt, 1992) highlight that the incentives for innovation (in terms of prospective post-innovation rents) may fall as competition increases. Indeed, recent empirical work indicates heterogeneity across industries. Using panel data from the United Kingdom, Aghion *et al.,* (2005) find that innovation will benefit from a reduction in product market regulation (PMR) in initially high-PMR industries, but may be harmed in those industries that are already highly competitive. Thus, the aggregate impact of PMR on innovation is theoretically ambiguous and becomes an empirical issue.

2.3.2 Employment protection legislation

22. In allowing resources to flow to their most productive uses, easier employment protection legislation (EPL) is thought to benefit entrepreneurial firms undertaking radical innovations (Saint Paul, 1997, 2002; Bartelsman *et al.,* 2010), which necessitate relatively large employment adjustments (Aghion and Howitt, 1997). This is supported by recent empirical evidence that higher EPL reduces R&D expenditure in innovative industries and that this effect is disproportionally large in sectors that are particularly turbulent (Andrews and Criscuolo, 2013).

23. Lowering EPL may not be unequivocally good for all firms. Acharya *et al.,* (2010) find a positive relationship between stricter labour laws governing dismissal of employees and patenting, arguing that employees may be incentivized to undertake innovative activities that are value-maximizing in the long-run if they do not fear losing their job. Similarly, greater employment protection may encourage firms to invest in firm-specific human capital that benefits productivity (Autor, 2003; Wasmer, 2006). Griffith and Macartney (2010) find that multinational firms do more patenting of incremental innovations in relatively high EPL countries and more patenting of radical innovations in low EPL countries. Such heterogeneous effects indicate that it may be difficult to identify the impact of a change in EPL on R&D expenditure or patenting in a cross-country study based on aggregate data.

2.3.3 Trade policy

24. Countries with policies that promote international trade are more exposed to the foreign stock of R&D and new technologies, production processes and organisational methods. Past studies have found that such exposure has a positive relationship with measures of domestic innovation (Jaumotte and Pain, 2005a; Falk, 2004a). Nevertheless, it is possible that access to foreign R&D may provide a disincentive for domestic R&D expenditure and that the two sources of R&D are partly substitutable.

2.3.4 Financial and bankruptcy policies

25. R&D projects often require substantial investments that need to be funded from retained earnings or external sources. However, many innovative firms are small and young with limited internal income or assets and have difficulty obtaining external private finance given that the outputs to innovation are relatively uncertain. Consequently, financial sector policies that influence the availability of credit or equity-financing to businesses may affect the existence and success of innovative firms.

26. Bankruptcy policy is likely to be important for firms engaged in radical innovation activities that expand the technological frontier. Such innovation is synonymous with entrepreneurship and experimentation strategies that imply frequent and repeated failure (Bartelsman *et. al.,* 2008). Countries that impose high exit costs for failed firms – through more punishing bankruptcy regimes – may deter experimentation, lowering the capacity for innovation. However, some investor protection is necessary, especially given that the availability of finance may be positively related to the degree of creditor recourse.

2.3.5 Policy complementarities

27. It should now be apparent that there are a broad range of policy tools that may influence the volume of private R&D, patenting and other types of innovation. However, a number of these policy instruments are likely to interact, potentially complementing one another or leading to policy conflicts. This is an issue that has received relatively limited attention in the existing empirical literature but which this paper investigates further. Past work notes that while patent rights are necessary to give firms an incentive to engage in innovative activities, such rights should be coupled with pro-competition policies to ensure innovators benefiting from IPR do not create monopolistic positions (OECD, 2006; Uppenberg, 2009). Similarly, Parente and Prescott (2000) argue that while greater trade openness enables the adoption

of new innovations from abroad, this might not be the case if high barriers to firm entry exist in the domestic market as incumbents that hold monopoly rights to existing technology may resist the adoption process. Such policy interactions can influence the potency of a policy adjustment on innovation activity and hence deserve careful consideration.

3. Empirical model

3.1 R&D model

28. An equation explaining privately-funded business R&D is specified to reflect both short-run dynamics and divergences from a long-run cointegrating relationship. This approach acknowledges that it may take time for R&D to react to changes in its determinants as businesses develop R&D plans and then obtain the necessary capital and labour resources. The dynamic non-linear error correction relationship is represented by the equation:

$$\Delta \ln(RDS_{it}) = \alpha_{1i}\Delta \ln(RDS_{it-1}) + \alpha_{2i}\Delta \ln(B\text{-}index_{t-1}) + \sum_{j=1}^{m} \rho_{ji}\bar{Z}_{jit} + \theta_i\left[\ln\left(\frac{RDS_{it-1}}{Y_{it-1}}\right) - \delta \ln\,(\text{user cost}_{\text{it}-1}) - \sum_{\text{k=m+1}}^{\text{n}} \gamma_{\text{ki}}\tilde{Z}_{\text{kit}}\right] + \alpha_i + \alpha_t + \mu_{it} \quad [1]$$

29. RDS is either annual R&D expenditure or the accumulated stock of R&D, in both cases in constant price US dollar purchasing power parity (PPP) terms for countries *i* at time *t*.[10] *Z* is a matrix that includes *m* variables that may affect the short-run evolution of R&D (*e.g.* inflation, GDP growth) and *n* variables that explain long-run cross-country differences in R&D (*e.g.* R&D fiscal incentives, framework conditions). The B-index is included as a dynamic term and captures the short-run effect of changes in the user cost of R&D. *Y* is real GDP in constant US dollar PPP terms. Factors that vary across countries but not across time are captured through country fixed effects (α_i), while time fixed effects (α_t) are included to absorb common global shocks. The lag length is chosen by running country-specific regressions of a base specification and consulting the Akaike and Schwarz' Bayesian information criterion.[11]

30. While either the flow or the stock of R&D can be modelled as the dependent variable, the primary focus of the analysis is the R&D stock. This owes to the fact that, as outlined in Figure 2, changes in the R&D stock are most relevant for augmenting the pool of existing knowledge and hence affecting productivity growth.

31. The construction of the real user cost of R&D follows Jaumotte and Pain (2005a) using an approach similar to that pioneered by Hall and Jorgenson (1967):

$$user\ cost_{it} = (B\text{-}index) * (r_{it} + \delta) \quad [2]$$

where *r* is the long-term real interest rate and δ the depreciation rate on R&D capital, assumed to be 15% per annum in all countries and time periods (Guellec and van Pottelsberghe, 2004; Hall and Mairesse, 1995).[12]

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10 The dependent variable relates to business R&D excluding expenditures financed by government.

11 This process is also followed for choosing the lag lengths in the patent and MFP models.

12 See Appendix 1 for a more detailed decomposition of the user cost term. Some recent work has suggested that R&D depreciation rates are higher than 15% (see Li, 2012). However, a sensitivity analysis indicates that the conclusions from the below estimation results are not highly sensitive to the chosen depreciation rate.

3.2 Patenting model

32. The model describing the evolution of the number of patents is broadly similar to that for movements in R&D detailed above. In contrast with the R&D model, but in keeping with the depiction of the innovation process in Figure 2, here the dependent variable is based on a flow rather than a stock measure, annual growth in the number of triadic patent families per capita:

$$\Delta \ln\left(\frac{\mathrm{Pat_{it}}}{\mathrm{Pop_{it}}}\right) = \alpha_1 \Delta \ln\left(\frac{\mathrm{Pat_{it-1}}}{\mathrm{Pop_{it-1}}}\right) + \sum_{j=1}^{m} \emptyset_{ji}\bar{Z}_{jit} + \alpha_2\left[\ln\left(\frac{\mathrm{Pat_{it-1}}}{\mathrm{Pop_{it-1}}}\right) - \alpha_3 \ln\left(\frac{\mathrm{RDS_{it-1}}}{\mathrm{Y_{it-1}}}\right) - \alpha_4 \ln\left(1 + \frac{\mathrm{RDS^G_{it-1}}}{\mathrm{RDS_{it-1}}}\right) - \sum_{k=m+1}^{n} \partial_{ki}\tilde{Z}_{kit}\right] + \alpha_i + \alpha_t + \mu_{it} \quad [3]$$

33. The stock of business sector R&D and the stock of non-business sector R&D ($\mathrm{RDS^G}$) are included as regressors (as in Figure 2), reflecting that innovation output is likely to be a function of the knowledge that has built up in an economy over time. The forms in which these terms enter the equation are taken from Jaumotte and Pain (2005a), with their separate inclusion designed to highlight any differential effects of the source of R&D on patenting activity. *Pop* is the working age population (15-64) and the *Z* terms represent other short-run ($\bar{Z}$) or long-run ($\tilde{Z}$) influences on patenting including government policies. Indeed, it is possible that policies that influence R&D may have an additional affect on the success of such activity. Country and time fixed effects are also included.

3.3 MFP model

34. In the spirit of past models of productivity growth (Nicoletti and Scarpetta, 2003; Griffith et. al., 2004; Conway et. al., 2006), the MFP equation is specified to allow for the role of technology transfer as a source of productivity growth for countries behind the technological frontier:

$$\Delta lnMFP_{it} = \delta(\Delta \ln MFP_{Lt}) - \rho \ln\left(\frac{MFP_{it-1}}{MFP_{Lt-1}}\right) + X'_{it}\beta + h_{it} + \alpha_i + \tilde{\alpha}_t + \varepsilon_{jt} \quad [4]$$

35. The first term in equation 4 represents MFP growth of the frontier country, while the second term is the productivity gap (in terms of productivity level) and reflects the expectation that productivity growth is higher the further a country is from the frontier. The vector *X* represents the stock of R&D or the number of patents as well as other sources of knowledge diffusion that may affect aggregate MFP. The influence of framework policies can be assessed through interacting policy variables with these indicators as well as the frontier gap term (though this is not explicitly illustrated in equation 4). Because the labour input for the calculation of MFP is the number of employed (see Data Annex for more details), a control variable for labour utilisation is included (*h)* which represents the number of hours worked per employee. Country fixed effects are included and following Bouis *et al.* (2011), five-year period dummies ($\tilde{\alpha}_t$) are used to control for common variations in trend productivity growth. Equation 4 can be seen as an error correction model derived from a first-order autoregressive distributed lag process in which the MFP level in each country is cointegrated with that of the leader (Nicoletti and Scarpetta, 2003). The model implies heterogeneity in equilibrium MFP levels, with the productivity gap for each non-frontier country converging to a constant value. As a result, changes in the factors captured by vector *X* impact the steady state levels of MFP across countries, but do not result in permanent changes in MFP growth rates.

36. The models represented by equations 1, 3 and 4 are estimated across the 19 countries over the 1983-2008 period for the R&D equation and 1986-2008 for the patent and MFP equations.[13] This is the same sample of countries used by Jaumotte and Pain (2005a), with seven additional years of data.

37. Assumptions of independent and identically distributed standard errors within countries are often violated, leading to the clustering of standard errors at the country level. Such a technique allows for a general form of heteroskedasticity as well as intra-cluster correlation (Primo *et. al.,* 2007). The fixed effects estimator is used which pools data across the individual countries and in doing so assumes that the long and short-run determinants of R&D are homogeneous across regions.[14]

4. Data

38. The main constraints to broadening the sample of countries or the time period of the analysis are insufficient data for either R&D expenditure or the B-index. Descriptive statistics are found in the Data Annex along with details of the construction of the R&D stock and MFP level variables used in the analysis. As mentioned, the MFP measure accounts for the contribution of the stock of physical capital and a labour input that is adjusted for changes in human capital.

4.1 Indicators of innovation

39. The OECD *Main Science and Technology Indicators Database* is the source of constant price R&D expenditure, employment and patent data. R&D expenditure series are available for most countries from 1981 and are deflated using the implicit GDP deflator from the OECD *National Accounts Database*. For patents, the number of triadic patent families by inventor's country of residence is used. As is generally the case (unless specified), linear interpolation is performed in instances of missing observations.

40. The foreign R&D stock variable is calculated for each country as the trade-weighted R&D of all other countries in the sample, employing the weighting scheme outlined by Lichtenberg and Van Pottelsberghe (1998). The weights are calculated from bilateral trade flow data from the IMF *Direction of Trade Statistics*.[15]

4.2 Innovation policies

41. Government financed business R&D is derived from the OECD *Science, Technology and R&D Statistics Database*. The measure of R&D tax generosity, the B-index, is available for large firms from 1981 with the historical series updated with data from the 2009 OECD *Science Technology and Industry Outlook*. In years where data are not available, the series is held constant at the last observed value. In

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13 Patent data prior to 1986 from the European Patent Office are thought to be unreliable (for details, see Jaumotte and Pain, 2005a). The use of starting values in the calculation of the R&D stock (for details of the construction see Data Annex) allow the R&D regressions to be run over the 1983-2008 period regardless of whether the dependent variable is the change in the stock or flow of R&D.

14 The assumption of slope homogeneity can lead to the fixed effects estimator producing inconsistent and potentially misleading results. Alternatively, the mean-group (MG) estimator (Pesaran and Smith, 1995) allows the intercepts, slope coefficients and error variances to differ across countries or the pooled mean-group (PMG) estimator (Pesaran, Shin and Smith (1997)) allows heterogeneous short-run coefficients, intercepts and error variances but constrains the long-run coefficients to be equal. However, conducting Hausman tests on the coefficients of the base R&D and patent equations estimated with each of the dynamic fixed effects, MG and PMG estimators indicates that pooling across countries yields efficient and consistent estimates and hence, that fixed effects estimation is appropriate. Results are available from the author upon request.

15 For example, in calculating the foreign R&D stock of country i in time t, the R&D stock of trading partner j is weighted according to the trade inflows from country j to country i in period t.

calculating the user cost of R&D capital, the long-term interest rate is measured from secondary market yields of 10 year government bonds and is taken from the OECD *Key Economic Indicators Database*.

42. The measure of patent rights is the cross-country index updated by Park (2008) which increases at higher levels of patent protection. The index takes into account five aspects of patent laws: extent of coverage, enforcement mechanisms, duration of protection, provisions for loss of protection and membership in international patent agreements. The raw data are available at five-year intervals between 1980 and 2005 and, for the purposes of the empirical analysis, the value is assumed to remain at the 2005 level from 2006 to 2008.

4.3 Framework policies

43. The indicator of PMR is the OECD measure of regulation in energy, transport and communications. This index summarises the regulatory provisions in the telecommunications, electricity, gas, post, rail, air passenger transport, and road freight sectors and has a longer time series than other such indicators. While the measure does not cover all industries, it captures those in which anti-competitive regulation tends to be most concentrated in the sample countries. The 'high barriers dummy' appearing in the patent and MFP regressions captures regulatory or administrative barriers to firm entry (Wölfl *et. al.,* 2009).[16] The measure of EPL relates to both regular and temporary contracts from the OECD *Employment and Labour Market Statistics* (for further details, see Nicoletti *et.al.,* 2000).

44. The index of banking regulation used in the R&D regressions does not have a time dimension and is taken from De Serres *et al.*, (2006) and compiled from the World Bank's *Bank, Regulation and Supervision Database* that draws on the responses to a survey conducted in 2003. The measure increases with the level of regulation in two broad areas: barriers to competition (relating to regulations for domestic entry, foreign entry, banking activity and government ownership) and stability (relating to accounting standards, auditing requirements, capital adequacy, liquidity and diversification, provisioning, internal management, ownership, discipline and enforcement, deposit insurance and supervisory structure).

45. The bankruptcy cost variable is a time-invariant indicator of the cost to close a business in 2004 sourced from the World Bank *Doing Business* project.

4.4 Control variables

46. Macroeconomic indicators include GDP growth, calculated from a measure of GDP in constant price US dollar PPP terms sourced from the OECD *National Accounts Database*, and inflation, which is measured by the Consumer Price Index from the OECD *Main Economic Indicators Database*. In the MFP regressions, average annual hours per worker is taken from the OECD *Employment and Labour Market Statistics*.[17]

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16 The dummy variable is constructed from the barriers to entrepreneurship (overall) sub-index of the OECD indicator of economy-wide PMR. This measure reflects obstacles to easy access to information on existing regulation, general or sector-specific administrative burdens for business start-ups and other general or sector-specific regulations that hinder firm entry.

17 This data is only available for Austria from 1995, constraining the number observations in the MFP regressions to 428 (rather than 437).

5. Estimation results

5.1 Private research and development

47. Table 1 presents the results from the estimation of equation (1). As discussed in section 3.1, the analysis is focused on the determinants of growth in the R&D stock, though the results of a base specification with the R&D flow as dependent variable is also presented (Column 8). The innovation policies of governments as well as some framework conditions are found to be important in explaining the stock of private sector R&D.

Table 1. The determinants of business R&D

1982-2008	Dependent Variable = ΔIn(R&D Stock)							Dependent Variable = ΔIn(R&D Flow)
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Short-run dynamics								
ΔIn(R&D Stock)$_{t-1}$	0.84***	0.85***	0.87***	0.84***	0.85***	0.84***	0.84***	
	(28.28)	(26.01)	(22.95)	(29.54)	(26.94)	(33.22)	(29.06)	
ΔIn(R&D Flow)$_{t-1}$								0.28***
								(5.24)
ECM$_{t-1}$	-0.013***	-0.012***	-0.012***	-0.013***	-0.014***	-0.027***	-0.013***	-0.06***
	(2.84)	(2.60)	(3.64)	(3.09)	(3.31)	(5.54)	(3.18)	(2.88)
ECM$_{t-1}$*(Banking Reg dummy)						0.006**		
						(2.55)		
ΔIn(B-index)$_t$	-0.03**	-0.03*		-0.04*		-0.04**	-0.03*	-0.08
	(1.96)	(1.84)		(1.95)		(2.09)	(1.87)	(1.25)
Inflation$_{t-1}$	-0.13***	-0.12***		-0.14***	-0.13***	-0.13***	-0.14***	-0.50***
	(3.47)	(2.78)		(3.30)	(3.10)	(3.80)	(3.20)	(3.61)
GDP growth$_t$	0.10**	0.098**		0.11***	0.11**	0.12***	0.11***	0.46***
	(2.36)	(2.24)		(2.65)	(2.34)	(2.88)	(2.71)	(2.66)
Long-run parameters								
In(Government Financed Business R&D)$_{t-1}$	0.36**	0.41**	0.56**	0.45***	0.34**	0.18**	0.47***	0.40***
	(2.02)	(2.08)	(2.16)	(2.73)	(2.17)	(2.26)	(2.72)	(3.03)
In(User Cost)$_{t-1}$	-0.98*			-1.15**	-0.80**	-0.49**	-1.00**	-1.06
	(1.65)			(2.06)	(2.08)	(2.44)	(2.04)	(1.60)
PMR$_{t-1}$		-0.23	-0.26*				-0.14	
		(1.35)	(1.76)				(1.04)	
In(Foreign R&D Stock)$_{t-1}$				-1.02*			-0.98*	
				(1.74)			(1.72)	
In(User Cost)$_{t-1}$ *(Policy Reversals dummy)					1.33**			
					(2.17)			
Constant	-0.07***	-0.051***	-0.06***	0.02	-0.07**	-0.07**	0.04	-0.51***
	(2.84)	(2.72)	(4.54)	(0.43)	(2.41)	(2.39)	(0.62)	(3.78)
Observations	512	512	512	512	512	512	512	493
Adjusted R^2	0.76	0.76	0.74	0.76	0.76	0.76	0.76	0.29

*** p<0.01, ** p<0.05m * p<0.10.
Note: t-statistics in parentheses. The regressions include country and time fixed effects and standard errors clustered at the country level. The long-run parameters and associated standard errors are calculated according to the technique outlined by Bardsen (1989). *banking reg* is a time invariant measure of banking regulation. *Policy reversals dummy* is a dummy for those countries in the top 10% of the distribution for reversals in R&D tax policy (Australia and Belgium).

5.1.1 Innovation Policies

48. Consistent with past studies, the long-run effect[18] of the user cost of R&D is estimated to be around unity and is substantially larger than the short-run effect.[19] The coefficient on the user cost term in

[18] While the short-run effects can be obtained from the coefficients of the fixed effects estimator, the long-run effects depend on the speed of adjustment term and require additional computation. The method outlined by Bardsen (1989; see Appendix 2 for details) is used for calculating the long-run coefficients and the associated error variances.

[19] Across the specifications presented in Table 1 Wald tests cannot reject that the long-run parameter equals one.

Column 7 implies that a decrease in the B-index by 0.05 units (holding long-term real interest rates and the depreciation rate constant) would encourage an increase in the long-run stock of business R&D by just under 6%. Such an increase in the generosity of R&D tax policy (decrease in the B-index) is equivalent to a shift in policy settings from those in the United States to the more generous ones in Japan in 2008 (for partial effects of the policy variables, see Table 3).

49. The coefficient on an interaction term between the long-run user cost and a dummy for countries with a very high number of instances in which R&D tax policy has reversed course is estimated to be positive and statistically significant (Column 5).[20] The sign and magnitude of the coefficient suggests that countries with very high policy volatility gain negligible benefit from a policy-induced reduction in the user cost of R&D.[21]

50. In contrast to Jaumotte and Pain (2005a), direct government support is found to be positively related to business-funded R&D.[22] This implies that government grant and subsidy schemes are complements rather than substitutes for private sector R&D funding.[23] While there is some instability in the parameter estimates across the specifications in Table 1, the elasticity in Column 7 implies that a 10% increase in direct government support for business R&D is met by an increase in the privately funded R&D stock by just under 5%. To give some perspective, 10% is around the average annual increase in government support across countries during the first six years of the sample.

51. A direct comparison between the efficacy of R&D tax incentives and direct government support is very problematic due to significant heterogeneity in the design, cost and effectiveness of such schemes across countries. With this in mind, evaluated at the sample mean and holding all else equal, the estimated coefficients in Table 1 imply a larger impact on private R&D of $1 of public funds spent on direct support than on a volume based R&D tax credit (a volume based regime is assumed for computational ease). However, caution is warranted in interpreting these results since single country econometric exercises suggest that the 'bang-for-the-buck' multiplier is larger for incremental based R&D tax credit schemes than volume based R&D tax credit schemes (Lokshin and Mohnen, 2008).

52. Re-estimating the specification in Column 1 over the 1982-2001 period, the time frame used by Jaumotte and Pain (2005a), Table 2 highlights that the direct government support variable is the only one to become statistically insignificant.[24] The sensitivity of this parameter to the sample period may reflect variation in the design of direct support policies through time. For example, Bloch and Graversen (2008)

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20 The dummy variable is for countries in the top 10% of the distribution of tax policy reversals (Australia and Belgium). Interaction terms between the user cost and a dummy variable for countries in the top quartile and top half of the distribution were not statistically significant at conventional levels, though the estimated sign of the coefficients were also positive. The measure of changes in the B-index is dropped in the regressions that include the policy reversals interaction variable given the dummy is defined with regard to movements in the B-index.

21 A hypothesis test finds that the impact of a decline in the user cost on R&D expenditure in such countries is not statistically different from zero.

22 David *et. al.* (2000) note that, when input supply is inelastic, studies at the aggregate level may report a positive relationship between publicly financed R&D and private R&D that stems from the positive effect of increased government demand on R&D input prices. To the extent that such input price movements are adequately reflected in the price deflators used to construct the constant price measures, such bias should be avoided. Optimally, a deflator reflecting upstream prices in the R&D sector would be used to completely allay such concerns, though no reliable such measure is currently available for the full range of countries in the sample.

23 Unreported regressions using the outlined base econometric specification do not provide support for the idea that the effectiveness of government funding for stimulating R&D increases up to a particular threshold but decreases thereafter (Guellec and Van Pottelsberghe, 2003).

24 Running the estimation over two unique sample periods, 1981-1994 and 1996-2008, confirms the sensitivity of the direct government support coefficient to the time period, with the variable only statistically significant in the latter.

note that past government support for R&D was often through contracts where the government would fund as well as purchase the output of firms' R&D activity. This necessitated a sizeable role for government in selecting the R&D projects to be undertaken and may have meant that much of the R&D performed was not widely commercially applicable or substituted for privately funded R&D as a result of rent seeking activity. Recently, however, the allocation of support has become more sensitive to market signals, with matching grants (where a firm commits to match, in a given proportion, the direct support received) an increasingly common feature of government funding programmes (see Blanco Armas *et al.,* 2006; Hall and Maffioli, 2008). Given that a matching scheme stipulates input additionality, it may not be surprising that the more recent time period is important to the empirical finding that government financing encourages additional private R&D.[25]

53. Another factor behind the observed increasing impact of direct government support may be the general scaling-back of such schemes recently observed across countries (discussed in Section 2.2.2 of this paper). Notwithstanding information asymmetries and the power of some rent-seeking firms, in rationalising direct support for private R&D governments may first scrap those programmes perceived to be crowding out private sector R&D or those deemed to be least effective in encouraging additional private innovation.

54. Focusing on another innovation policy, a tightening of patent rights should normally raise the potential returns to R&D investment for firms (Falk, 2004a; Varsakelis, 2001), but the coefficient on the IPR term is not found to be statistically different from zero (and is even negative, see Column 2 of Appendix 3).

5.1.2 Framework Policies

55. The empirical results provide only weak evidence that a decrease in product market regulation has a positive effect on the stock of R&D. While the coefficient on the PMR term is estimated with a negative sign across the specifications in Table 1, the estimate is only weakly significant in 1 of the 3 regressions. With higher PMR limiting new entrants, the estimated (albeit at most weakly significant) sign accords with the theoretical prediction of patent race models that incumbents will invest less in R&D than entrants as successful innovations may replace incumbent-owned technology that is relatively profitable (Reinganum, 1983). In contrast to the industry based findings of Aghion *et. al.,* (2005), unreported regressions find little evidence at the country level that the innovation effects of a decline in PMR are more modest (or harmful) for countries with initially higher levels of competition.

56. There is some limited evidence that the financial regulatory environment influences the speed with which movements in the long-run parameters affect R&D. This is tested, and presented in column 6, by including an interaction variable between the ECM term and a time-invariant indicator of banking regulation that captures regulatory measures relating to bank entry and stability (described in Section 4.3). The positive coefficient estimate suggests that the stock of R&D may be slower to adjust to changes in the user cost or direct government support in those countries with stricter banking regulation. In such countries financing options may be fewer, slowing the response of firms to a new policy initiative. However, this result should be treated with caution given that the indicator of banking regulation is only observed at one point in time and a time-varying index of financial reform was not found to have a statistically significant effect on business R&D.[26]

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25 Although the private funds used to match a government grant could come at the expense of another of a firm's R&D projects. Indeed, the empirical evidence of the importance of matching grants for stimulating R&D spending is rather mixed (for a review, see Klette and Moen, 2011).

26 The measure of financial reform is an aggregate that summarises financial sector policy along seven dimensions: credit controls and reserve requirements, interest rate controls, entry barriers, state ownership in the banking sector, financial

57. In contrast with the finding of Jaumotte and Pain (2005a), Columns 4 and 7 highlight the negative and statistically significant coefficient estimate for the foreign R&D stock. This implies that domestic and foreign R&D are substitutes, a result in keeping with the evidence of Bloom and Griffith (2001) that domestic R&D is positively related to the cost of doing such activity abroad. This idea was further investigated with the inclusion of the foreign user cost as a determinant of domestic R&D.[27] However, the estimated coefficient was statistically insignificant despite having the expected positive sign (see Column 3 of Appendix 3).

58. EPL is not found to have any discernable effect on business R&D (see Column 4 of Appendix 3). This is unsurprising given the theoretically ambiguous direction of the aggregate-level relationship already discussed.

5.1.3 Dynamic effects

59. The dynamic parameter estimates highlight the importance of macroeconomic factors for the evolution of business R&D in the short run. The positive coefficient on the GDP growth term suggests pro-cyclicality in R&D spending.[28] Higher inflation is estimated to reduce private R&D, possibly because price instability may create uncertainty over the real value of future cash flows and cause firms to defer investment decisions.

60. The ECM term is significant in all of the specifications in Table 1, giving support for a model that allows short-run adjustments that correct for disequilibrium in the cointegrating relationship with the long-run factors. Consistent with past work (Jaumotte and Pain, 2005a) and the idea that it may take time for firms to obtain the necessary capital and labour resources to markedly change R&D expenditure, the impact of the long-run parameters is estimated to be very protracted. The ECM coefficients in Columns 1-5 imply that just 1.2-1.3% of the adjustment of R&D in response to a shock to one of the long-run parameters occurs each year.

61. The lagged dependent variable is statistically significant in all of the specifications presented in Table 1. While a least squares model with a lagged dependent variable may create bias in the estimated coefficients when the time dimension of the panel is small (Nickell, 1981), the 28 years of data utilised in this model is large relative to most cross-country panel studies. Indeed, re-estimation with the Arellano-Bond estimator (Arellano and Bond, 1991), designed to correct for such bias, suggests that there is no statistically significant bias present in the Table 1 coefficient estimates.

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account restrictions, prudential regulations and supervision of the banking sector and securities market policy (for details, see Abiad et.al., 2008).

27 Following Bloom and Griffith (2001), the variable was calculated with weights based on average foreign direct investment flows from the domestic to the foreign country over the sample period.

28 Previous work (Barlevy, 2007) suggests that while counter-cyclicality might make sense given lower opportunity costs for the resources employed in the R&D process, R&D activity is usually found to be pro-cyclical. This may be because firms are more inclined to introduce innovations during boom-times to extract the highest benefit from R&D that is often only partially excludable and will soon be adopted by other firms. In addition, in the presence of credit constraints, firms' R&D spending will fluctuate with company earnings (Andrews & de Serres, 2012b).

Table 2. Robustness of the estimates for the R&D equation

	Dependent Variable = Δln(R&D Stock)	
	(1) 1982-2008	(2) 1982-2001
Short-run dynamics		
Δln(R&D Stock)$_{t-1}$	0.842**	0.81***
	(28.28)	(18.83)
ECM$_{t-1}$	-0.013***	-0.022***
	(2.84)	(4.74)
Δln(B-index)$_t$	-0.03**	-0.04**
	(1.96)	(2.10)
Inflation$_{t-1}$	-0.13***	-0.15***
	(3.47)	(2.80)
GDP growth$_t$	0.10**	0.15***
	(2.36)	(2.92)
Long-run parameters		
ln(Government Financed Business R&D)$_{t-1}$	0.36**	0.120
	(2.02)	(0.88)
ln(User Cost)$_{t-1}$	-0.98*	-1.03**
	(1.65)	(1.96)
Constant	-0.07***	-0.11***
	(2.84)	(5.48)
Observations	512	379
AdjR2	0.76	0.75

*** p<0.01, ** p<0.05m * p<0.10.
Note: t-statistics in parentheses. The regression includes country and time fixed effects and standard errors are clustered at the country level.

Table 3. The partial effects of policy determinants on business R&D

	(1) Sample mean	(2) Std deviation	(3) Assumed Δ in policy	(4) Long-run coefficient	(5) Partial Effect (%)
B-Index	0.94	0.05	-0.05	-1.00	5.8
Government Financed Business R&D	2246	657	230 (10% ↑)	0.47	4.8
PMR	3.55	1.18	-0.35	-0.14	4.8

Note: The long-run coefficients are taken from column 7 of Table 1. The magnitude of the assumed change in policy is in line with frequently observed annual policy movements across countries through the sample period. The standard deviation is calculated as the average of the country standard deviations (rather than the standard deviation of the pooled sample). For the B-index, the long-run coefficient is for the user cost term, but the partial effect is calculated based on a rise in the B-index holding all other components of the user cost constant.

5.1.4 Unreported results

62. Unreported results of the analysis include further exploration of the role of innovation policies on R&D. No evidence was found that public research, either performed by the higher education sector or government labs, encouraged private R&D. This may reflect the broad range of research that is undertaken by such institutions, a large part of which is not immediately commercially applicable. Differential effects from the design of R&D tax incentives were explored by interacting country dummies for the type of R&D tax regime (*e.g.* incremental or volume-based tax credits and whether tax incentives existed for collaboration between business and public institutions) with the user cost variable. However, the estimated effects were not statistically significant. This is likely to partly owe to differences in the design of R&D tax regimes that cannot be adequately summarised by a time-invariant dummy.

63. Following some past evidence of a positive relationship between domestic R&D and foreign direct investment (FDI; Kuemmerle, 1999), a variable reflecting policy barriers to FDI was included.[29] While the estimated coefficient was not statistically significant, such policies may be most relevant for certain types of firms or industries and best investigated using more disaggregated data.

64. While differences in industry composition are likely to partly explain cross-country variation in R&D intensity, such differences should be captured by the country fixed effects. Although country dummies will not control for the impact of changes in industry composition through time, several measures of industry composition were included in the R&D regressions but were not found to be statistically significant.[30]

5.2 Patenting

65. The estimation results from the patent model (Equation 3) provide evidence of the posited relationship between the stock of R&D and the flow of new patents outlined in Figure 2 as well as the influence of innovation-specific and framework policies.

5.2.1 R&D as a determinant of new patents

66. The stocks of business and non-business R&D are estimated to have a positive and statistically significant influence on the number of patents per capita (see Table 4). Evaluated at the sample mean with the estimated coefficients from Column 3 of Table 4, a 1% increase in business R&D will increase the number of ne patents per capita by just under 1% in the long-run, while a 1% increase in non-business R&D will lead to a 0.4% rise. The differential effect of business compared with non-business R&D is consistent with the finding of de Rassenfosse & van Pottelsberghe (2009) that the number of patents per researcher increases with the share of total R&D performed by the business sector.

67. Column 7 presents a specification where the distinction between business and non-business sector R&D is relaxed, with the estimated coefficient suggesting that a 1% rise in the total R&D stock is associated with a 0.6% increase in patenting in the long-run. When reporting such results, the potential for reverse causality should be acknowledged as some "development" may occur after a patent application is made (Czarnitzki et.al., 2008).

5.2.2 Innovation policies

68. There is evidence that tax incentives for R&D have a positive effect on patenting, even after controlling for the impact of R&D. The estimated long-run elasticity in Column 3 of Table 4 implies that the flow of patents per capita increases by around 2.5% following an increase in the generosity of R&D tax incentives equivalent to a 0.05 unit decline in the B-index (for partial effects of the policy variables, see Table 5). Such a reduction corresponds to the average change in the B-index in the sampled countries since 2000. Furthermore, Columns 1, 2, 6 and 7 of Table 4 suggest that the B-index has a short run effect on patenting activity.

69. The empirical link between R&D tax incentives and patenting may reflect that the internal funds available to a firm for developing patents or for undertaking non-R&D expenditures that contribute to

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29 FDI restrictions are proxied by the OECD FDI Restrictiveness Index that reflects foreign equity restrictions, screening and prior approval requirements, rules for key personnel and other restrictions on the operation of foreign enterprises (for details, see Golub, 2003).

30 Past work finds that the rank of countries by R&D intensity does not change substantially after controlling for differences in industrial structure (OECD, 2006).

innovation are influenced by the size of R&D tax incentives received. In addition, some countries allow patent-related expenditures to be eligible under R&D tax incentive schemes (Warda, 2006).[31] One of the risks identified with introducing an R&D tax credit is that firms reclassify unrelated operating expenses as R&D to reduce their tax bill (see Hall and Van Reenen, 2000). If such activity was pervasive, it is likely that – holding R&D constant – a decrease in the B-index (*i.e.* an increase in the generosity of R&D tax incentives) would be associated with a fall in patenting activity. Instead, these results seem to suggest that an increase in R&D tax generosity will make R&D more productive in terms of patent outcomes.

70. There is evidence that more protective IPR is associated with higher patenting activity. The coefficient in Column 3 suggests that an increase in patent protection equivalent to Portugal moving IPR policy settings in line with Britain in 2008 (an increase in the index of 0.15) is associated with a 3.5% increase in patenting.[32] A natural question is the extent to which such an increase indicates more innovation or simply a higher propensity for firms to file patent applications. The fact that the IPR term was not statistically significant in the R&D regressions does not lend support to the idea that strengthening patent rights will increase innovation intensity. That said, it is possible that strengthening IPR encourages greater innovation outside of formal R&D programmes.

71. As discussed earlier, a key aim of this paper is to investigate any policy complementarities or trade offs that may exist. With this objective in mind, an interaction term between IPR and a dummy variable for those countries with above average barriers to firm entry is included in the patent regressions. The estimated coefficient (Column 6) is negative and statistically significant, which suggests that tightening IPR has a weaker impact on patenting in countries with high barriers to entry. Given that raising patent rights entails granting patent holders an (albeit temporary) increase in market power, such a change in policy may reinforce the high barriers to firm entry that exist in some countries.[33] Young firms are often an important source of new ideas (Akcigit and Kerr, 2010) and the inability of firms to gain access to markets in such countries may be reflected in a lower number of patents. Indeed, the size of the estimate on the interaction term implies that the positive effect on patenting of an increase in IPR is largely offset in those countries with above average barriers to firm entry.

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31 However, the inclusion of an interaction term between the B-index and a dummy variable for such countries is not found to be statistically significant.

32 The fact that a component of the IPR index is the 'patentability of software' and a large proportion of patents in some countries are software-related should be kept in mind when interpreting this result.

33 For further discussion see OECD (2006).

Table 4. The determinants of patents per capita

1986-2008	Dependent Variable = ΔIn(Pat per cap)						
	(1)	(2)	(3)	(4)	(5)	(6)	(7)
Short-run dynamics							
ΔIn(Patents per cap)$_{t-1}$	0.025						
	(0.22)						
ECM$_{t-1}$	-0.49***	-0.51***	-0.51***	-0.46***	-0.47***	-0.52***	-0.48***
	(3.93)	(6.75)	(7.04)	(6.19)	(6.49)	(7.15)	(7.40)
ΔIn(B-index)$_{t}$	-0.62**	-0.55**				-0.53**	-0.50**
	(2.17)	(2.24)				(2.22)	(2.22)
Inflation$_{t-1}$				-1.52*			
				(1.92)			
Long-run parameters							
In(Business R&D/GDP)$_{t-1}$	1.40***	0.99***	0.93***	1.30***	1.54***	1.14***	
	(3.34)	(3.30)	(3.05)	(3.08)	(3.63)	(3.42)	
In(1+Non-business R&D/Business R&D)$_{t-1}$	1.21***	0.90**	0.89**	1.36***	2.18***	1.23***	
	(2.84)	(2.13)	(2.13)	(3.71)	(6.70)	(3.06)	
In(Total R&D)$_{t-1}$							0.64***
							(3.11)
In(B-index)$_{t-1}$	-0.95***	-0.82***	-0.44**			-0.69***	-0.74***
	(3.24)	(3.31)	(2.39)			(2.97)	(4.44)
In(IPR)$_{t-1}$		0.84***	0.99***			0.72**	0.99*
		(2.68)	(3.01)			(2.11)	(1.77)
PMR$_{t-1}$			-0.09**			-0.07*	-0.10**
			(1.99)			(1.70)	(2.54)
In(Foreign R&D Stock)$_{t-1}$				0.33**	0.38***		
				(2.35)	(2.93)		
In(Foreign R&D Stock)$_{t-1}$*(High Barriers dummy)					-0.30***		
					(2.68)		
In(IPR)$_{t-1}$*(High Barriers dummy)						-0.78**	
						(2.50)	
Constant	3.33**	2.36***	2.27***	1.61	2.16*	2.97***	-2.34
	(2.51)	(3.04)	(3.055)	(1.56)	(1.68)	(2.89)	(1.61)
Observations	418	418	418	418	418	418	418
AdjR2	0.24	0.26	0.25	0.23	0.25	0.27	0.24

*** p<0.01, ** p<0.05m * p<0.10.
Note: t-statistics in parentheses. The regressions include country and time fixed effects and standard errors clustered at the country level. The long-run parameters and associated standard errors are calculated according to the technique outlined by Bardsen (1989). *High Barriers dummy* equals one for those countries with average barriers to entry over the sample period in the top 50% of the distribution. These countries are Austria, Belgium, Switzerland, Germany, Spain, Finland, France, Italy and Japan.

5.2.3 Framework Policies

72. Tighter anti-competitive regulation as represented by an increase in PMR is found to have a direct negative impact on patenting, supporting other evidence of a role for pro-competition policies in encouraging innovation (Column 3). A hypothetical reduction in regulation in Finland in 2008 equivalent to the PMR indicator falling to the sample average in that year (a decline of 0.35) is estimated to result in a 3% rise in patents per capita.

73. An important role for international knowledge spillovers is highlighted by the finding that greater exposure to foreign R&D is associated with higher domestic patenting (Column 4). This contrasts with the finding in the R&D regressions and indicates that while greater access to foreign R&D may cause some firms to scale back domestic R&D expenditure, knowledge flows from abroad have a positive effect on innovation outputs given a constant stock of domestic R&D. The estimated coefficient implies that an increase in exposure to trading partner's R&D stocks from the average level in Spain (around the sample

average in 2005) to the higher level in Canada (corresponding to the 75th percentile) would boost patents per capita by around 20% in the long run.[34]

74. The results also suggest that policies affecting competition and trade can be complementary in fostering innovation output. Column 5 presents the findings from a specification in which the high barriers to entry dummy is interacted with the measure of the foreign R&D stock. The estimated coefficient on the interaction term is negative, indicating that the positive effect on domestic patenting of higher exposure to foreign R&D is almost completely offset in those countries where high barriers to firm entry exist. As discussed, this may reflect incumbent firms with monopoly rights over existing technologies resisting the adoption of new innovations from abroad.

5.2.4 Dynamic effects

75. The estimated coefficient on the ECM term across the specifications in Table 4 suggests that 50% of the long-run effect of a change in a policy determinant will occur in the following year, with 50% of the remaining effect being felt in the year after and so on. This is a much faster response to movements in the long-run parameters than estimated in the R&D regression, suggesting markedly shorter lags of policy in affecting patenting activity than R&D. This is not entirely surprising given that once the R&D stock is determined it is likely to require less planning and resources for a firm to increase or decrease the volume of patent applications, and perhaps grants, than to significantly adjust the volume of R&D expenditure.

76. There is very weak evidence that inflation has a short-run negative effect on patenting activity above and beyond its impact on R&D. However, the variable is only statistically significant in the specification in Column 4. The lagged dependent variable is not found to be statistically significant and is consequently omitted from all the specifications presented from Columns 2 to 7.

Table 5. The partial effects of policy determinants on patents per capita

	(1)	(2)	(3)	(4)	(5)
	Sample mean	Std deviation	Assumed Δ in policy	Long-run coefficient	Partial Effect (%)
B-Index	0.94	0.05	-0.05	-0.44	2.5
IPR	4.10	0.50	0.15	0.99	3.5
PMR	3.55	1.18	-0.35	-0.09	3.1

Note: The long-run coefficients are taken from column 3 of Table 4. The assumed change in policy is in line with the magnitude of observed annual policy movements through the sample period. The standard deviation is calculated as the average of the country standard deviations (rather than the standard deviation of the pooled sample).

5.2.5 Unreported results

77. The impact of absorptive capacity (proxied by average years of schooling or the ratio of business researchers to industry employment) on patenting was also investigated, but the estimated coefficients on the relevant variables were statistically insignificant. In common with the R&D regressions, there was no discernable effect of some framework policies such as those relating to EPL and bankruptcy regimes on patenting at the country-level.

[34] Taken together, the estimated coefficients in Table 1 and Table 4 imply that an increase in foreign R&D will have a negative effect on patenting through the business R&D channel that will only be partially offset through the direct positive effect of greater access to the foreign knowledge stock on patenting. This must be interpreted with caution, however, as the coefficient on the foreign R&D stock term in the R&D regressions does not appear to be very robust (discussed in Section 5.4).

78. The determinants of the stock (instead of the flow) of patents may also be of interest, particularly if productivity gains derive from the cumulated pool of publicly available patented technology rather than only new innovations (as in Figure 2). Reassuringly, re-estimating the regressions with the patent stock as the dependent variable does not change any of the policy conclusions arising from the results in Table 4 (See Appendix 4 for results from the patent stock regressions).[35]

5.3 Multifactor productivity

79. As suggested in Figure 2, a key reason for encouraging innovation is the belief that such activity will result in productivity gains. Innovations developed either domestically or from abroad may be important in this process. The empirical framework in this paper examines both of these channels, investigating the link between indicators of domestic innovation (the stock of R&D and patents) and productivity, as well as the role of productivity developments in technological frontier countries that may diffuse to non-frontier countries. The transmission of innovations – from either domestic or international sources – into higher productivity can be influenced by government policy settings, as illustrated by the empirical results.

5.3.1 The impact of R&D and patenting on productivity growth

80. Despite its drawbacks as a proxy for innovation, the number of domestic patents are found to be positively associated with MFP growth (Columns 1 to 3).[36] This is the case whether a stock or flow measure of patents is used as the regressor, but relies on the presence of Japan in the sample (for a robustness discussion see Section 5.4).[37] Consistent with the process outlined in Figure 2, the results in Table 6 relate to the patent stock (see Appendix 5 for results for patent flows) and reflect not only the direct productivity effect from patented innovations but also any effect of knowledge spillovers on follow-on innovators that can access relevant technical information once patents are granted. Nonetheless, the results of the specification in Column 2 suggest that the positive effect of higher patenting on MFP is lessened when PMR is relatively high. This may reflect the fact that stricter regulation can impede the efficient allocation of resources (Andrews and Cingano, 2012a) and thus make it more difficult for firms to commercialise and maximise the returns from new technologies.

81. The role of absorptive capacity in explaining MFP growth is investigated in Column 3 through the introduction of an interaction term between the number of patents and the share of business enterprise researchers in employment. The coefficient is estimated to be positive and statistically significant, suggesting that an increase in patenting has a larger effect on MFP growth when the proportion of researchers is relatively high. This is consistent with past work (Griffith *et.al.,* 2004) and highlights the importance of absorptive capacity for the proliferation of knowledge spillovers once a new idea is made public.

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35 Following past work (Griliches and Cockburn, 1988; Bloom and van Reenen, 2002) patent stocks are derived using the perpetual inventory method with an annual depreciation rate of 30%, though the results are robust to assuming other commonly used depreciation rates for knowledge assets (*e.g.* 15% used by Hall *et. al.,* 2005). The method used to calculate starting values is analogous to that for the R&D stocks detailed in the Data Annex.

36 Including the control variable for business researchers as a share of total industrial employment reduces the chance that the estimated impact of an increase in patents is being overstated by reflecting an increase in the size of the research sector.

37 The independent variable is the stock of patents in units of 10,000. Unreported regressions (available from the author upon request) indicate that the results in Columns 1-3 of Table 6 are robust to controlling for population size. The population size variable was dropped from the specifications presented here as it was not statistically significant at conventional levels.

Table 6. The estimated effect of knowledge flows for MFP growth

1986-2008	Dependent variable = d.log(MFP)																
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)	(16)	(17)
MFP gap from frontier $_{t-1}$	-0.03**	-0.03**	-0.03**	-0.03**	-0.03**	-0.02	-0.02	-0.03**	-0.09***	-0.03**	-0.04**	-0.02	-0.02	-0.05*	-0.03**	-0.03**	-0.03**
	(2.47)	(2.24)	(2.40)	(2.34)	(2.15)	(1.46)	(1.33)	(2.11)	(3.69)	(2.11)	(2.29)	(1.49)	(1.44)	(1.75)	(1.88)	(1.80)	(1.92)
MFP growth of frontier country $_{t}$	0.31***	0.30***	0.30***	0.31***	0.34***	0.32***	0.31***	0.32***	0.31***	0.31***	0.31***	0.32***	0.32***	0.32***	0.32***	0.32***	0.32***
	(8.22)	(7.81)	(7.82)	(8.13)	(8.84)	(8.06)	(8.07)	(9.60)	(8.37)	(8.18)	(8.39)	(8.63)	(8.48)	(8.42)	(8.18)	(8.12)	(8.48)
Patent Stock $_{t-1}$	0.005*	0.008***	0.008**														
	(1.65)	(2.68)	(2.55)														
PMR $_{t-1}$		-0.002	-0.002	-0.001	0.0004	-0.001	-0.001	0.001	0.003	-0.001	-0.0002	-0.001	-0.001	-0.002			
		(1.24)	(1.11)	(0.43)	(0.27)	(0.28)	(0.60)	(0.47)	(1.38)	(0.35)	(0.11)	(0.55)	(0.58)	(0.93)			
(PMR) $_{t-1}$ * (Patent Stock) $_{t-1}$		-0.012***															
		(4.08)															
Hours worked $_{t}$	0.11***	0.10**	0.10***	0.09***	0.10***	0.11***	0.10***	0.09***	0.10**	0.09***	0.09***	0.07**	0.07**	0.07**	0.10***	0.10***	0.12***
	(2.93)	(2.87)	(2.85)	(3.03)	(3.26)	(3.38)	(3.01)	(2.82)	(2.79)	(3.02)	(2.83)	(2.57)	(2.49)	(2.45)	(3.69)	(3.42)	(4.18)
Business researchers/Total Employment $_{t-1}$	0.002***	0.002***	0.002***														
	(2.86)	(2.86)	(2.93)														
(Business researchers/Total Employment) $_{t-1}$ * (Patent Stock) $_{t-1}$			0.008***														
			(3.39)														
Business R&D Stock/GDP $_{t-1}$				0.33**				0.26	0.25*	0.33***	0.28**	0.32***	0.32***	0.26**			
				(2.54)				(1.51)	-1.864	-2.642	-2.36	-2.858	-2.873	-2.453			
Foreign R&D Stock/GDP $_{t-1}$					0.007			0.005									
					(1.53)			(1.11)									
Government Basic Research Stock/GDP $_{t-1}$						0.79		0.51									
						(1.30)		(0.74)									
Higher Education Research Stock/GDP $_{t-1}$							0.77	0.47									
							(1.22)	(0.84)									
(PMR) $_{t-1}$ * (MFP gap from frontier) $_{t-1}$									0.015***								
									(2.64)								
Trade Openness $_{t-1}$										0.005	-0.02						
										(0.30)	(1.14)						
(Trade Openness) $_{t-1}$ * (MFP gap from frontier) $_{t-1}$											-0.11***						
											(4.91)						
Exposure to the frontier/GDP $_{t-1}$												0.05*	0.07*	0.07*			
												(1.75)	(1.97)	(2.09)			
(Exposure to the frontier/GDP) $_{t-1}$ * High barriers dummy													-0.10**	-0.11***			
													(2.11)	(2.69)			
(Bankruptcy Cost) * (MFP gap from frontier) $_{t-1}$														0.004*			
														(1.66)			
B-index $_{t-1}$															0.02		
															(1.19)		
Government R&D Subsidies $_{t-1}$																0.0000	
																(0.88)	
IPR $_{t-1}$																	0.004
																	(0.67)
Constant	-0.19***	-0.17***	-0.17***	-0.18***	-0.19***	-0.20***	-0.18***	-0.20***	-0.21***	-0.18***	-0.16***	-0.14***	-0.13***	-0.13**	-0.20***	-0.18***	-0.22***
	(3.10)	(3.02)	(3.04)	(3.22)	(3.72)	(3.39)	(3.54)	(3.68)	(3.10)	(2.97)	(2.61)	(2.67)	(2.62)	(2.54)	(3.71)	(3.47)	(4.00)
Observations	428	428	428	428	428	428	428	428	428	428	428	428	428	428	428	428	428
AdjR2	0.263	0.274	0.272	0.265	0.257	0.254	0.254	0.271	0.277	0.264	0.271	0.276	0.28	0.284	0.252	0.25	0.25

*** p<0.01, ** p<0.05m * p<0.10.

Note: t-statistics in parentheses. The regressions include country and time fixed effects, and standard errors are clustered at the country level. *High Barriers dummy* is a dummy for those countries with average barriers to entry over the sample period in the top 50% of the distribution (Austria, Belgium, Switzerland, Germany, Spain, Finland, France, Italy and Japan). The variables used to construct the interaction terms for PMR/patents and business researchers/patents are deviations from the sample mean, so that the estimated coefficients relate to marginal effects evaluated at the mean value. Similarly, the trade openness variable in the Trade Openess/MFP gap interaction term is de-meaned.

82. The stock of business R&D to GDP is estimated to have a positive effect on MFP growth (Column 4).[38] It must be acknowledged that, especially in the case of multinational enterprises, domestic R&D may be used to benefit businesses outside the domestic economy and that such activity is not explicitly captured in the empirical model. Nonetheless, the estimated link between business R&D and domestic productivity is statistically significant, though the magnitude is in the lower range of estimates from the existing literature (for a review, see Parsons and Phillips, 2007).[39] There is no evidence of a positive impact of R&D performed outside the business sector: the estimated coefficients on terms relating to the stock of government basic research (Column 6) and higher education R&D (Column 7) are not statistically significant. It is possible that these types of R&D affect MFP with long and variable lags since they are not directly performed by the business sector, although experimenting with longer lag structures did not uncover a stronger statistical relationship.[40] This is consistent with much of the existing empirical literature that finds the returns to many forms of publicly financed R&D to be near zero (Sveikauskas, 2007). While the estimation also found no direct impact of the foreign R&D stock on MFP growth (Column 5), much of this effect may be captured in the terms relating to the MFP gap and MFP growth of the frontier country (see below).

5.3.2 The effect of knowledge flows from technological leader countries

83. Highlighting the importance of the diffusion of innovations from abroad, MFP growth in the frontier country is found to have a positive and significant effect on MFP in less productive countries.[41] Additionally, the estimated coefficient on the MFP gap term indicates that technological adoption is more beneficial for countries that are further behind the productivity frontier. While of similar magnitude to estimates in past work (Griffith *et. al.,* 2004; Nicoletti and Scarpetta, 2003) the gap term is statistically insignificant in 4 of the 17 specifications, which may reflect a degree of multicollinearity with some of the other regressors.

84. The estimation results also provide some evidence that international knowledge spillovers can be influenced by government policy. The coefficient on the interaction term in Column 9 indicates that the speed of convergence to the frontier will be slower for countries that have higher levels of product market regulation. This is consistent with the empirical evidence in Section 5.2.3 of this paper and past research (Conway *et.al.,* 2006) that suggests that incumbents with high market power may resist the adoption of new innovations from abroad.

85. The estimated coefficient on the interaction term in Column 11 indicates that productivity convergence will be faster for countries that are more open to trade. Greater trade openness may assist the diffusion of foreign knowledge through the ideas that are embodied in imported goods and is often

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38 Given the empirical link established in Section 5.2.1, R&D and patenting are not included as regressors at the same time in the MFP regression. Setting aside the issues with multicollinearity, if both variables are included in the same regression (along with frontier growth, MFP gap from the frontier and hours worked), the business R&D coefficient remains relatively unchanged from that presented in Column 4 of Table 6 while the patents term becomes statistically insignificant at conventional levels.

39 Of course, past studies are mostly based on less recent data than the present analysis. A series of re-estimations of the coefficient on the business R&D term over time periods truncated before 2008 indicates that the size of the estimated positive effect of business R&D on TFP tends to fall as samples include more recent data. Policy conclusions from this exercise are limited, however, as the diminishing size of the R&D coefficient is not robust to dropping one country at a time from the sample.

40 When all of the R&D variables are included in the same specification (Column 8), the business R&D term becomes statistically insignificant at conventional levels. This is partly due to an increase in the standard error that the pairwise correlation coefficients indicate may arise from multicollinearity with the other measures of domestic R&D.

41 The frontier country is controlled for, so that the coefficient on the frontier growth variable is the estimated effect for non-frontier countries.

positively related to other factors such as foreign direct investment (Seim, 2009) and international labour mobility (Ortega and Peri, 2012) that can benefit productivity growth.[42]

86. A number of past studies have explored the importance of geographical proximity to technological leaders in explaining knowledge spillovers and the innovation intensity of non-frontier entities (*e.g.* Audretsch and Feldman, 2003). Here, this spatial dimension is represented by a variable reflecting geographical distance from a country's capital city to the capital city of the frontier country. A country is a very broad geographic unit for which to investigate spatial knowledge spillovers, with existing studies more inclined to focus on cities or even postal codes. Nevertheless, the results in Column 12 indicate that countries with higher geographic exposure to the technological leader exhibit higher productivity. This effect is dependent on framework policies though, with the benefits of spatial knowledge flows completely offset in economies with high barriers to firm entry that restrict the ability of young firms to build on the ideas generated in neighbouring countries (Column 13).

87. There is also weak support for the idea that government policies which increase the cost of firm exit may cause resources to be trapped in inefficient firms that would otherwise be released to businesses that are relatively adept at technological adoption (Bartelsman *et al*., 2008).[43] This is illustrated by the positive coefficient on the 'bankruptcy cost' interaction term in Column 14 which suggests that technological adoption from abroad is slower in countries with more punishing bankruptcy regimes.

5.3.3 Innovation policies and MFP growth

88. Columns 15, 16 and 17 of Table 6 present the results when policy instruments that appear to be influential in encouraging private R&D and patenting activity are included in the MFP regression. More generous R&D tax incentives and direct government support, and stronger patent rights do not appear to have a direct positive effect on MFP growth, despite the regressions not controlling for the stock of patents or domestic business R&D.[44] This is somewhat surprising given that these policy variables were found to affect the measures of innovative activity that are significant determinants of productivity growth (in Sections 5.1 and 5.2). Possible explanations for the lack of a statistical relationship between innovation policies and MFP may be that:

- The indirect nature of the relationship means that the estimation is more likely to be affected by measurement error.

- The types of R&D or patents that these policies encourage are not positively related to productivity. Fiscal incentives induce the marginal project that will have a relatively low value to businesses and perhaps also to society. This would be surprising in the case of direct support measures that are thought to be targeted at R&D activities with high social worth, but may highlight the information asymmetries that are often seen as a reason against such government intervention. In relation to IPR, the lack of a significant finding may suggest that tightening patent rights causes an increase in firm's propensity to patent without significantly increasing innovation intensity.

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42 This supports the conclusions of Giles and Stroomer (2006). In the presence of concerns about the potential endogeneity of the trade openness variable (Frankel and Romer, 1999), an avenue for further work may be to confirm the result using instrumental variable (IV) estimation (insofar as an appropriate time-varying instrument can be found).

43 This is consistent with the empirical findings of Andrews and Cingano (2012) that low exit costs make it less likely that resources are tied up in inefficient firms.

44 The finding that stricter patent rights are not associated with higher MFP growth contrasts with the results of Bouis *et.al.,* (2011).

- Although the activity induced by innovation policies may benefit productivity, such policies may also have unintended detrimental effects for MFP. As discussed, tightening patent rights involves affording some market power to innovators which can have negative implications for competition. Similarly, recent work suggests that R&D tax incentives can protect incumbents to the detriment of potential entrants, slowing down the reallocation process (Bravo-Biosca *et al.,* 2012).

- Fiscal incentives for R&D entail an opportunity cost in the form of the welfare-enhancing projects that could otherwise be funded by the government or the private sector activities suppressed by any additional taxation levied on firms to pay for incentives. If the foregone projects are as beneficial to productivity as the innovation encouraged by fiscal incentives, there should be no identifiable effect of these R&D policies on aggregate productivity growth.

89. To gain a better understanding of whether innovation-specific policies have an overall benefit to society, a full net welfare analysis of the policy measures is required. While such an exercise requires reliable cross-country estimates for a number of parameters that are outside the scope of this paper. Box 1 outlines the basic framework for such an analysis for fiscal support measures. This makes clear that innovation policies are not necessarily welfare-enhancing, and whether they accrue a net social benefit will depend to a large extent on the magnitude of the spillovers from induced innovation activity and the distortions that such policies and their financing create. The relative dimensions of these effects are likely to depend on a variety of policy and institutional factors, motivating further investigation at the individual country level. One example of this type of analysis for the Canadian federal tax credit for scientific research and experimental development finds a net economic gain from the policy (Parsons and Phillips, 2007), though this conclusion is fairly sensitive to a number of assumptions.

Box 1. A framework for calculating average welfare gain/loss from an R&D tax incentive/subsidy

A positive relationship between an R&D tax incentive or subsidy and measures of innovation or MFP growth does not necessarily indicate that the policy provides a net welfare gain to society. Such policies raise costs as they must be financed through an increase in tax revenue that will impose an excess burden on the economy by creating distortions in the allocation of resources. Furthermore, the schemes result in administration costs for the government and compliance costs faced by participating firms. Given that firms would not undertake the induced R&D in the absence of subsidisation, it is very unlikely that the private rate of return to such projects will outweigh these manifold costs. Thus, for the policy to be welfare-enhancing overall, there must be significant positive externalities in the form of spillovers from the R&D activity. Parsons and Phillips (2007) incorporated each of these factors into a partial equilibrium model for evaluating the welfare gain or loss from an R&D policy. This is summarised by the following equation:

$$\Delta W = \Delta PS + E - T - (A - C)$$

Where W is total welfare change per dollar of subsidy, PS is the net welfare change to producers (encapsulating the increase in producer surplus for subsidised firms less the cost to other firms that must pay for the subsidy through higher taxes), E is the externality resulting from the induced R&D, T is the marginal excess burden incurred from distortionary taxation and A and C are the administration and compliance costs of the scheme respectively.

5.4 Robustness

90. Robustness tests were undertaken on the results for the R&D, patent and MFP regressions. In general, these reveal that the sign and magnitude of the estimated coefficients are not sensitive to slight modifications in the time period or the countries included in the sample, though such sample variations can cause some coefficients to become statistically insignificant at conventional levels. This should be kept in mind when interpreting the estimation results, especially given that such robustness tests are not highly demanding.

91. Estimating the specification for the R&D equation presented in Column 4 of Table 1 but dropping one country at a time, the user cost becomes marginally insignificant in two (of 19) regressions, though in these instances the coefficient is significant at the 12-13% level. The estimated coefficient for the foreign R&D stock appears to be the least robust of the long-run parameters, with the estimate statistically insignificant in 9 of the 19 regressions.[45] The coefficient on the direct government support variable is significant regardless of which country is omitted. However, as illustrated in Table 2 and discussed above, the coefficient on this variable is the only one that becomes statistically insignificant when the time period is shortened considerably.

92. In the patent regressions, small variations in the length of the sample have no impact on the statistical significance of the coefficients in the specification presented in Column 3 of Table 4. While the terms relating to non-business sector R&D, the B-index and PMR become statistically insignificant in a few instances when one country is dropped at a time, the business R&D term is statistically significant in all of the 18-country regressions.[46]

93. All of the variables in the MFP specifications presented in Columns 2 and 4 of Table 6 remain statistically significant in regressions that exclude four years of observations from either the beginning or the end of the sample. The terms relating to the MFP gap, growth of the frontier country, business R&D and the various control variables remain statistically significant when any one country is excluded from the sample. However, the patents variable (along with the patents/PMR interaction term) becomes statistically insignificant when Japan is dropped. Applying the estimated coefficients from Table 6 to country-specific parameter values within-sample, the model cannot explain the extent of the recent MFP slowdown in a number of countries (highlighted in Figure 1A). This can be partly attributed to utilising coefficients that are the average effect across countries and any future analysis at the individual country level is likely to be helpful in better determining the magnitude of productivity effects by region.

6. Conclusion

94. This paper explores the policy determinants of business R&D and patenting activity and establishes an empirical link between such measures of innovation and productivity growth at the country level. The effect of various policies on the diffusion of knowledge has also been examined and where possible, any consequences stemming from the interaction of government policies highlighted. The results suggest that innovation specific policies such as R&D tax incentives, direct government support of business R&D and patent rights achieve their objective of encouraging private sector innovative activity (insofar as such activity is adequately proxied by business R&D and patent count measures). However, no evidence of a direct effect of such policies on aggregate productivity growth could be found. Given that the economic impact of innovation policies may be heterogeneous across countries, any future attempt to collect cross-country data on the design of these measures would be informative.

95. A recurring theme through the findings is the importance of well-designed framework policies relating to competition in incentivising innovation and the returns to new ideas. While there is evidence that lower PMR may have a positive effect on private innovation activity, the results also suggest that pro-competition policies are important for the effective diffusion of knowledge from both domestic and overseas sources.

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45 The user cost term becomes insignificant when either Denmark or Portugal are excluded, while the foreign R&D variable is statistically insignificant without either Australia, Denmark, Germany, Ireland, Netherlands, Portugal, Spain, Switzerland or the USA in the sample.

46 The non-business sector R&D variable becomes insignificant when Australia, Ireland or Portugal are excluded. This is the case for the B-index term when Australia or Portugal are excluded and the PMR variable without Switzerland or Finland.

96. Although using highly aggregated data is preferable for assessing the spillovers to innovation, the estimated effects presented in this paper are averages across countries, sectors and firms. As such, the findings will benefit from any further work using industry or firm level data that can explore the channels through which these aggregate effects become apparent.

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DATA ANNEX

R&D Stocks

97. R&D stocks are calculated using the perpetual inventory method followed by Jaumotte and Pain (2005a). Specifically, the starting value is calculated according to the formula $S_{i,t=0} = R_{i,t+1}/(g_i + \delta)$ where g is the sample mean growth rate of R&D expenditures over the estimation period and δ is the constant depreciation rate of R&D capital. In subsequent time periods, the R&D stock evolves according to the accumulation equation $S_{i,t+1} = R_{i,t+1} + (1 - \delta)S_t$.

98. For the R&D regressions, the business sector stock is calculated with a starting value at 1980. This is not the case for Portugal which, due to missing data, has a starting value at 1981. For the patent regressions, the non-business sector R&D stock is taken as the difference between the whole-economy and business sector stocks. As whole-economy R&D expenditure data for Belgium are only available from 1983, the R&D stocks for all countries used in these regressions are calculated with a starting value at 1982. The non-business sector stock will include higher education expenditure on R&D, government intramural expenditure on R&D and direct government support for private R&D.

Multifactor Productivity

99. MFP is calculated in the manner outlined by Johansson and Murtin (2012). Specifically, the supply side of the economy is modelled according to a Cobb-Douglas production function with constant returns to scale:

$$Y_{it} = K_{it}^{\alpha}(A_{it}hc_{it}L_{it})^{1-\alpha}$$

100. where *Y*, *K*, *A*, *hc* and *L* denote output, physical capital, technical progress (MFP), human capital per worker, total employment and subscript *t* and *i* denote year and country. The share of capital is set equal to 1/3. After some manipulations, MFP is derived as:

$$A_{it} = Y_{it}/(\frac{K_{it}}{Y_{it}})^{\alpha/(1-\alpha)}hc_{it}L_{it}$$

101. GDP is expressed in constant 2005 PPP USD terms, capital stocks are taken from the OECD *Productivity Database* or calculated from investment series (excluding residential housing investment) based on the perpetual inventory method assuming a 4% annual depreciation rate. Human capital stocks are derived from data relating to the average number of years of schooling across the population aged 25-64 and an assumption for the returns to education (see Johansson and Murtin (2012) for further details).

Geographical exposure to the frontier

102. The variable in the MFP regressions representing geographical exposure to the MFP leader for a country *i* is calculated by weighting the frontier level of MFP by the distance between the capital city of country *i* and the capital city of the frontier country in kilometres. Distances are obtained from the webpage of Jon Haveman at Macalester College.[47] In the regressions, the variable enters as weighted units of frontier MFP per unit of domestic GDP.

[47] http://www.macalester.edu/research/economics/page/haveman/Trade.Resources/TradeData.html#Gravity

DESCRIPTIVE STATISTICS

R&D Regression (1982-2008)					
Variable	Obs	Mean	Std. Dev.	Min	Max
R&D Stock	512	94999	199225	475	1302874
R&D Flow	512	17611	36949	107	234252
B-index	512	0.94	0.11	0.56	1.05
Inflation	512	0.04	0.03	-0.01	0.27
GDP growth	512	0.03	0.02	-0.06	0.11
User Cost	512	0.18	0.03	0.08	0.26
Government Financed Private R&D	512	2250	6644	2	44375
PMR	512	3.5	1.4	0.9	6.0
Foreign R&D	512	8840	10524	225	71473

Patent Regression (1986-2008)					
Variable	Obs	Mean	Std. Dev.	Min	Max
Patents per capita	418	59	47	0	188
B-index	418	0.94	0.11	0.56	1.05
Inflation	418	0.03	0.02	-0.01	0.130
Business R&D/GDP	418	0.06	0.03	0.00	0.15
(1+Non-business R&D/Business R&D)	418	1.94	0.59	1.34	4.782
Total R&D	418	176809	352537	2029	2066418
IPR	418	4.22	0.55	1.67	4.880
PMR	418	3.23	1.24	0.94	5.83
Foreign R&D Stock	418	10263	11110	534	71473

MFP Regression (1986-2008)					
Variable	Obs	Mean	Std. Dev.	Min	Max
TFP gap from frontier	428	-0.31	0.19	-0.78	0.000
TFP growth of frontier country	428	0.007	0.025	-0.081	0.058
Patent stock	428	0.63	1.17	0.000	4.99
PMR	428	3.28	1.27	0.94	5.83
Hours worked	428	1.69	0.15	1.35	2.10
Business researchers/Total Emp.	428	4.60	2.84	0.23	14.35
Business R&D stock/GDP	428	0.062	0.034	0.004	0.149
Foreign R&D stock/GDP	428	1.44	1.01	0.12	7.54
Government Basic Research stock/GDP	428	0.014	0.007	0.002	0.034
Higher Education Research stock/GDP	428	0.023	0.009	0.004	0.049
Trade Openness	428	0.69	0.35	0.16	1.83
Exposure to the frontier/GDP	428	0.047	0.064	0.000	0.371
Bankruptcy Cost	428	7.41	4.81	1.00	22.00
B-index	428	0.94	0.11	0.56	1.05
Government R&D subsidies	428	2213	6456	3	44375
IPR	428	4.20	0.578	1.670	4.880

APPENDIX 1 – CALCULATING THE USER COST OF R&D

The user cost of R&D can be written as:

$$UC_{it} = \left[\frac{1 - A_{it}^{d} - A_{it}^{c}}{1 - v_{it}}\right](r_{it} + \delta_{it})\left(\frac{PRD_{it}}{P_{it}}\right)$$

where A^d and A^c denote the present value of depreciation allowances and tax credits and v the corporate tax rate. The first term in the user cost equation represents the B-index (described in Warda (2001)), the final term is the price deflator for R&D relative to the price deflator for the goods and services produced. Consistent with the approach taken by Jaumotte and Pain (2005a), the price deflator term is assumed equal to unity in the empirical work.

APPENDIX 2 – CALCULATING STANDARD ERRORS FOR THE LONG-RUN PARAMETERS

The long-run parameters from the ECM model are calculated by employing the transformation detailed by Bardsen (1989). This gives the procedure for a general ECM model such as:

$$\Delta Y_t = \alpha_0 + \alpha_1^* Y_{t-1} + \beta_1^* \Delta X_t + \beta_2^* X_{t-1} + \varepsilon_t$$

Where the long-run multiplier for variable X_t is calculated as $\hat{\theta}_X = -\widehat{\beta_2^*}/\widehat{\alpha_1^*}$. A disadvantage of following this procedure is that the standard error from the long-run multiplier is not directly estimated. Instead, the variance-covariance matrix for the estimated equation must be obtained and the variance of θ_X calculated as:

$$\widehat{var}(\hat{\theta}_X) = (\hat{\alpha}_1^*)^{-2}[\widehat{var}(\hat{\beta}_2^*) + (\hat{\theta}_X)^2 \widehat{var}(\hat{\alpha}_1^*) + 2\hat{\theta}_X \widehat{cov}(\hat{\beta}_2^*, \hat{\alpha}_1^*)]$$

APPENDIX 3 – UNREPORTED RESULTS FROM THE R&D REGRESSION

	Dependant Variable = Δln(R&D Stock)			
	(1) Base	(2)	(3)	(4)
Short-run dynamics				
Δln(R&D Stock)$_{t-1}$	0.842***	0.843***	0.843***	0.842***
	(28.28)	(28.41)	(28.80)	(27.99)
Δln(R&D Flow)$_{t-1}$				
ECM$_{t-1}$	-0.013***	-0.012***	-0.011***	-0.013***
	(2.84)	(2.77)	(2.93)	(2.80)
ECM$_{t-1}$*Banking Reg				
Δln(B-index)$_t$	-0.035**	-0.036**	-0.035*	-0.035*
	(1.96)	(2.00)	(1.94)	(1.95)
Inflation$_{t-1}$	-0.133***	-0.143***	-0.139***	-0.129***
	(3.47)	(2.78)	(3.28)	(3.33)
GDP growth$_t$	0.105**	0.104**	0.103**	0.105**
	(2.36)	(2.34)	(2.33)	(2.38)
Long-run parameters				
ln(Government Financed Private R&D)$_{t-1}$	0.359**	0.412**	0.356**	0.367**
	(2.02)	(2.07)	(2.09)	(2.00)
ln(User Cost)$_{t-1}$	-0.98*	-1.210	-1.007*	-0.969
	(1.65)	(1.63)	(1.65)	(1.56)
ln(IPR)$_{t-1}$		-0.479		
		(0.42)		
ln(Foreign User Cost)$_{t-1}$			0.83	
			(0.76)	
EPL$_{t-1}$				-0.094
				(0.65)
Constant	-0.070***	-0.061**	-0.052*	-0.065**
	(2.84)	(2.06)	(1.76)	(2.46)
Observations	512	512	512	512
AdjR2	0.759	0.759	0.759	0.759

*** p<0.01, ** p<0.05m * p<0.10.
Note: t-statistics in parentheses. The regressions include country and time fixed effects, standard errors are clustered at the country level.

APPENDIX 4 – THE DETERMINANTS OF GROWTH IN THE PATENT STOCK

1986-2008	Dependent Variable = Δln(Pat Stock per cap)						
	(1)	(2)	(3)	(4)	(5)	(6)	(7)
Short-run dynamics							
Δln(Patent Stock per cap)$_{t-1}$	0.296***	0.285***	0.286***	0.296***	0.294***	0.278***	0.281***
	(5.58)	(6.08)	(6.18)	(5.32)	(5.90)	(6.75)	(5.78)
ECM$_{t-1}$	-0.16***	-0.16***	-0.16***	-0.14***	-0.15***	-0.17***	-0.14***
	(4.11)	(3.84)	(4.26)	(4.21)	(4.48)	(3.87)	(4.92)
Δln(B-index)$_t$	-0.20**	-0.19**				-0.18**	-0.16**
	(2.26)	(2.20)				(2.16)	(2.24)
Inflation$_{t-1}$				-0.46			
				(1.61)			
Long-run parameters							
ln(Business R&D/GDP)$_{t-1}$	1.28***	0.97***	0.90***	1.18***	1.41***	1.10***	
	(3.22)	(2.83)	(2.62)	(2.93)	(3.53)	(3.14)	
ln(1+Non-business R&D/Business R&D)$_{t-1}$	0.90***	0.67*	0.66*	1.03***	1.80***	0.95**	
	(2.68)	(1.76)	(1.74)	(3.00)	(6.88)	(2.43)	
ln(Total R&D)$_{t-1}$							0.62**
							(1.98)
ln(B-index)$_{t-1}$	-0.96***	-0.85***	-0.44**			-0.71***	-0.68***
	(3.24)	(3.38)	(2.25)			(2.96)	(3.41)
ln(IPR)$_{t-1}$		0.63***	0.79***			0.54	0.90***
		(2.46)	(3.07)			(1.62)	(3.37)
PMR$_{t-1}$			-0.10**			-0.09**	-0.12**
			(2.33)			(1.99)	(2.59)
ln(Foreign R&D Stock)$_{t-1}$				0.33*	0.37**		
				(1.94)	(2.43)		
ln(Foreign R&D Stock)$_{t-1}$*(High Barriers dummy)					-0.28***		
					(2.69)		
ln(IPR)$_{t-1}$*(High Barriers dummy)						-0.70**	
						(1.97)	
Constant	1.23***	1.01**	0.98**	0.65	0.83	1.19***	-0.45
	(2.79)	(2.41)	(2.56)	(1.47)	(1.63)	(2.44)	(0.82)
Observations	418	418	418	418	418	418	418
AdjR2	0.19	0.20	0.20	0.18	0.19	0.21	0.19

*** p<0.01, ** p<0.05m * p<0.10.
Note: t-statistics in parentheses. The regressions include country and time fixed effects, standard errors are clustered at the country level and calculated according to the technique outlined by Bardsen (1989) for the long-run parameters. *High Barriers dummy* is a dummy for those countries with average barriers to entry over the sample period in the top 50% of the distribution. These countries are Austria, Belgium, Switzerland, Germany, Spain, Finland, France, Italy and Japan.

APPENDIX 5 – MFP AND THE FLOW OF NEW PATENTS

1986-2008	Dependent variable = d.log(MFP)		
	(1)	(2)	(3)
MFP gap from frontier t-1	-0.03**	-0.03**	-0.03**
	(2.40)	(2.01)	(2.14)
MFP growth of frontier country t	0.31***	0.30***	0.30***
	(8.22)	(7.76)	(7.68)
Patent Flow $_{t-1}$	0.0018*	0.0031***	0.0031**
	(1.86)	(2.72)	(2.34)
PMR $_{t-1}$		-0.003	-0.002
		(1.32)	(1.19)
(PMR) $_{t-1}$ * (Patent Flow) $_{t-1}$		-0.0036***	
		(4.17)	
Hours worked $_{t}$	0.11***	0.10***	0.10***
	(2.93)	(2.93)	(2.95)
Business researchers/Total Employment $_{t-1}$	0.002***	0.002***	0.002***
	(2.84)	(2.80)	(2.88)
(Business researchers/Total Employment) $_{t-1}$ * (Patent Flow) $_{t-1}$			0.002***
			(2.71)
Constant	-0.19***	-0.17***	-0.18***
	(3.11)	(3.05)	(3.10)
Observations	428	428	428
AdjR2	0.27	0.27	0.27

*** p<0.01, ** p<0.05m * p<0.10.
Note: t-statistics in parentheses. The regressions include country and time fixed effects, standard errors are clustered at the country level.

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