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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 bene…t of the UK had started in the …rst half of the 19th century. But as Landau and Rosenberg (1992, 78¤.) 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 …gure, 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 …lled a vacuum that was not …lled by distinguished British chemists such as Dalton, Davy and Faraday. At the same time [1865], Hofmann received an extremely attractive o¤er 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 di¤erent 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 these discussions; but similar concerns have been voiced in Germany regarding the country's ability to

[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 Harho¤ (2002).

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 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.

[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.

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 statistics 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.

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

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 …rms.[6]

It is very di¢cult 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 …nancing frameworks in the two countries also show remarkable di¤erences:

i) Large German …rms 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 …nancial institutions, such as pension funds and insurance companies, who tend to hold diversi…ed portfolios with small stakes in many …rms, is substantially higher in Britain than in Germany.[7]

ii) Managers of German …rms 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 …rm.

iii) German …rms 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 …nally realized as a "friendly" merger) demonstrate that such acquisitions are still the exception in German stock markets.

iv) Patterns of corporate …nance are broadly similar in most developed countries, with internal …nance from retained pro…ts accounting for a large majority of investment spending by large companies in both Britain and Germany.[9] However other di¤erences in corporate …nancial behaviour have been documented, notably that the share of pro…ts paid out as dividends to shareholders tends to be both higher and more rigid in Britain

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

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

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

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

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

than in Germany.[10]

v) Finally, although the extent of such di¤erences can be exaggerated, there are potentially important ways in which the interactions between large …rms (which constitute the majority of …rms in our sample) and banks di¤er in the two countries. For example, a long term relationship with a single, dominant bank is more common in Germany, and re‡ected in the representation of banks on the supervisory boards of large German …rms.[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 di¤erences would appear to matter for corporate investment behaviour. If there are many competing suppliers of …nance to …rms, each of them having common information about the risks and prospective returns available on each …rm's investment opportunities, then only the cost of …nance, or the rate of return required by these investors, should in‡uence 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 pro…ts should have no in‡uence on investment outcomes. This view con‡icts with a substantial body of empirical evidence which suggests that corporate investment may display 'excess sensitivity' to indicators of the availability of internal …nance, such as current or recent pro…ts or cash ‡ow. Whilst it is extremely di¢cult to test for the presence of signi…cant '…nancing constraints', many researchers have suggested that these are an important in‡uence 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 …nance does indeed become a signi…cant factor in the …rm'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 …nance from

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[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 …rms in the two countries. Harho¤ and Körting (1999) show that the debt of German SMEs is typically concentrated among a few issuing banks or other institutions.

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

debt or new share issues, leaving the investment spending of some …rms constrained by a shortage of internal funds, then it is possible that institutional di¤erences between the …nancial systems in di¤erent 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 …rms, may help to mitigate some of the sources of these …nancing constraints. Conversely …nancial systems that are characterised by transient, arms' length relationships between owners, managers and suppliers of outside …nance may be more prone to signi…cant …nancing constraints.[13] This may be re‡ected 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 di¤erence between these variants lies in their normative implications. For example, if …nancial constraints are present in the UK (at least to a larger extent than in Germany), then investment in R&D could be ine¢ ciently 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 di¤erences between the UK and Germany re‡ect di¤erences in the cost of internal …nance, 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 …rms should nonetheless be quite revealing. If there are no detectable di¤erences between …rms in these two countries, this would cast doubt on the importance of the di¤erent characteristics of the …nancial systems described above. If there are substantial di¤erences between the behaviour of apparently similar …rms in the two countries, this at least raises the possibility that the aforementioned di¤erences have real e¤ects.

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

[13] They may of course provide o¤setting advantages, such as more e¤ective allocation of capital to high return activities, particularly at times when signi…cant reallocation of resources is warranted by developments in technology or in the broader economic environment.

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 …rm-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 di¢cult, 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 di¤erences 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 speci…cations used here, we …rst 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 …rm i in year t, n_{it} log employment, k_{it} log capital stock and α_t representing a year-speci…c intercept. Of the error components, η_i is an unobserved …rm-speci…c e¤ect, 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 ($E[x_{i1}e_{it}] = E[x_{i1}m_{it}] = 0$ for $t = 2, ..., T$) yields the following moment conditions

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

for $s \geq 2$ when $w_{it} \sim MA(0)$, and for $s \geq 3$ 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 $E[\Delta n_{it}\eta_i^*] = E[\Delta k_{it}\eta_i^*] = E[\Delta r_{it}\eta_i^*] = 0$ and that the initial conditions satisfy $E[\Delta y_{i2}\eta_i^*] = 0$, then we obtain the additional moment conditions

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

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).

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

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 …rms in both countries. Our samples of R&D performing …rms contain data on more than 200 …rms in each country, comprising essentially all the large manufacturing …rms that report R&D expenditures in both cases. For UK …rms, 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 …rms in Germany, limiting the analysis to public, quoted companies would be much less representative and therefore less comparable than to include large private 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 …rms 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 …rms, the accounting information was obtained from worldwide consolidated accounts.[17] Wherever possible we also used data from worldwide consolidated accounts for German …rms. 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 …rms in Germany or the UK. This is intentional, since these …rms are less likely to be impacted by the host country's …nancing 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

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

[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 …rms, with intra-group transactions netted out.

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 …rms 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 …rms in 1987, when there were further signi…cant changes to accounting standards that make comparability to earlier years problematic.

Finally we note that the accounting de…nitions of R&D used in Britain and Germany were both based on the Frascati manual classi…cation and hence very similar during these periods, as were the tax treatments, so that companies had 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 ‡ow measures of R&D and investment expenditures. For UK …rms we considered two measures of investment, that either include or exclude …xed capital acquired through takeovers.[18] Stocks of …xed capital and accumulated R&D were calculated from the ‡ow 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 …rms that perform R&D in the two countries. The size distribution of these …rms, 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. Pro…tability as indicated by the ratio of cash ‡ow plus expensed R&D to capital is also found to be very similar in the two samples. The striking di¤erence concerns the ratio of R&D expenditure to sales, which is found to be twice as high on average in our sample of German …rms. We will study these di¤erences in more detail in the next section. See also Bond, Harho¤ and Van Reenen (1999) for more details on the descriptive statistics.

The main …nding 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 di¤erences

[18] The German investment data excludes such acquisitions of …xed capital, which is a less signi…cant factor for German companies.

are also apparent in the …nancing of BERD - German …rms rely strongly on their own domestic …nancial resources, while UK …rms receive a large share of BERD …nancing 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 O¢ce are more than three times more frequent than the corresponding number of UK applications. Both in terms of GDP and population, the countries di¤er[19] by factors of 48.7% (GDP) and 39.8% (population).[20] While these …gures may also re‡ect export intensity (international patent applications are typically sought for products that are marketed abroad), they underline that these two countries di¤er dramatically with respect to standard technology and innovation indicators.

6. Results

6.1. R&D Expenditures

In Table 3, we consider the di¤erences in R&D intensities by industry. With only one notable exception (machinery, data processing and o¢ce equipment), the average 1991 R&D intensity in German …rms is larger than the corresponding …gure for UK …rms. Since size di¤erences between the two samples may mask the true underlying di¤erences, 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 …rms. We used separate industry dummy variables for each country and included …ve size group variables and time dummy variables for each year. In eight out of twelve industries, the R&D intensities of German …rms are signi…cantly larger than those of the corresponding UK …rms. In three industries no signi…cant di¤erence can be detected, and only in machinery, data processing and computers do we …nd an industry in which the UK R&D intensity is signi…cantly higher. Thus, the aggregate picture is not just a function of national industry composition (as one might suspect), but mostly one of …rm-level di¤erences 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 de…nition which has been in use for more than 40 years. Therefore, we do not expect major discrepancies to arise from di¤erent de…nitions of R&D.

[19] Germany relative to the UK.

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

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 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 misspecification; 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

[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.

by participants, and that consequently the British …rms that do engage in R&D are a self-selected group where …nancing constraints tend to be less binding.

7. Conclusions and Further Research

Di¤erences in the relationship between industry and …nance in Britain and Germany have long attracted the interest of economic historians and commentators. An in‡uential view suggests that Britain's …nancial 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 …rms to di¤er by a considerable margin. These di¤erences 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 brie‡y . On the supply side, the overall scienti…c infrastructure in a country can be of relevance, since private …rms do not develop R&D opportunities from …rst principles, but from scienti…c foundations developed on in public-sector research institutions and universities. On the demand side, the nexus between corporate governance, corporate …nance 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 …rms 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 di¤erences 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 …nancial system. However, all of these arguments appear to imply that the required rate of return to R&D actually undertaken by UK …rms may be higher than for corresponding German …rms which we …nd con…rmed in our test. To test this hypothesis even more precisely, it would be ideal to have a structural model of R&D and pro…tability in which the required rate of return

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

is estimated directly. In this paper, we make a first step towards such an assessment. Thus, the results 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 …rms from two major sources: …nancial accounts data (balance sheets and pro…t and loss accounts) from Hoppenstedt, and R&D expenditure data collected from the Bundesanzeiger, the o¢cial 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 …nancial statements. Thus starting in the …scal year of 1987, all Gesellschaften mit beschränkter Haftung (GmbHs, limited liability corporations) and Aktiengesellschaften (AGs, stock-based corporations) had to submit their annual …nancial statements to the Commercial Register. Only the larger …rms have to have their statements audited, smaller ones need not submit a statement of pro…ts and losses, and the balance sheet can be abbreviated signi…cantly. Medium-sized and large …rms are required to publish their statements in the Bundesanzeiger. The size requirements are satis…ed 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 …rms to comment on their R&D activities (§289 Handelsgesetzbuch, para 2). However, there is no legal speci…cation as to the format of R&D reporting. About 90 percent of the …rms 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 de‡ator does not a¤ect 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 …rst 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.

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