Corporate R&D and Productivity in Germany and the United Kingdom

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Abstract

This paper analyzes differences in R&D spending and in the impact of R&D on productivity between German and UK firms. We confirm that German firms spend significantly larger amounts on R&D than their UK counterparts, even after controlling for firm size and industry effects. Using a dynamic production function approach, we find that the R&D output elasticity is approximately the same in both countries, implying a much larger rate of return on R&D in the UK than in Germany. We discuss several explanations for this result.

Keywords: Corporate governance, R&D, productivity, financial constraints, panel data
JEL classification: L13, 031, C25

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1. Introduction and Motivation

The history of Germany and the United Kingdom includes many episodes in which innovation and technological leadership were major determinants of economic performance and welfare. The chemical industry provides a telling example. Towards the middle of the 19th century, the UK - the motherland of industrialization - began to lose its tremendous lead in chemical technology, one of the most important industrial arts of those days. Leading German chemists had initially moved to the UK, and a brain-drain to the benefit of the UK had started in the first half of the 19th century. But as Landau and Rosenberg (1992, 78ff.) point out, conditions for innovation in the UK did not progress in the second half. The most productive chemists of the day moved back to Germany. Hofmann, a student of Liebig, was a telling example: "(...) [Hofmann] was a singularly attractive and creative figure, who had moved to England in 1845 to teach chemistry. Liebig had preceded him in a triumphal tour of England in 1842, at a time when Liebig's ability to popularize chemistry by showing its usefulness to industry and agriculture filled a vacuum that was not filled by distinguished British chemists such as Dalton, Davy and Faraday. At the same time [1865], Hofmann received an extremely attractive offer to return to Germany. He had become disappointed with the unprogressiveness of the British dye industry, the backward state of organic chemical education, and the lack of sympathy on the part of business, the government, and the very conservative banks. In Germany, a very different atmosphere prevailed." For a number of reasons, the development of the chemical industry in the UK stalled - although the country had commanded a dominant position in 1850. But by 1913, Germany was producing 140,000 tons of synthetic dyes, Switzerland generated 10,000 tons, and England had fallen back to producing only 4,000 tons of the highly prized and industrially important raw material.[1]

In both countries, researchers and policy-makers are again interested in the contribution of innovation and R&D to productivity growth.[2] The notion of a less than desirable innovation performance of the UK has been a leitmotiv in

[1] See also Freeman (1982, chapter 3). Other industries that have seen a similar reversal of national leadership positions include motor-cycles, automobiles, computers, television sets, and consumer electronics. See Porter (1992) for a discussion of competitive advantages and their determinants at the country level.

[2] Cf. Hutton (1995). References on the German side of the debate can be found in Fier and Harhoff (2002).

these discussions; but similar concerns have been voiced in Germany regarding the country's ability to generate a sufficiently large number of startups in new technological fields (where Great Britain - e.g., in biotechnology - has been more successful). Focusing on innovation in established industries, some observers have suggested that economic and social conditions in Germany may be more suitable for the task of industrial innovation; they point to differences in R&D spending, patent statistics and other indicators which suggest that the UK is lagging. However, most of these assessments come from the popular or the business press, and there has been a dearth of precise scientific analyses which determinants of R&D spending and innovation are at the root of the observed differences between the two countries.

This paper seeks to extend the scientific base of these controversies. While the policy debate has typically focused on the narrow contexts of R&D, patenting and venture capital, we take a broader look at the supply of and demand for R&D opportunities.[3] We first discuss possible rationales for the presumed differences in R&D spending and innovation in these two countries. We consider a number of factors that affect the supply of projects that could be pursued by private enterprises, as well as the factors that impact on the hurdle rate of return demanded by managers and investors from such projects.

Using a newly constructed dataset, we then take a detailed look at R&D spending at the firm level and confirm that there are indeed pronounced discrepancies between German and UK firms. The first main empirical result of our paper is that German firms are outspending British competitors by a ratio of roughly two to one, even after controlling for industry and size effects. Out of twelve industries, German firms have significantly higher R&D intensities in eight; in three industries, there are no significant differences, and in only one sector (machinery, data processing, and office equipment) do we observe a higher R&D intensity in the UK than in Germany. Thus, the aggregate picture is not just a function of national industry composition (as one might suspect), but mostly one of firm-level differences in R&D spending. Some fraction of this discrepancy may be due to measurement problems, but the overall results are consistent with the patent application numbers at the European Patent Office, which are highly correlated

[3] See Fier and Harhoff (2002) for a discussion of how post-WWII federal R&D policies in Germany have been affected by such concerns.

with R&D expenditures. Therefore, we take the stylized fact that German firms - *ceteris paribus* - spend more on innovation than their British counterparts as the starting point of our paper.

The second part of our empirical analysis is more complex as we attempt to measure the rate of return to R&D itself. While there is a large literature of studies with a similar objective, it is clear to scholars in this field that the task is rather complex. We attempt to solve the estimation problem by employing dynamic production functions in a panel data setting. We use our estimates of the production function coefficients to derive the expected marginal rate of return as the product of the R&D elasticity of revenue times the inverse of the R&D intensity (R&D expenditures divided by revenue). We can demonstrate that the revenue elasticities with respect to R&D are very similar in both countries. Together with the evidence on R&D spending, this implies that the rate of return to R&D must be significantly higher in the UK than in Germany. We interpret these results as evidence against the hypothesis that the scientific-technological opportunities for R&D projects in the two countries are the sole cause for the observed differences in spending. For a number of reasons, differences in corporate governance and finance systems appear to be at least partly responsible for the differences in R&D spending.

To the best of our knowledge, this result is novel. For investments in physical capital, a number of interesting studies with analogous results exist.[4] This seems to confirm the view that rates of return differ across the two countries in a systematic way - returns in the UK and US appear to be higher than in continental European economies. Our results suggest that a similar pattern characterizes the returns to R&D in Germany and the United Kingdom.

The remainder of the paper is structured as follows. In section 2, we review theoretical arguments which may account for persistent differences in the R&D investment decisions of UK and German firms which are facing the same, global product market conditions. We discuss our econometric techniques to test this hypothesis in section 3, where we describe our dynamic specifications for production functions. Estimation via GMM techniques is addressed in section 4. In section 5, we briefly describe our data and discuss differences between UK and German firms with respect to their R&D spending. Both in the descriptive sta-

[4] See, for example, Börsch-Supan (1999) or McKinsey Global Institute (1997).

tistics and in simple regressions of R&D intensity on firm size and industry sector variables, we find that German firms outspend their British competitors considerably. Section 6 presents the results from the dynamic production functions. The final section concludes.

2. Determinants of Firm-Level R&D Decisions

Our analysis seeks to detect possible differences in the productivity contribution of R&D activities in relatively large German and UK firms. To conceptualize our arguments, consider Figure 1. In the upper panel (Case 1), we depict two downward sloping curves summarizing the relationship between the marginal rate of return from R&D and R&D expenditures at the firm level in two countries. Even if firms in the two countries face the same financial requirements, i.e., to return to their investors a rate of return r^*, they will spend different amounts on R&D, since the supply of suitable R&D projects differs. Thus, our discussion of determinants of R&D spending first focuses on factors that affect the set of technological and scientific R&D opportunities available to firms. We argue that commercial R&D opportunities are mainly determined by the extent of basic research in a country, by the human capital available to firms and by the extent to which private enterprises have access to research results from public research institutions and university laboratories; i.e., by the efficiency of public-private technology transfer mechanisms. Thus, firms in one country may undertake less R&D because they achieve their desired marginal product of investment in new knowledge at lower levels of R&D than firms in other countries do - the number of projects yielding the market rate of return may simply be lower.

In the second polar case (Case 2), we assume that firms in different countries face the same R&D project supply curve, giving them access to identical opportunities for R&D. But suppose that for reasons to be discussed below, firms in one country will only select projects with rates of return larger than r_1 whereas firms in the other country face a lower hurdle rate r_2. This case may come about as a consequence of a higher risk premium for UK firms, perhaps as a result of more severe asymmetric information between firms and suppliers of finance; or as the implication of a corporate governance regime in which managers perceive higher costs, perhaps because long-term investments make firms vulnerable to hostile take-overs and are therefore - to some degree - avoided; or as a consequence of weakerer control over investment policies by shareholders, resulting in higher agency costs. In this case the observed difference in R&D spending will be caused by heterogeneous financial requirements. As we emphasize below, it is of some interest to distinguish between these two polar cases. Clearly, either of the polar cases may not reflect real economies fully - a convex combination of both situations may be possible. It is even feasible that firms in the country with higher hurdle rates have sufficiently fertile R&D opportunities that we see a combination of high R&D expenditures and high rates of return (compared to the second country).

Let us consider a number of determinants of the technological opportunities available to firms located in a given country, with particular attention being given to differences between the UK and Germany.

i) Firms typically profit from basic R&D undertaken by publicly funded research laboratories and/or universities. Technological opportunities available to private firms (see Cohen and Levin 1989) are therefore contingent on the extent to which new ideas are developed. While publicly supported R&D organizations exist in all industrialized nations, the German economy appears to profit from a number of large networks of laboratories - e.g. the more than 120 Fraunhofer Institutes, or the Max-Planck-Institutes which have employed a very successful licensing strategy over the last 20 years.

ii) While some of the ideas generated in public-sector R&D laboratories may be mobile and can be exploited on a global basis, there are good arguments to suggest that the flow of new ideas is not without geographic friction. Localized spillovers are presumably one of the main reasons for the emergence of technology clusters such as Silicon Valley, the biotechnology cluster around Cambridge (UK), or the emergence of a biotechnology industry south of Munich. Porter (1992) argues that localized spillovers together with a high degree of competition can lead such clusters to dominate other regions in terms of knowledge production. The efficiency of close cooperation and communication between the private and the public sector may also be an important factor in determining the rate at which new ideas can reach the private sector. Again, Germany appears to profit from a thick layer of institutional arrangements between universities and private corporations. These are particularly strong in the chemicals, pharmaceuticals, automobiles and the machine tool industries. Some of these ties date back to the 19th century when the newly founded chemical firms in Germany were instrumental in luring back eminent scientists like Hofmann from Great Britain (Landau/Rosenberg 1992).

iii) Until the beginning of 2002, German professors at universities have had considerable leeway to transfer their intellectual property to private corporations - without sharing the returns with their respective research institution. The so-called "Hochschullehrererfinderprivileg" (professorial inventor privilege) allowed them to exploit the rights to their intellectual property without sharing the returns with the home university or any of the funding organizations. While it is very difficult to obtain comprehensive quantitative evidence, it appears clear that a considerable share of the intellectual property created at public universities in Germany has found its way to large private corporations.[5] This may very well have come at the expense of academia-based spinout firms.[6]

It is very difficult to assess how these factors operate in combination. Our qualitative assessment would lead us to suggest that technological opportunities for industrial R&D in relatively large corporations (but not necessarily in startups) are better developed in Germany than in the United Kingdom. This argument has also been put forth by Soskice (1999) who suggests that the German national innovation system is geared towards providing good conditions for incremental R&D which typically takes place in large corporations.

The corporate governance and financing frameworks in the two countries also show remarkable differences:

i) Large German firms are more likely to remain privately owned and unquoted on stock markets than their counterparts in Britain. Even among public, quoted companies, share ownership remains much more concentrated in Germany than it is in Britain. Moreover, the extent to which corporate equity is owned by financial institutions, such as pension funds and insurance companies, who tend to hold diversified portfolios with small stakes in many firms, is substantially higher in Britain than in Germany.[7]

ii) Managers of German firms are much more likely to be monitored by a single large shareholder, or small group of related shareholders, who own a controlling interest in the firm.

[5] Large corporations often offered university-based inventors to cover their patenting expenses and to pay a fixed honrarium in exchange for control over the intellectual property.

[6] See Gruber and Harhoff (2002) for an assessment of the recent changes in the respective law.

[7] Edwards and Fischer (1994) provide comparative evidence on share ownership patterns.

iii) German firms are much less likely to be subject to a hostile takeover.[8] Much publicized cases, such as the hostile takeover of Mannesmann AG by Vodafone or the attempted takeover of Thyssen by Krupp (which failed initially and was then finally realized as a "friendly" merger) demonstrate that such acquisitions are still the exception in German stock markets.

iv) Patterns of corporate finance are broadly similar in most developed countries, with internal finance from retained profits accounting for a large majority of investment spending by large companies in both Britain and Germany.[9] However other differences in corporate financial behaviour have been documented, notably that the share of profits paid out as dividends to shareholders tends to be both higher and more rigid in Britain than in Germany.[10]

v) Finally, although the extent of such differences can be exaggerated, there are potentially important ways in which the interactions between large firms (which constitute the majority of firms in our sample) and banks differ in the two countries. For example, a long term relationship with a single, dominant bank is more common in Germany, and reflected in the representation of banks on the supervisory boards of large German firms.[11] Even if bank participation in German boards has been decreasing lately, the role of banks is still powerful due to the proxy vote system which allocates the voting rights of equity owners who do not actively participate in shareholders' meetings to the banks at which the deposits are being held.

In perfectly working capital markets, none of the aforementioned differences would appear to matter for corporate investment behaviour. If there are many competing suppliers of finance to firms, each of them having common information about the risks and prospective returns available on each firm's investment opportunities, then only the cost of finance, or the rate of return required by these investors, should influence company investment behaviour. Details of the contractual arrangements between lenders and borrowers assume secondary importance, and in particular the availability of internally generated funds in the form of retained profits should have no influence on investment outcomes. This

[8] Franks and Mayer (1990) provide comparative evidence on corporate takeover activity.

[9] See, for example, Corbett and Jenkinson (1997).

[10] Correia de Silva (1996) provides comparative evidence on corporate dividend behaviour.

[11] Edwards and Fischer (1994) provide a thorough account of the relationship between banks and firms in the two countries. Harhoff and Körting (1999) show that the debt of German SMEs is typically concentrated among a few issuing banks or other institutions.

view conflicts with a substantial body of empirical evidence which suggests that corporate investment may display 'excess sensitivity' to indicators of the availability of internal finance, such as current or recent profits or cash flow. Whilst it is extremely difficult to test for the presence of significant 'financing constraints', many researchers have suggested that these are an important influence on corporate investment. Theoretical analyses of capital markets with imperfect or asymmetric information, or other 'imperfections' such as taxes and transactions costs, have rationalised the possibility that outside investors may require a higher rate of return on externally funded investment projects than existing investors require from internally funded projects - in which case the availability of low cost internal finance does indeed become a significant factor in the firm's investment behaviour. Perhaps surprisingly, much of the empirical evidence relates to large, publicly traded US and UK companies.[12]

If it is the case that imperfect information raises the cost of external finance from debt or new share issues, leaving the investment spending of some firms constrained by a shortage of internal funds, then it is possible that institutional differences between the financial systems in different countries may have a substantive impact on investment outcomes. In particular institutional arrangements which promote longer term relationships and the associated exchange of information between shareholders and managers, or between banks and firms, may help to mitigate some of the sources of these financing constraints. Conversely financial systems that are characterised by transient, arms' length relationships between owners, managers and suppliers of outside finance may be more prone to significant financing constraints.[13] This may be reflected either in the overall level of investment, or in the allocation of investment between relatively safe, short term activities and relatively risky, longer term ventures such as R&D.

The difference between these variants lies in their normative implications. For example, if financial constraints are present in the UK (at least to a larger extent than in Germany), then investment in R&D could be inefficiently low. Similarly, the threat of takeovers could be harmful in the sense that managers shy away from long-term investments with positive value to share-holders. Conversely, if the

[12] Hubbard (1998) provides a recent survey of research in this area.

[13] They may of course provide offsetting advantages, such as more effective allocation of capital to high return activities, particularly at times when significant reallocation of resources is warranted by developments in technology or in the broader economic environment.

differences between the UK and Germany reflect differences in the cost of internal finance, then the British situation may very well be preferable. These distinctions are not our main concern in this paper - we merely wish to test whether the lower R&D investments observed in the UK coincide with a higher rate of return to R&D. A comparative study of corporate investment and R&D behaviour by British and German firms should nonetheless be quite revealing. If there are no detectable differences between firms in these two countries, this would cast doubt on the importance of the different characteristics of the financial systems described above. If there are substantial differences between the behaviour of apparently similar firms in the two countries, this at least raises the possibility that the aforementioned differences have real effects.

3. Static and Dynamic Models of Production

The paper relates to a large body of literature on the relationship between R&D and productivity, and on the impact of corporate governance on productivity. Recent surveys of the main empirical results and methods employed in estimating the productivity impact of R&D have been presented by Mairesse and Mohnen (1994) and Mairesse and Sassenou (1991). While there have been studies on this issue in virtually all of the major industrialized countries, the case of productivity and R&D in European countries, and in Germany and the UK in particular, has remained relatively unexplored so far. One of the key problems in the past has been the availability of suitable firm-level data for a detailed econometric analysis. In this paper, we use datasets that have only recently become available due to changes in publication requirements, and we apply a dynamic production function methodology which was recently developed by Blundell and Bond (2000).

Estimating the impact of R&D in production functions has been found to be difficult, to say the least. The empirical issues are summarized by Griliches (1979). Several surveys (e.g., Mairesse and Sassenou, 1991; Mairesse and Mohnen, 1994) have also documented major differences between time-series and cross-sectional estimates, and in particular the tendency of time-series estimators to yield results that would suggest strongly decreasing returns to scale. Potential explanations for these discrepancies have been discussed by Mairesse (1992). In this paper, we follow suggestions outlined by Blundell and Bond (2000) who apply GMM techniques developed by Arellano and Bover (1995) and Blundell and Bond (1998) to the estimation of dynamic Cobb-Douglas production functions.

3.1. The Basic Model

The exposition in this section follows closely the discussion in Blundell and Bond (2000). To outline the specifications used here, we first consider the Cobb-Douglas production function in labour and capital

$$y_{it} = \beta_n n_{it} + \beta_k k_{it} + \alpha_t + (\eta_i + v_{it} + m_{it}) \tag{3.1}$$

$$v_{it} = \rho v_{i,t-1} + e_{it}$$

$$e_{it}, m_{it} \sim MA(0)$$

with y_{it} being log sales of firm i in year t, n_{it} log employment, k_{it} log capital stock and α_t representing a year-specific intercept. Of the error components, η_i is an unobserved firm-specific effect, v_{it} is a possibly autoregressive (productivity) shock and m_{it} reflects serially uncorrelated (measurement) errors. Constant returns to scale would imply $\beta_n + \beta_k = 1$, but in most cases, we do not restrict the coefficients and test the CRTS hypothesis.

We are interested in consistent estimation of the parameters (β_n, β_k, ρ) when the number of firms (N) is large and the number of years (T) is fixed. Both employment (n_{it}) and capital (k_{it}) are potentially correlated with the firm-specific effects (η_i), and with both productivity shocks (e_{it}) and measurement errors (m_{it}).

The model has a dynamic (common factor) representation

$$\begin{aligned} y_{it} &= \beta_n n_{it} - \rho\beta_n n_{i,t-1} + \beta_k k_{it} - \rho\beta_k k_{i,t-1} + \rho y_{i,t-1} \\ &\quad + (\alpha_t - \rho\alpha_{t-1}) + (\eta_i(1-\rho) + e_{it} + m_{it} - \rho m_{i,t-1}) \end{aligned} \tag{3.2}$$

or

$$y_{it} = \pi_1 n_{it} + \pi_2 n_{i,t-1} + \pi_3 k_{it} + \pi_4 k_{i,t-1} + \pi_5 y_{i,t-1} + \alpha_t^* + (\eta_i^* + w_{it}) \tag{3.3}$$

subject to two non-linear (common factor) restrictions $\pi_2 = -\pi_1\pi_5$ and $\pi_4 = -\pi_3\pi_5$. Given consistent estimates of the unrestricted parameter vector $\pi = (\pi_1, \pi_2, \pi_3, \pi_4, \pi_5)$ and $var(\pi)$, these restrictions can be tested and imposed using minimum distance to obtain the restricted parameter vector (β_n, β_k, ρ). Notice that $w_{it} = e_{it} \sim MA(0)$ if there are no measurement errors ($var(m_{it}) = 0$), and $w_{it} \sim MA(1)$ otherwise. As in the static case, constant returns to scale may be imposed by expressing all regressors relative to the labor input and by dropping the labor input variables themselves from the regression.

3.2. Production Functions With Measured R&D

The specification studied in section 3.1 readily extends to production functions with more than two factors. In particular, we consider using measured R&D as a third input in the production function. This approach builds on the classical work by Griliches (1984) and his students, but extends it to have an explicitily dynamic structure. The model we consider is now

$$y_{it} = \beta_n n_{it} + \beta_k k_{it} + \beta_r r_{it} + \alpha_t + (\eta_i + v_{it} + m_{it}) \tag{3.4}$$

$$v_{it} = \rho v_{i,t-1} + e_{it}$$

$$e_{it}, m_{it} \sim MA(0)$$

where r_{it} is a measure of R&D inputs. We consider two measures: the log (g_{it}) of a cumulated R&D stock (G_{it}) constructed from a perpetual inventory formula

$$G_{it} = (1-\gamma)G_{i,t-1} + R_{it}$$

where R_{it} is R&D expenditure by firm i in year t; and the log (r_{it}) of R&D expenditure (R_{it}) directly. The latter can be motivated as a steady state approximation to the stock, since in steady state (at growth rate μ) we have

$$R_{it} = (\gamma + \mu)G_{i,t-1}$$

and

$$G_{it} = (1+\mu)G_{i,t-1}$$

so that

$$G_{i,t-1} = \left(\frac{1}{1+\mu}\right) G_{it}$$

and

$$R_{it} = \left(\frac{\gamma+\mu}{1+\mu}\right) G_{it}$$

and

$$r_{it} = \ln\left(\frac{\gamma+\mu}{1+\mu}\right) + g_{it}$$

The approximation has been suggested by Bean (1981), but has not been used so far in the R&D/productivity literature. If the steady state approximation is reasonable, the use of the flow variable may be preferred to direct estimates of the R&D stock in situations where the appropriate depreciation rate γ is unknown or firm specific. The approach also allows us to circumvent problems that arise in relatively short time series due to measurement errors in the starting values for the perpetual inventory method.

4. GMM Estimation

4.1. First Differences

A standard assumption on the initial conditions ($E\left[x_{i1}e_{it}\right] = E\left[x_{i1}m_{it}\right] = 0$ for $t = 2, ..., T$) yields the following moment conditions

$$E\left[x_{i,t-s}\Delta w_{it}\right] = 0 \text{ where } x_{it} = (n_{it}, k_{it}, r_{it}, y_{it}) \tag{4.1}$$

for $s \geqslant 2$ when $w_{it} \sim MA(0)$, and for $s \geqslant 3$ when $w_{it} \sim MA(1)$. This allows the use of suitably lagged levels of the variables as instruments, after the equation has been first-differenced to eliminate the firm-specific effects (cf. Arellano and Bond, 1991).

Note however that the resulting first-differenced GMM estimator has been found to have poor finite sample properties (bias and imprecision) when the lagged levels of the series are only weakly correlated with subsequent first differences, so that the instruments available for the first-differenced equations are weak (cf. Blundell and Bond, 1998). This may arise here when the marginal processes for employment (n_{it}), capital (k_{it}) and R&D (r_{it}) are highly persistent, or close to random walk processes, as is often found to be the case. For this reason, we consider further restrictions on the model which may yield more informative moment conditions.

4.2. Levels

If we are willing to assume that $E\left[\Delta n_{it}\eta_i^*\right] = E\left[\Delta k_{it}\eta_i^*\right] = E\left[\Delta r_{it}\eta_i^*\right] = 0$ and that the initial conditions satisfy $E\left[\Delta y_{i2}\eta_i^*\right] = 0$, then we obtain the additional moment conditions

$$E\left[\Delta x_{i,t-s}(\eta_i^* + w_{it})\right] = 0 \tag{4.2}$$

for $s = 1$ when $w_{it} \sim MA(0)$, and for $s = 2$ when $w_{it} \sim MA(1)$ (cf. Arellano and Bover, 1995).[14] This allows the use of suitably lagged first differences of the variables as instruments for the equations in levels.

For an $AR(1)$ model, Blundell and Bond (1998) show that there can be dramatic gains in both asymptotic and finite sample efficiency from exploiting additional moment conditions of this type, in cases where the autoregressive parameter is only weakly identified from the first-differenced equations. Moreover this can also result in substantial reductions in finite sample bias.

4.3. System Estimation

Both sets of moment conditions can be exploited as a linear GMM estimator in a system containing both first-differenced and levels equations. We report results for a one-step GMM estimator, for which inference based on the asymptotic variance matrix has been found to be more reliable than for the asymptotically more efficient two-step estimator. Simulations suggest that the loss in precision that results from not using the optimal weight matrix is unlikely to be large (cf. Blundell and Bond, 1998).

5. Data

For the purpose of this and a related study[15], we have compiled new datasets combining publicly available sources of information for large manufacturing firms in both countries. Our samples of R&D performing firms contain data on more than 200 firms in each country, comprising essentially all the large manufacturing firms that report R&D expenditures in both cases. For UK firms, these are all public companies whose shares are quoted on the London stock exchange and for which published company accounts data was available from Datastream International. For firms in Germany, limiting the analysis to public, quoted companies would be much less representative and therefore less comparable than to include large pri-

[14] Further lagged differences can be shown to be redundant if all available moment conditions in first differences are exploited.

[15] See Bond, Harhoff and Van Reenen (1999).

vate and unquoted companies in the sample.[16] We have therefore collected data on large manufacturing Gesellschaften mit beschränkter Haftung (GmbHs, limited liability corporations) and both quoted and unquoted Aktiengesellschaften (AGs, stock-based corporations). Company accounts data were obtained from the Hoppenstadt and Creditreform databases, and this was supplemented with information on R&D from the Bundesanzeiger, a German government source. In the German case, this information on R&D expenditures was checked by comparison to responses given by firms in the Mannheim Innovation Panel. In the UK case, the accounting data on R&D was checked by comparison with the Department of Trade and Industry's R&D scoreboard, and by a limited number of telephone enquiries. For all UK firms, the accounting information was obtained from worldwide consolidated accounts.[17] Wherever possible we also used data from worldwide consolidated accounts for German firms. We further checked that our results were robust to the exclusion of German companies where we could not be sure that the data was from worldwide consolidated accounts. We note that our data do not cover the subsidiaries of foreign firms in Germany or the UK. This is intentional, since these firms are less likely to be impacted by the host country's financing and corporate governance regimes.

The time periods covered by these samples were dictated by disclosure requirements for R&D information, and other major reforms in accounting procedures. Both samples cover the time period from 1987 to 1996. In Britain, the European Community's Fourth Company Law directive prompted improvement in the reporting of R&D expenditures beginning in 1985, and this became essentially compulsory for large and medium-sized firms following the Statement of Standard Accounting Practice (SSAP) 13 in January 1989. In Germany, the publication of statements on R&D activities in the Bundesanzeiger became compulsory for large and medium-sized firms in 1987, when there were further significant changes to accounting standards that make comparability to earlier years problematic.

Finally we note that the accounting definitions of R&D used in Britain and Germany were both based on the Frascati manual classification and hence very similar during these periods, as were the tax treatments, so that companies had

[16] This is a limitation of earlier comparative studies of company investment behaviour in Britain and Germany, such as that reported in Bond, Elston, Mairesse and Mulkay (2003).

[17] For example, if company A owns two subsidiaries, B located in Britain and C located in South Africa, the worldwide consolidated accounts refer to the combined activities of all three firms, with intra-group transactions netted out.

no stronger incentives to classify particular expenditures as 'research and development' in one country than the other. To improve comparability across the countries we rely wherever possible on flow measures of R&D and investment expenditures. For UK firms we considered two measures of investment, that either include or exclude fixed capital acquired through takeovers.[18] Stocks of fixed capital and accumulated R&D were calculated from the flow data on expenditures using similar procedures in both countries. Further details of these data issues are provided in the data appendix to this paper.

Table 1 reports some basic descriptive statistics for our samples of large manufacturing firms that perform R&D in the two countries. The size distribution of these firms, measured by either employment or sales, is broadly similar. Investment accounts for a similar proportion of sales in both samples, whether or not we include capital acquired through takeovers in the UK case. Profitability as indicated by the ratio of cash flow plus expensed R&D to capital is also found to be very similar in the two samples. The striking difference concerns the ratio of R&D expenditure to sales, which is found to be twice as high on average in our sample of German firms. We will study these differences in more detail in the next section. See also Bond, Harhoff and Van Reenen (1999) for more details on the descriptive statistics.

The main finding of similar business investment rates but substantially lower business R&D intensity in the UK are also consistent with more aggregate data sources, as can be seen from the data in **Table 2a** and **Table 2b**. The ratio of business expenditures (BERD) on R&D to GDP has been considerably higher in Germany than in the UK, in particular when we focus on the time period from 1980 to 1993. Pronounced differences are also apparent in the financing of BERD - German firms rely strongly on their own domestic financial resources, while UK firms receive a large share of BERD financing from the government (17.3% vs. 11.3% in Germany) or from overseas (13.4% vs. 2.7% in Germany). As **Figure 2** demonstrates, German patent applications at the European Patent Office are more than three times more frequent than the corresponding number of UK applications. Both in terms of GDP and population, the countries differ[19]

[18] The German investment data excludes such acquisitions of fixed capital, which is a less significant factor for German companies.

[19] Germany relative to the UK.

by factors of 48.7% (GDP) and 39.8% (population).[20] While these figures may also reflect export intensity (international patent applications are typically sought for products that are marketed abroad), they underline that these two countries differ dramatically with respect to standard technology and innovation indicators.

6. Results

6.1. R&D Expenditures

In **Table 3**, we consider the differences in R&D intensities by industry. With only one notable exception (machinery, data processing and office equipment), the average 1991 R&D intensity in German firms is larger than the corresponding figure for UK firms. Since size differences between the two samples may mask the true underlying differences, we extend the analysis in **Table 4** which summarizes the results from R&D intensity regressions using the pooled sample of all observation years of UK and German firms. We used separate industry dummy variables for each country and included five size group variables and time dummy variables for each year. In eight out of twelve industries, the R&D intensities of German firms are significantly larger than those of the corresponding UK firms. In three industries no significant difference can be detected, and only in machinery, data processing and computers do we find an industry in which the UK R&D intensity is significantly higher. Thus, the aggregate picture is not just a function of national industry composition (as one might suspect), but mostly one of firm-level differences in R&D spending. Some fraction of this discrepancy may be due to measurement problems, but as we pointed out before, the measurement of R&D expenditures in both cases is based on the Frascati Manual definition which has been in use for more than 40 years. Therefore, we do not expect major discrepancies to arise from different definitions of R&D.

6.2. Dynamic Production Functions With R&D

The main econometric results of our study are contained in **Table 5a** (UK firms) and **Table 5b** (German firms). In combination with the system GMM approach to panel estimation described in section 4.3, the dynamic production function

[20] In 1992, the population of the UK was 57.6m and GDP amounted to 1,882.6 billion DM. The respective figures for Germany (East and West) were 80.4 million inhabitants and 2,798.8 billion DM of GDP.

specification works remarkably well in both samples. Conversely, the OLS, within-groups and first-differenced GMM estimators are characterized by the problems described in the R&D-productivity literature.We reject either the common-factor restriction or the constant-returns-to-scale hypothesis for all of these estimators. The SYS2 and SYS3 estimators both pass these tests in the German sample, while common factor restrictions are rejected in the SYS3 estimation of the UK panel. The Sargan test and the difference Sargan tests do not indicate any serious mis-specification; moreover, the specification passes the test for no serial correlation of second order in the first-differenced residuals.

The most relevant coefficient estimate is the estimator of β_R. For the UK, we obtain a preferred estimate of 0.065 (SE 0.024) while the estimate for the German sample is 0.079 (0.042). Since $\partial Y/\partial R = \beta_R Y/R$, we can approximate the ratio of marginal returns to R&D in the UK and Germany from these coefficients and the data in Table 3 as $(\beta_{R,UK}/\beta_{R,G})(Y/R)_{UK}/(Y/R)_G = (0.065/0.079)(5.84/2.42) = 1.986$.[21] While this result is subject to a number of qualifications, we consider it to be broadly consistent with the econometric evidence described in Bond, Harhoff and Van Reenen (1999). If technological opportunities alone were responsible for higher R&D spending in Germany, we should not observe this drastic difference in the respective rates of return. Thus, the corporate governance and finance aspects appear to play an important role.

These results are closely related to a companion paper (Bond, Harhoff and Van Reenen 1999) where we find that for German firms, cash flow is not informative in simple econometric models of fixed investment, R&D, and the R&D 'participation' decision. In identical specifications for British firms, cash flow *is* relevant for investment and R&D participation, although not for the level of R&D spending given participation. In the UK, we also find that investment is less sensitive to cash flow for R&D-performing firms. These results suggest that financial constraints are more significant in Britain, that they affect the decision to engage in R&D rather than the level of R&D spending by participants, and that consequently the British firms that do engage in R&D are a self-selected group where financing constraints tend to be less binding.

[21] Note that the elasticity estimate for the German sample is rather noisy - hence, this approximation will have to be confirmed with a larger sample, and thus with a more precise estimate of the R&D revenue elasticity.

7. Conclusions and Further Research

Differences in the relationship between industry and finance in Britain and Germany have long attracted the interest of economic historians and commentators. An influential view suggests that Britain's financial system may have been less conducive to long-term investment than Germany's, and links this to Britain's relative economic decline over the 20th Century.[22] In this paper, we have discussed potential reasons which could cause the R&D decisions of German and British firms to differ by a considerable margin. These differences emerge in the interplay between the supply of suitable R&D projects and the criteria by which corporations choose the extent and nature of their R&D activities. On both issues, there are large literatures which we only discuss very briefly . On the supply side, the overall scientific infrastructure in a country can be of relevance, since private firms do not develop R&D opportunities from first principles, but from scientific foundations developed on in public-sector research institutions and universities. On the demand side, the nexus between corporate governance, corporate finance and the legal system is crucial. We conclude from our survey of the literature that a combination of comparatively low R&D expenditures in the UK (as compared to Germany) and comparatively high required rates of return would support the argument that demand-side issues are at work. British firms require a higher rate of return from R&D investments and, consequently, relatively little R&D is undertaken. The empirical results from our dynamic production function estimates appear to be consistent with that hypothesis.

Naturally, there are a host of potential explanations for the results obtained in our study. The observed differences may be driven by larger share-holder concentration, the impact of equity holdings by banks, the lack of a market for corporate control in Germany, or by other institutional features of the financial system. However, all of these arguments appear to imply that the required rate of return to R&D actually undertaken by UK firms may be higher than for corresponding German firms which we find confirmed in our test. To test this hypothesis even more precisely, it would be ideal to have a structural model of R&D and profitability in which the required rate of return is estimated directly. In this paper, we make a first step towards such an assessment. Thus, the results

[22] Gerschenkron (1968) provides a classic exposition of this position. Hutton (1995) provides a more recent account.

are an encouraging first step towards a more detailed analysis of the determinants of R&D spending and innovation performance in the UK and Germany.

Data Appendix

Germany

The German dataset contains information on manufacturing firms from two major sources: financial accounts data (balance sheets and profit and loss accounts) from Hoppenstedt, and R&D expenditure data collected from the Bundesanzeiger, the official bulletin of the German government. The data are available from 1987 onwards, since earlier data are not directly comparable for a number of reasons. Currently, the database includes R&D information up to 1996.

In 1985, several changes were introduced into German corporate law (§289 Handelsgesetzbuch), most of them triggered by the European Community's Fourth Company Law directive on harmonization of national requirements pertaining to financial statements. Thus starting in the fiscal year of 1987, all *Gesellschaften mit beschränkter Haftung* (*GmbH*s, limited liability corporations) and *Aktiengesellschaften* (AGs, stock-based corporations) had to submit their annual financial statements to the Commercial Register. Only the larger firms have to have their statements audited, smaller ones need not submit a statement of profits and losses, and the balance sheet can be abbreviated significantly. Medium-sized and large firms are required to publish their statements in the Bundesanzeiger. The size requirements are satisfied if two or more of the following conditions are met: revenues in excess of DM 32 million, more than 250 employees, or balance-sheet total in excess of DM 15 million.

A discussion of the situation of the business (*Lagebericht*) is part of the published statement. Besides establishing new publication requirements, the 1985 law also requires firms to comment on their R&D activities (§289 Handelsgesetzbuch, para 2). However, there is no legal specification as to the format of R&D reporting. About 90 percent of the firms covered in our data report R&D expenditures and the number of R&D employees.

Output (Y). The output measure used in this paper is nominal sales. Using real sales measures based on a common output deflator does not affect the results.

Capital stock (K) was computed using the historic cost values taken from the Anlagenspiegel as the starting value for a perpetual inventory procedure with a depreciation of 8 percent per annum for all years following the first year for which historic cost data were available (typically 1987).

Knowledge capital stocks (G) in 1987, the initial year of most of the time series observations, were computed from the usual permanent growth approximation. Stock data for the following years were computed on the basis of perpetual inventory calculations, using a depreciation rate of 15 percent.

Employment (N) is measured by the end-of-year number of employees.

United Kingdom

During the 1980s political pressure built up to improve rates of R&D disclosure. These began in 1985 in the Companies Consolidated Act of that year, continued in 1987 with the publication of Exposure Draft 41 committing the authorities to greater regulation and finally in January 1989 in SSAP (13) revised. This essentially made reporting of R&D expenditures compulsory for larger firms (defined as having satisfied at least two out of the following three criteria: more than 2,500 employees, turnover of at least £80m and balance sheet total exceeding £39m). In the event disclosure rates rose rapidly throughout the 1980s in expectation of reform and many of the larger R&D performers had already been disclosing. The original SSAP 13 in 1977 required disclosure only of that portion of R&D which is capitalised. The rules over capitalisation are very strict and only a very small fraction of firms capitalise any of their R&D. When they do it tends to be a very small proportion of their R&D budget.

The R&D numbers we use are taken from the company accounts (consolidated group total, DS119). When any R&D is capitalised that part of the capitalised R&D that is was written off in that year is included in the R&D flow measure. The primary source of the information was the Datastream on-line service which essentially covers all firms on the UK Stock Exchange. We also compared the numbers which EXSTAT datafile and the R&D Scoreboard (DTI, various years).

Knowledge capital stocks (G) The R&D in initial year of most of the time series observations, were again computed from a permanent growth approximation as in Hall and Mairesse (1995). Stock data for the following years were computed on the basis of perpetual inventory calculations, using a depreciation rate of 15 percent.

Capital stock (K) was computed by adjusting the historic cost values taken from the Datastream for inflation, and by applying a perpetual inventory procedure with a depreciation of 8 percent per annum for all years following the first year for which historic cost data were available. When data was available we used

1973 as the starting year.

Output (Y). Nominal sales as in Datastream Item 104.

Employment (N) is measured by the end-of-year number of employees, taken from Datastream Item DS219.

References

[1] Arellano, M. and S. R. Bond (1991). "Some Tests of Specification for Panel Data: Monte Carlo Evidence and an Application to Employment Equations," *Review of Economics and Statistics*, Vol. 58, pp. 277-297.

[2] Arellano, M. and O. Bover (1995). "Another Look at the Instrumental Variable Estimation of Error-Component Models," *Journal of Econometrics*, Vol. 68, pp. 29-51.

[3] Bean, C. R. (1981). "An Econometric Model of Manufacturing Investment in the UK," *Economic Journal*, Vol. 91, pp. 106-121.

[4] Bond, S.R., D. Harhoff and J. Van Reenen (1999). "Investment, R&D and Financial Constraints in Britain and Germany," Institute for Fiscal Studies Working Paper no. 99/5 , London.

[5] Blundell, R. and S.R. Bond (1998). "Initial Conditions and Moment Restrictions in Dynamic Panel Data Models," *Journal of Econometrics,* 87.

[6] Blundell, R. and S.R. Bond (2000). "GMM estimation with persistent panel data: an application to production functions," *Econometric Reviews*, 19.

[7] Bond, S.R., J.A. Elston, J. Mairesse, and B. Mulkay (2003). "Financial factors and investment in Belgium, France, Germany and the UK: a comparison using company panel data", *Review of Economics and Statistics.*

[8] Börsch-Supan, A. (1999). "Capital productivity and the nature of competition," *Brookings Papers on Economic Activity (Microeconomics)*, 205-244.

[9] Cohen, W. C. and R. C. Levin (1989). *Handbook of Industrial Organization.* Amsterdam: North-Holland.

[10] Cuneo, P. and J. Mairesse (1984). "Productivity and R&D at the Firm Level in French Manufacturing," in: Z. Griliches (Ed.). *R&D, Patents, and Productivity*, pp. 375-392. Chicago: University of Chicago Press.

[11] Correia De Silva, L. (1996). "Dividend payout behaviour of German companies", D.Phil. thesis, University of Oxford.

[12] Edwards, J. and K. Fischer (1994). *Banks, Finance and Investment in Germany*, Cambridge: Cambridge University Press.

[13] Fier, A. and D. Harhoff (2002). "Die Evolution der bundesdeutschen Forschungs- und Technologiepolitik: Rückblick und Bestandsaufnahme," *Perspektiven der Wirtschaftspolitik* (forthcoming).

[14] Franks, J. and C. Mayer (1990). "Capital markets and corporate control: a study of France, Germany and the UK," *Economic Policy*, 1990, 191-231.

[15] Freeman, C. (1982). *The Economics of Industrial Innovation.* Cambridge, Mass.: MIT Press.

[16] Gerschenkron, A. (1968). "The Modernization of Entrepreneurship", in A. Gerschenkron (ed): *Continuity in History and Other Essays.* Cambridge, MA: Harvard University Press.

[17] Goto, A. and K. Suzuki (1989). "R&D Capital, Rate of Return on R&D Investment and Spillover of R&D in Japanese Manufacturing Industries," *Review of Economics and Statistics*, Vol. 71, No. 4, pp. 555-564.

[18] Griliches, Z. (1979). "Issues in Assessing the Contribution of Research and Development to Productivity Growth," *Bell Journal of Economics.* Vol. 10, pp. 92-116.

[19] Griliches, Z. (1986). "Productivity, R&D, and Basic Research at the Firm Level in the 1970's," *American Economic Review.* Vol. 76, No. 1, pp. 141-154.

[20] Griliches, Z. and J. Mairesse (1984). "Productivity and R&D at the Firm Level," in: Z. Griliches (Ed.). *R&D, Patents, and Productivity,* pp. 339-374. Chicago: University of Chicago Press.

[21] Gruber, M. and D. Harhoff (2002). "Die Neufassung des Hochschullehrererfinderprivilegs," *Betriebliche Forschung und Praxis*, 59-66.

[22] Hall, B. (1993). "Industrial R&D During the 1980s: Did the Rate of Return Fall?," *Brookings Papers on Economic Activity (Microeconomics)*, No. 2, pp. 289-343.

[23] Hall, B. and J. Mairesse (1995)."Exploring the relationship between R&D and productivity in French manufacturing firms," *Journal of Econometrics*, Vol. 65, pp. 263-293.

[24] Harhoff, D. (1998). "R&D and Productivity in German Manufacturing Firms," *Economics of Innovation and New Technology*, Vol. 6, pp. 29-49.

[25] Hubbard, R.G. (1998). "Capital-Market Imperfections and Investment", *Journal of Economic Literature*, Vol. XXXVI, 193-225.

[26] Hutton,W. (1995). *The State We're In*, London: Verso.

[27] Landau, R. and N. Rosenberg (1992). ""The Chemical Industry in Britain and Germany," in: N. Rosenberg, R. Landau and D. C. Mowery (eds.): *Technology and the Wealth of Nations*, Stanford University Press.

[28] Mairesse, J. (1992). "Time-series and cross-sectional estimates on panel data: why are they different and why should they be equal?," in: J. Hartog, G. Ridder and J. Theeuwes (eds.): *Panel Data and Labor Market Studies.* Amsterdam: North-Holland.

[29] Mairesse, J. and B. Hall (1994). “Comparing the Productivity of Research and Development in French and United States Manufacturing Firms,” mimeo.

[30] Mairesse, J. and M. Sassenou (1991). “R&D and Productivity: A Survey of Econometric Studies at the Firm Level”, *Science-Technology-Industry Review*, No. 8, pp. 317-348.

[31] Mairesse, J. and P. Mohnen (1994). “R&D and Productivity Growth: What have we learned from Econometric Studies?,” Paper Presented at the Conference on Evolutionary Economics of Technological Change, Strasbourg, Oct. 6-8, 1994.

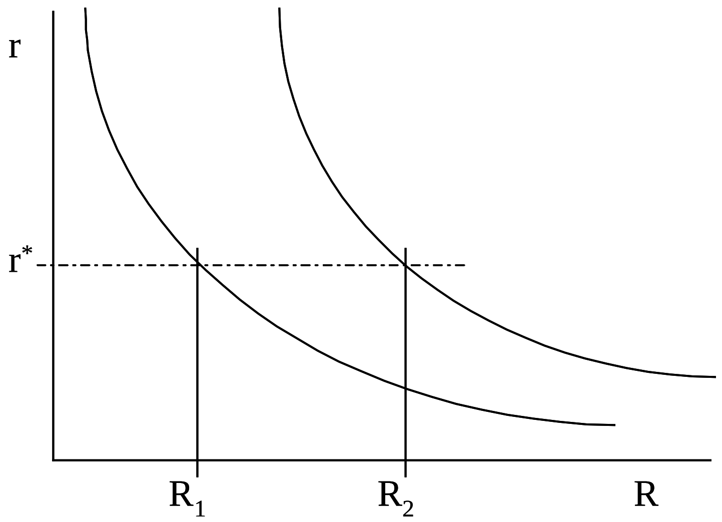
[32] McKinsey Global Institute (1997). *Removing barriers to growth and employment in France and Germany.* Frankfurt: McKinsey Global Institute.

[33] Porter, M. E. (1992). *The competitive advantage of nations.* London: MacMillan.

[34] Van Reenen, J. (1997). “Why has Britain had slower R&D growth?,” *Research Policy*, Vol. 26, pp. 493-507.

Figure 1
Rate of Return and R&D Investment

Case 1
Diverging Supply of R&D Opportunities,
Common Hurdle Rate



Case 2
Common Supply of R&D Opportunities,
Diverging Hurdle Rates

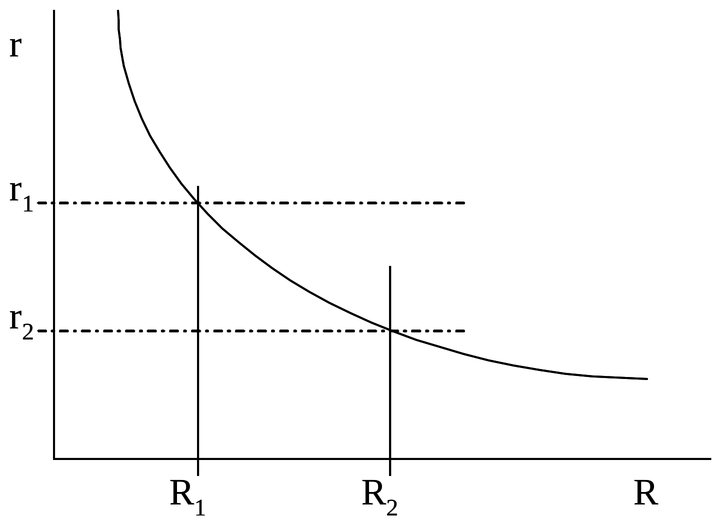


Figure 2

UK and German Patent Applications
at the European Patent Office, 1985-1994

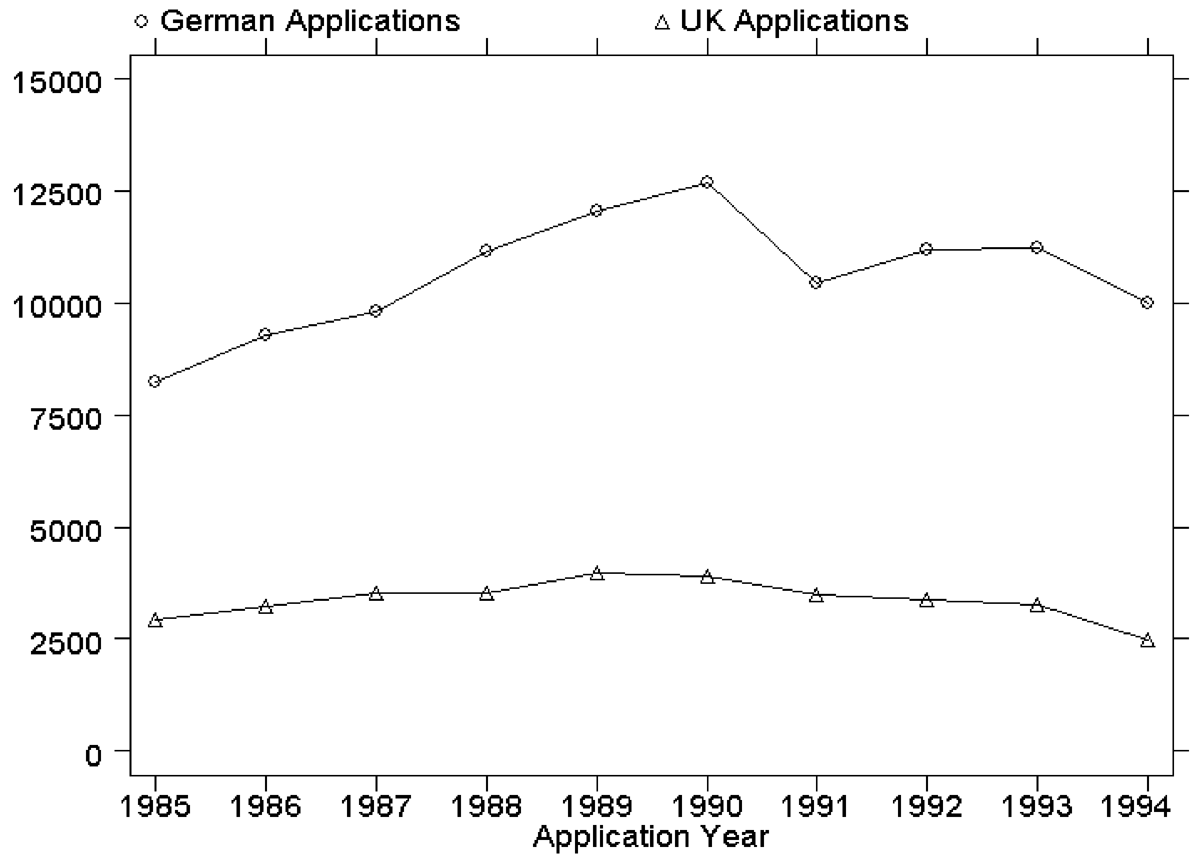


Table 1
Descriptive Statistics (1991)

UK Firms (230 observations in 1991)

	Median	Lower Quartile	Upper Quartile	Mean
sales (Y)	441.7	109.3	1,920.6	3,428.1
capital (K)	260.7	45.5	1,615.3	2,675.6
employees (N)	2,525	685	9,240	14,444
R&D (R)	4.83	1.76	19.34	65.33
R&D capital stock (G)	21.20	6.60	92.20	329.44
R&D expenditures/sales (%)	1.23	0.47	2.84	2.34
Investment/sales (%)	4.62	2.88	7.58	7.12

German Firms (205 observations in 1991)

	Median	Lower Quartile	Upper Quartile	Mean
sales (Y)	717.0	236.6	2,153.8	4,889.2
capital (K)	146.0	44.8	2,153.8	1,537.7
employees (N)	2,878	1,008	7,560	18,684
R&D (R)	21.7	9.1	84.9	225.2
R&D capital stock (G)	113.7	45.7	378.9	1,064.0
R&D expenditures/sales (%)	3.76	1.88	6.14	5.12
Investment/sales (%)	5.64	3.52	7.81	6.57

Note: All values in million Mark (1991). Values for UK firms were converted to DM at an exchange rate of 2.93DM/£.

Table 2a

R&D as Share of GDP

	1973-93	1973-93	1973-79	1973-79	1980-93	1980-93
	UK	GER	UK	GER	UK	GER
BERD/GDP	1.4	1.7	1.4	1.4	1.4	1.9

Source: OECD Historical Statistics (1995)

Table 2b

Financing of BERD (1989)

	UK	GER	EU	OECD
Industry Own Financed	69.5%	86.0%	78.8%	79.6%
Overseas Financed	13.4%	2.7%	6.9%	n.a.
Government Financed	17.2%	11.3%	14.4%	18.0%

Source: OECD Main Science and Technology Indicators (1996)

Table 3
Mean R&D Intensity by Industry and
Composition of the Samples (1991)

Sector	German Firms			UK Firms		
	R/Y	N	%	R/Y	N	%
Chemicals, Pharmaceuticals	7.98	43	21.0	3.39	29	12.6
Plastic Materials, Rubber	7.34	8	3.9	0.72	2	0.9
Mining, Quarrying, Ceramic Products, Glass	1.81	6	2.9	1.11	2	0.9
Petroleum Refineries	1.00	6	2.9	0.95	4	1.7
Iron and Steel, Non-ferrous Metals, Foundries, Metal Drawing and Steel Construction	3.02	12	5.8	0.65	6	2.6
Machinery, Data Processing and Office Equipment	5.82	38	18.4	7.32	17	7.4
Road and Other Vehicles	4.61	21	10.1	2.59	21	9.1
Electrical Machinery, Precision and Optical Instruments	7.64	37	17.9	3.21	55	23.9
Structural Metal Products, Musical Instruments, Toys	1.71	2	1.0	1.45	1	0.4
Wood Products, Pulp, Paper and Paperboard, Printing and Duplication, Leather, Leatherware, Footware, Textiles and Apparel	0.05	1	0.5	0.61	25	10.9
Food, Beverages and Tobacco	1.72	2	1.0	0.50	16	7.0
Other	4.32	29	14.0	0.94	52	22.6
	5.12	205	100%	2.34	230	100%

Table 4
Results from R&D Intensity Regressions
with Firm Size and Year Controls

Sector	German Firms			UK Firms			
	R/Y	S.E.	N	R/Y	S.E.	N	p
Chemicals, Pharmaceuticals	8.05	0.37	392	5.19	0.42	220	<0.001
Plastic Materials, Rubber	7.80	0.58	65	2.23	1.00	17	<0.001
Mining, Quarrying, Ceramic Products, Glass	3.55	0.62	51	2.89	0.99	17	0.540
Petroleum Refineries	2.80	0.63	51	2.40	0.76	31	0.648
Iron and Steel, Non-ferrous Metals, Foundries, Metal Drawing and Steel Construction	4.47	0.50	98	2.30	0.66	45	<0.001
Machinery, Data Processing and Office Equipment	*6.46*	0.38	339	*8.66*	0.46	118	*<0.001*
Road and Other Vehicles	6.31	0.46	161	4.28	0.44	166	<0.001
Electrical Machinery, Precision and Optical Instruments	8.03	0.39	275	4.89	0.36	397	<0.001
Structural Metal Products, Musical Instruments, Toys	2.06	1.02	15	2.27	1.37	8	0.898
Wood Products, Pulp, Paper and Paperboard, Printing and Duplication, Leather, Leatherware, Footware, Textiles and Apparel	6.28	1.73	5	2.40	0.44	186	0.024
Food, Beverages and Tobacco	8.20	0.91	20	1.99	0.47	127	<0.001
Other	5.30	0.40	189	2.57	0.39	376	<0.001

Note: The table reports the industry sector dummy coefficients, standard errors and number of observations within a given industry from a pooled sample of German and UK firm-year observations (N=3,369) with dummy variables for firm size groups and years as covariates of the regression equation. The reference group contains firms with fewer than 500 employees in 1989. The threshold values for defining the other size groups are 1,000, 5,000, 10,000, 50,000, and 100,000 employees. For each country, a separate set of industry dummy variables was included. The overall R-squared (SEE) of the regression was 0.568 (3.792). The p-value in the right-hand column refers to the probability of rejecting the null hypothesis that the UK dummy coefficient is equal to the respective coefficient for German firms.

Table 5a

Dynamic Production Functions with R&D - UK Firms

Dependent Variable: ln(sales)

	OLS	WG	DIF2	DIF3	SYS2	SYS3
y_{-1}	0.960	-0.021	0.436	0.467	0.836	0.848
	(0.011)	(0.009)	(0.089)	(0.117)	(0.054)	(0.063)
k	0.236	0.537	0.106	0.116	0.305	0.390
	(0.049)	(0.044)	(0.115)	(0.144)	(0.096)	(0.120)
k_{-1}	-0.216	0.223	-0.034	-0.114	-0.256	-0.305
	(0.049)	(0.050)	(0.076)	(0.102)	(0.089)	(0.106)
n	0.551	-0.067	0.589	0.584	0.572	0.470
	(0.063)	(0.038)	(0.075)	(0.089)	(0.076)	(0.086)
n_{-1}	-0.537	0.568	-0.240	-0.241	-0.489	-0.445
	(0.065)	(0.056)	(0.088)	(0.110)	(0.077)	(0.096)
lnR	0.053	-0.328	0.053	0.044	0.076	0.069
	(0.011)	(0.066)	(0.025)	(0.028)	(0.025)	(0.029)
lnR_{-1}	-0.046	0.055	-0.036	-0.026	-0.043	-0.011
	(0.011)	(0.011)	(0.021)	(0.025)	(0.021)	(0.025)
m1 (p-value)	0.928	0.000	0.000	0.001	0.000	0.000
m2 (p-value)	0.448	0.569	0.626	0.546	0.711	0.281
Sargan (p-value)	-	-	0.301	0.420	0.280	0.388
Difference Sargan (p-value)	-	-	-	-	0.790	0.656
ρ	0.980	-0.042	0.463	0.497	0.859	0.939
	(0.009)	(0.001)	(0.079)	(0.106)	(0.052)	(0.052)
β_K	0.320	0.543	0.132	0.091	0.315	0.560
	(0.041)	(0.043)	(0.106)	(0.141)	(0.067)	(0.098)
β_N	0.553	0.076	0.594	0.590	0.595	0.442
	(0.056)	(0.026)	(0.106)	(0.082)	(0.071)	(0.080)
β_R	0.044	-0.296	0.054	0.044	0.065	0.051
	(0.010)	(0.054)	(0.072)	(0.026)	(0.024)	(0.028)
Common Factor Restrictions (p-value)	0.002	0.041	0.868	0.811	0.388	0.008
CRTS (p-value)	0.053	0.000	0.048	0.029	0.937	0.780

Note: 239 firms, 1469 observations for OLS, 1230 observations for all other columns. Definition of variables: n - ln(end-of-year employees), k - ln(end-of-year real capital), ln$R$ - ln(real R&D expenditures), y - ln(nominal sales). Regressions include time dummies for each year. Time period: 1988-1996. The set of instruments for the DIF2 (DIF3) estimates includes k, n, y and lnR in levels lagged 2 (3) periods or more (up to 6 periods). The set of instruments for the SYS2 (SYS3) estimator contains first differences of k, n, y and lnR lagged 1 period (2 periods) as additional instruments for the levels equations.

Table 5b

Dynamic Production Functions with R&D - German Firms

Dependent Variable: ln(sales)

	OLS	WG	DIF2	DIF3	SYS2	SYS3
y_{-1}	0.953	0.362	0.279	0.146	0.574	0.656
	(0.010)	(0.050)	(0.112)	(0.163)	(0.096)	(0.106)
k	0.146	0.171	0.025	0.026	0.127	0.208
	(0.060)	(0.053)	(0.155)	(0.164)	(0.148)	(0.232)
k_{-1}	-0.129	-0.071	-0.014	0.008	-0.073	-0.133
	(0.058)	(0.037)	(0.093)	(0.115)	(0.120)	(0.193)
n	0.584	0.648	0.648	0.677	0.574	0.543
	(0.064)	(0.056)	(0.116)	(0.130)	(0.121)	(0.124)
n_{-1}	-0.557	-0.250	-0.038	0.019	-0.198	-0.323
	(0.062)	(0.058)	(0.125)	(0.166)	(0.105)	(0.135)
lnR	0.072	0.052	0.009	-0.015	0.076	0.083
	(0.031)	(0.030)	(0.051)	(0.046)	(0.053)	(0.044)
lnR_{-1}	-0.070	-0.020	-0.116	-0.062	-0.076	-0.044
	(0.032)	(0.026)	(0.063)	(0.073)	(0.047)	(0.040)
m1 (p-value)	0.007	<0.001	0.001	0.049	<0.001	<0.001
m2 (p-value)	0.656	0.351	0.507	0.681	0.343	0.296
Sargan (p-value)	-	-	0.201	0.285	0.441	0.653
Difference Sargan (p-value)	-	-	-	-	0.872	0.734
ρ	0.959	0.377	0.385	0.239	0.632	0.649
	(0.009)	(0.040)	(0.092)	(0.108)	(0.090)	(0.100)
β_K	0.182	0.157	-0.013	0.028	0.249	0.295
	(0.049)	(0.041)	(0.093)	(0.089)	(0.078)	(0.119)
β_N	0.668	0.637	0.678	0.697	0.600	0.591
	(0.053)	(0.052)	(0.111)	(0.122)	(0.114)	(0.110)
β_R	0.093	0.054	0.010	-0.008	0.079	0.079
	(0.026)	(0.029)	(0.050)	(0.044)	(0.042)	(0.043)
Common Factor Restrictions (p-value)	0.006	0.944	0.262	0.917	0.284	0.858
CRTS (p-value)	0.181	0.003	0.020	0.068	0.325	0.661

Note: 234 firms, 1427 observations for OLS, 1193 observations for all other columns.Definition of variables: n - ln(end-of-year employees), k - ln(end-of-year real capital), ln$R$ - ln(real R&D expenditures), y - ln(nominal sales). Regressions include time dummies for each year. Time period: 1988-1996. The set of instruments for the DIF2 (DIF3) estimates includes k, n, y and lnR in levels lagged 2 (3) periods or more (up to 6 periods). The set of instruments for the SYS2 (SYS3) estimator contains first differences of k, n, y and lnR lagged 1 period (2 periods) as additional instruments for the levels equations.

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