

Investment, R&D and Financial Constraints in Britain and Germany

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ABSTRACT. – This paper tests for the importance of cash flow on investment in fixed capital and R&D using firm-level panel data in two countries between 1985 and 1994. For German firms, cash flow is not informative in simple econometric models of fixed investment or R&D. In identical specifications for British firms, cash flow is informative about investment, although not about the level of R&D spending conditional on the R&D participation decision. In the UK, we also find that investment is less sensitive to cash flow for R&D-performing firms, and that cash flow predicts whether firms perform R&D or not. We confirm that these differences do not simply reflect a greater role for current cash flow in forecasting future sales. 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.

Investissement, R&D et contraintes financières au Royaume-Uni et en Allemagne

RÉSUMÉ. – Ce papier étudie l'effet du cash-flow sur l'investissement en capital fixe et en R&D à partir de données individuelles d'entreprises couvrant deux pays entre 1985 et 1994. Pour les firmes allemandes, le cash-flow n'apparaît pas significatif dans des modèles économétriques simples d'investissement en capital fixe ou en R&D. À partir de spécifications identiques, les estimations pour les firmes du Royaume-Uni montrent un effet significatif du cash-flow sur l'investissement mais pas sur le niveau des dépenses de R&D conditionnellement à la décision d'entreprendre de la R&D. Au Royaume-Uni, nous trouvons également que l'investissement est moins sensible au cash-flow pour les firmes faisant de la R&D et que le cash-flow influence la décision de faire ou non de la R&D. Nous confirmons que ces différences ne reflètent pas simplement un effet plus important du cash-flow courant comme prédicteur des ventes futures. Ces résultats suggèrent que les contraintes financières sont plus significatives au Royaume-Uni, qu'elles affectent la décision d'entreprendre de la R&D plutôt que le niveau des dépenses de R&D des participants, et que par conséquent, les firmes qui entreprennent de la R&D sont un groupe « auto sélectionné » pour lequel les contraintes financières tendent à être moins importantes.

Further results are available in the Working Paper version (BOND et al, 2003). We would like to thank Charles Calomiris, Jason Cummins, Bronwyn Hall, Charles Himmelberg, Glenn Hubbard, Charles Hulten, Tor Jakob Klette, Jacques Mairesse, Colin Mayer, two anonymous referees and participants in seminars at CEMFI, Columbia, Essex, LSE, NYU, Oxford, Paris, SOAS and Toulouse for helpful comments. Financial support from the Anglo-German Foundation and the ESRC is gratefully acknowledged. The usual disclaimer applies.

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1 Introduction

Are financial constraints a significant determinant of company investment activities? Numerous papers have addressed this question in the last decade.¹ This paper is novel in two principal respects. First, we investigate whether the impact of financial variables differs between firms in Britain and Germany. Second, we investigate whether the impact of financial variables differs between investment in fixed capital and investment in research and development (R&D).² ALFRED MARSHALL (1919, p.347) was neither the first, nor the last, to draw critical comparisons between the system of finance for innovation in Britain relative to that in Germany. Despite this interest there have been no systematic attempts to exploit firm level information on R&D investment and cash flow to identify any differences in the importance of liquidity constraints across these two nations.

Testing for financial constraints is intrinsically difficult. Financial variables such as cash flow contain information about expected future profitability which may be relevant for investment decisions even under the null hypothesis of perfect capital markets. Recent econometric tests have relied on finding differential sensitivity to cash flow between sub-samples of firms that are thought to be differentially affected by financial constraints *a priori*; and/or on structural econometric models which control for the influence of expected profitability under particular, usually highly restrictive, assumptions. There are at least two major problems with these methodologies. First, the allocation of firms to 'constrained' and 'unconstrained' regimes is often based on outcomes which, at least in part, are chosen endogenously by firms (e.g. dividend payments, employment size, corporate structure). Second, as KAPLAN AND ZINGALES (1997) have forcefully noted, even results based on structural models (e.g. Q models, Euler equations) have generally found some sensitivity to cash flow even for the sub-samples of supposedly 'unconstrained' firms. At the same time, recent evidence of lumpy and irreversible adjustment has cast doubt on the specification of most existing structural models.³

Companies in Britain and Germany operate under strikingly different financial systems. To the extent that financial constraints on investment expenditures result from a cost premium for external sources of finance, these national differences may be associated with a difference in the significance of financial constraints. This cost premium could reflect asymmetric information and conflicts of interest between shareholders, managers and suppliers of outside finance. Share ownership in Germany tends to be more concentrated than in Britain, which may mitigate asymmetric information and conflicts of interest between shareholders and managers. Bank representation on supervisory boards and long-term repeated relationships between banks and firms in Germany may mitigate asymmetric information between lenders and borrowers. Large German firms are more likely to remain

1 See SCHIANTARELLI (1996) and HUBBARD (1998) for surveys.

2 There have been some previous studies investigating financing constraints and R&D (see HALL (2002) for a survey). HALL (1992), HIMMELBERG and PETERSON (1994) and HAO and JAFFE (1993) focus on the US, whilst HARHOFF (1998) uses German data. MULKAY et al. (2001) compare France and the US, whilst HALL et al. (1999) present comparative results for France, Japan and the US. BHAGAT and WELCH (1995) find larger cash flow effects on R&D for British and US firms than for other G7 countries.

3 See CABALLERO (1999) for a review.

unquoted, hostile takeovers are extremely rare, and dividend payout ratios tend to be both lower and less rigid in German firms than in British firms.⁴ Many economic historians have suggested that Britain's financial system may be less conducive to long-term investment, and linked this to Britain's relative economic decline in the 20th Century.⁵ If these differences between national financial systems are truly exogenous and related to the impact of financial constraints, this variation offers a potentially compelling source of identification.

Why look at R&D as well as fixed investment? There are good reasons to believe that some types of investment are more likely to be subject to financial constraints than others. Investments in intangible assets tend to be both riskier and harder to collateralize than investment in fixed assets; they may therefore be more prone to financing constraints. In addition, the very act of seeking outside support for an R&D project could leak information to rivals and therefore reduce the prospective value of innovation. The disappointing growth of aggregate R&D spending in Britain over the last twenty years, compared to aggregate R&D spending in other OECD countries (see Section 2), is often blamed on problems in financing R&D investment.

A small literature has emerged which does suggest that company R&D spending is sensitive to cash flow, but the results are often weak. This is unsurprising. Two key features of R&D investment are that establishing an R&D programme involves significant sunk costs, and large fluctuations in the level of spending in existing research programmes are very costly.⁶ Financial constraints, if they are significant at all, may manifest themselves more in the decision to set up R&D facilities, rather than in decisions about yearly levels of spending in existing research programmes. We therefore consider the R&D "participation" decision, as well as the level of R&D spending by those companies that do engage in R&D. We also consider the relationship between fixed investment and cash flow separately for R&D performing and non-R&D performing companies. In each case we believe that the contrast between British firms and German firms is likely to be informative. For example, if the UK financial system makes it more expensive for firms to raise external finance for R&D investment, those firms that do engage in R&D may consist predominantly of firms who are confident that they can finance their R&D commitments from internal sources.⁷ In this case financial constraints would tend not to be binding for these companies, so the fixed investment of R&D performing firms may display *lower* sensitivity to cash flow than the fixed investment of non-R&D performing firms in Britain. However if financial constraints are not significant for German companies, we should find no cash flow sensitivity in the investment behaviour of either the R&D performing firms or the non-R&D performing firms in Germany.

The plan of the paper is as follows. In Section 2 we set the scene by briefly reviewing aggregate trends in fixed investment and R&D in Britain and Germany, and we describe the firm level datasets that we have compiled and used in our analysis. Section 3 outlines some simple econometric models of fixed investment and R&D which we use in this comparison. Section 4 contains the main empirical

4 See EDWARDS and FISCHER (1994) for evidence on share ownership, FRANKS and MAYER (1995) for evidence on takeovers, and CORREIA DA SILVA (1996) for evidence on dividends.

5 See GERSCHENKRON (1968) for a classical exposition or HUTTON (1995) for a more recent re-statement of this position.

6 Around sixty percent of R&D spending goes on the wages of R&D personnel. These are generally highly skilled workers, for whom there are large hiring, firing and training costs.

7 In other words, having 'deep pockets' may be an important consideration in the R&D participation decision (SCHUMPETER, 1942).

results, where we first examine fixed investment and R&D equations for R&D performing firms in both countries. We then estimate fixed investment equations for samples which pool together both R&D and non-R&D performing firms and test whether there is a differential sensitivity to cash flow between R&D performers and non-R&D performers. Section 5 considers a series of potential criticisms concerning the interpretation of the cash flow variable, estimates of the R&D participation decision, and measurement issues. Section 6 offers some concluding comments.

In short, our preferred specifications show *sensitivity of fixed investment to cash flow for our sample of British companies but not for our sample of German companies. The level of R&D spending by R&D performers is not sensitive to cash flow in either country. Within Britain there is greater sensitivity of fixed investment to cash flow for non-R&D performing companies than for R&D performing companies, and the R&D performing companies are significantly more profitable. Within Germany, we do not find these differences.* These findings are robust to a variety of alternative empirical specifications, and are not accounted for by other leading explanations of the cash flow effects. This evidence is consistent with the hypothesis that British firms face significant financial constraints, and suggests that the British financial system may discourage some companies from engaging in R&D.

2 Aggregate Trends and Company Datasets

The company datasets for the two countries are obtained from different sources. For the UK the data is drawn from the Datastream on-line service which covers all companies quoted on the UK stock market. R&D data is available for some companies since the early 1970s, but for these companies R&D disclosure was completely voluntary. Changes to the accounting conventions governing R&D disclosure after 1985 mean that a representative sample is only available in later years. For Germany changes in disclosure requirements took effect from 1987 and we use R&D information from the *Bundesanzeiger* supplemented by other sources of accounting data to construct the firm level dataset. This includes both quoted and unquoted AGs (stock companies) and GmbHs (limited liability corporations), which is important in the German context where many large R&D performing firms are not quoted on the stock market.⁸ For each country, we obtain two samples. The first includes essentially all the large firms who report R&D expenditures. The second sample also includes firms who did not report R&D, and for which we were able to verify that they were not performing R&D according to standard definitions. The Data Appendix has a full description of the construction of both databases.

We attempt to use variables that are comparable across countries, even though the national accounting definitions are not precisely the same. The main variables we

⁸ Although we have two more years of data for the UK (1985 and 1986) than Germany there are fewer British firms in the pre-1989 period. Thus the overall sample sizes are roughly the same across the two countries which is an advantage when making inferences based on common significance levels.

use are flows of fixed investment, R&D investment, sales, gross operating profits, and cash flow. Investment spending is obtained from the sources and uses of funds account, and not inferred from changes in the balance sheet. We use real sales as a proxy for output. A measure of the stock of capital at current replacement cost was estimated from the flow data on investment using a standard perpetual inventory method, in a similar way for each sample (see Data Appendix for more details).

Before describing the firm level data in more detail, we present some aggregate evidence on fixed investment and R&D in the UK and Germany.⁹ Table 1a considers total gross fixed capital formation (GFCF) as a share of GDP since 1960. The top row shows clearly that Germany invested more of its GDP throughout the period 1960-1993. The second row excludes housing investment. This accounts for part of the difference between the countries, although not all of it. The final row considers only machinery and equipment investment, which narrows the gap further, although Germany still invests more in the later period.

TABLE 1A
Fixed Investment as % of GDP

	1960-93	1960-93	1960-79	1960-79	1980-93	1980-93
	UK	GER	UK	GER	UK	GER
Total GFCF	18.2	22.4	18.6	23.7	17.4	20.4
Total GFCF (excl. housing)	14.4	15.9	14.8	16.7	13.7	14.5
Machinery and Equipment	8.4	8.7	8.7	8.7	8.0	8.6

Source: OECD Historical Statistics (1995)
GFCF = Gross Fixed Capital Formation

TABLE 1B
Business Enterprise R&D as % 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/DSTI ANBERD (1995)

TABLE 1C
Business Enterprise Research and Development (BERD)

	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)

9 See BOND and JENKINSON (1996) and VAN REENEN (1997) for more detailed international comparisons of aggregate investment and R&D respectively.

Table 1B considers R&D conducted by the business sector. The proportion of GDP devoted to Business Enterprise R&D (BERD) is higher in Germany than Britain, particularly in the more recent period. A final interesting fact is that domestic industry finances a much lower proportion of business R&D spending in the UK than in Germany (see Table 1C). The government finances a larger proportion of business enterprise R&D in the UK than in Germany (notably in military R&D). It is clear then that domestic, privately funded business R&D is considerably lower as a share of GDP in Britain than in Germany.

Turning now to the company data, Table 2 contains some simple descriptive statistics for the sample of firms who reported R&D in 1992.¹⁰ On average the British and German firms are of similar size (as measured by employment). Although the mean and median German firm is slightly larger, British firms are larger at the upper tail of the distribution. These are typically large firms, even for firms quoted on the UK Stock Exchange, a point that will be returned to in discussing the empirical results. In terms of sales, the British firms are slightly larger at the mean, but German firms are larger at the median. So in terms of size distribution, our two samples are reasonably well matched.

Investment comparisons are also made in Table 2. These are more difficult because the investment figures in German company accounts do not include fixed capital acquired through acquisitions of new subsidiary companies, whereas the British figures do. The 'wide definition' of UK investment (including acquisitions) suggests that British and German firms look very similar, even that UK firms invest a slightly higher share of their sales than their German counterparts at the mean. Excluding these acquisitions (the 'narrow definition') reveals that at both the mean and the median UK firms invest slightly less than German firms in direct purchases of fixed capital. This appears broadly consistent with the aggregate figures for machinery and equipment in Table 1A.¹¹

Typically, researchers using R&D data have constructed a cash flow measure that adds back R&D expenditures to conventionally measured cash flow, since most R&D costs are expensed in company accounts (e.g. HALL, 1992; HIMMELBERG and PETERSON, 1994). In Table 2 the ratio of this cash flow measure (i.e. gross of R&D) to the capital stock appears similar across the two countries. This disguises the fact that German firms have much higher R&D and somewhat lower cash flow net of R&D costs than UK firms. German corporations are much more R&D intensive than British companies. The average German company in the sample invests about 6% of sales in R&D, compared to 3% in the UK. The aggregate figures for this period are broadly consistent with this 'R&D gap'.¹² This consistency between the OECD data and the company accounting data is reassuring as although the accounting definitions of R&D in both countries are based on the

10 We report descriptives for a single year where we have a large cross section of firms in both countries. Very similar results are obtained for other years.

11 The narrow measure is more comparable to the aggregate figures, since one firm acquiring capital from another does not raise aggregate investment. The wide measure is probably more suitable for models of company investment, but this is not available for our German sample. In the empirical work reported below we use the wide definition of investment for the UK, where acquisitions are far more important than in Germany. In fact our UK results were similar whichever measure was used.

12 Aggregate industry-funded business R&D intensity is only about 60% higher in Germany (combining Tables 1B and 1C). The difference between the firm level and the aggregate figures arises mainly from the fact that the firm level figures refer to all R&D conducted worldwide, whereas the aggregate figures refer only to R&D conducted within a territorial area.

common Frascati manual definition, it may be that in practice German accountants take a wider view of what constitutes R&D.¹³ The 'R&D gap' between Britain and Germany is not simply due to a different industrial composition. Table A1 in the Data Appendix shows that, even within industries, British firms have lower R&D intensities. Neither can it be explained by tax incentives, as R&D was treated in a very similar manner for tax purposes in the two countries - during our sample periods, essentially all R&D could be expensed in computing corporate tax liabilities (see BLOOM et al, 1998, for more details of the tax treatment of R&D across countries).

Table 3 looks at the second samples we have constructed which include non-R&D performing firms. We focus here on industries with above median R&D intensity and label these 'high tech' industries. Comparing R&D and non-R&D firms across all sectors could be misleading because there is practically zero R&D in many industries. These 'high tech' sectors include some industries which are not typically thought of as being very science-based (such as motor vehicles), but our samples are not large enough to adopt a narrow classification.

The first striking feature of Table 3 is that R&D performing firms ('R&D>0') tend to be both larger and more profitable (as reflected in cash flow) in both countries. The difference in profitability is greater in Britain than Germany, however, and would be even greater if we measured cash flow gross of R&D costs. This suggests that cash flow may be a more important influence on the decision to set up an R&D programme (the R&D participation decision) in Britain than in Germany. It is also interesting to note that far more firms in our sample perform R&D in Germany (83%) than in the UK (53%).

As a final piece of preliminary analysis we consider a simple 'difference in differences' estimator. We are seeking to identify financial constraints from the correlation of differences in investment with differences in cash flow (to remove fixed effects). Recognizing that there may be a correlation for reasons unrelated to financial constraints we are also using the *difference* in this correlation across *different* countries. To illustrate this we pooled the data across all firms in both countries in all years and estimated a simple model where the rate of investment in fixed capital (I_t / K_{t-1}) was regressed against sales growth (Δy_t) and cash flow (C_t / K_{t-1}). The model is estimated in first differences and also includes a dummy for UK firms and for each time period. As expected, the results from this regression show that sales growth and cash flow are highly correlated with investment, and that British firms had slower growth in investment over this time period:

$$\Delta(I_t / K_{t-1}) = -.016(.006)UK + .256(.036)\Delta(C_t / K_{t-1}) + .053(.016)\Delta\Delta y_t \\ + \textit{time dummies} \\ (t = 1987, \dots, 1994; NT = 1687; \textit{robust standard errors in brackets; OLS}).$$

Of more interest, however, is an interaction term between cash flow and the UK dummy. This interaction term tests whether investment is more sensitive to cash

13 In the econometric specifications, controlling for unobserved firm-specific effects should help to mitigate the effects of this sort of measurement error.

flow in Britain than in Germany. Including this additional term generated the following results:

$$\Delta(I_t / K_{t-1}) = -.009(.006)UK + .137(.031)\Delta(C_t / K_{t-1}) + .388(.090)[UK * \Delta(C_t / K_{t-1})] + .049(.016)\Delta\Delta y_t + \text{time dummies}$$

Consistent with the view that British firms display more sensitivity to cash flow, the coefficient on this interaction term is positive and highly significant. This remains so when we add further interaction terms between the UK dummy and sales growth, and with the time dummies. On one level the paper is mainly concerned with probing the robustness of this interaction effect.

Despite the interest of these descriptives, one may have good reason to be sceptical about drawing any straightforward conclusions about financial constraints. We have done nothing here to control for a whole host of data and econometric problems. The next section confronts these problems in a more explicit econometric framework.

TABLE 2

Descriptive Statistics for R&D Performing Firms

		Mean	s.d.	Q25	Q50	Q75
<i>Employment</i> (1000s)	UK	16.134	38.551	0.645	2.142	10.153
	GER	16.538	47.823	0.800	2.422	7.570
<i>Sales</i> (£m)	UK	1.361	4.314	0.038	0.122	0.659
	GER	1.109	3.174	0.045	0.167	0.498
$(I/Y)_t - \text{narrow}$	UK	0.053	0.051	0.029	0.042	0.062
	$(I/Y)_t - \text{wide}$	UK	0.064	0.063	0.031	0.046
GER		0.058	0.054	0.031	0.049	0.066
I/K_{t-1}	UK	0.137	0.113	0.070	0.105	0.162
	GER	0.119	0.085	0.069	0.103	0.150
$(R\&D_t + \text{Cash}_t)/K_{t-1}$	UK	0.319	0.256	0.154	0.230	0.426
	GER	0.311	0.293	0.155	0.236	0.359
Cash_t/K_{t-1}	UK	0.222	0.181	0.110	0.173	0.281
	GER	0.171	0.171	0.077	0.126	0.207
$(R\&D/Y)_t$	UK	0.028	0.036	0.006	0.016	0.032
	GER	0.060	0.065	0.023	0.045	0.074

NOTE:- These are reported for the samples of R&D performing firms in 1992 (175 UK firms and 201 German firms).

TABLE 3
Descriptive Statistics for R&D and Non-R&D Firms in the High Tech Sectors

A. United Kingdom						
	R&D>0			R&D=0		
	Mean	S.D.	Median	Mean	S.D.	Median
Employment (1000s)	10.663	28.080	1.392	1.927	5.673	0.595
Sales (£m)	1.004	4.206	0.089	0.194	0.623	0.041
$(I/Y)_t$	0.065	0.061	0.049	0.130	0.311	0.037
I_t/K_{t-1}	0.145	0.124	0.112	0.142	0.148	0.098
$Cash_t/K_{t-1}$	0.254	0.212	0.193	0.163	0.170	0.125
Firms		131			94	
B. Germany						
	R&D>0			R&D=0		
	Mean	S.D.	Median	Mean	S.D.	Median
Employment (1000s)	18.600	55.60	2.552	1.051	5.311	0.457
Sales (£m)	1.182	3.410	0.161	0.066	0.096	0.023
$(I/Y)_t$	0.058	0.037	0.052	0.072	0.051	0.064
I_t/K_{t-1}	0.123	0.080	0.108	0.139	0.087	0.128
$Cash_t/K_{t-1}$	0.143	0.120	0.114	0.115	0.099	0.122
Firms		202			42	

NOTE:- These are reported for samples of firms in 1992 in the high tech sectors of both countries.

3 Models of Investment and R&D

In this paper the econometric specifications for fixed investment and R&D in the two countries are treated symmetrically. Different dynamics and costs of adjustment are allowed for (the estimated parameters can be different for British and German firms) but the specifications are identical for both countries. We also use the same basic framework to model both investment spending and R&D spending, although details of the specifications differ. This is primarily a matter of convenience. We want to compare common specifications across countries, rather than

search for the best specification of the investment and R&D equations in each country. Nevertheless the approach has some disadvantages, which are discussed in more detail below.

The basic framework we use is an error correction model, which specifies a long-run or 'target' level of the capital stock (or stock of accumulated R&D), but which allows a flexible specification of the adjustment dynamics to be estimated from the data. The main advantage of these models is that they are not rejected out of hand by the data, and the estimated models have reasonable long-run and short-run properties. This is in sharp contrast to more structural models such as Q models and Euler equations, which are often found to have the wrong signs on key explanatory variables or to imply implausibly slow speeds of adjustment.¹⁴ The main disadvantage of the error correction models is that the estimated dynamics compound influences from both capital adjustment and expectations-formation processes. Thus the finding of a significant coefficient on cash flow cannot be interpreted directly as evidence of financing constraints. We return to this issue in Section 5 and Appendix B, where we show that *differences* in the effect of cash flow between Britain and Germany cannot simply be explained by current cash flow being a better predictor of future sales. Furthermore, the significant cash flow effect in our R&D participation equation for UK firms is robust to the inclusion of a measure of expected future profitability based on analysts' earnings forecasts.

3.1 An error correction model of investment

The error correction model we consider specifies the long-run desired level of the capital stock as a log-linear function of output and the user cost of capital. Letting k_{it} denote the (natural) log of the desired capital stock for firm i in period t , y_{it} denote the log of output and j_{it} denote the log of the user cost of capital, we write the desired capital stock as

$$(3.1) \quad k_{it} = a + y_{it} - \sigma j_{it}.$$

In the absence of any adjustment costs or barriers to immediate adjustment, this would be the optimal capital stock for a profit maximizing firm with a constant returns to scale CES production function (cf. CABALLERO, ENGEL and HALTIWANGER (1995)). This formulation nests the possibility of a fixed capital-output ratio ($\sigma = 0$) and a Cobb-Douglas production function ($\sigma = 1$).¹⁵

In the presence of adjustment costs, for example, the actual capital stock will not adjust immediately to this target level. Recognizing that the adjustment process may be complex, we nest this expression for the long-run capital stock within a general autoregressive-distributed lag (ADL) dynamic regression model, and use a 'gene-

14 There is some debate over whether the Q model can be 'rescued' by using tax changes to generate instrumental variables for Q (see CUMMINS, HASSETT and HUBBARD, 1994, for example) or by measuring Q based on analysts' earnings forecasts rather than stock prices (see BOND and CUMMINS, 2001).

15 With $\sigma = 1$, equation (3.1) describes the optimum capital stock in the Cobb-Douglas case, whether or not there are constant returns to scale. With this qualification noted, we will nevertheless refer to a long-run unit elasticity with respect to output as a test of constant returns to scale in what follows.

ral-to-specific' specification search to let the data determine the relevant dynamics within our samples. We use an ADL(2,2) model parameterised in error correction form (cf. BEAN, 1981), which separates out short-run and long-run effects

$$(3.2) \quad \begin{aligned} \Delta k_{it} = & \alpha + \rho_1 \Delta k_{i,t-1} + \beta_0 \Delta y_{it} + \beta_1 \Delta y_{i,t-1} + \gamma_0 \Delta j_{it} + \gamma_1 \Delta j_{i,t-1} \\ & + \theta(k-y)_{i,t-2} + \phi y_{i,t-2} + \omega j_{i,t-2} + \varepsilon_{it}. \end{aligned}$$

Notice that the term in the (second) lagged level of output tests the restriction that the long-run elasticity of capital with respect to output is unity.

To implement this model using company panel data, we assume that variation in the user cost of capital can be controlled for using additive year-specific effects (μ_t) and firm-specific effects (η_i). To investigate whether financial variables have explanatory power for investment, we include current and lagged terms in the ratio of cash flow to the beginning-of-period capital stock ($C_{it}/K_{i,t-1}$). Finally we use the approximation $\Delta k_{it} \approx I_{it}/K_{i,t-1} - \delta_i$, where δ_i is the (possibly firm-specific) depreciation rate, subsumed into the unobserved firm-specific effects (η_i). Thus we obtain a model for the investment rate rather than the growth rate of the capital stock

$$(3.3) \quad \begin{aligned} \left(\frac{I_{it}}{K_{i,t-1}} \right) = & \mu_t + \rho_1 \left(\frac{I_{i,t-1}}{K_{i,t-2}} \right) + \beta_0 \Delta y_{it} + \beta_1 \Delta y_{i,t-1} + \theta(k-y)_{i,t-2} \\ & + \phi y_{i,t-2} + \psi_0 \left(\frac{C_{it}}{K_{i,t-1}} \right) + \psi_1 \left(\frac{C_{i,t-1}}{K_{i,t-2}} \right) + \eta_i + \varepsilon_{it}. \end{aligned}$$

We require $\theta < 0$ to be consistent with 'error correcting' behaviour (i.e. a capital stock above its desired level is associated with lower future investment), and $\phi = 0$ to be consistent with long-run constant returns to scale.

It is well known that significant coefficients on the cash flow variables in this type of model cannot be interpreted directly as evidence of financial constraints.¹⁶ In the presence of convex adjustment costs, for example, the current level of the capital stock would depend not just on current output and prices, as in equation (3.1), but also on the inherited level of the capital stock, and on expectations of future output and prices.¹⁷ To illustrate the implications as simply as possible, suppose that the desired capital stock in the absence of adjustment costs is proportional to output, and that the actual capital stock in the presence of adjustment costs is given by

$$k_{it} = \alpha k_{i,t-1} + \beta y_{it} + \gamma E_t [y_{i,t+1}]$$

where $E_t[y_{i,t+1}]$ denotes the expected value of $y_{i,t+1}$ given information in period t . Clearly, if expectations of future output depend on financial variables as well as

16 See, for example, FAZZARI, HUBBARD and PETERSEN (1988). For more recent contributions criticising the interpretation of cash flow in investment equations, see KAPLAN and ZINGALES (1997), GOMES (2001) and ABEL and EBERLY (2003).

17 See NICKELL (1978), chapter 11, for example.

past output, then these financial variables would be significant in a reduced form model of investment, even in the absence of financing constraints. For example, if

$$E_t [y_{i,t+1}] = \pi_0 y_{it} + \pi_1 y_{i,t-1} + \pi_2 \left(\frac{C_{it}}{K_{i,t-1}} \right) + \pi_3 \left(\frac{C_{i,t-1}}{K_{i,t-2}} \right)$$

then we obtain the reduced form model

$$k_{it} = \alpha k_{i,t-1} + (\beta + \gamma \pi_0) y_{it} + \gamma \pi_1 y_{i,t-1} + \gamma \pi_2 \left(\frac{C_{it}}{K_{i,t-1}} \right) + \gamma \pi_3 \left(\frac{C_{i,t-1}}{K_{i,t-2}} \right)$$

which illustrates how these models compound influences from the structural adjustment process (γ) and the expectations-formation process (the π coefficients).

Whilst this is clearly the case for reduced form models, a similar problem will affect any structural models that are not correctly specified. Many studies have therefore focused on differences in the coefficients on financial variables between different sub-samples of firms, where one sub-sample is considered more likely to be affected by financing constraints on *a priori* grounds.¹⁸ For this reason we will emphasize differences in the results on the cash flow terms between British firms and German firms, and between R&D firms and non-R&D firms in each country. However we will go one step beyond the common practice in the literature by investigating whether differences in the cash flow coefficients in the investment equations can be accounted for by differences in the ability of cash flow to predict future sales (i.e. by differences in the π coefficients in simple models of the processes generating real sales).

3.2 An error correction model of R&D

Our basic approach to modelling R&D spending parallels our approach to modelling investment spending, as outlined above. We view R&D spending as a flow which is adjusted to achieve some desired level of an underlying stock, in this case the stock of accumulated R&D or 'knowledge'. The knowledge stock (G_{it}) is given conceptually by $G_{it} = (1 - \delta_i^R) G_{i,t-1} + R_{it}$, where R_{it} is the current level of R&D spending and δ_i^R is the (possibly firm-specific) rate at which research capital depreciates. Parallel to equation (3.2), this would suggest an error correction model for R&D of the form

$$(3.4) \quad \Delta g_{it} = \alpha^R + \rho_1^R \Delta g_{i,t-1} + \beta_0^R \Delta y_{it} + \beta_1^R \Delta y_{i,t-1} + \gamma_0^R \Delta j_{it}^R + \gamma_1^R \Delta j_{i,t-1}^R + \theta^R (g - y)_{i,t-2} + \phi^R y_{i,t-2} + \omega^R j_{i,t-2}^R + \varepsilon_{it}^R$$

18 The basic idea is that if cash flow explains investment only because unobserved expectations of relevant future conditions are conditioned on cash flow, and both sub-samples have similar investment and expectations-formation processes, then similar coefficients on cash flow should be obtained for both sub-samples under the null of no financing constraints. For example, the coefficients $\gamma \pi_2$ and $\gamma \pi_3$ in the example above would then be common to different sub-samples.

where g_{it} is the log of the stock of accumulated R&D and j_{it}^R is the user cost of capital for R&D.

The main difference from the case of fixed investment, however, is that whilst company accounts contain some information on the value of the fixed capital stock, they contain no information on the value of the R&D capital stock. This need not be a serious problem if long time series are available on the R&D expenditure flows, but for both British and German companies the available series on R&D spending are generally short. For this reason we rely on a steady state approximation to 'measure' the stock of R&D capital, rather than trying to construct a direct estimate.

For a firm in steady state (at growth rate v_i) we have $G_{it} = (1+v_i)G_{i,t-1}$ so that

$$\begin{aligned} R_{it} &= (\delta_i^R + v_i)G_{i,t-1} \\ &= \left(\frac{\delta_i^R + v_i}{1 + v_i} \right) G_{it} \end{aligned}$$

and

$$r_{it} = \ln \left(\frac{\delta_i^R + v_i}{1 + v_i} \right) + g_{it}$$

where r_{it} is the log of R&D expenditure (cf. Bean, 1981). If this steady state approximation is reasonable, we can replace g_{it} in equation (3.4) by the observed r_{it} , provided we allow for a firm-specific intercept. In fact, our empirical specification is more general than this, and controls for some deviations of actual R&D spending from its steady state level by the inclusion of year dummies and the autoregressive-distributed lag dynamics. Thus, our error correction model for R&D takes the form:

$$\begin{aligned} \Delta r_{it} &= \mu_t^R + \rho_1^R \Delta r_{i,t-1} + \beta_0^R \Delta y_{it} + \beta_1^R \Delta y_{i,t-1} + \theta^R (r - y)_{i,t-2} \\ (3.5) \quad &+ \phi^R y_{i,t-2} + \psi_0^R \left(\frac{C_{it}}{K_{i,t-1}} \right) + \psi_1^R \left(\frac{C_{i,t-1}}{K_{i,t-2}} \right) + \eta_i^R + \varepsilon_{it}^R. \end{aligned}$$

As in the case of fixed investment, we require $\theta^R < 0$ for error correcting adjustment, and $\phi^R = 0$ for constant returns to scale.

We prefer this specification for R&D, but not for fixed investment. This is partly because of the availability of fixed capital stock data, partly because observations where investment is negative would be lost, and partly because the steady state approximation is less likely to be reasonable in the case of investment: the investment series are typically less smooth than the R&D series. It should also be noted that we compared this approach with one where we explicitly measured the stock of accumulated R&D capital using perpetual inventory procedures. We found that the latter approach did not yield sensible empirical results in the context of an error correction model.

3.3 Estimation

To estimate these dynamic regression models using panels containing many firms and a small number of time periods, we use a system GMM estimator developed by ARELLANO and BOVER (1995) and BLUNDELL and BOND (1998, 2000). This estimator controls for the presence of unobserved firm-specific effects and for the endogeneity of the current-dated explanatory variables. The system GMM estimator uses equations in first-differences, from which the firm-specific effects are eliminated by the transformation, and for which endogenous variables lagged two or more periods will be valid instruments provided there is no serial correlation in the time-varying component of the error terms. This is tested by examining tests for serial correlation in the first-differenced residuals (see ARELLANO and BOND, 1991). These differenced equations are combined with equations in levels, for which the instruments used must be orthogonal to the firm-specific effects. Obviously the level of the dependent variable must be correlated with the firm-specific effects, and we want to allow for the levels of all the explanatory variables to be potentially correlated with the firm-specific effects, so this rules out using the levels of any variables as instruments for the levels equations. However, BLUNDELL and BOND (1998, 2000) show that in autoregressive-distributed lag models, first-differences of the series can be uncorrelated with the firm-specific effects provided that the series have stationary means. We therefore experimented with lagged differences of the variables as instruments for the levels equations.

The precise instruments that we use are reported in the notes to the tables below. Essentially we use lags of all the firm-level variables in the model. Instrument validity was tested using a Sargan test of over-identifying restrictions, and by Difference Sargan comparisons to the GMM estimator which just uses the equations in first-differences.

4 Main Results

We begin by reporting the results of the investment equations in Table 4 and then discuss the R&D equations in Table 5. Column (1) in Table 4 contains the empirical results of estimating a version of equation (3.3), without the cash flow terms and imposing constant returns to scale, for our sample of UK R&D performing companies. It should be compared with column (4) which has an identically specified model for the German R&D performing companies. For both countries we find evidence of a correctly signed error-correction term (the capital-output ratio) which is significant at conventional levels. There is also some indication that the speed of adjustment is faster in Britain than in Germany. The output growth terms are positive and significant in both countries. Furthermore, the diagnostic tests appear satisfactory with no evidence of second order serial correlation in the first-differenced residuals or rejection of the overidentifying restrictions in either country.

We then consider adding cash flow terms to this basic specification. Notice that our preferred measure of cash flow for the R&D performing companies is cash flow

TABLE 4
Fixed Investment Models

	(1)	(2)	(3)	(4)	(5)	(6)
Dependent Variable: I_t/K_{t-1}						
		UK			Germany	
I_{t-1}/K_{t-2}	-0.153 <i>0.082</i>	-0.200 <i>0.084</i>	-0.200 <i>0.073</i>	0.057 <i>0.066</i>	0.010 <i>0.071</i>	0.010 <i>0.060</i>
Δy_t	0.204 <i>0.089</i>	0.179 <i>0.089</i>	0.179 <i>0.081</i>	0.152 <i>0.050</i>	0.150 <i>0.051</i>	0.149 <i>0.044</i>
Δy_{t-1}	0.149 <i>0.064</i>	0.103 <i>0.054</i>	0.103 <i>0.055</i>	0.135 <i>0.037</i>	0.123 <i>0.049</i>	0.122 <i>0.045</i>
C_t/K_{t-1}	-	0.001 <i>0.218</i>	-	-	-0.003 <i>0.109</i>	-
C_{t-1}/K_{t-2}	-	0.290 <i>0.142</i>	0.290 <i>0.103</i>	-	0.146 <i>0.095</i>	0.147 <i>0.100</i>
$(k-y)_{t-2}$	-0.187 <i>0.057</i>	-0.141 <i>0.052</i>	-0.142 <i>0.053</i>	-0.099 <i>0.041</i>	-0.085 <i>0.055</i>	-0.084 <i>0.053</i>
Sargan (p-value)	0.410	0.512	0.386	0.480	0.325	0.309
Cash Flow terms (p)	-	0.019	0.005	-	0.288	0.139
LM (1)	-3.937	-4.305	-4.289	-3.010	-3.171	-3.116
LM (2)	-0.282	-0.035	-0.034	-1.150	-1.286	-1.242
Observations	588	588	588	666	666	666
Firms	199	199	199	209	209	209

NOTES:- Asymptotically robust standard errors are reported below coefficients; estimation by system GMM using DPD98 package one-step results (Arellano and Bond, 1998); full set of time dummies included; 'Sargan' is a Sargan-Hansen test of the overidentifying restrictions (p-value reported); 'Cash Flow terms' is a Wald Test of the joint significance of the included cash flow terms (p-value reported); 'LM (k)' is the test statistic for the absence of k-th order serial correlation in the first-differenced residuals, distributed $N(0,1)$ under the null; in columns (1) and (4) instruments are $y_{t-2}, y_{t-3}, y_{t-4}, I_{t-2}/K_{t-3}, I_{t-3}/K_{t-4}, (k-y)_{t-2}, (k-y)_{t-3}$ in the differenced equations and $\Delta I_{t-1}/K_{t-2}, \Delta \Delta y_{t-1}$ in the levels equations; in columns (2), (3), (5) and (6) we also include $C_{t-2}/K_{t-3}, C_{t-3}/K_{t-4}$ in the differenced equations.

net of R&D expenditures. We found this measure to be more informative about the investment behaviour of British companies than cash flow gross of R&D costs.¹⁹ As we discuss further below, this is consistent with our view that most of the R&D budget is regarded as a pre-committed expenditure,²⁰ not sensitive to short run fluctuations in the firm's financial position, rather than as a potential source of finance for fixed investment.

Columns (2) and (5) include these cash flow terms. A clear difference emerges in these results insofar as the cash flow terms are jointly significant for our British sample but are insignificant at conventional levels for our German sample (see the Wald tests reported at the base of the columns).²¹ Relaxing the constant returns to scale assumption by including an additional term in the level of output was found to be unnecessary as the additional lagged output terms were insignificant in both

19 Neither measure was informative for German companies.

20 Evidence on the high adjustment costs of pre-committed R&D can be found in many papers including HAO and JAFFE (1993) and LACH and SCHANKERMAN (1989).

21 This pattern is consistent with the evidence presented in BOND et al (2003), using a smaller sample of German firms that are quoted on the stock market (publicly traded *Aktiengesellschaften*).

TABLE 5
R&D Models

	(1)	(2)	(3)	(4)
Dependent Variable: Δr_t				
	UK		Germany	
Δr_{t-1}	-0.178 <i>0.129</i>	-0.278 <i>0.101</i>	-0.107 <i>0.065</i>	-0.132 <i>0.060</i>
Δy_t	0.627 <i>0.214</i>	0.382 <i>0.240</i>	0.486 <i>0.169</i>	0.424 <i>0.186</i>
Δy_{t-1}	0.633 <i>0.314</i>	0.561 <i>0.220</i>	0.173 <i>0.063</i>	0.138 <i>0.069</i>
C_t/K_{t-1}	-	0.272 <i>0.614</i>	-	0.269 <i>0.216</i>
C_{t-1}/K_{t-2}	-	0.143 <i>0.539</i>	-	-0.049 <i>0.184</i>
$(r-y)_{t-2}$	-0.132 <i>0.054</i>	-0.159 <i>0.044</i>	-0.070 <i>0.047</i>	-0.064 <i>0.039</i>
Sargan (p)	0.44	0.865	0.82	0.827
Cash Flow terms (p)		0.347		0.210
LM (1)	-2.52	-2.596	-3.70	-3.73
LM (2)	-1.83	-2.396	0.550	0.500
Observations	389	389	666	666
Firms	159	159	209	209

NOTES:- Asymptotically robust standard errors are reported below the coefficients; estimation by system GMM using DPD98 package one-step results; full set of time dummies included; 'Sargan' is a Sargan-Hansen test of the overidentifying restrictions (p-value reported); 'Cash Flow terms' is a Wald Test of the joint significance of the included cash flow terms (p-value reported); 'LM (k)' is the test statistic for the absence of k-th order serial correlation in the first-differenced residuals, distributed $N(0,1)$ under the null; in column (1) instruments are y_{t-3} to y_{t-6} and r_{t-3} to r_{t-6} in the differenced equations and Δy_{t-2} and Δr_{t-2} in the levels equations; in column (2) we also include C_{t-3}/K_{t-4} to C_{t-6}/K_{t-7} in the differenced equations and $\Delta(C_{t-2}/K_{t-3})$ in the levels equations; in column (3) we use y_{t-2} to y_{t-6} and r_{t-2} to r_{t-6} , in the differenced equations and Δy_{t-1} and Δr_{t-1} in the levels equations; in column (4) we also include C_{t-2}/K_{t-3} to C_{t-6}/K_{t-7} in the differenced equations and $\Delta(C_{t-1}/K_{t-2})$ in the levels equations.

countries.²² Finally in columns (3) and (6) we drop the insignificant current cash flow variable. Again, the included lagged cash flow term is highly significant for our sample of UK firms, but not significant at conventional levels for our sample of German firms.²³

Turning to the R&D results presented in Table 5, the error correction terms are again correctly signed, but determined with less precision in Germany than in the UK. Another important difference is that, unlike the fixed investment equations,

22 When added to the specifications in columns (2) and (5), the estimated coefficients (*standard errors*) on the second lag of output were 0.007(0.013) in the UK and 0.011(0.010) in Germany. In these more general specifications, cash flow was again an informative indicator for investment in our UK firms, but not in our German firms.

23 We also experimented with including longer lags of cash flow but these were insignificant in both countries. For example, added to the most general UK specification of column (2), C_{t-2}/K_{t-3} had a coefficient of 0.037 with a standard error of 0.063.

cash flow is insignificant in both the British and German samples. Again, the results reported here use cash flow net of R&D costs. Similar results were found in the R&D equations for cash flow measured gross of R&D expenses.²⁴ A natural interpretation of this is that transitory cash flow fluctuations are unlikely to have an important impact on a firm's R&D expenditures, which are largely committed somehow in advance. The diagnostics revealed evidence of more persistent serial correlation in the residuals in the UK R&D equations implying that it is necessary to use longer lags of the instruments than in Table 4.²⁵ This is why there are fewer observations for the UK sample in this table as we lose one extra cross section of data. We experimented with including lagged R&D in the investment equations and lagged investment in the R&D equations, along the lines of LACH and SCHANKERMAN (1989), but found these variables to be insignificant.²⁶

These results are provocative but open to the criticism that we have focused only on R&D performing firms. It seems likely that the R&D performers are a self-selected group whose behaviour may be systematically different from other firms. To address this issue we collected additional data on non-R&D performing companies in both countries. Comparing these groups of firms is somewhat hazardous as many of the non-R&D firms are located in low-tech industries where there is simply no opportunity for any firm to do R&D. To avoid merely picking up differences in industrial structure, rather than differences between R&D and non-R&D firms, we focus here on firms in 'high tech' industries defined to be those sectors with an above average ratio of R&D to sales.²⁷ We re-estimated the fixed investment equations on this sample and the results are reported in Table 6.²⁸

Again we observe that cash flow is significant in the UK investment equation (column 1), but not in the German investment equation (column 4). Column (2) then allows the cash flow effects to be different for the firms performing any R&D compared to the firms who do not perform R&D (R&D=0). Interestingly, there appears to be evidence that cash flow has a greater impact on investment for the non-R&D performers than for the R&D performers in our UK sample.²⁹ Moving to a more parsimonious model in column (3) where we drop some of the insignificant terms confirms that this difference is indeed statistically significant. In Germany, by contrast, cash flow remains insignificant for all samples that we examine (although

24 We were concerned that although adding R&D back to measured cash flow (to obtain gross cash flow) may be theoretically more satisfactory, it could generate a strong positive endogeneity bias as R&D would appear on both left and right hand sides of the estimated equation.

25 If we ignore this misspecification problem and use the invalid t-2 instruments, the cash flow terms become jointly significant in the UK equation (p-value of 0.03) and the error correction term appears to be insignificant (0.015 (0.043)). In Germany if we drop the t-2 instruments, the cash flow terms remain insignificant (p-value of 0.50).

26 Other UK studies find mixed results in this regard. Neither TOIVANEN and STONEMAN (1998) nor NICKELL and NICOLITSAS (1996) find significant evidence that firm-level R&D affects subsequent investment, as LACH and SCHANKERMAN (1989) did. The former paper claims to identify some effect of lagged investment on R&D, however, and the latter paper finds evidence for an impact of industry-level R&D on firm-level investment.

27 Industries were chosen based on median R&D to sales intensity. The 'high tech' sample includes aircraft, chemicals, drugs, electrical machinery, non-electrical machinery, vehicles, office and computing equipment, transport equipment, petroleum refineries and products, rubber and plastics, radio and TV equipment and instruments.

28 Since some of these firms do no R&D we cannot, of course, estimate the R&D equations.

29 Notice that we do not include the R&D status interaction with cash flow in the instrument set because of the potential endogeneity of R&D status. The results are little changed, however, were we to include it. For example, including the interaction term in column (3) then gives a linear cash flow coefficient (*standard error*) of 0.245(0.102) and a coefficient (*standard error*) on the interaction of cash flow and non-R&D status of 0.460(0.144).

TABLE 6

Fixed Investment Equations - R&D and Non-R&D Performers in High Tech Industries

	(1)	(2)	(3)	(4)	(5)	(6)
Dependent Variable: I_t/K_{t-1}						
		UK		Germany		
I_{t-1}/K_{t-2}	0.0002 <i>0.070</i>	-0.007 <i>0.054</i>	-0.037 <i>0.067</i>	0.072 <i>0.072</i>	0.068 <i>0.071</i>	0.092 <i>0.046</i>
Δy_t	0.271 <i>0.095</i>	0.266 <i>0.101</i>	0.292 <i>0.099</i>	0.141 <i>0.062</i>	0.156 <i>0.078</i>	0.012 <i>0.060</i>
Δy_{t-1}	0.031 <i>0.088</i>	0.049 <i>0.086</i>	0.054 <i>0.093</i>	0.108 <i>0.054</i>	0.114 <i>0.057</i>	0.086 <i>0.024</i>
C_t/K_{t-1}	0.311 <i>0.159</i>	0.079 <i>0.176</i>	- <i>0.183</i>	-0.231 <i>0.180</i>	-0.211 <i>0.160</i>	-
C_{t-1}/K_{t-2}	0.146 <i>0.135</i>	0.188 <i>0.153</i>	0.183 <i>0.107</i>	0.060 <i>0.135</i>	0.043 <i>0.140</i>	-
(R&D=0)* C_t/K_{t-1}	-	0.674 <i>0.298</i>	0.662 <i>0.221</i>	-	-0.191 <i>0.478</i>	-
(R&D=0)* C_{t-1}/K_{t-2}	-	-0.177 <i>0.340</i>	-	-	0.347 <i>0.564</i>	-
$(k-y)_{t-2}$	-0.072 <i>0.069</i>	-0.084 <i>0.069</i>	-0.089 <i>0.077</i>	-0.064 <i>0.053</i>	-0.066 <i>0.051</i>	-0.061 <i>0.023</i>
Sargan (p)	0.555	0.833	0.827	0.704	0.663	0.578
Cash Flow -linear (p)	0.002	0.170	0.087	0.214	0.306	-
Cash Flow -interaction (p)	-	0.051	0.003	-	0.828	-
LM (1)	-4.474	-4.678	-4.277	-4.715	-4.833	-4.017
LM (2)	0.576	0.996	0.665	-1.526	-1.569	-1.493
Observations	1107	1107	1107	800	800	800
Firms	263	263	263	246	246	246

NOTES:- Asymptotically robust standard errors are reported below coefficients; UK results are in columns (1) - (3), German results in columns (4) - (6); estimation by system GMM using DPD98 package one-step results; full set of time dummies included; instrument set is the same as in Table 4, columns (2),(3),(5) and (6). R&D=0 indicates that the firm does not perform any R&D.

the sum of the point estimates on cash flow are larger for the non-R&D performers). The preferred model for Germany is that in column (6) where the cash flow terms are excluded altogether.³⁰

Our interpretation of these results is that our sample of British firms are subject to significant financial constraints whereas our German firms appear not to be. Although clear from the basic investment equations, this difference is not revealed in the R&D equations because the main point at which financial constraints bite is in the decision to engage in R&D, rather than how much to spend in existing R&D programmes. The R&D performing firms in the UK are a self-selected group who choose to make long term commitments to R&D programmes, partly on the

30 In Britain the Wald test of the joint significance of the two terms dropped in moving from column (2) to column (3) is $\chi^2(2) = 0.906$ (p-value of 0.64). In Germany the Wald test for all four cash flow terms dropped between columns (5) and (6) is $\chi^2(4) = 7.320$ (p-value of 0.12).

basis that they do not expect to be seriously affected by financial constraints - this explains why cash flow tends to matter less for these firms' investment decisions than for other UK companies.

5 Further Investigations

An implication of our interpretation that cash flow affects R&D participation, rather than R&D spending conditional on participation, is that a firm is more likely to set up an R&D programme if it has (and expects to have) strong cash flow. It is difficult to test this hypothesis directly as very few firms are observed to change R&D status in our dataset. This is partially because we concentrate on large firms and partially because transitions between R&D status come through company entry and exit which we do not explicitly model.³¹ The infrequency of transitions from R&D to non-R&D status is nevertheless consistent with our view that engaging in R&D implies a long term commitment to financing an inflexible R&D budget.

Table 7 offers some evidence on this issue by reporting a probit model for R&D status as a function of lagged cash flow, lagged real sales (to proxy firm size) and industry dummies. In order not to inflate the precision of the estimates we do this for one cross section in 1992, where we have a large number of firms "similar patterns were found using other years".

Firm size is positively correlated with the probability of conducting R&D in both countries, as one would expect. More importantly, lagged cash flow is strongly and significantly correlated with whether a firm performs any R&D in Britain, but not in Germany.³² For our British sample it is also possible to include financial structure variables available on the balance sheet. The lagged ratio of debt to capital has a significantly negative coefficient when added to the probit model for the UK (-1.548 with a standard error of 0.514) but the cash flow term remains significantly positive (1.366 with a standard error of 0.576).

These results are consistent with our view that the UK firms that are more likely to be affected by financing constraints (i.e. those with low profitability and/or high debt) are less likely to participate in R&D. Of course, they may also reflect reverse causation, with high profitability being the result of successful R&D. But if this is the case it is puzzling that a similar relationship is not observed in our German sample.

Our interpretation is open to a large number of objections, some of which are addressed in BOND et al (2003). We examine whether differences in the effect of cash flow on fixed investment between R&D and non-R&D firms in Britain might just reflect differences in firm size. We also explore whether differences in the effect of cash flow on investment between British and German firms could be explained by cash flow providing a better proxy for demand expectations in Britain by exami-

31 We are implicitly assuming that the inclusion of fixed effects is sufficient to control for selectivity problems.

32 Evaluating the marginal effect of cash flow on the probability of performing R&D at sample means reinforces this conclusion. The marginal effect is 0.404 in Britain and 0.000008 in Germany.

TABLE 7

Probits for R&D Status in High Tech Industries

Dependent Variable: one if R&D>0 and zero otherwise	(1)	(2)
	UK	Germany
C_{t-1}/K_{t-2}	1.098 <i>0.535</i>	0.068 <i>0.974</i>
y_{t-1}	0.477 <i>0.178</i>	3.853 <i>1.119</i>
Industry dummies	yes	yes
Log L	-118.02	-77.18
Pseudo R ²	0.184	0.223
Observations	212	218
Firms	212	218

NOTES:—The coefficients and standard errors are taken from probit ML estimates of whether a firm performed R&D in 1992 or not. These are estimated for firms in R&D intensive sectors only. 58.2% of this sample of UK firms reported positive R&D in 1992, compared to 82.8% in Germany.

ning VARs of sales (and sales growth) as functions of distributed lags of cash flow. We also examine issues of industry composition by analysing the heterogeneity of the cash flow coefficient across industries. We show that none of these alternatives provides a convincing explanation, and that our results are also robust to a series of measurement issues.

6 Conclusions

This paper has examined the cash flow sensitivity of investment in both fixed capital and R&D, for samples of large firms in Britain and Germany. We argued that the well known institutional differences across the financial systems in these two countries offer a powerful test for the importance of financial constraints for investment in market economies. Despite the common belief that financial constraints cause British firms to invest less than their German counterparts, particularly in long-term investments like R&D, there is almost no micro-econometric evidence in this area. We have assembled data for essentially all the firms who report R&D in Britain and Germany since the mid 1980s, and tested the hypothesis that the availability of internal finance is more important in explaining investment for our sample of British firms than for our sample of German firms during this period.

Our results are easily summarised. Cash flow matters for the fixed investment of British firms, but not German firms. In neither country does cash flow appear to be important for the flow of R&D spending. In Britain cash flow matters more for the fixed investment decisions of non-R&D firms than it does for R&D firms, and there is a significant correlation between cash flow and whether or not a firm performs R&D. We interpret this set of results as suggesting that our sample of UK firms face a higher wedge between the costs of external and internal finance than

our sample of German firms. Thus they are more cautious about undertaking long term commitments to R&D programmes than their German counterparts, and those British firms that choose to do R&D are a self-selected sample with 'deep pockets', for whom financial constraints are less likely to be binding. Our basic findings held up when subjected to a battery of robustness tests including explicit estimation of forecasting equations for sales, and consideration of differences in firm size and industry composition.

There are of course numerous problems and criticisms still remaining. Our results apply only to samples of larger firms in a specific period. The macro-economic turbulence induced by such events as German re-unification in 1989 and British exit from the European Exchange Rate Mechanism in 1992 may make this sample period unusual. From our perspective, these events provide a number of exogenous shocks to the financial position faced by our companies and are therefore a useful source of exogenous variation. It may be, however, that future examination in more stable periods will reveal different results. Another criticism is that the distinction between 'German' and 'British' firms is becoming meaningless in a world of increasingly global financial markets and increasingly multinational corporations. However the systematic differences found here between apparently similar samples of large companies in the two countries suggest that national financial systems still matter when it comes to raising finance for long-term investment. Thirdly, our results explain why fewer British firms perform R&D, but they do not explain why even amongst the R&D performers there are lower R&D intensities in Britain compared to Germany. This could be linked to other problems such as differential skills and training patterns across the two countries. Examining different R&D activities within firms who conduct R&D in both countries would be extremely useful in examining the importance of these other factors. Fourthly, our results look across industries and it would be interesting to look in more depth at a single industry to ensure that the results we describe here are not driven by any residual composition effects.

Finally, although we are confident that we have identified important differences between the two countries, we are still faced with a serious challenge in explaining the exact mechanisms that cause financial constraints to be more significant in the UK. EDWARDS and FISCHER (1994), among others, have cast doubt on the importance of long term relationships between banks and firms in Germany. Other potentially important differences relate to the proportion of companies whose shares are quoted (and actively traded) on stock exchanges, the concentration of share ownership and the monitoring role played (or not played) by institutional shareholders, the level and flexibility of dividend payout ratios, and the effects of hostile takeover activity. Identifying which of these or other factors are the root cause of differences in the impact of financing constraints on firms' investment activities will be a priority in our future research. ■

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Appendix A: Data

1. Germany

The German dataset contains information on manufacturing firms from three major sources: financial accounts data (balance sheets and profit and loss accounts) from Hoppenstedt (commercial suppliers of databases) and Creditreform (a large credit rating agency), 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 due to accounting regulatory changes. 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* (GmbHs, 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). The data used in this paper originate with financial statements and respective appendices published in the *Bundesanzeiger*. To obtain the respective data, the 1993 volume of the *Bundesanzeiger* was searched for any published statements that indicated R&D activities. These roughly 900 records provided the master list of companies for the data collection. The statements of these companies were then tracked backwards to 1987 and forward to 1994. Whenever companies provided quantitative items on their R&D activities, the record was entered into the database. A list of companies which had published similar information in 1987 was provided by B. SCHWITALLA and H. GRUPP and used to check the completeness of our own data search. See SCHWITALLA (1993) for a description of the 1987 cross-section.

R&D Investment (R). Quantitative data on R&D activity were recorded from the *Bundesanzeiger* if one or several of the following items were available: i) R&D expenditures, ii) R&D employees, iii) R&D intensity with respect to sales, iv) R&D intensity with respect to total number of employees, v) growth rates of any of these indicators. For about 200 firms, comparable data from the Mannheim Innovation Panel (MIP) were available for two or more years. The R&D figures were nearly identical, leaving aside rounding errors in the survey responses. Since the MIP survey explicitly asks for R&D according to the Frascati definitions, the correspondence between the two sources is reassuring. Since the operationalisation of the theoretical model requires data on R&D expenditures, the respective information had to be imputed for a small number of cases for which it was not available

directly. In the case of items ii) and iv), industry-specific regression coefficients from a previous analysis of the 1987 and 1989 Stifterverband surveys were used to impute R&D expenditures from R&D personnel data. These regression results are available upon request.

In addition to the R&D items, the Bundesanzeiger statements were also used to collect information on investment and capital stocks evaluated at historical costs. The data obtained from the Bundesanzeiger were then matched to commercially available balance sheet data published by Creditreform or Hoppenstedt. The latter two sources were also used to construct a large sample of firms satisfying the publication requirements of the *Handelsgesetzbuch*, but without information on their R&D activities. The information whether a firm from this group performs R&D or not was obtained in telephone interviews with the respective firms (unless matched Bundesanzeiger data clearly indicated that it was active in R&D). The telephone survey asked firms whether they had a dedicated R&D laboratory within their enterprise. This definition was chosen to be consistent with our presumption that setting up an R&D laboratory may entail considerable costs. These steps leave us with three groups of firms for which financial accounts data was available: R&D performers with R&D expenditures, R&D performers with information on R&D expenditures missing, and firms which definitely did not perform R&D. In order to have consistent samples when we estimate R&D investment equations (for which R&D expenditure data are needed) and investment equations for R&D performers and firms which do not undertake R&D, we used only the first and the third groups of firms in this paper.

Using ownership information from a variety of sources, all subsidiaries of foreign firms were excluded. Similarly, we excluded all non-independent firms in order to avoid measurement problems caused by transfer pricing, etc. The following sections briefly describe the other variables and their definitions.

Investment (I). The data on additions to plant, property and equipment came from the detailed Anlagenspiegel tabulation of assets in each of the Bundesanzeiger entries. The tabulation also includes their value at historical cost.

Capital stock (K) was computed by adjusting the historic cost values taken from the Anlagenspiegel 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.

$$P_t^I K_t = (1 - \delta) P_{t-1}^I K_{t-1} \left(\frac{P_t^I}{P_{t-1}^I} \right) + P_t^I I_t$$

$$\text{where : } \begin{cases} K_t & : \text{Capital Stock} \\ P_t^I & : \text{Price of Investment Goods} \\ I_t & : \text{Real Investment} \\ \delta & : \text{Depreciation rate} \end{cases}$$

The starting value was based on the net book value of tangible fixed capital assets in the first observation within our sample period, adjusted for previous years inflation. Subsequent values were obtained using accounts data on investment and disposals, and national price indices for investment goods prices.

Output (Y). This is simply sales deflated by the aggregate GDP deflator.

Cash Flow (C). For the purpose of the regressions, cash flow is computed as funds available for investment net of R&D spending, i.e. as net income plus depreciation (see the text for discussion of construction cash flow gross of R&D spending). We also experimented with measures of cash flow which include the firms' contributions to internal pension schemes (see Appendix B in BOND *et al.* 2003).

2. Britain

The UK data is taken from the accounts of firms listed on the UK stock market whose main area of sales was in the manufacturing industries. This data was obtained from the Datastream on-line service.

R&D investment (R). Since 1989 R&D expenditures have to be reported for firms which 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 anticipation of reform and many of the larger R&D performers had already been disclosing.³³ The R&D numbers we use are taken from the company accounts (consolidated group total, Datastream item 119). When any R&D is capitalised, that part of the capitalised R&D that was written off in that year is included in the R&D flow measure. We also found our numbers were consistent with the EXSTAT datafile and the R&D Scoreboard (two other company-level databases).

Investment (I). The basic variable used is total new fixed assets. Unlike Germany this includes not only purchases of plant, machinery and buildings but also net fixed assets acquired through acquisitions of other companies. This is clearly very important in the UK where there are a large number of takeovers and mergers. This was item DS435 (= DS431+DS432) before 1992. After 1992 we used DS1024 plus any positive values of DS479. Disposals are not included as the series pre-1992 appears to be contaminated by measurement error. To check the robustness of the results we experimented with different definitions of the investment series by (a) including disposals and (b) using the narrower definition of investment to exclude acquisitions. The results reported are robust to these different definitions and the correlations between the alternative investment series were very high (above 0.95).

Capital stock (K) was computed in the same way as in Germany by adjusting the historic cost values of net fixed assets taken from 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). Sales, Datastream item 104 deflated by an aggregate producer price index.

Cash Flow (C). For the purpose of the regressions, cash flow is computed as funds available for investment, i.e. as net income plus depreciation.

33 For an extensive discussion of the probability of disclosure and attempts to deal with the selectivity issue in earlier periods, see MENEZES-FILHO, ULPH and VAN REENEN (1998) or BELCHER (1996).

3. Sample procedures for both countries

Only firms whose main activities were in manufacturing were kept. Non-profit firms and subsidiaries of foreign firms were deleted as well. Firms engaged in large scale merger or takeover activity were either split (i.e. treated as a new firm after the restructuring) or dropped from the sample. The dataset is trimmed so that observations were excluded if the following ratios were in the upper or lower percentile of the respective sample distribution: (I/K_{t-1}) , (C/K_{t-1}) , (Y/K_{t-1}) . The database still contains a small number of nonconsolidated statements for Germany, in particular when comparability over time requires their use (see Appendix B in BOND et al (2003)).

Clearly these samples are not representative of the population of firms in either country. They are representative of all the major R&D performers in each economy, however, and account for the vast bulk of all R&D performed. There is a spread of firms across different industries, although it can be seen from Table A2 that Germany has a greater proportion of firms in the machinery sectors than the UK. Note that we have used unbalanced panels (see Table A3) to mitigate survivor bias and the inclusion of fixed effects in all the estimated models should go some way to controlling for selectivity problems. We use two extra years of data in the UK (1985 and 1986) than in Germany to keep the sample sizes roughly comparable (there were fewer UK firms than German firms declaring R&D in the 1987-88 period before SSAP(13) took effect).

TABLE A1

Industry Breakdown: R&D Performers

	UK	GER	UK	GER
	R&D/Y	R&D/Y	% in Sample	% in Sample
Chemical & allied industries	3.3	6.6	16%	21%
Electrical engineering	5.4	7.8	19%	25%
Mechanical Engineering	4.0	5.6	21%	27%
Metals	0.4	2.9	2%	9%
Food, drink, tobacco	0.5	1.3	8%	2%
Other	1.2	4.4	34%	16%

TABLE A2

Industry Breakdown for R&D and Non-R&D Performers

Industry	Code	% of sample		'R&D' Industry?
		U.K	Germany	
Chemicals (inc. drugs)	3+5	10%	12%	yes
Food, Drink, Tobacco	8	14%	15%	no
Non-electrical Machinery	12	8%	17%	yes
Electrical Machinery	6	5%	12%	yes
Textiles	24	11%	8%	no
Paper and Printing	18	12%	3%	no
Office Equipment (inc. computers)	15	7%	1%	yes
Motor Vehicles	11	8%	5%	yes
Metal Products	7	6%	5%	yes
Others (none with >5%)		19%	22%	

NOTES: Tables A1 and A2 are taken from the samples in 1992. Firms classified by principal operating industry by sales.

TABLE A3

Balance of Panel

No of years	R&D>0		High Tech Industries	
	UK	GER	UK	GER
3	40	25		
4	39	28	33	41
5	68	37	54	39
6	27	55	29	46
7	9	46	27	57
8	6	43	18	63
9	3		33	
10	7		69	
Firms	199	209	263	246

TABLE A4

Distribution of Observations over Years

Year	R&D>0		High Tech Industries	
	UK	GER	UK	GER
1985	23	-	150	-
1986	29	-	164	-
1987	39	129	183	157
1988	44	138	205	175
1989	90	200	224	228
1990	145	214	233	247
1991	168	213	234	255
1992	175	200	225	244
1993	159	175	210	220
1994	114	99	143	129
Observations	986	1368	1971	1655

NOTE:- There are more observations here than in the regressions because some cross sections are lost when using lags as right hand side variables and instruments