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Working Party No. 1 on Macroeconomic and Structural Policy Analysis

INNOVATION POLICIES: INNOVATION IN THE BUSINESS SECTOR

ANNEX 3: FROM IDEAS TO DEVELOPMENT: THE DETERMINANTS OF R&D AND PATENTING

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ANNEX 3. FROM IDEAS TO DEVELOPMENT: THE DETERMINANTS OF R&D AND PATENTING

A3.1 Introduction

1. The review of the existing theoretical and applied literature on innovation in Annex 2 highlighted a number of key science policies that have been used widely in OECD countries. Many governments pursue some or all of these policies simultaneously, in an effort to alleviate perceived market failures that adversely affect the incentive for private firms to innovate. What is lacking however, is an empirical quantification of the relative effectiveness of different policies, whether they operate in a linear or non-linear manner, and whether they have different effects on different stages of the overall innovation process.

2. The analysis in this Annex uses three separate panels of cross-country data to provide an empirical assessment of the importance of framework conditions and policies and science policies on business sector R&D intensity and national patenting per capita. The primary reason for focusing on business sector R&D is that this component of R&D was found to be most important for the growth of GDP per capita in OECD (2003a). It also accounts for well over half of total R&D spending in most OECD economies. However, this does not mean that the scale of research undertaken in the non-business sector does not matter. The analysis in this Annex finds that it has a significant positive influence on business sector R&D intensity, as well as on patenting per capita.

3. The wide range of possible influences on innovation and their complex inter-linkages with each other means that the analysis is conducted in several different stages. In the first part of the Annex (Section 2) a model is developed and estimated for business sector R&D expenditure; this is estimated initially using only economy-wide framework variables and then using both framework variables and indicators to capture various specific innovation policies and features of the science system. Both are found to be important for understanding cross-country differences in R&D intensity. In the second part of the Annex (Section 3) a positive empirical link between R&D and subsequent rates of patenting is established and the range of explanatory variables from the R&D model is used to test whether any have additional effects on patenting over and above their effects on R&D.

4. These initial steps indicate that the share of scientists and engineers in the total workforce is one of the important factors behind cross-country differences in R&D intensity. This is not simply because scientists are usually necessary for research to be undertaken.[1] The evidence also suggests that they expand absorptive capacity, enabling better use to be made of the knowledge developed in other countries. Yet, in the short-run at least, it may be very difficult for countries to both raise the employment of scientists and engineers in the private R&D sector and to expand the size of the public research sector significantly. This is because the supply of available researchers may be relatively inelastic. If so, attempts to expand the public research sector would raise the cost of real resources for the private sector. Thus the third part of the Annex (Section 4) extends the previous analysis by taking a closer look at the labour market for scientists and engineers, estimating jointly equations for employment and wages. Private sector research output is treated as endogenous in this model, and instrumented using the remaining set of explanatory factors identified in the first two parts of the Annex.

5. The final section of this Annex (Section 5) combines together the long-run components of the estimated input (or output), employment and wage relationships to provide estimates of the eventual effects of changes in particular framework factors and policies on R&D and patenting. Two broad conclusions emerge from this work. First, there are a wide variety of different policy influences on aspects of the innovation system. Both framework factors and specific science policies matter and can have a direct and indirect effect on innovative activities. Second, there is clear evidence of policy trade-offs. In particular, policies that stimulate the demand for scientists and engineers will also raise the cost of real R&D resources, especially in the period before labour supply can adjust.

6. In contrast to the work undertaken for the OECD Growth Project -- which looked at the influences on R&D intensity in a cross-sectional panel of manufacturing industries (Bassanini and Ernst, 2002), the focus of the research in this Annex is on aggregate economy-wide developments through time. The use of data with a greater degree of aggregation can be expected to reveal different insights. For example, cross-sectional data can say little about the importance of factors that vary only slowly over time, such as real interest rates. Economy-wide data are also more likely to incorporate the wider spillover benefits from innovation between firms, industries and countries.[2]

A3.2 The determinants of business sector R&D intensity

7. This section summarises the empirical work to develop a stand-alone model of business sector R&D intensity. The initial sub-section discusses the specification of the model and a number of important data issues that have to be addressed prior to estimation. The empirical work itself is in two stages; in the first, the role of macroeconomic and other economy-wide influences is explored. In the following sub-section the model is augmented further with the additional variables designed to capture various specific innovation policies and features of the science system. The final sub-section uses the resulting model to provide an initial accounting decomposition of cross-country differences in business sector R&D intensity to show the relative importance of different factors.

A3.2.1 The structure of the R&D model

8. The empirical structure of the model is based on the structural modelling approach advocated by Hall and van Reenen (2000) and employed by Bloom and van Reenen (2002) and Parisi and Sembellini (2003). This approach models the stock of R&D expenditure in an analogous fashion to the stock of fixed capital expenditure, with the R&D stock assumed to be one input into a production process that can be approximated by a CES production function. The first order condition that R&D is acquired up to the point at which its marginal revenue product is equal to its marginal cost can be used to derive a long-run relationship of the form:[3]

$$\ln(RD_{it}) = \alpha + \beta \ln(Y_{it}) + \lambda \ln(\tau_{it}) + \sum_{j=1}^{n} \gamma_j Z_{jit} + u_{it} \qquad [1]$$

Here, RD_{it} is used to denote the stock of R&D expenditure at constant prices for each of i=1…N countries, over t=1..T observations,[4] Y is real output, τ denotes the real user cost of R&D, and Z_j is a vector of *n* variables that might have an additional influence on R&D. The coefficient on the user cost provides a point estimate of the elasticity of substitution between different factors of production. Long-run constant returns to scale would imply that β=1.

9. The real user cost of R&D can be constructed using an expression similar to the standard Hall-Jorgenson formula for the real user cost of fixed capital:

$$\tau_{it} = \left[\frac{1 - A^{d}_{it} - A^{c}_{it}}{1 - \upsilon_{it}}\right](r_{it} + \delta_{it})(PRD_{it} / P_{it}) \qquad [2]$$

Here, A^d and A^c denote the present value of depreciation allowances and tax credits, υ the corporate tax rate, r the real interest rate and δ the depreciation rate on R&D capital, assumed to be 11% per annum in all countries (Carson *et al*., 1994).[5] The real interest rate is measured using the current ten-year government bond rate corrected for the average consumer price inflation rate over the past two years. The first term in [2], the tax ratio, corresponds to the B-index measure described in Warda (2001) and used by Guellec and van Pottelsberghe (2000).[6] This series is available on an annual basis back to 1981. The final term in [2] represents the price deflator for R&D relative to the price deflator for the goods and services produced. This is assumed to be unity in the empirical work.[7]

10. The first order condition [1] relates to the stock (S) rather than the flow (R) of R&D, corresponding to the notional idea that firms are seeking to make use of knowledge stocks as well as flows. Much of the applied literature on the cross-country impact of R&D on productivity growth makes use of constructed R&D stocks to try and capture this (see, for example, Coe and Helpman, 1995 and Lichtenberg and van Pottelsberghe, 1998). As there are no official data on R&D stocks it is necessary to create them.[8] Business sector R&D stocks at constant prices were constructed for the period 1973-2001 for all OECD with sufficient historical data on the flow of business sector expenditure.

11. This modelling approach ensures consistency with other academic studies and provides a useful baseline specification for further empirical work. But it requires several important assumptions to be made, none of which is necessarily entirely valid. This implies a degree of caution in drawing strong conclusions from the resulting estimates. The first key assumption is that expenditure on R&D can be treated as if it were a form of capital. In practice, R&D expenditures consist of the wages and salaries of researchers, expenditure on supplies and materials that are intermediate inputs necessary to undertake research, and investment in equipment. However, all these forms of expenditure can be expected to yield a continued flow of benefits over time and so it appears reasonable to regard R&D expenditure as an expenditure that can be capitalised (Fraumeni and Okubo, 2002).

12. A second key assumption concerns the means of estimating the real level of R&D expenditure, as price deflators for R&D are not readily available. The conventional approach, and the one adopted in this Annex, is to proxy the unobserved R&D deflator by the GDP deflator.[9] The advantages of this assumption are that the GDP deflator embodies changes in both the cost of labour and the price of fixed capital equipment,[10] as well as being readily available across countries and over time. However, it is possible that inaccuracies can arise if there are significant changes in the relative prices of the components of R&D expenditures or periods of rapid growth in economy-wide productivity (Mansfield, 1987; Dougherty *et al.*, 2003). In particular, the productivity effect can mean that use of the GDP deflator leads to an overestimate of the real resources devoted to R&D.[11] There is little that can be done about this directly in the absence of a full scale exercise to calculate comparable R&D expenditure deflators for all OECD countries over time.

13. Firms are likely to face considerable adjustment costs in changing R&D levels to their desired values (Bloom and van Reenen, 2002). It takes time to recruit scientists and it takes time to identify and acquire other non-labour inputs, such as capital equipment and knowledge developed elsewhere. To allow for this, a dynamic non-linear error-correction equation is estimated:

$$\Delta \ln(RD_{it}) = \alpha_i + \alpha_t + \alpha_1 \Delta \ln(Y_{it}) + \alpha_2 \Delta \ln(\tau_{it}) + \sum_{j=1}^{m} \zeta_j \bar{Z}_{jit} + \theta \left[\ln(RD_{it-1} / Y_{it-1}) - \lambda \ln(\tau_{it-1}) - \sum_{k=1}^{n-m} \gamma_k \tilde{Z}_{kit} \right] + \mu_{it} \quad [3]$$

14. Long-run constant returns to scale are imposed, so that even though the dependent variable is the growth of the R&D stock (or flow) the long-run parameters ultimately determine business sector R&D intensity. The vector Z is partitioned into *m* variables that may affect the short-run evolution of R&D and *n-m* variables that may affect long-run cross-country differences in intensity. Excluded factors that vary across countries but not across time will be picked up by the country fixed effects (α_i), and excluded factors that vary over time, but not across countries will be picked up by the time dummies (α_t).[12]

15. This R&D model is initially estimated using standard panel data techniques and a balanced panel of data for 19 OECD economies over the period 1982-2001, giving a total of 380 observations in all.[13] The majority of the estimation results shown use the business sector R&D stock as the dependent variable in equation [3] ($RD_i = S_i$); however some specifications are also re-estimated using the flow of business sector R&D expenditures ($RD_i = R_i$) to check for consistency. As would be expected, there is a close relationship between the long-run coefficients in the stock and the flow specifications.

A3.2.2 Estimation results with macroeconomic factors

A3.2.2.1 Baseline models

16. The initial regression with the basic model is reported in column [1] of Table A3.1. This table is split into two parts, as are subsequent tables. The upper part reports the long-run coefficients and the lower part shows the coefficients on the dynamic terms in the equation. The long-run coefficient on the user cost of R&D capital is found to be significant, and implies that a fall of 1% in the user cost will eventually raise the R&D stock by slightly over 1%. This is similar to the elasticity found by Bloom and van Reenen (2002) in their related analysis using a smaller sample of OECD economies, and implies that changes in tax incentives for R&D could have a sizeable effect on expenditure. It is clear however, that full adjustment to the long-run equilibrium stock can be protracted, given the small size of the coefficient on the equilibrium-correction term. The first year impact of a 1% fall in the user cost is to raise the stock of R&D by just 0.01%, with half of the eventual long-run adjustment being complete after 10 years.

[Table A3.1 Framework conditions and R&D expenditures]

17. The dynamic parameters also demonstrate the clear importance of macroeconomic factors for understanding the evolution of business R&D expenditure. The rate of growth of the R&D stock is sensitive to cyclical conditions as well as the level of output and the level of real interest rates embodied in the user cost of capital. Robust output growth and low and stable inflation both have a positive influence on the rate of growth of R&D, suggesting that a stability-oriented macroeconomic framework provides a favourable environment for investment in innovation. This result is found also in all the remaining specifications of the model in Tables A3.1 and A3.2.

[Table A3.2 The combined determinants of R&D expenditures]

18. In column [2] of Table A3.1 the initial specification is re-estimated using the growth in the flow of real R&D expenditures as the dependent variable. In this case, the long-run relationship ultimately determines R&D intensity measured using the flow of expenditure. As expected, this is found to be similar

to the relationship for the R&D stock, with any (steady state) scalar differences being picked up in the fixed effects. The user cost of R&D capital remains significant, although the long-run elasticity declines to just over 0.8%. The coefficients on the dynamic terms also continue to be significant, although their magnitude differs from those in the stock equation since the time taken to adjust the flow of expenditure by a given proportion is much shorter than the time taken to adjust the stock of R&D by an equivalent extent.[14] The greater variation in the flow data is apparent from a comparison of the standard error from the stock model in column [1] with that from the flow model in column [2].

19. The regressions reported in columns [3] to [6] examine the robustness of the basic model in column [1]. These, and all the subsequent regressions in Table A3.1 are for the stock of R&D, rather than the flow. In column [3] the user cost term is split into its two components -- the tax component and the remaining term which is the sum of the real interest rate and the depreciation rate. The magnitude of the long-run coefficient on the tax component is higher than on the other term, but it is not particularly well determined and it is possible to impose equal long-run coefficients on the two components [p-value = 0.538]. In contrast, the dynamic tax term is significant but the dynamic term in the real component is not. The results from excluding this latter term are shown in column [4] of Table A3.1.

20. It is possible that the choice of depreciation rates for the R&D stock could affect the estimation results. The sensitivity of the results for the initial equation is shown in columns [5] and [6] in Table A3.1. In column [5] the depreciation rate is changed from the initial assumption of 11% per annum to 16%, with the user cost term being adjusted accordingly. In column [6] the depreciation rate is lowered to 6% per annum. In each case the R&D stock is recalculated. The regression results suggest that the significance of the included variables is not particularly sensitive to the choice of depreciation rates, although the magnitude of the coefficients do change. As would be expected, the higher the depreciation rate, the more the stock equation begins to look like the flow equation, with the user cost elasticity becoming smaller and the parameters on the dynamic terms becoming larger in absolute terms. Reducing the depreciation rate to less than 11% has the opposite effect. Taking the results in columns [1]-[6] together, it is reasonable to conclude that the choice of depreciation rate, whilst arbitrary, does not have an undue effect on the resulting estimated parameters.

21. In the remainder of this section, the equation in column [4] is taken as a simple baseline model into which other variables capturing aspects of economy-wide framework conditions are introduced.

A3.2.2.2 Profits and financial development

22. The literature on the financing of R&D expenditures, discussed in detail in Section 5 of Annex 2, highlights the potential sensitivity of R&D expenditure to the availability of both internal and external finance. Many studies have suggested that internal finance is especially important, given the difficulties of attracting finance from external investors for R&D projects with uncertain commercial applications. For firms without sufficient levels of cash-flow, especially small or new firms, the availability of venture capital finance has also been shown to be a key factor. Unfortunately, cross-country data on the size of the venture capital market are not available for much of the sample period used in estimation. But it is likely that some of the cross-country differences in venture capital provision will be correlated with cross-country differences in stock market capitalisation,[15] and so the latter is used as a proxy. Initial estimations used three particular variables to try and capture the diverse influences of different financial factors -- (pre-tax) corporate profits as a share of GDP, the sum of stock market capitalisation plus credit provided to the private sector by deposit money banks (a measure of financial development) as a share of GDP, and the proportion of this accounted for by stock market capitalisation. All are entered with a one year lag.[16]

23. Initial results, not shown in Table A3.1, suggested that while all three sources of finance mattered jointly, it was difficult to disentangle their separate influences. One possibility would be to use a principal

component of the series. An alternative, pursued here, is to also include interaction terms in order to test for non-linearities in their joint effects. The preferred specification is shown in column [7] of Table A3.1. Significant positive effects are found for the profit share of GDP, aggregate financial market development as a share of GDP and the ratio of stock market capitalisation to total financial market development. The latter result is (weakly) consistent with the hypothesis that equity-based financial systems potentially offer a more favourable financial environment for firms seeking to raise external finance. In addition, a significant negative coefficient is found on the interaction term between the profit share and aggregate financial development. This implies that the importance of enhanced financial development may lessen when profits are high, with more R&D being financed from internal resources.[17]

A3.2.2.3 Product and labour market regulations

24. Indicators of cross-country differences in product and labour market regulations (PMR and EPL) and restrictions on inward foreign direct investment (FDIRES) are introduced in the regression reported in column [8] of Table A3.1. The expected impact of changes in each of these indicators is theoretically ambiguous, as discussed in Annex 2. Enhanced product market competition can provide incentives to innovate and escape competition, but possibly only up to a certain point, after which the prospective rents from innovation start to diminish. EPL could constrain the ability of firms to undertake innovation-driven workplace reorganisations, but could equally well encourage incremental process innovations arising from specialist knowledge in a workforce that has considerable company and occupation-specific experience.[18] Restrictions on inward FDI may slow the rate at which foreign knowledge is brought into national economies, but equally they can provide a more favourable competitive environment for prospective innovators amongst national firms, especially in large economies.[19]

25. The variables used are the time-varying PMR indicator for anti-competitive regulations in non-manufacturing industries, the EPL indicator used recently in the empirical work on labour force participation (Jaumotte, 2003) and the cross-country indicator of FDI restrictions used by Nicoletti *et al.* (2003).[20] All are entered with a one year lag.

26. The initial estimation results show that the PMR indicator has a significant negative coefficient, implying that tighter regulatory controls will have an adverse impact on R&D expenditures, other things being equal. The coefficients on the EPL and FDIRES terms are not significant, either individually or jointly. Further estimation, not reported here, showed that a squared PMR term was also insignificant when added to the model.[21]

A3.2.2.4 The full effects of framework conditions

27. A complete model with all indicators of economy-wide framework factors is shown in column [9] of Table A3.1. Five additional variables are introduced at this stage, all of which try to capture different dimensions of the openness of the economy and the extent of exposure to foreign knowledge. For all countries, the diffusion of knowledge developed outside the country is likely to be an important element of the generation of new research ideas. The available stock of foreign knowledge is measured using a trade weighted average of R&D stocks in partner countries to domestic GDP, with weights constructed using the information in the bilateral trade matrix of the OECD INTERLINK model and partner country GDP.[22] Figure A3.1 shows that the foreign R&D stock is larger in absolute value and relative to the domestic R&D stock for smaller countries, which are more open. Both stock measures are expressed as a share of domestic GDP.

[Figure A3.1 Domestic and foreign business R&D stocks, 1996-2000]

28. Other things being equal, more open economies will have a greater exposure to the foreign knowledge stock at any point in time. To capture the general tendency for all economies to become more open over time, an interaction term between the foreign R&D stock and trade openness is also included, along with the separate trade openness variable.[23] Trade openness is measured as the ratio of exports plus imports to GDP, after correcting for country size (OECD, 2003a).[24]

29. Three additional variables are also included in the general model -- a measure of import penetration and dynamic and lagged levels terms in the real exchange rate. Import penetration is defined as imports relative to final domestic expenditure corrected for the import content of exports. Although there is some overlap between this measure and international openness, their joint inclusion does, in principle, allow a test of whether exporting helps to improve access to the foreign knowledge stock, as suggested by some theoretical models. Import penetration may also be a further measure of domestic product market competition, as several previous empirical studies have suggested (Blundell *et al.*, 1999).

30. Existing empirical evidence of the impact of real exchange rate on innovation is discussed in Section 5 of Annex 2. In general, changes in the real exchange rate have three main effects.[25] First, they can signal a change in the competitive pressures facing companies. Secondly, they may affect financial pressures if companies seek to absorb the impact of exchange rate changes in their profit margins. Finally, the real exchange rate may affect the location decisions of internationally mobile research-intensive companies. The combined impact of these separate influences is ambiguous as they can operate in different directions.[26] Some of these effects will already be captured in the level of production, the profit share and import penetration, but others will not, since less (or more) long-term investments are taking place at a given output level than might otherwise be expected.

31. In the unrestricted combined model (column [9]) the foreign knowledge stock term has a significant positive coefficient and the two real exchange rate terms have significant negative coefficients (at the 10% level or above). The openness and import penetration terms, the interaction of openness and the foreign R&D stock and the indicator of inward FDI restrictions are all insignificant [p-value of joint deletion = 0.13], as is the EPL term. However removing only the FDIRES, EPL and import penetration terms results in the other coefficients becoming significant, as shown in column [10] of Table A3.1.[27]

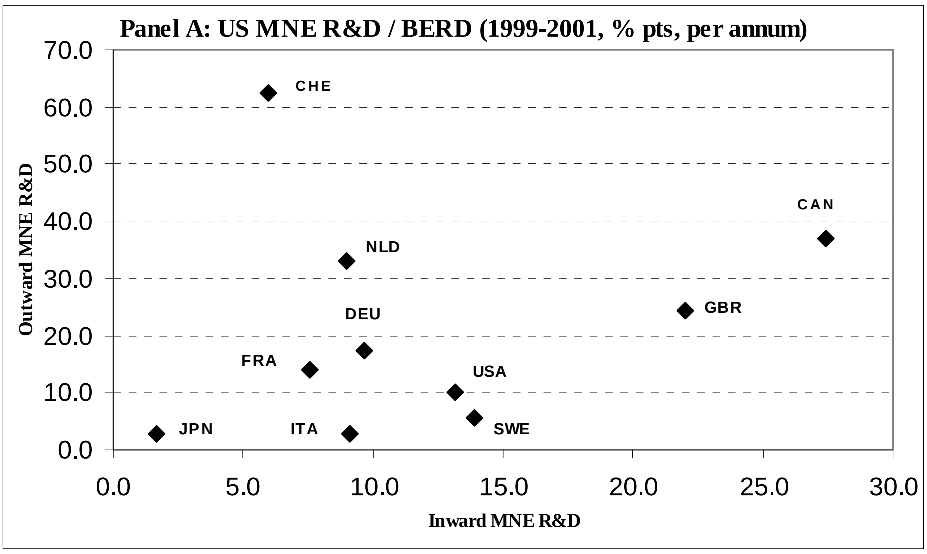
32. The relative lack of significance of the FDI indicator variable does not mean that inward and outward foreign direct investment is not an important source of knowledge transfer. At least some effects may already be captured through the foreign R&D stock term, since this is known to be an important determinant of FDI decisions (Barrell and Pain, 1999). It is also the case that more direct measures of the activities of the affiliates of foreign-owned firms have significant effects on national R&D intensities, as shown in the Box. Here, the analysis, for a smaller number of countries and a shorter sample period, suggests that the share of business sector R&D undertaken by the foreign affiliates of multinational companies provides a positive stimulus to aggregate R&D expenditures, whilst higher levels of R&D abroad by domestic companies reduce their R&D performed at home. Thus there is some ambiguity about the overall effects of FDI and restrictions on its extent. Data on the activities of foreign affiliates are, however, harder to obtain on a comparable basis across countries over a long time period, and so are not included directly in the main empirical specification.

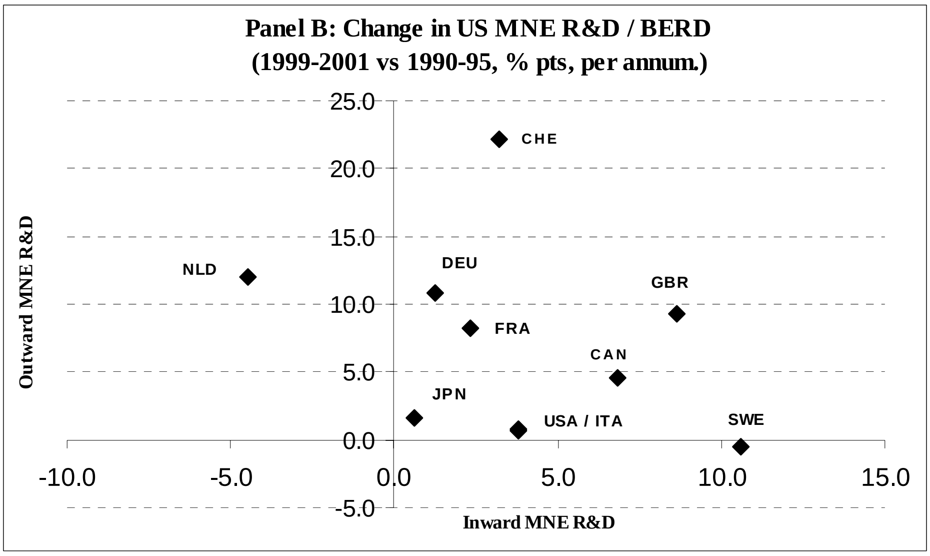
Box. The influence of the activities of the foreign affiliates of multinational companies on domestic R&D intensities

There has recently been a growing policy interest in the location of research and development activities undertaken by the foreign affiliates of multinational companies. This interest is especially marked in the case of relatively small, open economies that have comparatively high levels of inward and outward foreign direct investment. For many years, the prevailing view was that outward foreign direct investment was motivated in part by the belief that it could improve market access and increase the rents earned on firm-specific innovations developed initially in the home country. Any R&D undertaken in other countries by the firm would then largely be developmental, making necessary adaptations to existing products and prototypes in order to satisfy the particular requirements of local markets (Mansfield *et al.*, 1979). An empirical implication of this model is that foreign direct investment would be one means by which technologies were transferred across national borders. More recently, prompted by the rising share of domestic R&D expenditures undertaken by foreign-owned firms in many OECD economies, attention has turned to the possibility that foreign direct investment may be motivated in part by the need for the firm to augment its knowledge base by sourcing foreign ideas and technologies.

The existence of positive productivity spillovers and agglomeration effects from inward investment in (some) industries and countries is relatively well known. But little is known about the impact of outward investment on domestic activities. The analysis undertaken here focuses on R&D performed by multinational companies inside the United States, and by foreign affiliates of US-owned companies. The focus on the United States is justified because this country is widely regarded as the technological leader. The figure below shows the level and evolution over the 1990s of the US inward and outward R&D flows of multinational companies (MNE) for ten OECD countries. Countries that appear relatively open include Switzerland, the Netherlands, the United Kingdom and Canada (Panel A). Cross-border R&D rose in almost all countries in the 1990s as a share of GDP and business R&D (Panel B).

Figure. **US inward and outward R&D flows of multinational companies**[1]





1. Inward MNE R&D refers to R&D performed by foreign affiliates of US-owned firms. For the United States, it refers to R&D performed by affiliates of foreign-owned firms. Outward MNE R&D refers to R&D performed in the United States by foreign affiliates of domestic firms. For the United States, it refers to R&D performed by foreign affiliates of US-owned firms. R&D inflows and outflows are scaled by domestic business R&D.
Source: USA MNE statistics.

In order to test for the existence of potential benefits from the activities of the foreign affiliates of multinational companies, a regression relating the change in domestic business R&D intensity to lagged changes in inward and outward R&D flows is estimated over the sample period 1992-2001. The results reported in the Table below suggest that inward R&D flows have potential positive spillovers on the subsequent growth of domestic R&D intensity. The effects from outward R&D flows on domestic R&D intensity are negative, suggesting that the relocation effect dominates the knowledge sourcing effect. However, the coefficients on inward R&D flows are greater than those on the outward R&D terms (in absolute value), implying that if inward and outward R&D grow at the same rate, the net effect will be to enhance the rate of growth of business sector R&D in all countries.

Table. **Foreign affiliate R&D and domestic business sector R&D**

Dependent variable: Δ $(BERD/GDP)_t$

	[1]	[2]
Δ $(BERD/GDP)_{t-1}$	0.411 (3.9)	0.403 (4.0)
Δ $(RDOUT/GDP)_{t-1}$	-0.185 (2.0)	-0.158 (1.7)
Δ $(RDOUT/GDP)_{t-2}$	-0.181 (2.0)	-0.198 (2.1)
Δ $(RDIN/GDP)_{t-1}$	0.411 (3.5)	0.383 (3.1)
Δ $(RDIN/GDP)_{t-2}$	0.203 (1.2)	0.228 (1.3)
Steady-state coefficients		
Δ (RDOUT/GDP)	-0.621 (2.2)	-0.596 (2.2)
Δ (RDIN/GDP)	1.042 (2.8)	1.023 (2.6)
$\bar{R}^2$	0.54	0.49
Standard Error	0.046	0.048
Log-Likelihood	146.9	157.7

1. Variable definitions: BERD denotes domestic business R&D; GDP is gross domestic product; RDOUT is R&D performed by foreign affiliates in the United States (R&D performed in all foreign affiliates for the United States); RDIN is R&D performed by all foreign-owned affiliates from the United States (for the United States this is R&D performed in all foreign-owned affiliates in the United States).
2. The estimation in column [1] includes Canada, France, Germany, Italy, Japan, the Netherlands, Sweden, Switzerland and the United Kingdom. The estimation in column [2] includes the same countries plus the United States. The sample period is 1992-2001 in both estimations. Time dummies and country fixed effects are included.
Source: OECD estimates.

33. In the restricted model there is a significant positive coefficient on the foreign stock as well as on the interaction of the foreign stock and openness. This suggests that more open economies may be more easily able to either access or benefit from foreign knowledge. However, this is counteracted in part by the significant negative coefficient on the openness term itself. One interpretation of this result is that there may be less need (or fewer resources) to undertake R&D in very open economies, many of whom are comparatively small. The two real exchange rate terms both have a significant negative coefficient, implying that a permanent appreciation in the level of the exchange rate will adversely affect R&D intensity, other things being equal. There is nothing directly in the equation to support the idea that a deterioration in product market competitiveness will force firms to try and improve product quality through additional R&D.

34. Overall, the equation indicates that many framework conditions are important for understanding cross-country differences in R&D intensity. In addition to stable macroeconomic conditions, the cost and availability of finance, the degree of anti-competitive product market regulations and the degree of exposure to the foreign knowledge stock all have significant effects. One interesting point from the results in Table A3.1 is that the coefficient on the user cost of capital appears very sensitive to the remaining factors included in any regression, although it is always negative and significant (at least the 10% level). R&D taxes and real interest rates appear to matter, but it is difficult to be confident about the precise magnitude of their effects.

A3.2.3 Estimation results with framework conditions and science indicators

35. In this section the model set out in column [10] of Table A3.1 is augmented with a number of additional variables that attempt to capture the influence of specific science policies and institutions. An initial model with all the new variables and also the framework variables is reported in column [1] of Table A3.2. The removal of three insignificant variables results in the equation shown in column [2] of Table A3.2. Both of these first two specifications use the stock of business sector R&D expenditure as the dependent variable. In the third column the restricted model is re-estimated using the flow of R&D expenditure.

36. The additional variables introduced into the model attempt to capture the diverse influences from direct government subsidies for private sector R&D, R&D in the non-business sector, linkages between businesses and universities, support for intellectual property rights, industrial structure and the human resources available for science and technology. The studies reviewed in Section 6 of Annex 2 suggested that there might be some important trade-offs between these factors, with some policies leading to the crowding out of the real resources available for R&D in the business sector.[28] Initial estimations, not shown in Table A3.2, suggested that whilst these additional factors were jointly significant, it was difficult to pin down their effects precisely without allowing for the trade-offs that many involve.[29] The final effects found for each are discussed briefly in turn.[30]

A3.2.3.1 Subsidies

37. The description of the literature on direct public funding for private R&D in Section 2 of Annex 2 indicated that there have been few clear conclusions as to the effectiveness of such funding in previous empirical studies. In part this may be because any financial support of this kind has to be offset elsewhere if aggregate levels of public expenditure are subject to specified limits.[31] To examine the relative balance of each of these potential effects, two separate terms were included in the unrestricted model -- R&D subsidies as a share of corporate profits and R&D subsidies relative to GDP.

38. The estimates suggest that an increase in subsidies relative to profits has a significant positive influence on R&D expenditure, but this is offset by a significant negative impact from subsidies as a share

of GDP. So subsidies are more likely to have a net beneficial effect when the profit share of GDP is low, other things being equal. At other times they may "crowd out" privately financed expenditure. Evaluated at the sample mean for the panel, the two coefficients together imply a very small positive effect from subsidies on private R&D.

A3.2.3.2 Non-business R&D and business-academic linkages

39. Research in the non-business sector is an important source of technical advance and may often provide new knowledge that can potentially be of use for commercial research. For this to occur, knowledge of new scientific advances has to be accessible for the private sector, as discussed in Section 3 of Annex 2. The scale of research in the non-business sector is relatively straightforward to measure (after correcting for breaks in data), but the extent of linkages between the business and non-business sectors could be measured in many different ways. Here, the extent of business financing of research in the non-business sector is used.[32] Although such funding should, in principle, be expected to stimulate private sector R&D, with firms gaining better access to basic research and "star" scientists (Berman, 1990; Zucker *et al.*, 2002), it could also have costs. For the firms concerned, funding of non-business research reduces the internal funds directly available to finance their own research. For other firms it may be harder to gain access to basic knowledge if the funding firm imposes exclusive rights for the commercial development of the funded research. Thus the aggregate impact of closer linkages between the two sectors is ambiguous.

40. To test the importance of these different factors, three terms were included in estimation -- R&D intensity in the non-business sector, the share of non-business research funded by businesses and business funding for non-business research as a share of corporate profits. The results in Table A3.2 indicate that all three of these terms are significant. Business sector R&D intensity is positively related to the level of non-business R&D intensity, consistent with the view that this sector generates basic knowledge which offers beneficial spillover effects for the private sector. Evaluated at the sample mean, a permanent increase in non-business R&D expenditure of 0.1% of GDP would raise business sector R&D by just under 9%. However, as shown in Section 4 of this Annex, this direct effect would be counteracted in part by the extent to which an expansion in the scale of non-business research would crowd out the real resources available to the private sector.

41. There are two offsetting effects from business funding of non-business research. Increases in the share of public research funded by businesses have a significant positive impact on private sector R&D, but this is offset if funding is high as a share of corporate (pre-tax) profits.[33] The net effect of these two forces remains positive on average, whether evaluated at the sample mean or at the mean for 1999-2001. At the sample mean, a 10% rise in funding by business of non-business research will raise the level of business R&D by about 1%.

A3.2.3.3 Intellectual property rights

42. A further component of regulation that could be expected to affect R&D and innovation is the strength of intellectual property rights. The discussion of the literature in Section 4 of Annex 2 indicates that the relationship between the IP system and innovative activity is a complex one. Stronger IP rights can encourage firms to undertake innovation, but equally they can make it harder for companies to access knowledge, and thus hinder cumulative innovation processes. There can also be interactions with the extent of product market competition, with the positive effect that competition has on innovation being weaker when IP protection is strong. This suggests that interaction terms between indicators of IPRs and competition should also be included in estimation.

43. The IPR indicator used in estimation is the cross-country index developed in Ginarte and Park (1997) and updated in Park and Wagh (2002).[34] The index has limitations, since the United States by 2000

has a score of 5, implying that patent rights cannot be strengthened further, but it does provide an indicator of the variation in the strength of patent rights between countries over time.[35]

44. The main conclusion that emerges from the empirical estimates is that it is difficult to find a well-determined and robust effect from the IPR index on R&D intensity once allowance is made for other explanatory factors. This is especially the case when using comparatively aggregated data. There is some evidence that higher levels of IPRs have a significant negative effect on R&D when import penetration is high, possibly because strong IP protection is preventing the full benefits of competition from being felt, but little direct evidence that it matters in its own right.

45. The unrestricted model in column [1] of Table A3.2 includes a separate IPR term, together with interaction terms between IPR and two measures of product market competition -- the PMR indicator and import penetration. None of these terms has a significant coefficient and they are also jointly insignificant [p-value of deletion = 0.145].[36] Discarding the interaction term with the product market regulation indicator results in the remaining two terms becoming jointly significant at the 6% level in the equation shown in column [2] of Table A3.2. However, when estimating the flow equation (column [3] of Table A3.1), the separate IPR variable becomes insignificant and the two IPR terms are again jointly insignificant [p-value of joint deletion = 0.125].

46. While there is little empirical support from this model (and also from the subsequent models) for the proposition that stronger intellectual property regimes are directly associated with higher R&D,[37] it is also possible that they could encourage other forms of innovation activity, such as patenting. This issue is explored further in the separate analysis of the determinants of the differences in cross-country patenting in Section 3 of this Annex. The analysis in Section 4 of this Annex on the labour market for scientists also finds that stronger IP protection can have indirect effects on R&D intensity through its impact on the demand for scientists and engineers.

A3.2.3.4 Industrial structure and human resources

47. Two potentially important quasi-structural features of the economy are the lagged value share of hi-tech manufacturing industries in total GDP and the lagged share of scientists and engineers in total (dependent) employment.[38,39] Both of these can be expected to be positively related to the level of economy-wide R&D, possibly endogenously, and could be important explanations for observed differences in R&D intensity across countries.[40]

48. The factors affecting the labour market for scientists and engineers are discussed in Section 6 of Annex 2 and explored further in Section 4 of this Annex. In the absence of scientists and engineers there would almost certainly be relatively little R&D -- though other forms of innovative activities could still take place. But there are at least two reasons why it is important to include this measure as a control in the regressions. First, differences in the number of scientists may be an important accounting explanation for cross-country differences in R&D intensity. Second, and perhaps more importantly, the number of scientists could affect the absorptive capacities of the economy, an idea easier to test when a variable for the scientists share is included directly in estimation. For many economies, especially small open ones, a particularly important aspect is the extent to which they have the ability to understand and benefit from knowledge developed elsewhere. To test this, an interaction term between the scientists' employment share and the foreign R&D stock is included.

49. The results suggest that considerable benefits could result from improving the human resources available for science and technology in the long-term, provided that were possible. The coefficients on both of the scientist terms are positive and significantly different from zero. Evaluated at the sample means, the coefficients in column [3] of Table [2] imply that a rise of 0.1 percentage points in the share of

scientists in total employment (sample mean = 0.33 percentage points) would eventually increase the flow of R&D expenditure at constant prices by about 16%. In contrast, the hi-tech output share variable was not found to be a significant factor in the general model, and was thus discarded.

A3.2.3.5 Economic conditions and framework policies

50. The inclusion of these additional features of the national science system also generates a noticeable overall improvement in the fit of the equation and the size and significance of the coefficient on the equilibrium-correction term.[41] Both suggest that it is important to control for these influences in any cross-country analysis of the determinants of R&D, as does a formal test of their joint significance. With one exception, the framework factors found to be significant in the first stage of the modelling exercise remain robust to the inclusion of the additional indicators for science policies and institutions. The exception is the interaction between openness and the foreign R&D stock which becomes insignificant once controls are included for the interaction between the scientists share and the foreign R&D stock.

51. The inclusion of the science indicators does however change the magnitude of the effects of the remaining framework factors. In particular, the long-run elasticity with respect to the user cost of capital has declines to approximately a third of a per cent, well below the effect found in the original baseline model in Table A3.1. One possible explanation is that the user cost, with the embodied tax credit effect, was previously picking up effects really due to other science-related policies. This illustrates that any estimate of the marginal impact of changes in tax incentives on R&D is likely to be sensitive to the specification of the model used.

52. Profitability, financial development, the product market regulation indicator, the foreign R&D stock and the real exchange rate all remain significant in the preferred specification. However, in general their impact is also reduced when the further controls are included in estimation.

A3.2.4 Accounting for cross-country differences in R&D intensity

53. A detailed discussion of the impact of changes in particular policy variables on R&D is given in Section 5 of this Annex. The final flow equation in Table A3.2 can also be used to provide an indication of the relative importance of each of the main variables for understanding current differences in business sector R&D intensity across countries. Table A3.3 shows the contribution of each of the main influences to the percentage deviation in R&D intensity from the OECD average in the year 2000, which was 1.6% of GDP.[42] The calculations for this have been undertaken using the long-run parameters shown in column [3] of Table A3.2. These calculations should be regarded illustrative of the principal influences, rather than precise estimates, as they abstract from the separate dynamic terms in the estimated equation and ignore the uncertainty around the estimated coefficients.

[Table A3.3 Decomposition of R&D intensity relative to OECD average in the year 2000]

54. The R&D data show a wide cross-country diversity. Two countries, Sweden and Finland, have a business sector R&D intensity that is more than twice the OECD average. R&D expenditures in the United States, Japan, Switzerland and Germany are all over 50% larger than the average. At the other extreme, Portugal, Spain and Italy have business sector R&D intensities more than 50% below the average. The main findings highlight that there is also a wide diversity in the different factors underlying these markedly different outcomes.

55. In some cases the coefficients are sufficiently large as to imply that R&D intensity would be up to twice that of the OECD average if all other influences were at the OECD average apart from the factor concerned. This is especially true of the aggregate “foreign exposure” effect shown in Table A3.3. This is a combination of the effects arising from the separate foreign stock and openness terms, plus the deviation

from the mean foreign stock evaluated at the average employment share of scientists. The impact of cross-country differences in this effect has a clear correlation with country size; smaller countries benefit from greater openness relative to the average economy. Thus the impact of foreign knowledge is particularly high in Ireland, Switzerland, the Netherlands and Belgium.

56. Another clear finding is that deviations in R&D intensity from the OECD average are heavily affected by the deviation of the share of scientists from the OECD average.[43] This emphasises the importance of taking a further step to explore the factors that influence the availability of scientists for the private sector. Most countries whose R&D intensities are above (below) the OECD mean, also have a scientist employment share above (below) the OECD mean. The United States, Japan, Sweden and Finland are the countries with the largest positive effects in the deviation of the scientists share from the mean; Australia, Italy, Spain, Portugal and the Netherlands have the largest negative effects.

57. Those countries that tend to have above (below) average effects from the private sector employment of scientists tend to experience a below (above) average effects from the share of non-business sector R&D in GDP. This suggests that it may be difficult to increase both simultaneously. But there are exceptions. Finland, Germany, Japan and Sweden all benefit from a share of non-business R&D and a scientists share that are above the OECD average. Of these, only Finland receives further benefits from the strength of linkages between the business and non-business sectors.[44]

58. Regulations can also result in national R&D intensities deviating markedly from the OECD average level. The low level of product market regulation in Australia, the United Kingdom and United States helps to raise their R&D intensity by 10% or more above the OECD average. In contrast, it reduces R&D intensity in Ireland, Italy and Portugal, by over 8% relative to the OECD average.

59. The effects from cross-country differences in intellectual property rights are shown in the column of Table A3.3 headed IPR. The degree of uncertainty around these estimates is especially high, as they stem from a combination of the separate insignificant IP term in column [3] of Table A3.2 and the deviation from the OECD mean IP level evaluated at the average import penetration level. In general, the magnitude of the differences across countries appears comparatively small. The effects are largest in the United States and Portugal. The United States has comparatively high IP protection and comparatively low import penetration, whilst Portugal has the opposite combination. This reduces R&D intensity in the United States and raises R&D intensity in Portugal relative to the OECD average.

A3.3 The determinants of patenting

A3.3.1 Patents as an indicator of innovative activity

60. There are several reasons why R&D expenditures should not be used as the sole measure of innovation. R&D is a measure of the inputs that go into the innovation process and thus it reflects innovative activity rather than innovative success. If returns to scale are not constant and/or market competition is imperfect, spending on R&D may not reflect fully the productivity of the resources used and the actual quantity of innovative activity that is undertaken. Equally, some innovations take place outside of the formal R&D process and so will not be captured by R&D expenditure at all. These limitations of input measures such as R&D emphasize the importance of looking at more direct output measures of innovative activity such as patents to see whether they yield different insights as to the determinants of innovation.[45] A natural question of policy interest is whether there is a close link over time between R&D and subsequent levels of patents. If so, policies that affect R&D will also be important for understanding cross-country differences in patenting.

61. Despite the frequency with which they are used, it is important to recognise that patents are also an imperfect measure of the quantity of innovative activity, as discussed in Section 4 of Annex 2. Patents may even obstruct innovation on occasions if they slow the diffusion of knowledge (with information on some research activities emerging only when applications are published) or act as barriers to market entry. Some inventions are not patented, and some patents may have little economic value. If so, observed changes in patenting may not accurately reflect underlying changes in innovative activities.

62. Two different measures of patents are examined in the empirical analysis of the link between R&D expenditures and patenting. Each has different advantages. Patent applications at the national patent office, or at the patent office in the largest regional market (henceforth referred to as domestic patents for simplicity) provide a broad measure of patenting that is likely to reflect the scale measure of research output which is needed for the labour demand analysis in Section 4 of this Annex.[46] Triadic patents are more easy to compare across countries and may have a higher value on average, but cover only a small subset of total patents.[47] The data used are for patent applications by priority date, as opposed to filing or grant dates. This provides a better indication of the date the invention was made and a more accurate measure of the inventive performance at any given point in time (OECD, 2003c). Data from the USPTO cover only granted patents, while other patenting offices report the total number of applications, whether the patent was granted or not. The innovation performance of a country is measured by the per capita number of patent applications with a domestically resident inventor (whether they are a national of the country or not). In cases where the invention was made jointly by inventors resident in different countries, an equal fraction of the patent is attributed to each country.

A3.3.2 The link between R&D and patenting

63. As the patent data used do not distinguish between patent applications from (or grants to) the business and the non-business sectors, it is important that any empirical model includes controls for both business and non-business R&D. The most appropriate model to estimate may be one with the accumulated stock of R&D, since there can be long lags between the time when the research is undertaken and the patent application is made. Research may be cumulative, implying that past R&D will increase the productivity of more recent research. If so, there is a further case for including a broader, more encompassing measure of R&D efforts. The basic approach is to include two separate terms: the log of the stock of business sector R&D and the log of 1 plus the ratio of the non-business R&D stock to the business R&D stock. If these two are found to have statistically similar coefficients they can be combined to show the combined effect using the log of the whole economy R&D stock.[48] The estimated equation reads:

$$\begin{aligned}\Delta \ln(Pat_{it}) &= \alpha_i + \alpha_t + \alpha_1 \Delta \ln(Pat_{it-1}) + \alpha_2 \ln(Pat_{it-1} / Pop_{it-1}) \\ &+ \alpha_3 \ln(RD^P_{it-1} / Y_{it-1}) + \alpha_4 \ln(1 + RD^P_{it-1} / RD^G_{it-1})) + \mu_{it}\end{aligned} \qquad [4]$$

where *Pat* denotes either the number of triadic patents or the number of domestic patents, *Pop* is the millions of population between the ages of 25 and 64, RD^P denotes the stock of business R&D and RD^G is the stock of non-business R&D.

64. The sample covers 19 OECD countries (18 in the case of domestic/regional patents) over the period 1986-2000.[49] Observations prior to 1986 are not included because the EPO was only founded at the end of the 1970s and numbers on EPO patent applications are not considered sufficiently reliable for empirical work at the beginning of the 1980s.[50] The equations are estimated with country fixed effects and time dummies, and the standard errors are corrected for heteroscedasticity. Results are reported in Table A3.4. The first two columns report estimation results for domestic patents, while the last two columns show results for triadic patents.

[Table A3.4 Relationship between patent applications and R&D stock]

65. The estimates for both domestic and triadic patents suggest that there is a clear positive link between R&D and subsequent patenting. In both column [1] and column [3] it can be seen that the principal effect comes from R&D in the business sector. There is also a positive contribution from R&D activity in the public sector. The public sector may be less likely to patent its innovations because it is not driven by commercial gain and in some cases because free access of society to fundamental discoveries may entail large social benefits. The aggregate effect of R&D activity in the public sector may also hide differences across countries according to the incentives that public research organisations (PROs) have for patenting their basic research. The restriction that the coefficients on the log of the stock of business R&D and the log of 1 plus the ratio of the non-business R&D stock to the business R&D stock are not significantly different can not be rejected at the 5% level. The restricted coefficient, which is shown in columns [2] and [4], implies that in the long run, a 1% increase in the stock of R&D to GDP yields an increase of about 2% in triadic patents per capita, and of 1.7% in domestic patents per capita.

A3.3.3. Additional policy influences on patenting

66. The findings from these simple regressions indicate that the level of patenting has risen considerably faster than the stock of knowledge, abstracting from other influences. The link between the two suggests that factors that stimulate research inputs (R&D) will also have a positive impact on the level of research outputs. What remains to be seen is if these policy-sensitive indicators have additional effects on research outputs over and above their effect on R&D. Particular interest lies in the impact of intellectual property rights and the use that can be made of foreign knowledge.

67. There are several reasons why these variables may have additional effects. First, they may affect the quantity and efficiency of innovation efforts which take place outside of the formal R&D process and result in patents. Second, some of these variables may also affect the efficiency of R&D inputs, and to the extent that this is not fully reflected in the prices of inputs, it would show up as an additional effect. Empirically, it is difficult to distinguish between the two hypotheses.

68. Initial regressions (not reported here) included, in addition to the two R&D stock terms, all the economy-wide framework conditions and the specific science policies and institutions included in the R&D model. Two other terms were also introduced: an interaction term between the stock of R&D to GDP and business-academic links (measured by the share of non-business R&D financed by business) which captures possible spillovers between research in the two sectors, and a measure of the average years of education in the population over 25.[51] The latter reflects the human capital available in the whole economy, especially outside the R&D sector. Streamlined versions of the equation are reported in Table A3.5. The variables that have been eliminated are jointly insignificant at the 5% level. The restriction that the coefficients on the two R&D stock terms are not significantly different cannot be rejected at the 5% level, and is imposed in columns [2] to [8].

[Table A3.5 Additional policy influences on patenting]

69. The broader measure of domestic (or regional) patents appears to be better determined by the model than triadic patents, for which only a subset of the determinants of domestic patents is significant. The goodness-of-fit (measured by the adjusted R squared) is also much larger for domestic patents than for triadic patents. The reason may be that triadic patents only capture a fraction of the innovation output and that some domestic factors may affect the incentives to patent in the own country but not necessarily in other markets. The comments below focus on domestic patenting, but indicate when the results also carry over to triadic patents. The preferred models for domestic and triadic patents are respectively in columns [4] and [8].

70. A strengthening of intellectual property rights leads to an increase in the propensity to patent out of a given amount of R&D, both for domestic and triadic patents. This is consistent with the evidence reported in Section 4 of Annex 2 that patenting has become a comparatively more important means of protecting innovation in recent years, though reduced patenting costs may also have contributed to this increase (as captured in the time dummies).[52] The empirical evidence shows only a modest positive effect of stronger IPR on R&D spending and suggests that stronger IPRs may increase more the propensity to patent innovation output than innovation output itself (see Section 5 of this Annex).

71. The number of domestic and triadic patents per unit of R&D also increases significantly with the size of the stock market (relative to GDP). This lends some support to the hypothesis discussed in Section 5 of Annex 2 that the incentives to patent ideas are stronger in market-based (as opposed to credit-based) financial systems because patents can be used as an asset to attract financial support. However, it cannot be excluded that market-based financial systems also increase the efficiency of research activities, by increasing competition for financial resources.

72. The evidence in the literature discussed in Section 5 of Annex 2 relates to the size of the venture capital market -- the segment of the stock market specialising in the financing of the early stage development of companies. However, data on venture capital are not available for many of the years included in the analysis. Moreover, over the period 1995-2001, a period for which the data are available, there is strong evidence of a significant positive correlation between the share of equity financing and the share of venture capital in GDP, even after country-specific factors are controlled for. Contrary to the evidence based on the size of the venture capital market, the size of the stock market is less likely to be endogenous to the scale of economy-wide innovation. Other sources of financing, including profits and credit, do not appear to influence the amount of patenting once R&D spending is controlled for.

73. Product and labour market regulations reduce significantly the amount of patenting for a given stock of R&D. The results differ somewhat from the R&D equation where only product market regulation was significant. The propensity to patent is more sensitive to foreign investment restrictions and employment protection legislation.[53] The negative effect of EPL on the propensity to patent applies to both domestic and triadic patents and can be interpreted in the following way. As discussed in Section A3.2.2 of this Annex, stricter EPL may change the composition of innovation towards incremental process innovations, due to the difficulty of undertaking workplace reorganisation (required by drastic innovations) and the accumulation of considerable company and occupation-specific knowledge in the workforce. On the other hand, incremental process innovations are less likely to be patented.[54] Cohen *et al.* (2000) report that the preferred protection method for process innovations is secrecy because they are not subject to public scrutiny and can more easily be kept secret. Evidence from the CIS3 (see Section 5 of Annex 4) also supports this hypothesis: stricter EPL does not affect the share of firms which are successful innovators but increases the share of process innovators amongst successful innovators. Moreover, a higher share of process innovators among successful innovators reduces the frequency of patenting relative to other forms of protection, even after controlling for country-specific effects and the total number of innovators. An alternative specification to that reported in column [4] would include IPR and an interaction term between IPR and EPL (column [5]). The interaction term is significantly negative, implying that stricter EPL reduces the effect of IPR on patenting.[55]

74. FDI restrictions into the domestic market reduce domestic patenting significantly. This effect may operate though a reduction of the level of competition. Lower competition will reduce the incentives to obtain protection in the domestic market through patents and may also reduce the productivity of research efforts. But the fact that FDI restrictions matter, rather than product market regulations, suggests that the lower propensity to patent is related to the behaviour of affiliates of foreign firms and/or access to foreign ideas. First, keeping foreign affiliates out of the domestic market reduces access to foreign ideas (through direct contacts) which could otherwise enhance the productivity of domestic research. Second, if

foreign affiliates are more likely to patent for a given amount of R&D, perhaps because they belong to larger multinational firms, FDI restrictions will reduce the propensity to patent.[56] This hypothesis can be tested directly by adding an interaction term between the index of IPR and the index of FDI restrictions to the regression (column [6]). When IPR, FDI restrictions and the interaction are introduced simultaneously they are individually insignificant but jointly significant at the 1% level. Dropping FDI restrictions, the interaction term of IPR and FDI restrictions is significantly negative providing support for the hypothesis.

75. Of the other foreign exposure variables, the interaction of the foreign stock and trade openness has a significant positive effect on domestic patenting. This suggests that exposure to foreign ideas through trade stimulates the outputs from formal R&D and/or informal research. Moreover, it is possible that domestic residents imitate foreign inventions to patent them in their own country. For a given level of the foreign stock, an increase in trade openness stimulates patenting.

76. There is some weak evidence that domestic patenting out of a given R&D stock increases with linkages between public and private research activities. The interaction term between business financing of non-business R&D and the total stock of R&D is significant when the stock of business and non-business R&D are introduced separately (column [1])[57] but becomes insignificant when the total stock of R&D is used instead (column [3]). There is no evidence that the share of scientists in employment increases patenting for a given level of R&D stock, possibly because education-related productivity is already reflected in their wages and thus in R&D spending. If anything the effect of the scientist share is negative (column [2]). The coefficient on the economy-wide human capital term, though positive, was not significant either.

77. Finally, the structure of public support for R&D appears to affect the amount of domestic patenting that is done for a given level of R&D spending. R&D tax incentives increase patenting significantly, while direct subsidies reduce them significantly. Two explanations can be envisaged. On the one hand, part of the government funding for business research may involve contract research that does not lead to patenting, particularly in the case of military research or fundamental scientific research. On the other hand, this finding could reflect that governments are less good at picking innovative research projects than the market mechanism (through which tax incentives work). It is interesting to note that the absence of a negative effect of tax incentives on the propensity to patent for given R&D spending does not support the idea that more generous R&D tax reliefs lead to a widespread reclassifying of spending into R&D, because a lower propensity to patent would otherwise be observed.

78. Once additional policy influences on patenting are controlled for, the long-run coefficient on the stock of R&D is much smaller, at around 1.1 compared with 1.7 in Table A3.4. This suggests that the coefficient on the stock of R&D was to some extent picking up the effect of other policies with which it is correlated.

A3.4 The determinants of R&D employment and real wages

A3.4.1 An overview of R&D labour markets

79. This section describes the recent evolution of business R&D employment and wages relative to the rest of the economy. The calculation and interpretation of such cross-country comparisons is not straightforward. Wages per employee can differ for many different reasons in different sectors of the economy, such as variations in hours worked. This kind of information is not readily available at present for the research sector. Another difference is that the number of R&D employees is usually expressed as full-time equivalents, whereas economy-wide measures, such as total dependent employment, are often based on the number of jobs. In countries where part-time work is common, this could lead to an overestimate of the relative wage of R&D employees and an underestimate of their employment share.

Thus the data shown should be regarded as indicative of cross-country differences, rather than as precise estimates.

80. Figure A3.2 shows cross-country differences in the share of business R&D employees in total dependent employment (people aged 25-64). At the end of the 1990s the share was highest in the United States,[58] Finland, Sweden, Japan, and Switzerland (above 1%) and lowest (less than ½ per cent) in Portugal, Spain, Italy and Australia. Business sector R&D employees is a broader measure of the personnel involved in the research process than the total numbers of scientists and engineers ("researchers"). However, a broadly similar ranking emerges from a comparison of the shares of business researchers in dependent employment (Figure A3.3).

[Figure A3.2 Business sector R&D employees]
[Figure A3.3 Business sector researchers]

81. The employment share of business R&D employees has increased in a majority of countries over the past two decades, with the largest absolute increases in several Nordic countries (Iceland, Finland, and Denmark) and Ireland. This general pattern was not uniform; there have been noticeable declines in the share in Switzerland, the United Kingdom and Germany. A majority of countries also show an increase over time in the share of researchers in total dependent employment. The one exception is the United Kingdom where it has declined.

82. Figure A3.4 shows that the average wage of R&D employees is above the economy-wide level of compensation per employee in all countries. Although several factors impair the comparability of relative wage levels across countries, they may be less important for changes over time within countries. Countries show a mixed picture, with decreases in the United States, Spain, Sweden, and Norway but increases in the United Kingdom, Japan, Germany, Austria, France, Italy, and Portugal. The relative wage remained broadly stable in other countries.

[Figure A3.4 Ratio of R&D wage and economy-wide compensation per employee]

83. One imperfect indicator of changes over time in the productivity of researchers is given by triadic patents per 1 000 business R&D employees, shown in Figure A3.5. A drawback of this measure is that triadic patents also reflect to some extent the output of the non-business research sector, and no data are available on the share of triadic patents applied for exclusively by the business sector. In almost all countries patents per researcher have risen over time between the latter half of the 1980s and the latter half of the 1990s. Growth was particularly rapid in some R&D intensive countries, such as Sweden and Finland, but also in some countries with comparatively low R&D intensity in the late 1980s, such as Iceland and Portugal.

[Figure A3.5 Triadic patents per 1 000 business R&D employees]

A3.4.2 The labour market model

84. This section outlines the basic structure of the employment and wage relationships that are estimated. It consists of two equations; the first equation describes the business labour demand for R&D employees and the second the real wage of R&D employees. These equations are estimated jointly, with innovation output also treated as endogenous. Two alternative proxies are used for innovation output -- business sector R&D expenditure and total domestic patents. Both are imperfect proxies.[59]

85. Lead terms of total domestic patents are used to proxy innovation output when using patents. Current patents are the outcome of R&D efforts made in previous years and do not directly reflect current labour demand and wages. It is assumed that the research output from current R&D efforts is observed in

patent applications taking place two years later.[60] Both the change in two-year ahead patents and the level of one-year ahead patents are treated as endogenous.

86. Instrumental variables are taken from the set of explanatory factors found previously to determine R&D and patenting in Tables A3.2 and A3.5 respectively.[61] As will be made clear, a number of assumptions have to be made before a quasi-structural model can be estimated on cross-country data. An alternative approach, making use of micro-econometric data sets, would clearly be worthwhile but is beyond the scope of the present Annex.

A3.4.2.1 Business sector R&D labour demand

87. Innovation output is assumed to be produced by labour and non-labour inputs, according to a standard CES production function. An expression for the long-run desired level of labour demand can be derived from the first-order conditions as:[62]

$$\ln(L_{it}*) = k_1 + \alpha \ln(R_{it}) - \sigma \ln(w_{it} / p_{it}) - (1-\sigma)\lambda T_t \qquad [5]$$

where R denotes (real) innovation output, L total research employment (scientists and other employees), T time, λ the rate of labour augmenting technological progress and (w/p) the real wage of R&D employees.

88. The elasticity of substitution between labour and non-labour inputs is denoted by σ; a direct point estimate of this is provided by the coefficient on the real wage. Other things being equal, R&D labour demand should be expected to increase with output and decrease with the real wage. The elasticity of substitution also determines the sign (and partially the magnitude) of the effect of labour-augmenting technological progress (λT) on labour demand. When σ is less than one, an increase in the efficiency with which labour is used will induce a decrease in labour demand, and *vice-versa*. When σ is equal to one, labour demand should not depend directly on labour-augmenting technological progress.

89. The basic labour demand specification in equation [5] can be extended in a number of ways. One common approach is to expand the term for labour-augmenting technological progress to include other exogenous determinants of labour efficiency in addition to time dummies (Barrell and Pain, 1999). It is reasonable to suppose that the efficiency of business researchers depends on the stock of knowledge from which they can draw. The knowledge stock is unobserved, but can be represented as a function of the factors that have already been shown to affect R&D spending and patenting in the previous sections of the Annex.

90. A second possible extension to the basic labour demand specification is to allow for liquidity effects on hiring decisions. Thus factors that affect liquidity, such as changes in R&D tax incentives, government R&D subsidies, the share of profits in value added, and the availability of external finance may have additional short-term effects on labour demand, in addition to any effect that will come through the level of output. A third step is to recognise that there will be adjustment costs faced by firms who want to change their workforce.

91. Allowing for these factors, the basic structure of the labour demand equation reads:

$$\begin{aligned}\Delta \ln(L_{it}) = \beta_i + \beta_t + \beta_1 \Delta \ln(R_{it}) + \beta_2 \Delta \ln(w_{it} / p_{it}) + \beta_3 \Delta \ln(\tau_{it}) + \sum_{j=1}^{m} \zeta_j \bar{Z}_{jit} \\ + \theta \left[\ln(L_{it-1}) - \alpha \ln(R_{it-1}) + \sigma \ln(w_{it-1} / p_{it-1}) + \sum_{k=1}^{n-m} \gamma_k \tilde{Z}_{kit-1} \right] + \mu_{it}\end{aligned} \qquad [6]$$

The vector Z, similar to the one in equation [3] of this Annex, is partitioned into *m* variables that may affect the short-run evolution of R&D employment and *n-m* variables that may affect long-run cross-country differences in R&D labour efficiency. Excluded variables are the scientists ratio and its interaction with the foreign R&D stock, the real exchange rate, output growth, and inflation. On the other hand, the level of human capital in the economy is introduced to capture any possible effect on the efficiency of R&D employees. Factors that vary across countries but not across time will be picked up by the country fixed effects (β_i), and factors that vary over time, but not across countries will be picked up by the time dummies (β_t). The growth real wages is endogenous and so this equation has to be estimated jointly with a wage equation.

A3.4.2.2 The real wage equation for business sector scientists

92. The starting point for the analysis is the conventional assumption that the real wages of business R&D employees increase with their average productivity and decrease with their unemployment rate. Neither of these is observed directly, and so assumptions have to be made. These are set out in detail in Appendix 1 to this Annex. The derived specification of the long-run wage relationship is:

$$\begin{aligned}\ln(w_{it}/p_{it})^* &= \phi_1\ln(R_{it}/L_{it}) + \phi_2\ln(L_{it}) + \phi_3\ln(1+R^G_{it}/R_{it}) \\ &\quad - \phi_4(hk_{it}) - \sum_{j=1}^{j=3}\pi_j\ln(RELW_{it-j}) - \phi_5\ln(INTW_{it-1}) - \phi_6(u^E_{it}) + \phi_7(EPL_{it})\end{aligned} \qquad [7]$$

The economy-wide unemployment rate (u^E) and the indicator of employment protection legislation are included as a proxy to capture differences in national labour market conditions and institutions. The supply of scientists and engineers is assumed to depend on the level of human capital (*hk*), as measured by average years of schooling, and the wages of scientists and engineers relative to those in the United States (*INTW*) and relative to other occupations in the country (*RELW*).[63] Productivity is represented by (real) R&D spending per R&D employee (or patents per R&D employee). The ratio of non-business R&D (R^G) to business R&D captures possible crowding out effects of public sector research through increased pressures on R&D wages.

93. Allowing for adjustment costs and additional dynamics for some variables, the real wage equation to be estimated is:

$$\begin{aligned}\Delta\ln(w_{it}/p_{it}) &= \beta_i + \beta_t + \beta_1\Delta\ln(R_{it}/L_{it}) + \beta_2\Delta\ln(L_{it}) + \beta_3\Delta\ln(1+R^G_{it}/R_{it}) + \beta_4\Delta(hk_{it}) + \beta_5\Delta(u^E_{it}) \\ &\quad + \theta\left[\ln(w_{it-1}/p_{it-1}) - \ln(w_{it-1}/p_{it-1})^*\right] + \mu_{it}\end{aligned} \qquad [8]$$

where *(w/p)** is as defined in equation [7].[64]

94. The employment and wage equations are estimated simultaneously over an unbalanced panel of 18 countries (17 countries for patents). As in previous sections, the sample period is 1982-2001 for the R&D model and 1986-2000 for the patent model. The estimation is done by three-stage least squares, which combines an instrumental variable approach to produce consistent estimates and generalised least squares to account for the correlation structure in the disturbances across the equations. Country fixed effects and time dummies are included in each equation. Initial regressions showed that the coefficients on subgroups of related variables in the vector Z had similar relative magnitude as in the estimated R&D flow equation (Table A3.2).[65] The R&D and patent models were re-estimated imposing, for some subgroups of variables, the constraints that the ratio of the coefficients is the same when they were accepted. Table A3.6 reports streamlined versions of the employment and wage equations, including (mostly) the significant variables. The eliminated variables are jointly insignificant at the 5% level.

[Table A3.6 Econometric estimates of the labour market model, OECD 1982-2001]

95. One difference between the R&D and the patent labour market models is that output in the patent model includes total patents including the patents applied for by the non-business sector. Information is lacking about the split of total patent applications into patents applied for by the business sector and by the non-business sector. For this reason, the business labour demand equation includes the stock of non-business R&D (scaled by GDP) in addition to including total patents. The expected effect of the stock of non-business R&D is to reduce the demand for business R&D employment implied by a given level of total patenting.

A3.4.3 Empirical estimates of the labour demand equation

96. As expected, the results reported in Table A3.6 show R&D employment to be positively correlated with innovation output, and responding negatively to the real R&D wage. In the short run, R&D employment is more sensitive to changes in R&D spending than to (future) changes in patenting. However, in the long run, the elasticity of R&D employment to innovation output is similar, at about 0.7. These relatively low values for the elasticity are consistent with the upward trend in R&D output per employee observed in most countries, though the latter trend could also be partly accounted for by the time dummies and other influences on technological progress. The responsiveness of demand to changes in growth is less pronounced than that found for the aggregate demand for R&D in Section 2 of this Annex. This suggests that firms try to retain their skilled researchers during economic cycles, implying that other forms of R&D expenditures are more pro-cyclical. On the other hand, increases in the real R&D wage significantly reduce R&D employment for a given level of innovation output. The short-run effects of a 1% wage increase is to reduce R&D employment by about 0.6-0.8% and the long-run elasticity is of a similar magnitude at about 0.65. This also implies that the long-run elasticity of substitution between labour and other factors of production is about 0.65 and thus less than 1.

97. There is evidence that financial liquidity affects the hiring of labour and a broader range of financial variables enter the labour demand equation in the patent model than in the R&D model. In both models, the profit share of GDP and more generous tax credits for R&D[66] (and government subsidies in the patent model) have additional positive effects on R&D employment, beyond their effect through innovation output. However, the long-run effect of tax credits is not significant suggesting that they may affect more the timing of the hiring decisions than the long-run level. There is some evidence that credit and market finance have also additional effects on R&D employment in the patent model. At the sample mean, market finance seems to exert a positive additional effect (net) on R&D employment while the influence of credit is negative. The generally weaker liquidity effects in the R&D model may be due to the fact that innovation output is measured by spending on R&D.

98. A number of other variables appear to have additional effects on R&D employment, though the two models yield somewhat different insights. This may not be so surprising since the controls used for innovation output are different in the two models. Some of these additional effects can possibly be interpreted as efficiency effects, whilst others cannot. Given the underlying model presented in the previous section, the relatively low estimated elasticity of substitution between labour and other factors of production implies that an increase in the efficiency of R&D employees may lead to a reduction in the employment of this factor of production. An effect which is common to both the R&D and the patent model is that of intellectual property rights. Intellectual property rights tend to reduce R&D employment for a given level of innovation output but this effect is reversed at higher levels of import penetration. At the sample mean (and over most of the sample), the net effect of stronger intellectual property rights is to raise R&D employment for a given level of innovation output. If the CES production function correctly reflects the production of innovation, this may provide indirect evidence that stronger IPR tend to reduce

the efficiency of R&D employees, possibly by preventing scientists from making efficient use of ideas developed elsewhere, as suggested in the discussion of Section 4 of Annex 2.

99. Turning to import penetration, an increase in foreign competition tends to reduce R&D employment for a given level of innovation output but this effect is reduced at high levels of IPR. There is some evidence that the net effect of import penetration is to reduce R&D employment for a given level of innovation output, at least at sample mean in the R&D model (the effect is insignificant at sample mean in the patent model). This in turn may suggest that increased foreign competition stimulates the efficiency of domestic R&D employees, though this efficiency-enhancing effect is reduced by stronger IPR.

100. The R&D model provides some evidence that foreign exposure may have additional effects on R&D employment above its effect through R&D spending. Access to foreign knowledge, captured by the interaction term between the stock of foreign knowledge and trade openness, seems to have a negative additional effect on R&D employment, possibly through an efficiency-enhancing effect of foreign knowledge spillovers on R&D employees. However, trade openness entered on its own increases R&D employment and its net effect (including its effect through the interaction term) is positive over most of the sample, suggesting that R&D employment may be an essential input to benefit from openness and access to foreign ideas.

101. The evidence on the additional effects of public research and business-academic links seems mixed. As expected, the stock of non-business R&D reduces business R&D employment for a given level of patenting. Although this may reflect a positive efficiency effect of ideas developed in the non-business sector on R&D employees, the stock of non-business R&D is also a direct source of patenting, as shown in Section 3 of this Annex. This would explain why it reduces business R&D employment for a given level of total patenting. In the R&D model, the business-academic links appear to have a positive additional effect on R&D employment, despite the negative liquidity effect of increased business funding of non-business R&D. This may suggest that an essential component of business-academic links is the existence of a large scientific workforce on the business side, if only to be able to absorb the knowledge generated in public research organisations. This is consistent with the evidence reported in Section 3 of Annex 2 that business-academic links involve co-operative agreements (not just outsourcing of research) with larger firms. In addition, close links with public research organisations may facilitate an attrition of key scientific personnel by large firms.

102. Given its specific form, the estimated labour demand equation can be rearranged to yield a long-run expression for productivity per employee. As the long-run output elasticity is less than 1, an implication of the estimates is that productivity per researcher will vary over time and across countries in proportion to the absolute number of researchers. This is exactly what many endogenous growth models might predict (Jones, 2004). The non-rivalrous nature of ideas means that the productivity of individual researchers is likely to depend on the number of other researchers with whom they can interact. If true, this would have interesting policy implications. Any measure that raised R&D employment might (eventually) have an even larger effect on output because of the concomitant increase in productivity per researcher. At the very least, this would offset some of the crowding out effects that might otherwise occur via higher relative wages.

A3.4.3.2 Empirical estimates of the wage equation

103. As shown in Table A3.6, a significant effect of R&D employees' productivity on the real R&D wage is found both in the short and in the long run.[67] A 1% increase in productivity translates into a 0.6% real wage increase in both the short and the long run in the R&D model. The magnitude of the effects is smaller for productivity measures based on patents per employee, at about 0.1 in the short run and 0.2 in the long run. The fact that the coefficients are less than one could be due to the economy-wide wage,

human capital terms and/or time dummies picking up additional effects. To some extent, it is not so surprising that the repercussion of productivity on real wages is not as large in the patent model since patents have grown much faster than R&D spending, and part of this growth may just reflect an increase in the propensity to patent rather than a true increase in productivity (see Section 3 of this Annex). The wage equation also shows that the economy-wide unemployment rate depresses the real wages of R&D employees in the short run. However, this effect is only significant in the patent model.

104. There is some evidence that non-business R&D drives up the wages of R&D employees, in particular when the scale of non-business research is large relative to business research. This suggests that non-business R&D may crowd out business R&D by raising the cost of R&D inputs, as discussed in Section 6 of Annex 2. Both models show a significant effect in the short run, though their predictions about the long run effects of non-business R&D differ. In the R&D model, non-business R&D exerts a long-run pressure on the real wages of R&D employees, while its long-run effect in the patent model is not significant. The predictions may not be as different as they may seem though because the productivity term in the patent model is constructed as the ratio of total patents (including public sector patents) to business sector employment. There is thus some long-run positive effect of public sector patents on the wages of R&D employees. Both long-run predictions are plausible a priori. Indeed, as discussed in Section 6 of Annex 2, there is no reason to believe that non-business R&D should necessarily increase real business wages in the long run, as the supply of researchers may increase over time.

105. Turning to supply-side factors, the wage equation provides evidence that the general accumulation of human capital and training helps raise the supply of qualified scientific personnel and eases personnel shortages, as discussed in Section 6 of Annex 2. An increase in the average years of education of the population over 25 reduces significantly the real wages of business R&D employees, mostly in the long run. The short-run effects are weakly significant or insignificant.

106. Current R&D wages are also positively correlated to the (twice lagged) economy-wide average wage. The economy-wide wage may just be a proxy for general increases in productivity which are reflected in all wages. However, because the long-run coefficient on the economy-wide wage is less than one, the relationship can be rewritten as a negative correlation between current R&D wages and the lagged ratio of the R&D wage to the economy-wide wage. This would suggest that increases in the relative wage of scientists contribute to increase the future supply of scientists by making career prospects in these fields relatively more attractive than other careers. Some supporting evidence for this interpretation has been found in the literature as reported in Section 6 of Annex 2. The increase in the supply of scientists may take place through an increase in the number of students who decide to enter science and engineering fields or through changes in profession (possibly through re-training).

107. The wage equation also provides some evidence that the international migration of scientists may help ease shortages of scientific personnel. Increases in the real wage of researchers in the United States appear to raise significantly the real (PPP-adjusted) wages of domestic researchers. Again, this relationship can be rewritten as a negative correlation between domestic R&D wages and the lagged ratio of domestic to international R&D wages. This suggests that an increase in domestic R&D wages relative to international levels (resulting for example from a shortage) may induce a net immigration of scientists which in turn helps ease labour market tensions. A comparable relative wage effect is not significant for the United States however.[68]

108. Finally, there is some evidence that stricter employment protection legislation significantly raises the real wage of business R&D employees. A possible explanation of this effect is that the increased employment protection provides employees with stronger negotiating power and they are able to extract a larger share of the rents. The implication of this finding is that stricter employment protection legislation may reduce R&D employment and depress innovative activity. Some previous OECD evidence identified a

negative correlation between EPL and R&D intensity, though the strength of this effect was found to differ according to industry and the system of wage bargaining, as discussed in Section 6 of Annex 2.

A3.5 The combined impact on innovation of changes in framework and science policies

109. The stand-alone models of R&D and patenting set out in Sections 2 and 3 of this Annex provide one means of estimating the partial effects of particular policies on output, employment and real wages. But many of these will have both direct and indirect effects because of their additional impact on the wages and employment of scientists and engineers. Their combined impact can be estimated by solving the set of activity, employment and wage equations and expressing the endogenous variables as a function of their exogenous determinants. Because the focus is on those policies that have a permanent effect on the long run levels of innovative activity, the analyses uses only on the long-run parameters of the employment, wage and activity relationships.[69] This abstracts from the time it may take for the full effects of policy changes to come through.[70] It is also the case that whilst the impact of changes in particular policies are shown independently, in practice there many be additional, indirect linkages between them that also need to be taken into account for a complete evaluation.[71]

110. The long-run effects of selected variables on innovation output, R&D employment and the real R&D wage are reported in Tables A3.7 and A3.8. The estimates in both tables are calculated using the sample means of the respective variables and assuming that all other factors are held constant.[72] Table A3.7 shows the impact of a unit change in the respective explanatory variables. Table A3.8 helps to put such a change in perspective by showing the impact for the average country of a one standard deviation change in the explanatory variables. The latter enables the effects of different factors to be more easily compared, and provides some indication of the impact of changes in policies over time. The standard deviation used is the average of the within-country sample standard deviations and not the cross-country standard deviation. This was necessary because of the scale of differences in some factors across countries and the feasible extent to which some policies may be changed. Calculations with the cross-country standard deviation, whether evaluated using the full sample of observations or a cross-section at a particular point in time, can be especially problematic when using indicator variables whose upper or lower limit is bounded. The partial effects on R&D and patenting from changes in the explanatory factors are also reported in Tables A3.7 and A3.8; these changes are conditional on a given level of employment of scientists.[73]

[Table A3.7 Long-run effects of policy and framework factors]
[Table A3.8 Long-run effects of a one standard deviation increase in policy and framework factors]

A3.5.1 Main results

111. The full long-run estimated effects show that each factor with a direct influence on R&D also affects patenting in a similar way. One factor, restrictions on inward FDI, affects only patenting. Two factors, the real wage for scientists in the United States and the number of years of education per worker, affect both R&D and patenting indirectly as a result of their impact on the wages and employment of scientists. For all factors, an increase in innovative activity (R&D or patenting) greater than the increase in the employment of scientists (*i.e.* an increase in R&D labour productivity) is reflected in higher real wages. Equally, reductions in innovative activity greater than reductions in employment are reflected in lower real wages.

112. The balance of the evidence for changes in tax incentives and subsidies for private R&D suggests that tax incentives are a more effective means of encouraging R&D.[74] More generous tax incentives stimulate additional R&D, whereas more generous subsidies have almost no effect. Such a finding appears

to be consistent with those from other studies, as discussed in Section 2 of Annex 2. However, the impact of a one standard deviation change in taxes is fairly small, generating a rise in R&D of 1.7%.

113. The principal effect of strengthening intellectual property protection is felt in patenting rather than in R&D. Stronger IP rights generate a marked rise in the number of patents, but have only a small positive impact on R&D.[75] A rise of 1 unit in the IPR index (roughly comparable to the actual changes seen over the sample period within many countries) is estimated to raise R&D expenditure by a little over 5%, but to raise total patents by over 30%. The effects on R&D come solely through the positive impact of stronger IPRs found in the employment equation. Higher employment raises the absorptive capacity of the economy. This is offset in part, but not completely, by labour efficiency being lower than it would otherwise be, as can be seen from the changes in the amount of R&D or patenting per scientist. It should also be noted that it is likely to take many years for the full effects to come through from a change in IPRs of the magnitude shown, given the significant rise in private sector employment of scientists that is required.

114. An increase in the share of non-business R&D in GDP is shown to have a positive effect on both private sector R&D and patenting. This remains the case even after allowing for the extent to which this change will raise the cost of private sector researchers. A rise of 1 standard deviation in the share of non-business R&D is estimated to raise business R&D expenditure by over 7% and patenting by just under 4%. The main factor behind these changes is that the expansion in basic research raises labour efficiency in the private sector.[76] The impact on the level of private sector employment is much smaller when using the labour demand relationship with patents than when using the relationship with R&D. Again, it is important to stress that the short-run effects from a rise in non-business research activity are likely to be much smaller. In particular, unless there is a net inflow of additional researchers from abroad, the higher demand from the non-business sector could have a strong adverse effect on the supply of scientists and engineers available for the business sector.

115. An increase in the share of non-business sector R&D funded by the business sector is also estimated to provide a positive stimulus to R&D spending and patenting, even after allowing for the negative effect it would have on the level of internal finance available to companies for their own activities. A rise of 1 standard deviation in the funding share would raise R&D spending by over 8%, and patenting by between 2-3%. In both cases the main source of the higher levels of activity is a higher level of employment in the private sector, rather than an improvement in the efficiency of researchers. As a considerable proportion of the additional workers would be likely to be recruited from the non-business sector, it may be that the positive stimulus from greater inter-sector collaboration would be offset by other factors.

116. An easing of product and labour market regulations and reductions in the restrictions faced by inward investors are all found to have a positive impact on innovative activity. Pro-competitive product market regulations help to stimulate business sector R&D markedly, with a reduction of 1 standard deviation raising R&D expenditure by almost 9%. Changes in the other two forms of regulation have a substantial effect on patenting levels, but have only a small effect on R&D expenditure.[77]

117. A rise in the corporate profit share and an increase in stock market capitalisation are both found to be associated with a higher level of innovative activity, but an increase in the share of private sector credit in GDP is not. A one standard deviation rise in the profit share (approximately 2% of GDP on average for the sample of countries) is estimated to raise R&D expenditure by a little over 5% and patenting by over 4%. A one standard deviation change in stock market capitalisation to GDP has a larger effect on R&D and (mostly) on patenting. In both cases the increase in activity is mainly attributable to an increase in the level of employment rather than to an increase in the efficiency of existing researchers. A decline in the level of real interest rates and a depreciation of the real exchange rate also raise R&D and

patenting, with the impact of a 1 standard deviation change being of a comparable magnitude to a 1 standard deviation change in the profit share.

118. The diffusion of knowledge clearly has an important impact on innovative activities. In particular, a rise in the foreign R&D stock is found to have a strong effect on the level of national R&D expenditures and also on patenting. This is consistent with the hypothesis that knowledge gradually diffuses across national borders. In fact a 1% rise in the foreign R&D stock is estimated to eventually lead to a rise in domestic R&D of more than 1%, possibly indicating that there are increasing returns to knowledge generation. However this is not reflected one-for-one in patenting, which is increased by just under 0.7%.[78]

119. A surprising feature of the results is that increasing international openness (in terms of raising the ratio of trade to GDP) reduces innovative activity, all else being equal. In interpreting this finding two factors must be borne in mind. First, if countries have a higher level of openness to trade then the stock of foreign knowledge accessible to them will be higher than it would otherwise be, because of the way in which the foreign R&D stock term is defined. Second, it is quite possible that some smaller countries could reduce their own innovative activities as they become more open, simply because it is better for them to concentrate on gaining the full benefits from the global knowledge stock. However, it is unlikely that all countries would be in this situation.

120. Finally, the impact of the two additional factors affecting innovative activities as a result of their influence on wages is comparatively small. An increase in average years of education in the population of working age has a small positive impact on R&D and patenting, and a rise in real wages in the United States has a negative impact on innovative activities in other countries, reflecting a decline the numbers of scientists employed in the business sector.

NOTES

1. On average across countries the wage-bill for R&D employees, a broader category than scientists and engineers, accounts for around one-half of nominal R&D expenditure.

2. Many important ideas and technologies can have an impact across the wider economy over time as knowledge spreads. One example is the widespread current use of just-in-time inventory control systems. An idea originally developed in Japan to prevent excessive inventories in car factories has spread globally and is now adopted by firms in both manufacturing and service industries.

3. This assumes perfect competition. If not, the price-cost mark-up would also need to be included.

4. The difficulties in defining an appropriate deflator for nominal R&D expenditures are discussed below.

5. Annual time dummies and country fixed effects are included in estimation. These will pick up the impact of any common changes over time due to time-varying depreciation rates, and any time-invariant differences in depreciation rates across countries arising from differences in asset composition.

6. Recent updates are published in the OECD *Science and Technology Scoreboard*.

7. The limitations of this assumption are discussed below.

8. A perpetual inventory method is used, with constant price R&D stocks generated from a fixed starting point over time using the accumulation formula $S_{i,t+1} = R_{i,t+1} + (1 - \delta_{i,t+1}) S_t$. Using the accumulation equation, and assuming that the steady state R&D stock grows at rate gi, an initial starting value for the stock at time t=0 can be estimated using $S_{i,t=0} = R_{i,t+1} / (g_i + \delta_i)$. Provided the depreciation rate is constant over time, the steady state growth rate of the R&D stock will be equivalent to the steady state growth rate of the flow of R&D expenditures, which can be estimated using the sample mean growth rate of Ri from the available data.

9. See, for instance, Carson *et al.* (1994).

10. The decline in the relative prices of investment goods over time in many countries is unlikely to have been matched by an equivalent decline in the relative cost of scientists and engineers.

11. R&D expenditures are a measure of inputs rather than of outputs. Hence their "true" deflator may not reflect the full impact of productivity increases recorded in an output measure such as the GDP deflator. One possible solution to this would be to try to construct a R&D deflator using a weighted average of (pre-tax) capital and labour costs. In practice, the problems that can result from the use of the GDP deflator depend on the extent to which the shares of labour and non-labour expenditures in total R&D expenditure have varied over time and the rate of productivity growth. If they are relatively constant, the difference is likely to be reflected in the country-specific fixed effects.

12. Factors can be excluded for several reasons, most notably if there are no data available for them to be included.

13. The countries are Australia, Austria, Belgium, Canada, Denmark, Finland, France, Germany, Ireland, Italy, Japan, the Netherlands, Norway, Portugal, Spain, Sweden, Switzerland, the United Kingdom and the United States. It was not possible to include the other OECD economies in estimation either because data were available only over a short period of time or because it was not possible to correct for breaks in the data. It would be possible to estimate the model over a significantly reduced sample, but this would make it harder to be able to estimate the importance of particular factors for long-run differences in R&D expenditures.

14. Half of the eventual long-run adjustment of the flow to a permanent change in the user cost is complete after six years in this particular model.

15. See the analysis in Annex 4.

16. The final term provides a test of whether equity finance is more important than credit. A further reason why stronger effects may be found from equity finance rather than credit is that the uncertain returns to R&D make it difficult to finance with debt, as this typically requires a regular schedule of repayments.

17. An interaction term between profits and the equity ratio was insignificant when added to this specification.

18. The evidence presented in Annex 4 using Community Innovation Survey data for the European Union economies also provides some support for the latter view, as it suggests that the share of product innovators in the total number of firms who undertake innovative activity is negatively related to the strength of EPL.

19. The presence of comparatively large, research intensive foreign companies might also drive up the wages of scientists and engineers in national economies, reducing the real resources available for R&D.

20. Further details can be found in Nicoletti and Scarpetta (2003) for the PMR indicator, in Golub (2003) for the indicator of FDI restrictions and in Allard (2003) for the EPL indicator.

21. Squared terms might be expected if there was a “U” or inverted-“U” shaped relationship between factors affecting product market competition and innovation expenditures..

22. The weights are calculated as suggested in Lichtenberg and van Pottelsberghe (1998). Their approach minimises the aggregation bias that can arise in alternative weighting schemes such as that proposed in Coe and Helpman (1995).

23. It is prudent when considering possible interaction terms to allow both terms to also enter the regression separately, at least in an initial unrestricted specification.

24. Another possible variable that might be included would be measures of the combined scale of outward and inward foreign direct investment. This may be picked up in part by the indicator of restrictions on inward FDI.

25. These effects may also arise from changes in exchange rate volatility, which is not considered here.

26. As already discussed, the enhanced competitive pressures following an exchange rate appreciation can raise the incentive to innovate, at least up to a point, but financial pressures, if attempts are made to maintain (volume) market shares, and greater net outward FDI could reduce the ability to do so.

27. The import penetration variable was deleted rather than the trade openness variable because the latter is interacted with the foreign stock. It is also possible to estimate an alternative model to [10] using import penetration levels and interaction terms rather than openness, but the fit of the equation is poorer.

28. This issue is explored further in Section 4 of this Annex.

29. A related point is made in the empirical study undertaken by Guellec and van Pottelsberghe (2000).

30. Although they are not shown in the reported tables, the regressions in Table 2 also contain controls for country size, using the logarithm of the population aged 15-64 and the square of this. These two terms appear to be largely orthogonal to the remaining regressors, suggesting they could also be picked up in the country fixed effects and the time dummies. Nonetheless, it was felt that it was preferable to include them explicitly in order to ensure that the science variables were not simply picking up a pure country size effect in some way. In all the equations the population levels term had a positive coefficient and the squared term a negative one, suggesting diminishing returns to size.

31. This may also be true of tax credits for R&D, although this is harder to test directly as the aggregate monetary value of these credits is more difficult to measure.

32. This will largely reflect business-funded research undertaken in universities and non-profit research institutes.

33. No allowance is made for the possibility that some funding to the non-business sector may be deductible from taxable income. This would reduce the post-tax costs to the firm from financing research activities elsewhere.

34. This has already been widely used in cross-country studies of the determinants of economic growth, including the OECD Growth Study (OECD, 2003a). The index is based on five aspects of national patent systems, with each country being assigned a score of between 0 and 1 according to the coverage, the duration and the enforcement of patent rights, membership of international treaties and restrictions placed on the use of patent rights. The score for each category is based on the weighted sum of the scores for a number of additional subcomponents.

35. Data are available at 5 year intervals since 1980, with the missing years constructed by linear interpolation between these points. All countries in the sample have strengthened their patent rights over time. The sample mean value of the indicator is 3.75; the mean value for 1998-2000 is 4.13.

36. The three terms plus the separate PMR and import penetration variables are jointly significant [p-value of joint deletion = 0.024].

37. As discussed in Annex 2, survey evidence suggests that patenting is the preferred method of protecting IP in only a small number of industries.

38. The industry share data are taken from the STAN database. Although a volume measure might be preferable, such data are not available for most countries at the level of disaggregation required. The classification of industries followed that adopted in the OECD *Science, Technology and Industry Scoreboard*, with the hi-tech sector comprising pharmaceuticals, aircraft, office machinery, communications equipment and medical and other scientific instruments.

39. Scientists and engineers refer to the researchers employed in the business R&D sector, which account for about two-thirds of business R&D employment. It is scaled by the economy-wide dependent employment.

40. The data are available for Switzerland and Ireland for only a small part of the estimation period. Attempts were made to develop a substitute series from other sources, but ultimately this did not prove feasible. Thus the coefficients reported for the hi-tech variable in the estimation results exclude data for Switzerland and Ireland. The average in-sample effect from the missing hi-tech variable in these countries will be captured in the fixed effect. Similarly, there is relatively little consistent data available for the number of scientists in Switzerland and Norway. Whilst an attempt was made at constructing missing data for the purposes of the cross-country graphical comparison, it did not prove feasible to use these in estimation..

41. This also implies that the estimated speed of adjustment of R&D expenditure following a permanent change in one of the explanatory factors has risen. For instance, the results in columns [2] and [3] of Table 2 imply that half the adjustment of the stock and flow of R&D to a 1% change in the tax component will be complete after 6 and 3 years respectively.

42. Because the dependent variable is logarithmic the average refers to the geometric average rather than the arithmetic one. The contributions of the explanatory variables plus the country fixed effects and an "unexplained" component are additive in the sense that they sum to the log-deviation of R&D intensity from the OECD mean. The contributions are expressed in terms of the per cent deviation of R&D intensity from the OECD mean by taking the exponential of each, subtracting 1 and multiplying by 100. The multiplicative sum of these deviations gives the total per cent deviation of R&D intensity from the OECD average. For the scientists contribution the estimated coefficients are applied to the data for those countries excluded from the estimation analysis.

43. This term also includes the deviation from the OECD mean share evaluated at the mean foreign R&D stock.

44. This raises the possibility that there may be some potentially useful insights to be learned from a more detailed analysis of the overall science system in Finland. A number of European countries, notably Germany and the Netherlands, have recently established cross-departmental bodies to co-ordinate national innovation policies. The impetus for this has been provided by the perceived success of the Finnish Science and Technology Policy Council, set up in 1987.

45. It would also be possible to look at other output measures such as trademark registrations or the use of copyrights. These differ from patents as they are applied for when products are completed and introduced into the market. Thus they may be more remote from R&D activities than patents.

46. For European countries, the "domestic" patent office is assumed to be the European Patent Office since a significant market for firms in these countries is likely to be the rest of the European Economic Area. For similar reasons, the "domestic" patent office for Canada is assumed to be the United States Patent and Trademark Office. This may exclude some patents that are registered only at a national patent office. Australia is included in the empirical models that use triadic patents, but not in the models that use domestic patents, as data for applications to the Australian Patent Office were not easily available.

47. Triadic patents, a measure developed by the OECD, are a patent family covering patents which have been applied for at the European, Japanese and American Patent Offices. The additional costs imposed on the patentee, and the delays involved in the extension of the protection to other countries suggest that such patents are more likely to have a high value.

48. The economy-wide stock of R&D was generated using a similar approach to that used to derive the business sector R&D stock, using whole economy R&D expenditure and an assumed depreciation rate of 11% per annum. The non-business R&D stock was defined as the difference between the aggregate and business sector stocks.

49. The countries included are Australia (only for triadic patents), Austria, Belgium, Canada, Switzerland, Germany, Denmark, Spain, Finland, France, the United Kingdom, Ireland, Italy, Japan, the Netherlands, Norway, Portugal, Sweden, and the United States.

50. In part this is because the rate of applications in the early years is likely to have been distorted, including many patents which had already been granted by national patent offices. It may also be the case that it took some time for applying to the EPO to be seen as a natural step when patenting inventions.

51. The indicator of educational attainment used in this paper is from Barro and Lee (2000).

52. All countries have strengthened their IPRs over the past two decades.

53. The index of product market regulation is only significantly negative when both foreign investment restrictions and employment protection legislation are dropped from the equation. But these restrictions are strongly rejected by the data.

54. A second (less likely) interpretation of the negative effect of EPL on the patent-to-R&D ratio is that stricter EPL may increase the cost of innovation by reducing the range of innovations to those which can be implemented without important workplace re-organisations.

55. When IPR, EPL, and the interaction between the two are introduced jointly, they are individually insignificant but jointly significant at the 1% level.

56. This is in line with the evidence discussed in Section 4 of Annex 2 that the majority of the increase in patent applications when patent protection is increased comes from foreign residents.

57. When both the share of non-business R&D financed by business and its interaction with the stock of R&D are included, they are individually and jointly insignificant.

58. Data on R&D employment are not available for the United States and the share of researchers in dependent employment is used instead. Given its very high level, it can safely be assumed that the share of R&D employment in dependent employment would be amongst the highest in the OECD. The United States has actually the highest share of researchers in dependent employment.

59. As discussed previously, R&D expenditures are strictly a measure of innovation inputs and patents are count data, with each patent having an equal effect on the aggregate.

60. Preliminary estimates showed no significant effect of current patents on employment and wages. Furman *et al.* (2002) assume a three year lag between research output and patenting. They state that their results are robust to changes in this lag structure.

61. In principle, the output equation could also be estimated jointly with the employment and wage relationships. But a larger sample was available for the output specifications than for the other two equations and it was judged that it was better to make full use of this.

62. This expression assumes perfect competition in product markets and that there is not a fixed supply constraint for researchers. The former would require that the price-cost mark-up be included in [4]. The second assumption can be justified by the observation that many trained scientists and engineers do not work in the research sector.

63. Comparative returns from different occupations are measured by the ratio of the wage of R&D employees (a proxy for wages in science and engineering fields) to the economy-wide average wage.

64. In the estimation, the term $\Delta \ln\left(1 + R_{it}^{G} / R_{it}\right)$ is linearised as $c\Delta \ln\left(R_{it}^{G} / R_{it}\right)$ where c denotes a constant.

65. Examples of related variables are the business financing of non-business R&D expressed as shares of non-business R&D and profits.

66. No specific allowance is made for individual country R&D tax credits such as the Netherlands WBSO credit that are targeted specifically at employment in the R&D sector.

67. When output and employment terms are entered separately, the restriction that their coefficients are equal in magnitude and opposite in signs cannot be rejected at the 5% level. However, this restriction cannot be tested for the short run effect of patents per employee because an (unknown) part of the coefficient on the change in business employment captures the denominator of Rg/R (see equation [8]).

68. Note that although the point estimate of the long-run effect of productivity on wages is larger at about 1.7 for the United States (because there is no significant international relative wage effect for the United States), it is not significantly different from 1.

69. For R&D, the long-run parameters are taken from the equations reported in column [3] of Table A3.2 and column [1] of Table A3.6. For patents, the long-run parameters are taken from the equations shown in column [4] of Table A3.5 and column [2] of Table A3.6.

70. Technical details of the solution procedure are summarised in Appendix 2.

71. One example is that changes in real interest rates and real exchange rates may not be fully independent of each other.

72. For example, in the absence of a model for the factor demands of the public sector, there is no feedback from changes in private sector employment and wages on to public sector employment, wages or R&D.

73. The long-run structure of the private sector R&D equation is substituted into the long-run structure of the patents equation to obtain the partial effects reported for the patent equation.

74. Care is needed in interpreting this result as generous tax incentives might require offsetting changes in other taxes or in public expenditure.

75. These calculations do not incorporate the effects from the two IPR terms shown in column [3] of Table 2, as the two coefficients are jointly insignificant.

76. As seen from the implicit changes to the level of activity per scientist employed in the private sector.

77. Restrictions on inward FDI are not found to be significant at all in any of the estimated equations in which R&D is the sole measure of innovative activity. Thus they affect only the patenting model.

78. If the level of R&D in all countries rises by 1% of GDP, the foreign stock will rise by less than 1% of GDP. For each country the foreign stock is derived by weighting together national R& D stocks using the ratio of bilateral trade to GDP in the partner country. The sample mean for the respective national R&D stock to GDP ratios is 8½ per cent of GDP, compared with a sample mean of 3½ per cent of GDP for the weighted foreign stocks.

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APPENDIX 1. THE DERIVATION OF THE WAGE SCHEDULE

121. A standard assumption of many economy-wide wage equations is that real wages depend positively on productivity and negatively on the unemployment rate. This would imply that the long-run real wage (w/p) equation for scientists and engineers could be expressed as:

$$\ln(w_{it} / p_{it})^* = \eta \ln(R_{it} / L_{it}) - \kappa(u_{it}) \qquad \text{(A1)}$$

where *u* denotes the unemployment rate of scientists and *R/L* represents the average productivity per worker.

122. This generates two further issues; how to measure the average productivity of scientists and how to proxy the unemployment rate. For the former, two alternative proxies are used in estimation -- real R&D expenditure per employee and patents per employee. The unemployment rate of scientists is not directly observed on a comparable basis for the sample countries. However, it can be replaced by the difference between the demand for scientists and the factors affecting their supply. Proxy measures can be found for each of these.[79]

123. For labour demand, the main issue is that account needs to be taken of demand from the public as well as the private sector. However, there is a lack of consistent time series data on employment of researchers outside the business sector. The approach adopted here is to assume that the ratio of non-business to business R&D employment is proportional to the ratio of their R&D spending and use this as a means of scaling up private demand to obtain a proxy for economy-wide demand.[80] The economy-wide demand for scientists is thus represented by:

$$\ln(L_{it}^D) = \ln(L_{it} + L_{it}^G) = \ln(L_{it}) + \ln(1 + L_{it}^G / L_{it}) \approx \ln(L_{it}) + \ln(1 + R_{it}^G / R_{it}) \qquad \text{(A2)}$$

where L and L^G denote respectively business sector and non-business sector demand for scientists, and R and R^G denote respectively business and non-business R&D spending.

124. As the aggregate supply of scientists is not directly observed,[81] three implicit determinants of supply decisions are introduced into the model. First, the supply of scientists is assumed to increase with the average years of education in the population over 25. As a larger fraction of the population goes into college education, the number of students in science and engineering fields should rise, as should the knowledge embodied in individual researchers.

125. Secondly, the number of students going into science and engineering fields is assumed to be influenced by the career prospects in these fields relative to other fields (Rosen and Ryoo, 2004). Comparative returns from different occupations are measured by the ratio of the wage of R&D employees (a proxy for wages in science and engineering fields) to the economy-wide average wage.[82]

126. Finally, the supply of scientists is assumed to increase when domestic wages for scientists increase relative to foreign wages for scientists, due to increased net immigration flows of scientists. The

level of foreign wages for scientists is captured by the United States wage for scientists.[83] For the United States itself, the domestic R&D wage is compared with the GDP-weighted average of R&D wages in other OECD countries.

127. The implicit labour supply equation is thus defined as:

$$\ln\left(L_{it}^{S}\right) = \zeta\left(hk_{it}\right) + \sum_{j=1}^{j=3} \pi_{t-j} \ln\left(RELW_{it-j}\right) + \rho \ln\left(INTW_{it-1}\right) \qquad \text{(A3)}$$

where *hk* denotes the average years of education in the population over 25, *RELW* the wage of scientists relative to the economy-wide average wage, and *INTW* the wage of scientists relative to international wages for scientists. Combining this specification with (A2) and substituting into (A1) yields the specification shown as equation [7] in the main text.

APPENDIX 2. DERIVATION OF THE REDUCED FORM COEFFICIENTS

128. The activity (R), employment (E) and wage (w) equations can be rewritten as a function of the endogenous variables (R, E, w) and a (subset of) vector of exogenous variables (Z), with γ denoting long-run elasticities or semi-elasticities. For example, the R&D model reads:

$$\ln(R) = \gamma_{RE} \ln(E) + \gamma_{RZ} \ln(Z) \qquad \text{(1a)}$$

$$\ln(E) = \gamma_{ER} \ln(R) + \gamma_{Ew} \ln(w) + \gamma_{EZ} \ln(Z) \qquad \text{(1b)}$$

$$\ln(w) = \gamma_{wE} \ln(E) + \gamma_{wR} \ln(R) + \gamma_{wZ} \ln(Z) \qquad \text{(1c)}$$

129. A number of approximations have to be made in order to log-linearise the effects of those variables that enter in a non-linear form. The approximation is made at the sample mean. For example, R&D employment enters the R&D equation through the share of scientists in the economy-wide employment. The share of scientists in employment can be re-expressed as:

$$\frac{SCI}{EMP_T} = \frac{E - TECHN}{E + NONRD} = \frac{E\left(1 - \frac{TECHN}{E}\right)}{E + NONRD} \qquad \text{(2a)}$$

where TECHN denotes R&D personnel who are not scientists and NONRD denotes non-R&D employment. The share of technicians in R&D employment and the level of non-R&D employment can be assumed constant. Taking a first-order Taylor approximation of the expression for the share of scientists in total employment around the natural logarithm of R&D employment yields:

$$\frac{SCI}{EMP_T} \approx c_1 + \frac{SCI_0}{EMP_{T0}}\left(1 - \frac{E_0}{EMP_{T0}}\right)\left(\ln(E) - \ln(E_0)\right) \qquad \text{(2b)}$$

where c_1 is a constant and the subscript 0 denotes the approximation point.

130. As another example, the ratio of non-business to business R&D enters the wage equation in a non-linear way. A first-order Taylor approximation of this term is taken around the natural logarithms of business and non-business R&D spending:

$$\ln\left(1 + \frac{R^G}{R}\right) \approx c_2 + \frac{\frac{R_0^G}{R_0}}{1 + \frac{R_0^G}{R_0}}\left(\ln\left(\frac{R^G}{R}\right) - \ln\left(\frac{R_0^G}{R_0}\right)\right) \qquad \text{(3)}$$

where c_2 is a constant and the subscript 0 denotes again the approximation point. Similar approximations (log-linear or linear depending on the variable) are taken for a number of determinants, including all the interaction terms.

131. In a second step, the model is solved to express the endogenous variables exclusively as functions of the exogenous determinants.[84] For the R&D model, this yields:

$$\ln(E) = [\gamma_{ER}\gamma_{RZ} + \gamma_{Ew}\gamma_{wR}\gamma_{RZ} + \gamma_{Ew}\gamma_{wZ} + \gamma_{EZ}]\ln(Z)/\gamma_0 \qquad (4)$$

$$\ln(w) = [\gamma_{wR}\gamma_{RZ} + \gamma_{wZ}]\ln(Z) + [\gamma_{wR}\gamma_{RE} + \gamma_{wE}]\ln(E)$$

$$\ln(R) = [\gamma_{RZ}]\ln(Z) + [\gamma_{RE}]\ln(E) \quad \text{with} \quad \gamma_0 = 1 - [\gamma_{ER}\gamma_{RE} + \gamma_{Ew}\gamma_{wR}\gamma_{RE} + \gamma_{Ew}\gamma_{wE}]$$

132. The patent model involves greater complications than the R&D model, because patents (the measure of output) depend on the stock of business R&D, which in turn may be affected by some of the exogenous determinants. The simulation model thus has to include an additional equation for the stock of business R&D, which is taken from column [2] of Table A3.2. Denoting the exogenous determinants by Z and the (semi-) elasticities by λ, this reads:

$$\ln(P) = \lambda_{PR}\ln(R) + \lambda_{PZ}\ln(Z) \qquad (5)$$

$$\ln(R) = \lambda_{RE}\ln(E) + \lambda_{RZ}\ln(Z)$$

$$\ln(E) = \lambda_{EP}\ln(P) + \lambda_{Ew}\ln(w) + \lambda_{EZ}\ln(Z)$$

$$\ln(w) = \lambda_{wE}\ln(E) + \lambda_{wP}\ln(P) + \lambda_{wZ}\ln(Z)$$

The model is solved in the same way as the R&D model.

NOTES

79. More precisely,

$$-u \approx \ln(1-u) = \ln(L^D) - \ln(L^S)$$

where L^D denotes the economy-wide demand for scientists and L^S the supply of scientists.

80. This approximation is valid if the labour intensity of the research process and the wages of scientists are comparable in the business and non-business sectors.

81. The aggregate supply includes qualified scientists in science and non-science occupations, plus those who are not in work.

82. This assumes implicitly either that students have backward-looking expectations or that the relative wage of scientists at the time of schooling is effectively the best predictor of future career prospects. It is also assumed that the current supply of scientists will have been affected by the lagged relative wages of scientists, as these influenced the schooling decisions of current graduates.

83. A broader measure of the international wage level for R&D employees, constructed as the GDP-weighted average of R&D wages in other OECD countries, did not have significant effects. Note that the United States R&D wage is proxied by the wage bill per researcher and not per R&D employee like in other countries (since data are not available on the number of United States R&D employees). This will not matter provided the share of researchers in total R&D personnel is stable over time.

84. The equation for R&D employment is solved by substituting in the wage and the output equations. This yields an expression for R&D employment exclusively in terms of the exogenous variables of the system. This expression can then be substituted back into the output equation to yield an expression for innovation output in terms of the exogenous variables of the system. Finally, the expressions for R&D employment and output are substituted into the wage equation to yield an expression for the R&D wage which depends exclusively on the exogenous variables of the system.

Table A3.1 **Framework conditions and R&D expenditures**

Dependent Variable = $\Delta \ln(\text{R\&D Stock})_t$ (except [2] where: $\Delta \ln(\text{R\&D Flow})_t$

	[1]	[2]	[3]	[4]	[5]	[6]
Long-run parameters						
$\ln(\text{User Cost})_{t-1}$	-1.063 (3.0)	-0.820 (2.4)		-1.050 (3.0)	-0.956 (3.0)	-1.209 (2.9)
$\ln(\text{Tax Component})_{t-1}$			-1.437 (1.9)			
$\ln(\text{Real Component})_{t-1}$			-0.943 (2.6)			
Dynamic Parameters						
ECM_{t-1}	-0.017 (4.9)	-0.088 (4.8)	-0.016 (4.8)	-0.016 (4.8)	-0.022 (5.3)	-0.012 (4.2)
$\Delta \ln(\text{R\&D Stock})_{t-1}$	0.829 (23.2)		0.825 (22.4)	0.833 (23.5)	0.816 (22.4)	0.833 (23.9)
$\Delta \ln(\text{R\&D Flow})_{t-1}$		0.348 (7.2)				
Output Growth_t	0.171 (5.0)	0.968 (5.4)	0.174 (5.2)	0.173 (5.2)	0.217 (5.1)	0.130 (5.0)
Inflation_{t-1}	-0.126 (3.8)	-0.552 (3.5)	-0.125 (3.7)	-0.135 (4.3)	-0.161 (4.0)	-0.092 (3.6)
$\Delta \ln(\text{User Cost})_t$	-0.010 (4.9)	-0.011 (0.4)			-0.011 (1.5)	-0.008 (1.8)
$\Delta \ln(\text{Tax Component})_t$			-0.029 (2.5)	-0.026 (2.7)		
$\Delta \ln(\text{Real Component})_t$			-0.002 (0.3)			
Observations	380	380	380	380	380	380
R^2adj.	0.931	0.453	0.931	0.931	0.909	0.951
Standard Error	0.80%	4.50%	0.80%	0.80%	1.01%	0.60%
Log-Likelihood	1317.8	663.4	1320	1319.5	1229.8	1426.8

Variable definitions: *User Cost* = real user cost of capital; *Tax Component* = tax component of user cost; *Real Component* = real interest plus depreciation rate; *Output Growth* = average GDP growth rate over current and previous year; *Inflation* = average rate of consumer price inflation in current and previous year. Figures in parentheses are the absolute values of heteroscedastic-consistent t-statistics.

Note: Columns [1] to [4] are models in which the annual depreciation rate of R&D capital is assumed to be 11%. The depreciation rate is changed to 16% in the model shown in column [5] and 6% in the model shown in column [6]. All subsequent regressions in Tables A3.1 and A3.2 use a depreciation rate of 11% per annum.

Table A3.1 **Framework conditions and R&D expenditures *(cont'd)***
Dependent Variable = Δ ln (R&D Stock)$_t$

	[7]	[8]	[9]	[10]
Long-run parameters				
ln (User Cost)$_{t-1}$	-0.814 (1.9)	-0.764 (1.7)	-1.346 (2.4)	-1.317 (2.6)
(Profits/GDP)$_{t-1}$	0.359 (2.6)	0.420 (2.6)	0.279 (1.9)	0.225 (3.2)
ln(Fin Dev)$_{t-1}$	1.726 (2.3)	1.984 (2.2)	1.122 (1.4)	0.817 (2.0)
ln(Equity Share)$_{t-1}$	0.231 (1.7)	0.282 (1.8)	0.383 (2.2)	0.279 (2.0)
(Prof Sh*ln(Fin Dev))$_{t-1}$	-0.073 (2.5)	-0.085 (2.6)	-0.051 (1.8)	-0.040 (2.8)
PMR$_{t-1}$		-0.266 (2.2)	-0.215 (1.9)	-0.162 (1.8)
EPL$_{t-1}$		0.144 (0.9)	0.083 (0.6)	
FDIRES$_{t-1}$		0.966 (1.0)	1.827 (1.5)	
ln (FSY)$_{t-1}$			0.519 (2.6)	0.519 (3.1)
[0.01*(Trade Adj)*FSY]$_{t-1}$			0.239 (1.5)	0.318 (2.3)
(Trade Adj)$_{t-1}$			-0.015 (1.0)	-0.026 (1.9)
(Import Pen)$_{t-1}$			-0.468 (0.9)	
ln (Real Ex Rate)$_{t-1}$			-0.485 (1.7)	-0.468 (1.8)
Dynamic Parameters				
ECM$_{t-1}$	-0.013 (3.8)	-0.013 (3.7)	-0.012 (3.6)	-0.013 (4.2)
Δ ln(R&D Stock)$_{t-1}$	0.824 (23.1)	0.834 (23.5)	0.817 (22.6)	0.809 (22.6)
Output Growth$_t$	0.148 (4.3)	0.148 (4.3)	0.112 (3.0)	0.121 (3.3)
Inflation$_{t-1}$	-0.071 (1.9)	-0.080 (2.1)	-0.101 (2.8)	-0.093 (2.6)
Δ ln(Tax Component)$_t$	-0.020 (2.0)	-0.019 (1.9)	-0.021 (2.2)	-0.023 (2.4)
Δ ln(Real Ex Rate)$_{t-1}$			-0.016 (2.3)	-0.015 (2.2)
Observations	380	380	380	380
R^2adj.	0.934	0.935	0.939	0.939
Standard Error	0.78%	0.78%	0.75%	0.75%
Log-Likelihood	1329.1	1332.2	1350.4	1348.5

Additional variable definitions: *Fin Dev* = ratio of bank credit plus stock market capitalisation to GDP; *Equity Share* = ratio of stock market capitalisation to Fin Dev; *Profits* = corporate profits; *Prof Sh* = Profit share of GDP; *PMR* = indicator of product market regulation in services; *EPL* = indicator of employment protection legislation, *FDIRES* = indicator of strength of FDI restrictions; *Trade Adj* = Trade openness adjusted for population size; *Real Ex Rate* = real exchange rate; *Import Pen* = ratio of imports to weighted domestic final expenditure. *FSY* = ratio of (trade-weighted) foreign R&D stock to GDP.

Table A3.2 **The combined determinants of R&D expenditures**

[1] and [2] Dependent Variable = Δ ln (R&D Stock)$_t$
[3] Dependent Variable = Δ ln (R&D Flow)t

	[1]	[2]	[3]
Long-run parameters			
ln (User Cost)$_{t-1}$	-0.356 (3.2)	-0.352 (3.2)	-0.307 (2.7)
(Profits/GDP)$_{t-1}$	0.127 (3.1)	0.127 (3.1)	0.121 (2.9)
ln(Fin Dev)$_{t-1}$	0.644 (2.8)	0.659 (2.8)	0.674 (2.9)
ln(Equity Share)$_{t-1}$	0.091 (2.4)	0.096 (2.5)	0.086 (2.6)
(Profit Share*ln(Fin Dev))$_{t-1}$	-0.025 (2.9)	-0.024 (2.8)	-0.023 (2.6)
PMR$_{t-1}$	-0.104 (0.7)	-0.065 (2.5)	-0.069 (2.6)
ln (FSY)$_{t-1}$	0.575 (1.8)	0.638 (2.4)	0.669 (2.5)
[0.01*(Trade Adj)*FSY]$_{t-1}$	0.065 (0.2)		
(Trade Adj)$_{t-1}$	-0.008 (2.3)	-0.007 (3.0)	-0.008 (3.0)
ln (Real Ex Rate)$_{t-1}$	-0.175 (2.5)	-0.172 (2.5)	-0.149 (1.9)
(Hi-Tech Ratio)$_{t-1}$	0.026 (0.8)		
(Scientists Ratio)$_{t-1}$	0.799 (2.5)	0.849 (2.8)	0.837 (2.3)
(Scientists Ratio*FSY)$_{t-1}$	0.184 (2.1)	0.199 (2.4)	0.234 (2.9)
(NBERD/GDP)$_{t-1}$	0.769 (3.8)	0.824 (4.3)	0.857 (4.3)
(Subsidies/Profits)$_{t-1}$	0.382 (3.7)	0.382 (3.7)	0.363 (3.1)
(Subsidies/GDP)$_{t-1}$	-1.570 (3.0)	-1.625 (3.1)	-1.474 (2.6)
(BEFUND/NBERD)$_{t-1}$	0.070 (3.7)	0.072 (3.8)	0.062 (3.1)
(BEFUND/Profits)$_{t-1}$	-1.662 (3.0)	-1.740 (3.1)	-1.386 (2.3)
IPR$_{t-1}$	0.110 (0.5)	0.214 (1.8)	0.159 (1.3)
IPR$_{t-1}$*PMR$_{t-1}$	0.011 (0.3)		
(Import Pen)$_{t-1}$	0.847 (1.6)	1.016 (2.4)	0.958 (2.2)
IPR$_{t-1}$*(Import Pen)$_{t-1}$	-0.215 (1.6)	-0.259 (2.3)	-0.221 (2.0)
Dynamic Parameters			
ECM$_{t-1}$	-0.050 (6.9)	-0.049 (6.9)	-0.267 (6.8)
Δ ln(R&D Stock)$_{t-1}$	0.697 (16.2)	0.699 (17.2)	
Δ ln(R&D Flow)$_{t-1}$			0.279 (4.4)
Output Growth$_t$	0.097 (2.4)	0.101 (2.5)	0.602 (2.5)
Inflation$_{t-1}$	-0.090 (2.8)	-0.083 (2.8)	-0.377 (2.3)
Δ ln(Tax Component)$_t$	-0.020 (2.0)	-0.020 (2.1)	-0.021 (0.4)
Δ ln(Real Ex Rate)$_{t-1}$	-0.019 (2.8)	-0.018 (2.7)	-0.084 (2.0)
Observations	380	380	380
R^2adj.	0.947	0.947	0.55
Standard Error	0.70%	0.70%	4.08%
Log-Likelihood	1381.9	1381.4	712.4

Variable definitions – see Table A3.1; *Hi-Tech Ratio* = share of hi-tech industries in GDP; *Scientists Ratio* = share of scientists and engineers in total dependent employment; *IPR* = index of intellectual property rights; *NBERD* = R&D expenditures in the non-business sector (flows); *Subsidies* = government funding of business sector R&D; *BEFUND* = business funding of non-business R&D.

Table A3.3 **Decomposition of R&D intensity relative to OECD average in the year 2000 (%, multiplicative)**

	Deviation from OECD Average	Explanatory Factors											Residual
		User Cost	Financial Factors	Exchange Rate	Non-BERD	Academic Links	Subsidies	Scientists	PMR	Foreign Exposure	IPR	Import Comp	
Australia	-38.4	1.6	1.1	7.2	11.2	-0.8	-1.3	-25.4	9.8	-49.1	-0.3	-0.1	7.9
Austria	1.3	0.0	-15.5	3.5	-1.8	-9.2	-0.2	-4.1	-1.2	21.3	-7.8	0.0	8.0
Belgium	27.0	-3.0	-3.9	0.5	-11.6	13.5	1.8	1.3	-2.4	107.0	1.7	-0.6	-3.9
Canada	-7.4	1.7	3.1	0.3	6.5	7.9	-1.3	-5.3	3.5	18.3	3.9	-0.5	11.1
Denmark	31.6	2.8	-10.1	-2.9	5.4	-9.9	1.0	-4.7	-1.1	55.7	-0.3	0.1	9.3
Finland	106.6	-0.2	1.6	3.5	28.2	3.5	-3.4	39.6	1.7	5.9	-0.3	-0.4	12.2
France	19.6	-1.9	0.8	2.4	11.4	-13.1	6.6	-7.1	-6.3	-20.9	1.9	0.1	-4.9
Germany	50.3	-5.0	-2.7	-2.4	3.6	-5.5	3.4	6.6	4.4	-24.5	-5.3	0.0	7.1
Ireland	-29.1	6.4	1.3	6.9	-27.4	22.8	-2.0	-2.2	-8.4	140.7	2.7	0.3	48.1
Italy	-54.2	-2.6	-3.4	0.4	-13.2	-3.5	-0.5	-35.3	-8.7	-29.8	-2.4	0.0	0.3
Japan	82.0	-2.2	-1.4	-6.2	15.7	-9.8	-1.2	61.2	-1.0	-70.5	-0.3	-0.3	7.5
Netherlands	-5.0	4.6	-0.9	-0.2	8.6	20.5	-2.3	-21.9	-1.3	110.1	-3.0	-0.1	-1.7
Norway	-19.5	-5.2	12.9	-3.9	-1.1	13.9	-5.4	17.5	3.6	5.0	3.2	-2.0	-33.2
Portugal	-80.9	5.6	-4.2	-1.5	-9.7	-8.1	-0.4	-44.5	-8.6	-7.0	21.5	2.0	10.3
Spain	-56.9	11.4	-3.0	-2.5	-20.3	5.7	1.3	-34.5	-2.5	-11.9	2.4	2.1	15.8
Sweden	153.8	-4.2	3.5	3.8	22.2	-12.1	3.5	50.7	4.3	18.8	-3.0	-0.1	-7.4
Switzerland	62.2	-2.8	17.6	-3.2	-2.0	-4.4	0.2	12.9	-5.4	110.4	1.7	-0.4	-23.4
United Kingdom	3.7	-3.6	13.4	-4.2	-5.3	2.1	4.1	-10.3	12.9	-10.3	-0.3	0.2	4.3
United States	75.2	-1.8	3.9	-0.4	-2.2	-3.1	-3.1	91.1	10.3	-70.2	-13.2	-1.0	8.3

All calculations are based on the coefficients reported in Column [3] of Table A3.2.
Non-BERD refers to the non-business R&D as a share of GDP. Academic links and subsidies refer to the combined effect of the two separate business funding and subsidy terms
Foreign exposure includes the impact of the foreign R&D stock terms and the openness term. Financial factors combines the profit share and financial market size variables.

Table A3.4 **Relationship between patent applications and R&D stock**[1]

	Total domestic patents				Triadic patents			
	Unrestricted [1]		Restricted [2]		Unrestricted [3]		Restricted [4]	
Dynamic parameters								
ECM_{t-1}	-0.559	(4.4)	-0.532	(4.3)	-0.688	(6.2)	-0.671	(6.0)
dln $(Patent)_{t-1}$	0.071	(0.6)	0.077	(0.6)	0.152	(1.6)	0.139	(1.3)
Long-run parameters								
ln $(Total\ R\&D\ stock/GDP)_{t-1}$			1.688	(6.0)			1.916	(5.0)
ln $(Bus.\ R\&D\ stock/GDP)_{t-1}$	1.350	(5.7)			1.722	(4.0)		
ln $(1+Non\text{-}bus.\ R\&D\ stock/Bus.\ R\&D\ stock)_{t-1}$	0.687	(1.3)			1.318	(1.5)		
Implied long-run elasticities								
ln $(Bus.\ R\&D\ stock/GDP)_{t-1}$	1.057	(6.0)	0.968	(6.0)	1.159	(5.0)	1.098	(5.0)
ln $(Non\text{-}bus.\ R\&D\ stock/GDP)_{t-1}$	0.293	(1.3)	0.721	(6.0)	0.563	(1.5)	0.818	(5.0)
Observations	284		284		277		277	
R^2adj.	0.4		0.37		0.3		0.3	
F test of equality b/w the R&D stock terms (p-value)	2.440	(0.12)			0.510	(0.5)		

1. Variable definitions -- see Tables A3.1 and A3.2 .
T-statistics are in parentheses, unless otherwise notified.

Table A3.5 **Additional policy influences on patenting**[1]

	Total domestic patents						Triadic patents	
	[1]	[2]	[3]	[4]	[5]	[6]	[7]	[8]
Dynamic parameter								
ECM_{t-1}	-0.576 (6.4)	-0.577 (6.4)	-0.564 (6.5)	-0.556 (6.4)	-0.543 (6.8)	-0.549 (6.4)	-0.608 (6.3)	-0.610 (6.8)
Long-run parameters								
ln (Total R&D stock/GDP)$_{t-1}$			1.066 (5.0)	1.063 (4.9)	1.155 (4.8)	1.068 (4.9)		1.174 (3.7)
ln (Bus. R&D stock/GDP)$_{t-1}$	1.090 (5.2)	1.137 (5.2)					1.155 (3.0)	
ln (1+Non-bus. R&D stock/Bus. R&D stock)$_{t-1}$	1.745 (3.2)	1.567 (2.6)					1.725 (1.5)	
[(BEFUND/NBERD)*ln (Total R&D stock/GDP)]$_{t-1}$	0.005 (1.8)	0.004 (1.5)	0.004 (1.3)				-0.002 (0.4)	
ln (B-index)$_{t-1}$	-0.959 (2.4)	-0.933 (2.3)	-1.052 (2.4)	-1.072 (2.4)	-1.186 (2.6)	-1.034 (2.3)	0.533 (0.8)	
(Equity/GDP)$_{t-1}$	0.002 (3.1)	0.002 (3.2)	0.002 (2.8)	0.002 (2.9)	0.002 (2.7)	0.002 (2.9)	0.001 (1.5)	0.001 (1.9)
(Subsidies/GDP)$_{t-1}$	-0.841 (3.2)	-0.766 (2.8)	-0.847 (3.0)	-0.881 (3.2)	-0.897 (3.2)	-0.830 (3.0)	0.192 (0.7)	
$FDIRES_{t-1}$	-1.111 (3.3)	-1.102 (3.2)	-1.061 (2.9)	-1.120 (3.0)	-1.178 (3.2)		0.004 (0.0)	
EPL_{t-1}	-0.177 (4.0)	-0.173 (3.9)	-0.189 (3.9)	-0.190 (3.9)		-0.182 (3.5)	-0.235 (2.6)	-0.238 (2.5)
[0.01*(Trade Adj)*FSY]$_{t-1}$	0.061 (2.5)	0.056 (2.3)	0.036 (1.8)	0.037 (1.8)	0.031 (1.5)	0.037 (1.7)	0.037 (1.0)	
IPR_{t-1}	0.188 (2.5)	0.186 (2.5)	0.175 (2.3)	0.183 (2.4)	0.271 (3.5)	0.300 (3.9)	0.240 (1.5)	0.220 (1.8)
(Scientists ratio)$_{t-1}$		-0.267 (0.9)						
[IPR*EPL]$_{t-1}$					-0.040 (4.0)			
[IPR*FDIRES]$_{t-1}$						-0.291 (2.9)		
Implied long-run elasticities								
ln (Bus. R&D stock/GDP)$_{t-1}$	0.359 (2.1)	0.480 (2.1)	0.621 (5.2)	0.609 (4.9)	0.662 (4.8)	0.612 (4.9)	0.414 (1.5)	0.673 (3.7)
ln (Non-bus. R&D stock/GDP)$_{t-1}$	0.755 (3.2)	0.677 (2.7)	0.463 (5.2)	0.454 (4.9)	0.493 (4.8)	0.456 (4.9)	0.733 (1.5)	0.501 (3.7)
Observations	269	269	269	269	269	269	266	266
R^2adj.	0.53	0.53	0.52	0.52	0.51	0.52	0.29	0.31
F test of equality b/w the R&D stock terms (p-value)	1.920 (0.17)	0.650 (0.42)						

1. Variable definitions -- see Tables A3.1 and A3.2.
T-statistics are in parentheses, unless otherwise notified.

Table A3.6 **Econometric estimates of the labour market model**[1]

Three-stage least squares with heteroskedasticity-consistent standard errors

Dependent variable:	Δln (Business R&D employment)$_t$			
Measure of output	Business R&D spending		Total domestic patents	
Dynamic parameters				
ECM_{t-1}	-0.164	(5.50)	-0.169	(5.12)
Δ ln (Business R&D employment)$_{t-1}$	0.101	(2.89)	0.083	(1.31)
Δ ln (Output)$_t$	0.569	(10.36)	0.074	(2.27)
Δ ln (R&D wage)$_t$	-0.640	(6.40)	-0.811	(9.10)
Δln (B-index)$_t$	-0.077	(2.29)	-0.263	(3.05)
Long-run parameters				
ln (Output)$_{t-1}$	0.712	(10.82)	0.744	(5.66)
ln (Non-business R&D stock/GDP)$_{t-1}$			-1.273	(4.37)
ln (R&D wage)$_{t-1}$	-0.625	(2.92)	-0.640	(1.98)
Profit/GDP$_{t-1}$	0.024	(2.03)	0.175	(3.68)
ln (Fin Dev)$_{t-1}$			0.499	(1.85)
ln (Equity share)$_{t-1}$			0.125	(3.68)
[Profit/GDP*ln(Dev Fin)]$_{t-1}$	-0.005	(2.03)	-0.033	(3.68)
(Subsidies/Profits)$_{t-1}$			0.184	(2.31)
(BEFUND/NBERD)$_{t-1}$	0.047	(2.62)		
(BEFUND/Profits)$_{t-1}$	-1.056	(2.62)		
(Trade Adj)$_{t-1}$	0.009	(1.98)		
[0.01*(Trade Adj)*FSY]$_{t-1}$	-0.093	(1.92)		
IPR_{t-1}	-0.105	(1.91)	-0.466	(3.68)
(Import Pen)$_{t-1}$	-0.631	(1.91)	-2.235	(3.44)
[IPR*(Import Pen)]$_{t-1}$	0.146	(1.91)	0.648	(3.68)
Observations	333		212	
"R-square"	0.85		0.68	

1. Variable definitions -- see Tables A3.1 and A3.2.
   Output and wages are in real terms.
   T-statistics are in parentheses.

Table A3.6 **Econometric estimates of the labour market model *(cont'd)*** [1]

Three-stage least squares with heteroskedasticity-consistent standard errors

Dependent variable:	$\Delta\ln$ (R&D wage)$_t$			
Measure of output	Business R&D spending		Total domestic patents	
Dynamic parameters				
ECM$_{t-1}$	-0.252	(7.36)	-0.267	(6.65)
Δ ln (Productivity)$_t$	0.657	(12.16)	0.069	(2.87)
Δ ln (Non-business R&D)$_t$	0.158	(4.40)	0.196	(3.75)
Δ ln (Business R&D)$_t$	-0.158	(4.40)		
Δ ln (Business R&D employment)$_t$ [2]			-0.548	(10.14)
Δ (Average education years)$_t$	-0.025	(1.53)		
Δ (Unemployment rate)$_t$	-0.002	(1.25)	-0.005	(2.20)
Long-run parameters				
ln (Productivity)$_{t-1}$	0.589	(8.48)	0.195	(3.05)
ln (1+Non-business R&D/Business R&D)$_{t-1}$	0.282	(3.81)		
ln (Economy-wide average wage)$_{t-2}$	0.224	(1.93)	0.687	(3.62)
ln (US wage for scientists)$_{t-1}$	0.650	(6.25)	0.422	(2.37)
Average education years$_{t-1}$	-0.026	(1.60)	-0.053	(2.26)
EPL$_{t-1}$	0.042	(2.02)	0.064	(1.84)
Observations	333		212	
"R-square"	0.68		0.43	

1. Productivity, R&D spending and wages are in real terms.
   Productivity is measured by real business R&D spending per business R&D employee in the R&D model
   and by total patents per business R&D employee in the patent model.
   T-statistics are in parentheses.
2. The current change in business R&D employment proxies the current change in real business R&D in the patent model.

Table A3.7. **Long-run effects of policy and framework factors (1% increase unless otherwise noted)**

Measured in percentage change of dependent variable

	Partial effects[1]		Reduced form effects					
			Business R&D			Total domestic patents		
	R&D spending	Patents	R&D spending	Employment	Wage	Patents	Employment	Wage
Science policies and institutions								
B-index	-0.31	-1.29	-0.48	-0.32	-0.04	-1.64	-1.16	-0.09
Subsidies for private R&D	0.01	-0.10	0.01	0.01	0.00	-0.09	0.04	-0.02
Business funding of non-business R&D	0.11	0.07	0.28	0.32	-0.06	0.08	0.06	0.00
Non-business R&D / GDP ratio[2]	8.57	5.97	11.86	6.12	3.72	6.44	1.53	0.94
IPR index[3]	0.00	18.28	5.41	10.05	-3.38	31.23	42.28	-2.13
The number of scientists	0.54	0.31	..	..	..	..	..	..
Share of scientists in total employment[2]	16.46	9.37	..	..	..	..	..	..
USA real wage of researchers	..	..	-0.54	-1.00	0.99	-0.10	-0.33	0.45
Years of education[3]	..	..	2.13	3.95	-3.90	1.33	4.35	-5.91
Economic conditions								
Profit share of GDP[4]	1.40	0.93	2.55	2.13	-0.06	2.08	3.75	-0.32
Private sector credit	0.04	-0.01	-0.08	-0.22	0.09	-0.18	-0.58	0.08
Stock market capitalisation	0.09	0.14	0.13	0.08	0.01	0.23	0.29	-0.01
Foreign R&D stock	0.94	0.53	1.45	0.96	0.11	0.67	0.47	0.04
Openness[4]	-0.80	-0.30	-0.50	0.56	-0.56	-0.38	-0.27	-0.02
Import penetration[4]	0.00	0.00	-0.72	-1.34	0.45	0.00	0.00	0.00
Real interest rate[4]	-1.95	-1.37	-3.04	-2.01	-0.24	-1.74	-1.23	-0.10
Real exchange rate	-0.15	-0.10	-0.23	-0.15	-0.02	-0.13	-0.09	-0.01
Framework policies (decrease)								
Product market regulation[5]	6.90	3.96	10.73	7.11	0.85	5.05	3.56	0.29
FDI restrictions[6]	..	11.20	..	..	..	14.28	10.06	0.81
Employment protection legislation[5]	..	18.99	3.48	6.47	-6.39	25.87	22.47	-5.97

1. Partial effect refers to the effect holding fixed the scientists ratio.
2.The simulated change is a 0.1% point increase.
3. The simulated change is a 1 unit increase.
4. The simulated change is a 1% point increase.
5. The simulated change is a 1 unit decrease.
6. The simulated change is a 1/10 unit decrease.

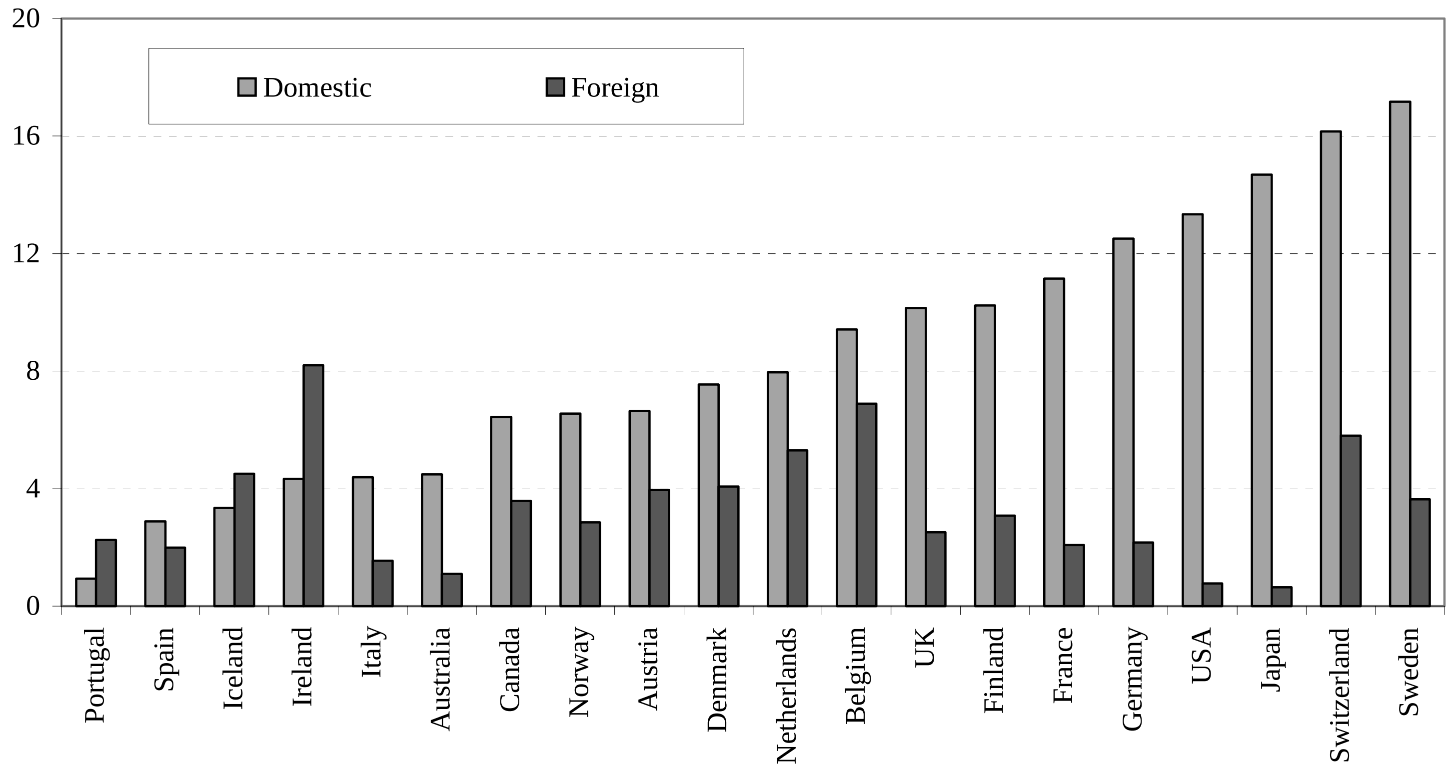
Table A3.8 **Long-run effects of a one standard deviation increase in policy and framework factors**[1]

Measured in percentage change of the dependent variable

	Simulation parameters		Partial effects[2]		Reduced form effects					
					Business R&D			Total domestic patents		
	Sample mean	Standard deviation	R&D spending	Patents	R&D spending	Employment	Wage	Patents	Employment	Wage
Science policies and institutions										
B-index	0.96	0.04	-1.12	-4.68	-1.73	-1.15	-0.14	-5.96	-4.20	-0.34
Subsidies for private R&D / GDP ratio	0.11	0.04	0.17	-3.26	0.26	0.17	0.02	-2.89	1.22	-0.79
Share of business funding in non-business R&D	4.82	1.44	3.25	1.97	8.32	9.43	-1.65	2.52	1.77	0.14
Non-business R&D / GDP ratio	0.68	0.06	5.15	3.59	7.14	3.68	2.24	3.87	0.92	0.57
IPR index	3.75	0.25	0.00	4.65	1.38	2.56	-0.86	7.95	10.77	-0.54
Share of scientists in total employment	0.33	0.07	12.01	6.84	..	..	..	..	..	..
USA real wage of researchers	78934	5092	..	..	-3.36	-6.24	6.16	-0.63	-2.05	2.79
Years of education	8.89	0.48	..	..	1.01	1.88	-1.86	0.63	2.07	-2.81
Economic conditions										
Profit / GDP ratio	23.89	2.07	2.89	1.93	5.27	4.41	-0.13	4.31	7.76	-0.66
Private sector credit / GDP ratio	73.98	13.81	0.64	-0.10	-1.43	-3.84	1.59	-3.16	-10.00	1.31
Stock market capitalisation / GDP ratio	48.88	26.83	3.82	6.18	5.72	3.52	0.61	10.01	12.49	-0.48
Foreign R&D stock / GDP ratio	3.46	0.32	8.23	4.64	12.80	8.48	1.01	5.91	4.17	0.34
Openness	0.00	11.39	-9.11	-3.41	-5.67	6.39	-6.43	-4.35	-3.06	-0.25
Import penetration	1.00	0.20	0.00	0.00	-0.15	-0.27	0.09	0.00	0.00	0.00
Real interest rate	4.71	1.63	-3.19	-2.23	-4.96	-3.29	-0.39	-2.85	-2.00	-0.16
Real exchange rate	1.01	0.15	-1.99	-1.40	-3.10	-2.05	-0.24	-1.79	-1.26	-0.10
Framework policies (decrease)										
Product market regulation	4.09	0.84	5.77	3.31	8.97	5.95	0.71	4.23	2.98	0.24
FDI restrictions	0.25	0.09	..	10.23	..	..	..	13.04	9.19	0.74
Employment protection legislation	2.22	0.25	..	4.83	0.89	1.65	-1.63	6.58	5.72	-1.52

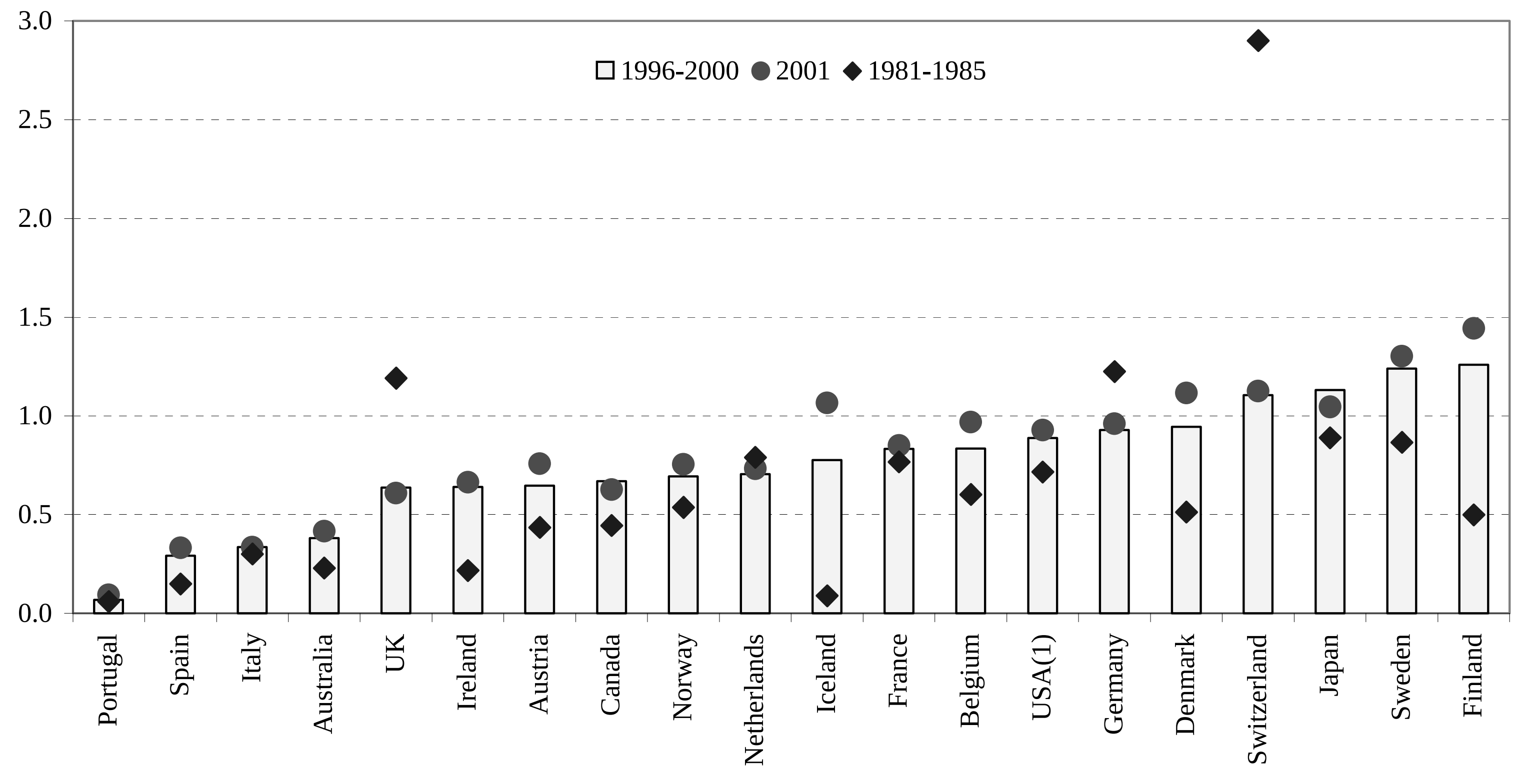
1. The standard deviation is the average of within-country standard deviations.
2. Partial effect refers to the effect holding fixed the scientists ratio.

Figure A3.1. **Domestic and foreign business R&D stocks, 1996-2000**
% of GDP, average per annum



Source: OECD estimates.

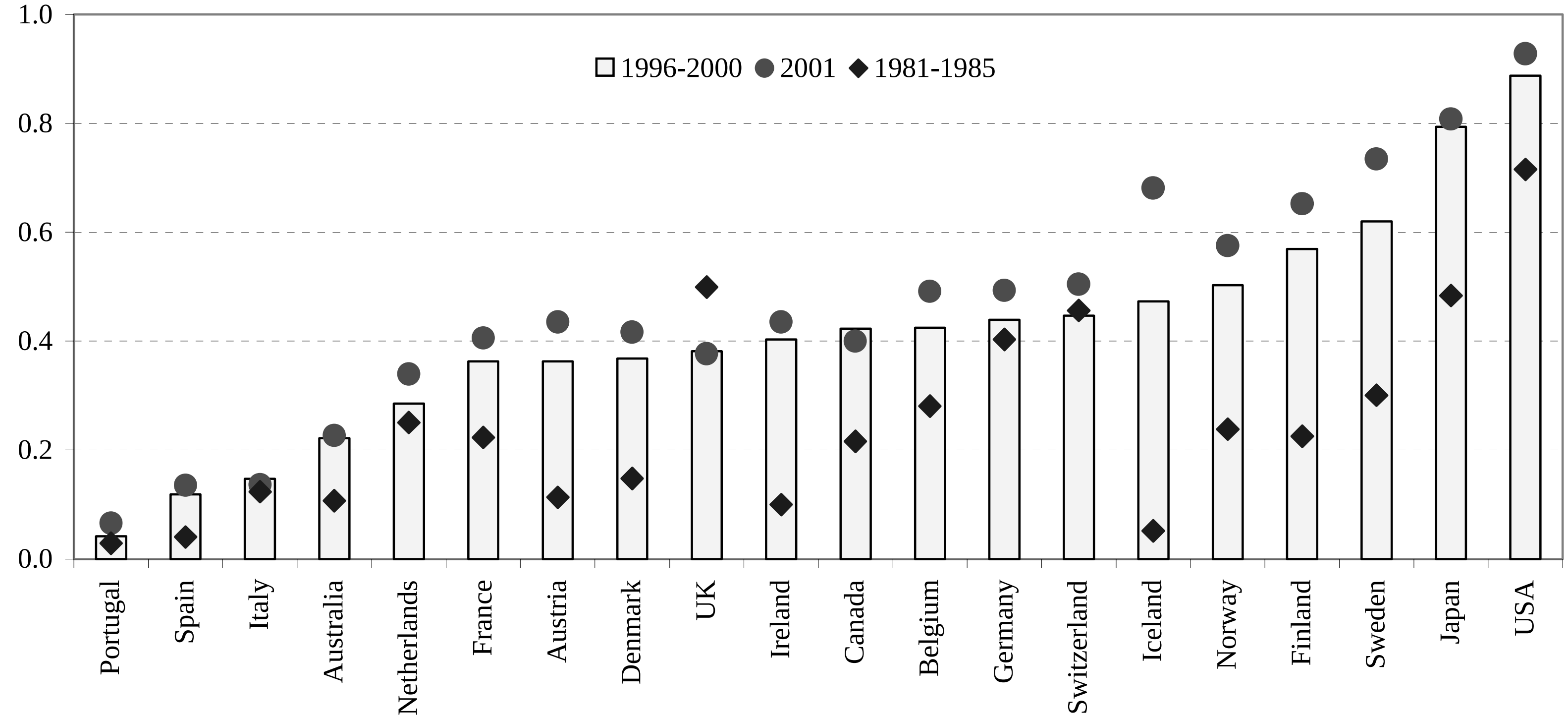
Figure A3.2. **Business sector R&D employees**
% of total dependent employment, average per annum



1. The United States can not be directly compared with other countries because its data refer to researchers as a share of total dependent employment.

Source: OECD Main Science and Technology Indicators database and R&D database.

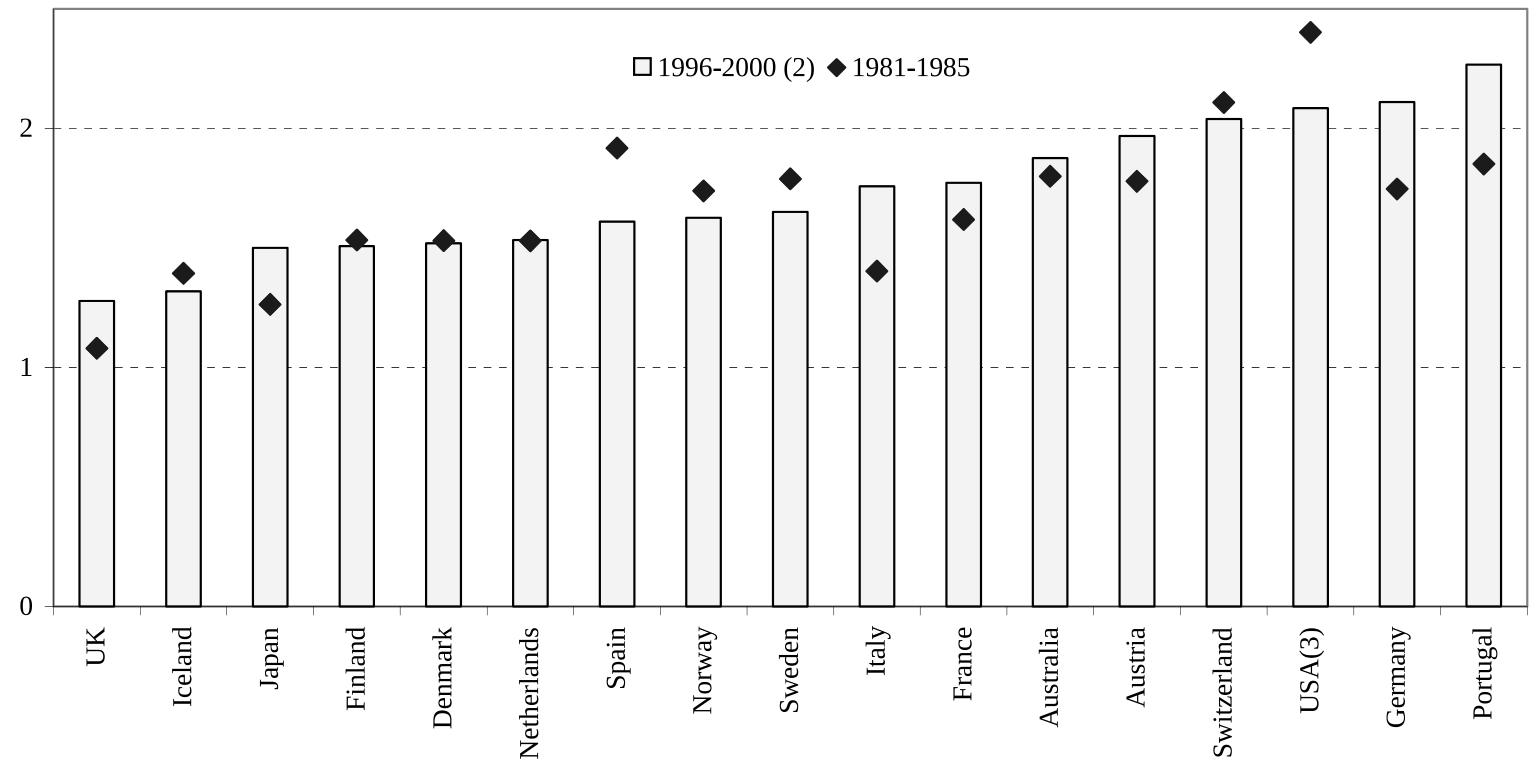
Figure A3.3. **Business sector researchers**
% of total dependent employment, average per annum



Source: OECD Main Science and Technology Indicators database and R&D database.

Figure A3.4. **Ratio of R&D wage and economy-wide compensation per employee**[1]

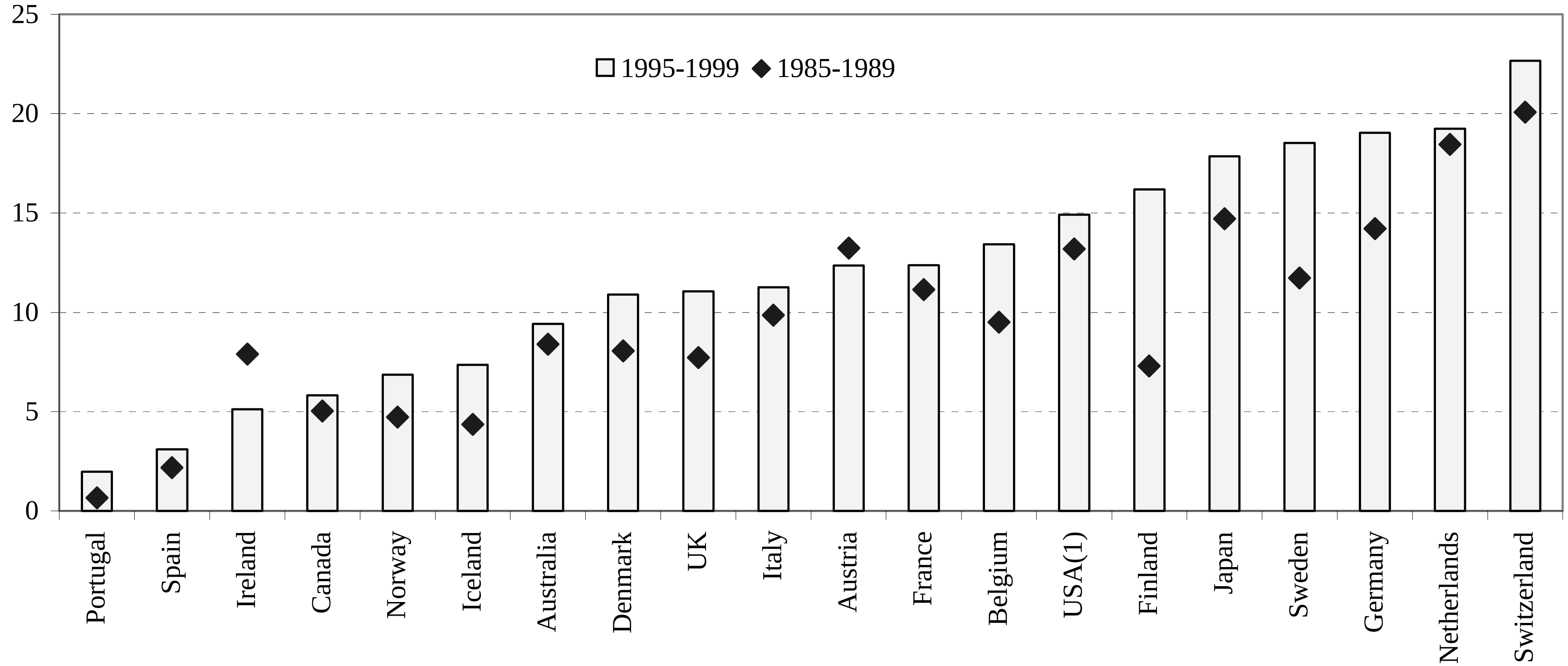
Average per annum



1. The R&D wage was calculated by dividing the business R&D wage bill by the number of business R&D employees.
2. Average over 1996-1998 for Austria, and 1996-1999 for Denmark, Germany, and Iceland. No data are available for Belgium, Canada and Ireland.
3. The United States can not be directly compared with other countries because the R&D wage bill was divided by the number of researchers.

Source: OECD Main Science and Technology Indicators database and R&D database.

Figure A3.5. **Triadic patents per 1 000 business R&D employees**
Average per annum



1. The United States can not be directly compared with other countries because its data refer to triadic patents per business sector researcher.

Source: OECD Main Science and Technology Indicators database and R&D database.