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Equity financing and innovation: Is Europe different from the United States?

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ABSTRACT

During the mid and late 1990s young, high-tech firms in the US experienced a supply shift in both internal and external equity fueling a finance-driven boom in corporate R&D. This paper examines whether R&D spending in Europe in a similar way was sensitive to fluctuations in the supply of internal and external equity during the late 1990s and early 2000s. I conjecture that UK and Continental Europe, due to their different financial systems, differ in terms of equity supply. I estimate dynamic R&D regression models for UK and Continental European high-tech firms separately and find significant joint cash-flow effects for newly listed firms in both samples. However, only new firms in the UK experienced a joint external equity effect as well. The findings of this paper suggest a channel through which market-based financial systems outperform the bank-based economies of Continental Europe.

1. Introduction

Recent evidence suggests that the US experienced a finance-driven R&D boom in the late 1990s (Brown, Fazzari, and Petersen, 2009 – BFP (2009) hereon). Young, high-tech firms benefited from supply shifts in both internal and external equity, and this relaxed otherwise binding financing constraints for R&D investment. The findings in BFP (2009) suggest that there exists a significant connection between finance, innovation, and growth. This paper examines whether R&D spending in Europe in a similar way was sensitive to fluctuations in the supply of internal and external equity during the late 1990s and early 2000s. The analysis focuses on R&D investment in the UK and nine other developed European economies (Continental Europe). The UK is particularly interesting because like the US it has a market-based financial system, and similar to the US it experienced a sharp stock issue boom in the late 1990s.

The results are based on a study of 700 publicly traded, high-tech firms, incorporated in Belgium, Denmark, Finland, France, Germany, the Netherlands, Norway, Sweden, Switzerland and the UK, with observations from the period 1995–2004. Roughly 40% of the firms are located in the UK. The study applies dynamic Euler equation models with generalized methods of moments (GMM) estimation with separate estimations for the UK and Continental Europe. Both internal and external equity are quantitatively large and jointly significant for new, high-tech firms in the UK. The regression for new, Continental European, high-tech firms provides only a significant joint cash-flow effect. The results are robust with regard to alternative sample splits, estimation procedures, and instrument lag lengths.

New, Continental European, high-tech firms also experienced a stock issue boom in the late 1990s, but this did not matter for R&D as it did for new firms in the UK. Both the increase in R&D-intensity and the stock issue boom were higher in the UK. In the boom year of 1999, new firms in the UK had an average R&D-intensity of 0.248 compared to 0.160 for Continental Europe. The major difference lies in the external equity[1] variable where new firms had an average of 0.333 in the UK and 0.220 in Continental Europe. The empirical analysis suggests that the reason for the higher R&D-intensity of UK firms is their access to external equity which they could spend on additional R&D investment.

My findings on European, high-tech firms corroborate BFP's (2009) US findings and contain important implications. High-tech firms in the US and the UK appear to have similar R&D-intensities and use of cash-flow. They also seem to depend on external equity to a similar degree. Thus, it appears that market-based financial systems are better at providing external funding of R&D investment and at lower costs. This conclusion is in line with existing literature which states that firms without adequate internal financial resources may face binding constraints for their R&D investments when capital-market imperfections are present (Carpenter and Petersen, 2002; Hall, 2002). This illustrates how the nature of a

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[1] Issued stock minus purchased stock divided by the total assets in the beginning of the year.

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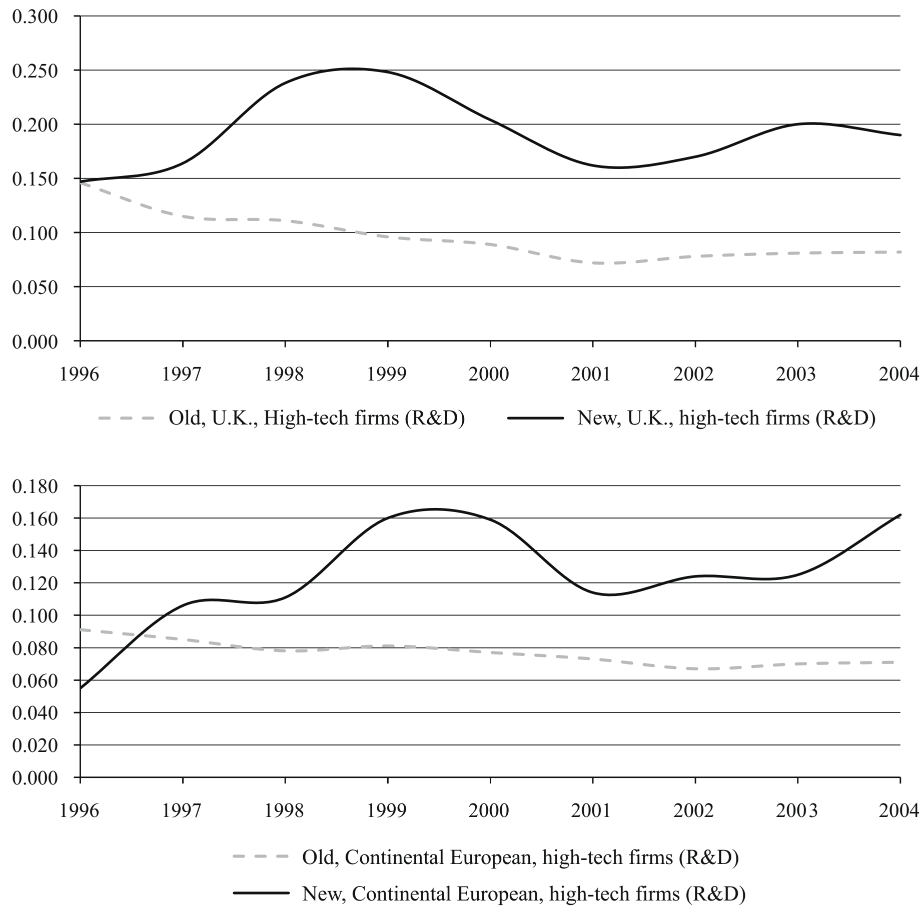

Fig. 1. Average R&D to total assets ratios for old, and new, high-tech firms in the UK (top graph) and in Continental Europe (bottom graph). R&D scaled by beginning of the period total assets for high-tech firms in the UK in the upper graph and in Continental Europe in the bottom graph. The full line represents new, high-tech firms (a firm is considered new if it had its IPO after 1995), and the dashed line represents old, high-tech firms (a firm present at the beginning of the sample period is considered old).

country's financial system may influence the economic growth of the country. Beck and Levine (2002) cannot find any evidence in favor of either market or bank-based financial systems as promoters of economic growth. The market-based financial systems of the US and the UK appear to support R&D-intensive firms better than bank-based systems of Continental Europe. Combining these findings with the importance assigned to R&D in endogenous growth models Aghion and Howitt, 1992, 1998) this observation is a potential explanation of why market-based financial systems outperform the bank-based economies.

The paper proceeds as follows. Section 2 presents the empirical strategy. Section 3 includes the presentation of the data alongside the descriptive statistics and graphical evidence. Section 4 presents the dynamic GMM results and tests their robustness. Section 5 summarizes and discusses the implications of the findings.

2. Econometrics and estimation

R&D investment specifications used in the empirical literature are almost exclusively transformations of capital investment specifications. To my knowledge, BFP (2009) are the first to apply an Euler equation model to R&D investment. The Euler equation model of BFP (2009) is originally derived in Bond and Meghir (1994) for capital investment. I apply the same specification.

The Bond and Meghir (1994) model relates capital investment rates between successive periods and derives from a dynamic optimization with symmetric and quadratic adjustment costs. The advantage of the Euler equation is as follows: by assuming that expectations are formed according to the previously mentioned dynamic optimization scenario, the Euler equation specification controls for expectational influences affecting the investment decision. Since this specification controls for expectational influences it is more straightforward and less ambiguous to interpret the estimation results and to draw conclusions from the econometric estimates.

The empirical model below is the same as in BFP (2009, p. 162). Following Bond and Meghir's (1994) model, a lagged negative cash-flow estimate indicates that the firm is not financially constrained. Besides the sign in front of lagged cash-flow, β_1 should be slightly larger than 1 and β_2 negative and slightly less than 1. Further, in the presence of no financing constraints, contemporaneous cash-flow and the external equity estimates should enter non-significantly. I estimate the Euler model without contemporaneous effects and without the external equity variables to explore the goodness of fit when no financing constraints are present as a first step in the empirical section. This version of the Euler model is referred to as the benchmark Euler model. The main estimating equation below follows BFP (2009) with the purpose of exploring corporate financing constraints affecting R&D. In practice this implies testing the impact of internal and external equity as financing sources of R&D investment.[2] The added variables, compared to Bond and Meghir's (1994) original model are: contemporaneous cash-

[2] Following BFP (2009) I do not include debt in the specification. The annual change of the long-term debt stock normalized by the beginning of the period stock of firm assets was also included in the empirical analysis but was as expected non-significant. Debt is generally not preferred for financing of R&D (see Hall, 2002; Hall and Lerner, 2009). I include long-term debt in the descriptive statistics though.

Table 1
Sample descriptive statistics for high-tech firms in the UK.

Variable and statistic	All UK firms	New firms	Old firms
rd_t			
Mean	0.170	0.194	0.094
25th	0.061	0.069	0.045
Median	0.111	0.131	0.080
75th	0.210	0.235	0.114
SD	0.192	0.212	0.067
CF_t			
Mean	0.207	0.215	0.179
25th	0.076	0.065	0.100
Median	0.181	0.186	0.175
75th	0.327	0.353	0.278
SD	0.238	0.256	0.160
stk_t			
Mean	0.290	0.333	0.119
25th	0.000	0.000	0.000
Median	0.003	0.003	0.002
75th	0.094	0.156	0.011
SD	1.035	1.136	0.426
Y_t			
Mean	1.261	1.293	1.134
25th	0.677	0.665	0.729
Median	1.143	1.160	1.029
75th	1.562	1.588	1.474
SD	1.005	1.085	0.577
dbt_t			
Mean	0.081	0.080	0.088
25th	0.000	0.000	0.000
Median	0.009	0.007	0.016
75th	0.076	0.074	0.094
SD	0.175	0.171	0.187

Sample descriptive statistics for all UK, high-tech firms in column 1 (the sectors considered high technology are SIC: 283, 357, 366, 367, 382, 384, and 737), for new, UK, high-tech firms in column 2 (a firm is considered new if it had its IPO after 1995), and old, UK, high-tech firms in column 3 (a firm present at the beginning of the sample period is considered old).

Table 2
Sample descriptive statistics for high-tech firms in Continental Europe.

Variable and statistic	All continental European firms	New firms	Old firms
rd_t			
Mean	0.125	0.136	0.077
25th	0.048	0.053	0.042
Median	0.089	0.101	0.067
75th	0.158	0.169	0.096
SD	0.135	0.146	0.048
CF_t			
Mean	0.182	0.179	0.196
25th	0.078	0.066	0.121
Median	0.167	0.160	0.182
75th	0.269	0.272	0.261
SD	0.195	0.208	0.125
stk_t			
Mean	0.185	0.220	0.025
25th	0.000	0.000	0.000
Median	0.000	0.000	0.000
75th	0.019	0.034	0.004
SD	0.809	0.887	0.104
Y_t			
Mean	1.221	1.195	1.334
25th	0.763	0.689	1.001
Median	1.104	1.051	1.289
75th	1.488	1.464	1.561
SD	0.899	0.963	0.520
dbt_t			
Mean	0.110	0.106	0.126
25th	0.005	0.003	0.027
Median	0.060	0.050	0.111
75th	0.155	0.146	0.184
SD	0.153	0.159	0.119

Sample descriptive statistics for all Continental European, high-tech firms in column 1 (the sectors considered high technology are SIC: 283, 357, 366, 367, 382, 384, and 737), for new, Continental European, high-tech firms in column 2 (a firm is considered new if it had its IPO after 1995), and old, Continental European, high-tech firms in column 3 (a firm present at the beginning of the sample period is considered old).

flow, since it is the standard measure in the literature for internal financing of investment; contemporaneous output since the high correlation between sales and cash-flow otherwise may inflate the cash-flow estimate; and contemporaneous and lagged net stock issuance (abbreviated $\text{stk}_{i,t}$ and $\text{stk}_{i,t-1}$, respectively).

$$\left(\frac{RD_{i,t}}{TA_{i,t-1}}\right) = \beta_0 + \beta_1\left(\frac{RD_{i,t-1}}{TA_{i,t-2}}\right) + \beta_2\left(\frac{RD_{i,t-1}}{TA_{i,t-2}}\right)^2 + \beta_3\left(\frac{CE_{i,t}}{TA_{i,t-1}}\right) + \beta_4\left(\frac{CF_{i,t-1}}{TA_{i,t-2}}\right) + \beta_5\left(\frac{Y_{i,t}}{TA_{i,t-1}}\right) + \beta_6\left(\frac{T_{i,t-1}}{TA_{i,t-2}}\right) + \beta_7\left(\frac{stk_{i,t}}{TA_{i,t-1}}\right) + \beta_8\left(\frac{stk_{i,t-1}}{TA_{i,t-2}}\right) + \alpha_t + \alpha_i + \varepsilon_{i,t}$$

All the variables are scaled by beginning of the period stock of firm assets. The model also includes a time-specific effect to control for aggregate changes potentially affecting the demand for R&D and also a firm-specific effect to control for unobserved constant determinants of firm-level R&D such as country-specific institutional differences.

I estimate the empirical model on groups of firms which are considered more or less likely to face binding financing constraints. The main sample split is based on "new" and "old" firms (I describe this split in the next section). This is to proxy for firm-age. Firm-age is likely correlated with information asymmetry related issues and is less endogenous than other splitting measures such as firm size and dividend policy. I predict, in line with BFP (2009), that the financial variables enter significantly from estimating the model on the new firm sample and that they are non-significant, or at least less important, for old firms.

The adjustment costs associated with R&D investment are supposedly higher than for other types of investment. The literature highlights two reasons for why this might be so. The lion's share of corporate R&D expenditure comprises salary to researchers and firms are normally reluctant to fire researchers since they have invested a lot of time and funds for training them. Firing R&D workers is also problematic due to the disclosure issues of R&D projects. Therefore firms choose to smooth their R&D expenditure to minimize the risk of having to drastically cut in the R&D budget. This topic is thoroughly discussed in Hall (2002), Hall and Lerner (2009) and Himmelberg and Petersen (1994).

The higher adjustment costs associated with R&D, and the subsequent smoothing of corporate R&D expenditure, make the R&D time series highly persistent. This is why modeling R&D investment requires a dynamic specification. Ordinary least squares (OLS) and within estimation are recognized as biased estimators of short dynamic panel data sets.[3] I therefore apply general methods of moments (GMM) estimation.

3. Data description and sample characteristics

3.1. Sample construction

This paper follows the sample selection of BFP (2009) as closely as possible in order to obtain comparable results. BFP (2009) re-

[3] See Bond (2002) and Roodman (2006, 2008) for descriptions of the estimation of dynamic panel data sets regarding OLS, within, and GMM estimation.

Table 3
Dynamic R&D regressions: the baseline and augmented Euler equation model.

Dep. variable: rd_t	Baseline Euler: UK firms	Baseline Euler: Continental European firms	Euler *w* financial variables: UK firms	Euler *w* financial variables: Continental European firms
rd_{t-1}	1.437***	1.056***	1.142***	0.652**
	(0.321)	(0.308)	(0.181)	(0.159)
rd^2_{t-1}	−0.840***	−0.373*	−0.591***	−0.124*
	(0.214)	(0.213)	(0.107)	(0.070)
Y_t			0.016	0.041
			(0.032)	(0.029)
Y_{t-1}	−0.076**	−0.029*	−0.072*	−0.047**
	(0.039)	(0.016)	(0.039)	(0.023)
CF_t			0.132	0.159**
			(0.082)	(0.069)
CF_{t-1}	0.029	0.015	0.074**	−0.050
	(0.098)	(0.038)	(0.010)	(0.041)
stk_t			0.194***	−0.019
			(0.045)	(0.058)
stk_{t-1}			−0.046***	0.014
			(0.018)	(0.033)
Observations	367	900	352	825
Instruments	87	87	87	87
CF χ^2 (*p*-value)			0.001	0.062
Stk χ^2 (*p*-value)			0.002	0.904
AR-(1)	0.014	0.003	0.015	0.001
AR-(2)	0.272	0.529	0.754	0.962
Hansen (*p*-value)	0.578	0.450	0.635	0.186

Dynamic R&D regressions on the UK, high-tech sample (columns 1 and 3) and the Continental European, high-tech sample (columns 2 and 4) are estimated with one-step systems GMM. Columns 1 and 2 are estimates from running the baseline Euler equation model assuming no financing constraints and columns 3 and 4 are estimates from running the augmented Euler equation model with financial variables testing for financing constraints. All regressions are performed including time dummies. Heteroskedasticity robust standard errors in parenthesis.
One step systems GMM estimates. Instruments differenced equation are lagged levels dated $t-3$ to $t-4$ and instruments level equation are lagged differences dated $t-2$. The χ^2 tests are tests of the null that the sum of current and lagged cash flow and net stock issuance respectively is zero. The AR-tests are asymptotically normally distributed under the null hypothesis of no serial autocorrelation. The Hansen *J*-test is chi-square distributed under the null of exogenous instruments.
* Indicate significance at 10%.
** Indicate significance at 5%.
*** Indicate significance at 1%.

strict their analysis to high-tech firms. They base their definition of high technology sectors on a report by the United States Commerce Department on US competitiveness in high technology.[4] Aerospace manufacturing is excluded from the high-tech sectors since its R&D activities are largely supported by the government, which is also the case for European aerospace manufacturing. The high-tech sectors are: drugs (SIC 283), office and computing (SIC 357), communications equipment (SIC 366), electronic components (SIC 367), scientific instruments (SIC 382), medical instruments (SIC 384), and software (SIC 737).

The sample of this paper is constructed from the Compustat Global database. The countries included in the sample are: Belgium, Denmark, Finland, France, Germany, the Netherlands, Norway, Sweden, Switzerland, and the United Kingdom. A firm is considered to belong to a certain country based on its "country of incorporation" in the Compustat Global database. The sample covers 1995–2004, compared to BFP's (2009) sample period of 1990–2004. I exclude firms outside the seven high technology sectors and also high-tech firms which have no R&D expenditure during the sample period. I further exclude firms if their sum of cash-flow to assets ratio is negative, in line with BFP (2009). Firms with negative sums of cash-flow to assets are generally outliers. Following these screening criteria, Compustat Global has data on roughly 700 R&D reporting high-tech firms incorporated in the 10 countries mentioned above. 280 of those are incorporated in the UK, which constitute about 40% of the sample.

BFP (2009) divide their sample into "young" and "mature" firms. Their definitions of young and mature are based on the number of years since the firm's stock price first appears in Compustat North-America. A firm is classified as young within the first 15 years after its first appearance in the database and classified as mature thereafter. I try to emulate this procedure as much as possible. Since I only have data for 1995–2004 I classify a firm as "new" if it had its IPO after 1995. A firm is classified as "old" if it is covered in the sample in 1995.

All variables are scaled by beginning of the period total assets and the key ratios are then trimmed at the one percent level for outliers. The variables used in the empirical analysis are described in the Appendix A.

3.2. Graphical evidence

Due to the vastly different financial systems of the UK and the other nine European countries I examine the UK separately. I refer to the remaining nine European countries as the Continental European sample.

In Fig. 1 R&D to total assets are presented for high-tech firms in the UK in the top graph and for Continental European firms in the bottom graph. Both graphs display heterogeneity regarding new and old firms. The new firms appear to diverge from the old firms for both samples in 1998. The pattern looks similar for both the UK and the Continental European sample. However the new, high-tech firms in the UK peak at about 0.250 compared to their Continental European counterparts at 0.160. The development of old, high-tech firms' R&D to assets is virtually flat and somewhat declining during the sample period for both sub-samples. New firms in the UK recorded R&D ratios of 0.238, 0.248 and 0.204 from 1998–2000 compared to 0.111, 0.160 and 0.159 for their Continental European counterparts. So, even though the graphs in Fig. 1 appear similar, the R&D-intensity for new firms in the UK is considerably higher than in Continental Europe. The rising R&D-intensity was partly caused by the many initial public offerings (IPOs) and seasoned

[4] See BFP (2009, p. 163, footnote 8).

Table 4
Dynamic R&D regressions for separate new and old firm samples.

Dep. variable: rd_t	Old UK firms	Old Continental European firms	New UK firms	New Continental European firms
rd_{t-1}	1.012***	0.950***	1.195***	0.671***
	(0.093)	(0.225)	(0.195)	(0.166)
rd_{t-1}^2	−0.475	−0.668	−0.621***	−0.144*
	(0.417)	(1.009)	(0.115)	(0.074)
Y_t	0.043***	0.037***	0.034	0.038
	(0.009)	(0.010)	(0.032)	(0.031)
Y_{t-1}	−0.048***	−0.038***	−0.071**	−0.051**
	(0.008)	(0.010)	(0.039)	(0.026)
CF_t	0.008	0.064*	0.142*	0.157**
	(0.012)	(0.034)	(0.073)	(0.071)
CF_{t-1}	0.002	−0.021	0.037	−0.019
	(0.016)	(0.030)	(0.083)	(0.038)
stk_t	0.046***	−0.068***	0.194***	−0.004
	(0.012)	(0.024)	(0.045)	(0.060)
stk_{t-1}	−0.048***	−0.025*	−0.044**	0.019
	(0.016)	(0.013)	(0.019)	(0.035)
Observations	85	148	267	677
Instruments	81	87	84	87
CF χ^2 (*p*-value)	0.548	0.131	0.058	0.037
Stk χ^2 (*p*-value)	0.845	0.000	0.001	0.728
AR-(1)	0.021	0.017	0.013	0.002
AR-(2)	0.423	0.123	0.531	0.939
Hansen (*p*-value)	1.000	1.000	0.993	0.522

Dynamic R&D regressions on the UK, high-tech sample separated into old firms (column 1) and new firms (column 3) and the Continental European, high-tech sample separated into old firms (column 2) and new firms (column 4). The regressions are estimated with one-step systems GMM. A firm present at the beginning of the sample period is considered old and a firm is considered new if it had its IPO after 1995. All regressions are performed including time dummies. Heteroskedasticity robust standard errors in parenthesis

One step systems GMM estimates. Instruments differenced equation are lagged levels dated $t-3$ to $t-4$ and instruments level equation are lagged differences dated $t-2$. The χ^2 tests are tests of the null that the sum of current and lagged cash flow and net stock issuance respectively is zero. The AR-tests are asymptotically normally distributed under the null hypothesis of no serial autocorrelation. The Hansen *J*-test is chi-square distributed under the null of exogenous instruments.

* Indicate significance at 10%.

** Indicate significance at 5%.

*** Indicate significance at 1%.

equity offerings (SEOs) during the late 1990s conducted by young, R&D-intensive firms. Even in Continental Europe younger firms went public, which is rarer than in the Anglo–Saxon countries. During more normal periods in the stock market, Continental European IPOs are generally conducted by older firms than in the US and UK (Ritter, 2003; Loughrann et al., 1994).

The UK sample does not display much heterogeneity in the cash-flow variable. Both old and new firms in the UK experienced a boom in internal equity at the beginning of the sample period and a subsequent decline towards the end. In the continental European sample, new firms experienced a rise in cash-flow starting in 1997 which peaked in 2000 above 0.250. But, during the 2001 recession, new firm cash-flow for Continental Europe fell below the level of 1996. Old, Continental European firms, on the other hand, were fairly consistent around 0.200 besides a small dip in connection to the recession at the beginning of the 2000s.

Due to the stock price increases of the late 1990s the supply of external equity also experienced an upward shift. Both new, UK and Continental European firms experienced a boom in stock issues normalized by total assets from 1998 to 2000. The UK firms' peak was in 2000 at 1.025 compared to 0.646 for new, Continental European firms. The external equity ratios plummeted in 2001 following the bust of the IT-bubble. For new, Continental European firms the drop was from 0.646 to 0.084. The drop for new firms in the UK was also significant, from the peak of 1.025–0.165. Old, high-tech firms did not experience similar supply shifts. The external equity ratio for Continental European, high-tech firms, new as well as old, remained near zero from 2001 and onwards.

3.3. Descriptive statistics

The development of R&D, cash-flow and stock issues (normalized by beginning of the period total assets) for both samples resembles what took place in the US during the same period. Table 1 contains descriptive statistics for the UK sample and Table 2 for the Continental European sample. The peak years, 1998–2000, of stock issues are well above the overall average for both the UK and the Continental European samples. The average external equity ratio of new, UK firms is 0.333 compared to the sample high of 1.025 recorded in 1999. In both Tables 1 and 2 there is heterogeneity between the new and old sub-samples. There are some noteworthy similarities and dissimilarities from comparing the European results to BFP's (2009) US sample.[5] In the UK sample, the R&D-intensity is virtually identical to that of the US reported in BFP (2009). Young firms in the US had an R&D to total assets average of 0.194 and mature firms had a 0.098 average. In the UK this average is 0.194 for new firms and 0.094 for old firms. The Continental European firms are less R&D-intensive, but they display the same type of heterogeneity in terms of new and old firms. New, Continental European firms have an R&D-intensity of 0.136 and old firms an intensity of 0.077. The cash-flow variable also displays similar heterogeneity between new and old firms as in BFP's (2009) US sample. New firms in the UK have an average cash-flow to assets of 0.215 and the old firm average is 0.179. Conversely, among Continental European firms old firms have higher average cash-flow to assets than new firms.

New UK firms display similar external equity use as their US counterparts (an average of 0.333). However, contrary to mature US firms which make use of very little external equity, old firms in the UK are also external equity dependent, albeit much less so than their new firm counterparts. Old, Continental European firms use little external equity, an average of 0.025. New, Continental European firms have an average external equity ratio of 0.220.

[5] See BFP (2009, p. 166: Table I) for the descriptive statistics of US high-tech firms.

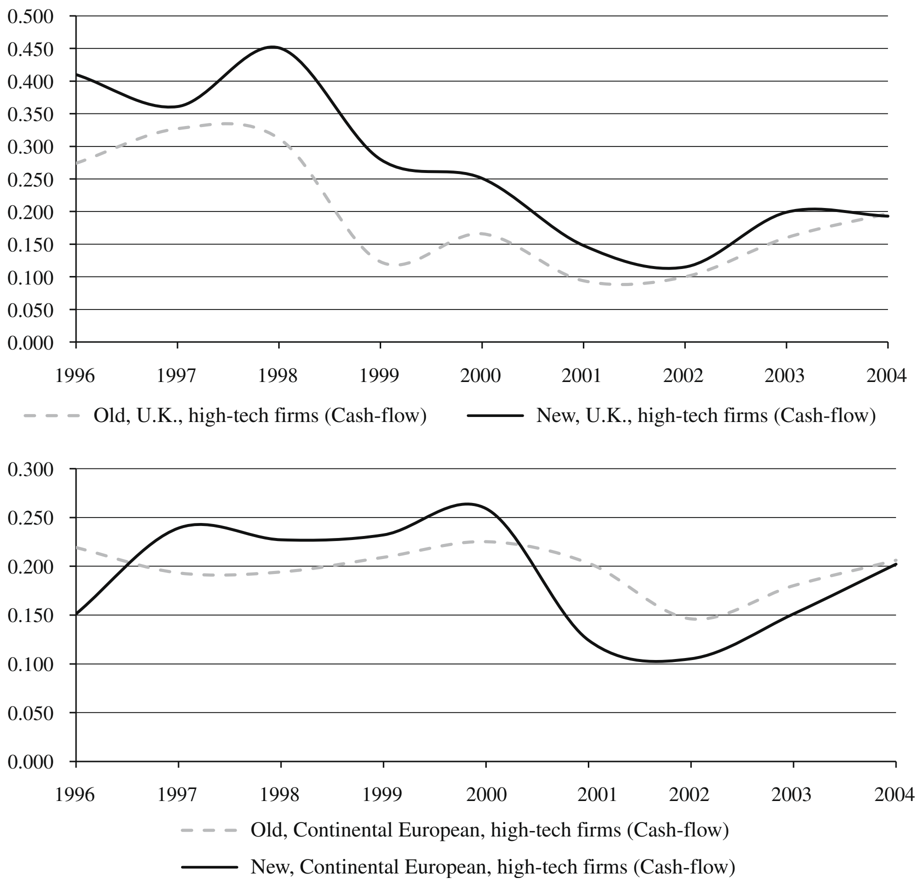

Fig. 2. Average Cash-flow to total assets ratios for old, and new, high-tech firms in the UK (top graph) and in Continental Europe (bottom graph). Cash-flow scaled by beginning of the period total assets for high-tech firms in the UK in the upper graph and in Continental Europe in the bottom graph. The full line represents new, high-tech firms (a firm is considered new if it had its IPO after 1995), and the dashed line represents old, high-tech firms (a firm present at the beginning of the sample period is considered old).

The graphical and descriptive analysis shows that new, high-tech firms in Europe experienced a supply shift, in particular, in external equity finance which coincided with a rise in R&D-intensity during the late 1990s and a subsequent decline in external equity supply and R&D-intensity in the early 2000s. New, high-tech firms in the UK appear to have experienced a greater external equity supply shift and subsequent increase in R&D-intensity than new, Continental European firms. I formally examine this in the next section.

4. Econometric results

4.1. Choice of estimator

This section presents one-step "systems" GMM estimates of dynamic Euler equation models. BFP (2009) use one-step first difference GMM instead. I prefer the systems GMM approach since the orthogonal transformation preserves sample size if there are gaps in the data and allows more instruments to be used which improves the precision of the estimates. Arellano and Bond (1991) suggest using one-step GMM since it is less plagued with finite sample bias compared to the two-step estimates. The main results are instrumented with $t-3$ and $t-4$ level values for the differenced equation and $t-2$ lagged differences for the level equation which allows the error structure to be an MA-(1) process. I evaluate the instruments' validity with AR-(1) and AR-(2) tests testing the null hypothesis of no serial autocorrelation and the Hansen J-test which is chi-square distributed under the null hypothesis of exogenous instruments.

4.2. Pooled sample results

Columns 1 and 2 of Table 3 contain the baseline Euler estimates for the pooled samples comprising all high-tech firms in the UK and in Continental Europe respectively. I estimate the baseline Euler model[6] in order to explore the goodness of fit of Bond and Meghir's (1994) model with no financing constraints.

The UK sample has lagged R&D estimates corroborating the baseline Euler model, around positive 1 for the lagged R&D variable and around negative 1 for the lagged quadratic R&D variable. However, the required negative lagged cash-flow estimate is neither present for the UK nor the Continental European pooled sample. For both sub-samples there is first order serial autocorrelation but the AR-(2) test cannot reject the null hypothesis of second order serial autocorrelation.

I proceed by augmenting the baseline Euler model by including the financial variables as is shown in Section 2. The augmented Euler equation model is applied to both samples and the results are presented in columns 3 and 4 of Table 3. The pooled UK results are very similar to the US results in BFP (2009). There are jointly significant cash-flow and external equity effects at below 1%. The size of the contemporaneous cash-flow and external equity estimates are similar to the US results of BFP (2009). The pooled Continental European sample does not display any external equity effect. Next I split the sample on new and old firms.

[6] The baseline Euler model is the specification from section 2 but without contemporaneous financial variables and no external equity variables.

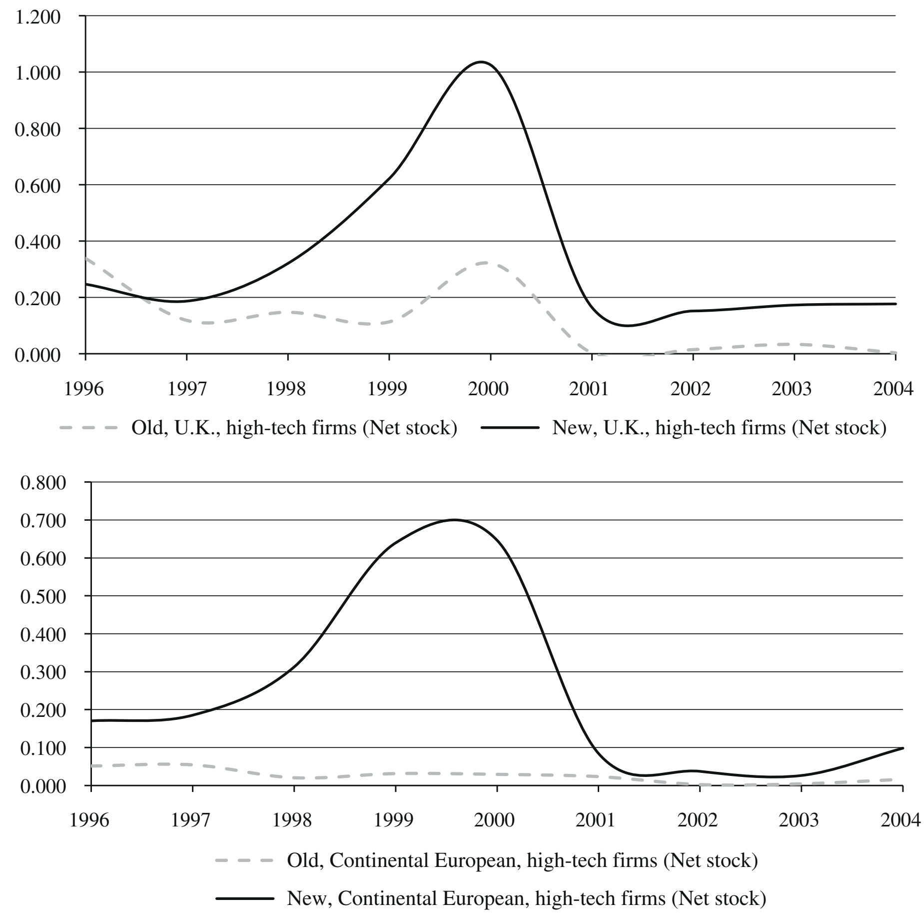

Fig. 3. Average net stock issues to total assets for old, and new, high-tech firms in the UK (top graph) and in Continental Europe (bottom graph). Net stock issues scaled by beginning of the period total assets for high-tech firms in the UK in the upper graph and in Continental Europe in the bottom graph. The full line represents new, high-tech firms (a firm is considered new if it had its IPO after 1995), and the dashed line represents old, high-tech firms (a firm present at the beginning of the sample period is considered old).

4.3. New and old firm estimates

I display the estimates of old firms in the UK and Continental Europe in columns 1 and 2 in Table 4. The old firm samples are close to the target values of positive 1 for lagged R&D and negative 1 for lagged quadratic R&D, especially the Continental European sample. The Continental European, old firms have a jointly significant negative external equity effect, thus not a sign of financing constraints. So, especially the old, Continental European firms corroborate the baseline Euler model since the financial effects are generally insignificant, lagged cash-flow is negative and the lagged R&D estimates are near their target values. Old, UK firms are also fairly close to the baseline Euler model. These results are highly plausible since older more mature firms likely can smooth their R&D spending over time.

Estimates for the new firms are compiled in columns 3 and 4 of Table 4. The new, Continental European sample rejects the baseline Euler equation model mostly due to the small size of especially the lagged quadratic R&D variables, falling from −0.668 to −0.144 and due to the significant joint cash-flow effect. The lagged R&D variables are qualitatively unchanged for the new, UK sample but this sample displays clear financial effects for both equity types ultimately rejecting the baseline Euler equation model. The financial variable estimates for new firms corroborate the graphical evidence of Figs. 2 and 3. The new, Continental European firms also display a significant joint cash-flow effect. In terms of external equity, new firms in the UK display a clearly significant relationship with R&D investment. New, Continental European firms do not share this relationship. This finding is highly plausible due to the different financial systems of the UK and the Continental European countries.

4.4. Robustness

I have conducted a number of alternative sample splits previously used in the literature to test the robustness of the results of Section 4.3. First I split on firm size (amongst others: Gertler and Hubbard, 1989; Almeida et al., 2004 use firm size as proxy for external finance access).[7] In Table 5 the sample is split at the median of average employment. I consider firms at or below the median of average employment small and firms above the median are large. For the Continental European sample it seems as if some of the firms classified as new are also large firms since the joint cash-flow estimate is significant for large firms and not for small firms. Otherwise, this split corroborates the new/old sample split reasonably well. This split actually appears to provide a cleaner split of the sample. Both the UK and Continental European large-firm sample corroborate the baseline Euler model in terms of lagged R&D estimates. Both lagged R&D and lagged quadratic R&D meet their target values. Neither cash-flow nor external equity is jointly

[7] Carpenter and Guariglia (2008) show that information asymmetry adversely affects small firms compared to large firms studying investment-cash flow sensitivities.

Table 5
Dynamic R&D regressions for separate small and large-firm samples.

Dep. variable: rd_t	Large UK firms	Large Continental European firms	Small UK firms	Small Continental European firms
rd_{t-1}	1.146***	1.147***	1.100***	0.745***
	(0.260)	(0.113)	(0.155)	(0.183)
rd_{t-1}^2	−1.069*	−1.028***	−0.539***	−0.189**
	(0.556)	(0.336)	(0.101)	(0.083)
Y_t	0.046*	0.013	−0.043	0.032
	(0.024)	(0.019)	(0.055)	(0.030)
Y_{t-1}	−0.045**	−0.027	−0.033	−0.047*
	(0.021)	(0.017)	(0.040)	(0.026)
CF_t	0.091**	0.156***	0.242***	0.113*
	(0.041)	(0.047)	(0.065)	(0.061)
CF_{t-1}	−0.031	0.084*	0.023	−0.045
	(0.040)	(0.049)	(0.088)	(0.039)
stk_t	0.004	0.070*	0.200***	0.069
	(0.022)	(0.047)	(0.035)	(0.047)
stk_{t-1}	−0.006	−0.017**	−0.072***	0.015
	(0.014)	(0.008)	(0.023)	(0.033)
Observations	186	536	166	289
Instruments	87	87	77	76
CF χ^2 (p-value)	0.152	0.007	0.000	0.307
Stk χ^2 (p-value)	0.959	0.114	0.005	0.108
AR-(1)	0.128	0.000	0.253	0.002
AR-(2)	0.062	0.623	0.522	0.197
Hansen (p-value)	1.000	0.312	1.000	0.863

Dynamic R&D regressions on the UK, high-tech sample separated into large firms (column 1) and small firms (column 3) and the Continental European, high-tech sample separated into large firms (column 2) and small firms (column 4). The regressions are estimated with one-step systems GMM. A firm is considered large if it is above the median of average employment during the sample period and subsequently considered small if it is at or below the median. All regressions are performed including time dummies. Heteroskedasticity robust standard errors in parenthesis.
One step systems GMM estimates. Instruments differenced equation are lagged levels dated $t-3$ to $t-4$ and instruments level equation are lagged differences dated $t-2$. The χ^2 tests are tests of the null that the sum of current and lagged cash flow and net stock issuance respectively is zero. The AR-tests are asymptotically normally distributed under the null hypothesis of no serial autocorrelation. The Hansen J-test is chi-square distributed under the null of exogenous instruments.
* Indicate significance at 10%.
** Indicate significance at 5%.
*** Indicate significance at 1%.

Table 6
Dynamic R&D regressions for the pooled samples: robustness.

Dep. variable: rd_t	UK firms: first difference GMM	UK firms: two-step systems GMM	Continental European firms: first difference GMM	Continental European firms: two-step systems GMM
rd_{t-1}	1.136***	1.147***	0.611***	0.708***
	(0.202)	(0.174)	(0.157)	(0.150)
rd_{t-1}^2	−0.550***	−0.592***	−0.101	−0.157**
	(0.110)	(0.106)	(0.069)	(0.073)
Y_t	0.007	0.012	0.037	0.042
	(0.038)	(0.033)	(0.028)	(0.027)
Y_{t-1}	−0.052	−0.069*	−0.048**	−0.047**
	(0.033)	(0.039)	(0.023)	(0.021)
CF_t	0.117	0.142	0.135**	0.148**
	(0.081)	(0.088)	(0.068)	(0.065)
CF_{t-1}	0.024	0.066	−0.004	−0.050
	(0.094)	(0.091)	(0.037)	(0.037)
stk_t	0.173***	0.192***	−0.011	−0.022
	(0.056)	(0.044)	(0.053)	(0.077)
stk_{t-1}	−0.065***	−0.046***	0.023	0.011
	(0.022)	(0.017)	(0.032)	(0.035)
Observations	352	352	825	825
Instruments	87	87	87	87
CF χ^2 (p-value)	0.107	0.007	0.038	0.137
Stk χ^2 (p-value)	0.075	0.001	0.775	0.837
AR-(1)	0.000	0.051	0.003	0.002
AR-(2)	0.782	0.755	0.886	0.846
Hansen's (p-value)	0.782	0.635	0.278	0.186

Dynamic R&D regressions corresponding to the one-step systems GMM results in Table 3 on the Euler equation model with financial variables (columns 3 and 4) are estimated with one-step first difference GMM (columns 1 and 3) and two-step systems GMM (columns 2 and 4). The two-step systems GMM results are estimated with Windmeijer-corrected standard errors. All regressions are performed including time dummies. Heteroskedasticity robust standard errors in parenthesis.
One step first difference GMM estimates in columns 1 and 3, and two-step Windmeijer-corrected systems GMM estimates in columns 2 and 4. Instruments differenced equation are lagged levels dated $t-3$ to $t-4$ and instruments level equation are lagged differences dated $t-2$. The χ^2 tests are tests of the null that the sum of current and lagged cash flow and net stock issuance respectively is zero. The AR-tests are asymptotically normally distributed under the null hypothesis of no serial autocorrelation. The Hansen J-test is chi-square distributed under the null of exogenous instruments.
* Indicate significance at 10%.
** Indicate significance at 5%.
*** Indicate significance at 1%.

significant for large firms in the UK which imply less binding financing constraints. Large, Continental European firms on the other hand display R&D investment cash-flow sensitivity both contemporaneously and jointly. The small-firm samples for both the UK and Continental Europe reject the null hypothesis in terms of not meeting the target values of the baseline Euler equation model. Especially the UK small-firm sample displays large financial variable effects corroborating the new firm split in Section 4.3.

I also split the sample based on whether the firm pays dividend or not (e.g. Fazzari et al., 1988; Gilchrist and Himmelberg, 1995) and whether the firm is above or below the median of average cash-flow volatility (e.g. Bates et al., 2009).[8] Firms which do not pay dividend and are above the median of average cash-flow volatility are considered more likely to be financially constrained. The regression results following these two additional splits supply similar evidence as the small/large split in Table 5. Non-dividend paying firms and firms with above the median cash-flow volatility display joint internal as well as external equity dependence for high-tech firms in the UK but not for Continental European firms, also in line with the new firm estimates in Table 4.

In Table 6 I present additional GMM-estimators as further robustness of the pooled UK and Continental European results originally estimated with one-step systems GMM in Table 3 (columns 3 and 4). One-step first difference GMM estimates are presented in columns 1 and 3 of Table 6. First difference GMM is mentioned in the literature to suffer from a weak instrument problem since it only uses lagged level values as instruments which leads to imprecise estimates (Mairesse et al., 1999; Alonso-Borrego and Arellano, 1999). The first difference GMM estimates are clearly generating less precise estimates for the UK sample. Both joint-effects are no longer significant. The contemporaneous effects are also smaller in magnitude as well as having larger standard errors. The Continental European sample is less obviously affected by the lower precision of the first difference GMM-estimator. The two-step systems GMM-estimator results with Windmeijer-corrected standard errors, presented in columns 2 and 4 of Table 6, are very close to the one-step estimates of Table 3. Considering alternative lag lengths of the original one-step systems GMM estimates does not affect the results very much.

The results obtained in this section with one-step systems GMM appear to be robust to the choice of GMM-estimator and lag-length of the instruments.

5. Summary and implications

I estimate dynamic Euler equation models for UK and Continental European, high-tech firms separately. I find that new, high-tech firms in the UK experienced supply shifts in both internal and external equity during the late 1990s which enabled them to invest more in R&D resulting in increasing R&D-intensities. The supply shifts of equity only translated into a cash-flow effect for new, Continental European firms resulting in lower R&D-intensities than for their UK counterparts. Both high-tech firms in the UK and Continental Europe experienced increasing external equity and R&D ratios during the booming economy of the late 1990s.

The UK regression results are very similar to BFP's (2009) findings for the US Brown and Petersen (2009) suggest that equity market improvements have enabled young firms in the US to raise their share of R&D out of total investment during the period 1970–2006 (see Ascioglu et al., 2008 and Agca and Mozumdar, 2008 for evidence of US financial system development, and its impact, over time). A plausible explanation for the lacking external equity effect for Continental European countries is that their equity markets are less developed than in the US and the UK.

The findings of this paper open avenues for future research. The financing of R&D is potentially a link through which financial development affects economic growth. The findings here suggest that a market-based financial system supplies public equity to R&D-intensive firms otherwise facing difficulties obtaining external finance. By improving the depth of their equity markets, Continental European countries may very well facilitate the financing of high-tech R&D and fuel economic growth by relaxing financing constraints.

[8] These two additional sample splits are not reported due to space constraints.

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Appendix A. The variables and their Compustat Global abbreviations

rd_t: Research and development expenditure in period t (XRD) normalized by beginning of the period book value of total assets (AT).

y_t: Net sales in period t (SALE) normalized by beginning of the period book value of total assets (AT).

CF_t: Gross cash-flow in period t normalized by beginning of the period book value of total assets (AT). Gross cash-flow is defined as after-tax income before extraordinary items (IB) plus depreciation and amortization (DP) plus research and development expenditure (XRD).

stk_t: Net cash raised from stock issues (external equity) in period t normalized by beginning of the period book value of total assets (AT). Net cash raised from stock issues is defined as the sale of common and preferred stock (SSTK) minus the purchase of common and preferred stock (PRSTK).

dbt_t: New long-term debt (DLTT) in period t normalized by beginning of the period book value of total assets (AT). New long-term debt is defined as the difference between long-term debt in period t and long-term debt in period $t-1$.

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