Financing constraints and R&D investments of large corporations in Europe and the US

Michele Cincera and Julien Ravet

This paper explores the existence and importance of financing constraints for R&D investments in large EU and US manufacturing companies over the period 2000–2007. The main results obtained by estimating error-correction equations suggest that the sensitivity of R&D investments to cash flow variations are important for European firms while US firms do not appear to be financially constrained. In terms of policy implications, these results suggest improving the conditions for access to external capital to finance R&D activities in the EU.

The existence of capital market imperfections such as asymmetric information between lenders and borrowers affects the capital investment decisions of a firm and introduces possible financing constraints, i.e. credit rationing by lenders. Such constraints may actually be even more pronounced in the case of intangible investments such as R&D since these activities are more risky by nature and typically provide less collateral to lenders than do capital goods. Based on a representative sample of worldwide firms active in R&D activities over the recent period, this study aims to assess the existence and importance of financing constraints on the R&D investments of firms. In particular, the differences in the extent to which these constraints differ across firms between the EU and the US are examined.

The empirical analysis is based on a consolidated sample of large R&D active companies in the manufacturing and services sectors. The sources of this information are the successive editions of the EU Industrial R&D Investment Scoreboards (2004–2008) conducted by the Joint Research Centre–Institute for Prospective Technical Studies (JRC-IPTS) of the European Commission (European Commission, 2009). This source is matched with the Compustat database (2009) gathering financial information, including the cash flow of the firms. The final sample used in the empirical analysis consists of an unbalanced panel of 1,962 firms over 2000–2007 which is representative of about 80% of all R&D carried out in the private sector worldwide. All variables are presented using constant exchange rates and prices and R&D stocks are constructed for each firm on the basis of the perpetual inventory method (Griliches, 1979).

The model used to identify the potential liquidity of the constraints of the firms is an error-correction model (ECM) for R&D investment. This model is derived from the optimal level of R&D investment when considering a constant elasticity of substitution (CES) production function of a profit-maximising firm. Financing constraints are measured by the sensitivity of R&D investment decisions to cash flow, assuming that investments of firms that face liquidity constraints are more likely to be sensitive to the availability of internal finance.

This model is estimated using econometric methods for panel data. Traditional fixed-effect estimators...
Financing constraints and R&D investments of large corporations

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Review of issues and empirical findings

It is widely agreed in the literature that given the existence of asymmetric information between firms and lenders and other agency costs or moral hazard problems, investments in physical capital and more particularly in R&D must primarily be funded by the firms’ internal resources. On the theoretical side, Stiglitz and Weiss (1981) and Myers and Majluf (1984) developed formal models of moral hazard problems in debt and equity markets. On the empirical side, since the pioneering work of Fazzari et al. (1988), many studies have examined the extent of liquidity constraints in the financing of physical investment. Risk-averse R&D managers will under-invest in risky R&D projects and managers tend to spend on activities that benefit them. These agency costs between the shareholders and the R&D management can be avoided by leveraging the firm. However, the costs of the external funds to finance the R&D projects will be higher compared to the internal funds of the firms (Jensen and Meckling, 1976). In addition, by nature, investments in intangibles such as R&D are riskier than ordinary investments and R&D managers often have better information regarding the likelihood of the success of their R&D projects than outside investors or lenders. Furthermore, R&D investments provide less collateral to outsiders who cannot make accurate appraisals of the values associated with this type of investment. As a result, R&D firms may encounter credit rationing by potential lenders and may be constrained if they do not have enough internal resources to finance their R&D projects.

Besides the risks and uncertainties inherent in R&D activities, strategic considerations are another source of asymmetric information between the borrower and the lender. Inventors may indeed be reluctant to fully or partially disclose information to the outside world with regard to the contents and the objectives of their technological activities, since this knowledge could leak out to their competitors. This imperfect appropriability of the returns of innovative activities arises from the non-rival and the partially-excludable property of the knowledge good. Non-rivalry means that the use of innovation by an economic agent does not preclude others from using it, while partial excludability implies that the owner of an innovation cannot impede others from benefitting from it free of charge.

Another essential characteristic of R&D that makes it different from ordinary investment is the presence of high adjustment and sunk costs. The wages of the R&D personnel, for instance, represent more than 50% of R&D expenditures and training. Firing or re-hiring these highly specialised personnel embedded in the intangible asset of the firm implies substantial costs. Hence the levels of R&D expenditures associated with any innovation projects are unlikely to substantially change from year to year. This feature makes it difficult to empirically assess the relationship between possible liquidity constraints and expenses in R&D investments since the changes in the costs of this type of capital can be weak in the short term. More fundamentally, given these high adjustment costs, a firm may decide to start new R&D programmes only if they know that they will have sufficient resources to pursue the R&D from the very beginning of the project to its end. In that case, liquidity constraints should not be a concern for the decision of the firm to engage in R&D activities.

There have only been a few studies examining financing constraints and R&D. Hall (2005) and more recently Hall and Lerner (2010) provide an extended review of the literature about financing constraints. According to Hall and Lerner (2010), most authors in the empirical literature on financing constraints have relied on two main approaches based on investment equations. The first has been to use a neo-classical accelerator model that can be augmented...
with dynamics and transformed into an ECM. The second approach has been based on an Euler equation (see Harhoff, 1998). Hall and Lerner (2010) concluded their review by stating that there is evidence that:

...debt is a disfavored source of finance for R&D investment [...], Anglo-Saxon economies seem to exhibit more sensitivity and responsiveness of R&D to cash flow than continental economies [...] and this greater responsiveness may arise because they are financially constrained, in the sense that they view external sources of finance as much more costly than internal.

However, this responsiveness may also be related to demand signals in thick financial equity markets. Comparisons between financing constraints faced by US firms and European firms, and more specifically French firms were investigated for the mid-1980s and early 1990s by Hall et al. (1999) and Mulkay et al. (2001). Hall et al. (1999) indicate that investment and R&D are only sensitive to cash flow in the US, and show evidence of a positive impact of both investment and R&D in predicting sales and cash flow for US firms while the results are somewhat more mixed in France and Japan. Mulkay et al. (2001) did not find any significant differences (for both countries) in the effects of output on physical and R&D investments. Yet cash flow or profit appears to have a much greater impact on both types of investments in the US than in France. Hence, the impact of financial factors on investment and R&D does not differ within a country but rather across countries. This finding indicates that the financial market environment specific to a country matters in explaining the impact of financial factors on investment.

Hall (1992) and Himmelberg and Petersen (1994) have focused on US firms. The study by Hall (1992) explores the relationship between investment, R&D and cash flow for US firms by taking into account the specific unobserved fixed effects and simultaneity of firms. The results point to a positive impact of cash flow for both types of investments, although this effect is more significant for physical investment, thus indicating the presence of liquidity constraints in addition to future demand expectations. On the basis of a sample of 179 small US firms in high-tech industries, Himmelberg and Petersen (1994) estimated the relationship between R&D investment, physical capital and internal finance. Their results support the Schumpeterian hypothesis, which states that internal finance is an important determinant of R&D expenditures. As stressed by Arrow (1962), moral hazard problems hinder the external financing of highly risky business activities such as innovation. The absence of collateral value for investment as with R&D creates adverse incentives and selection problems in debt and equity markets.

Examples of studies carried out for European countries include: Harhoff (1998), Bond et al. (1999), Czarnitzki (2006), Bougheas et al. (2001), Cincera (2003) and Savignac (2008). Harhoff (1998) found an important sensitivity of R&D and investment to cash flow for accelerator and error-correction equations for German firms. Significant results are found for small firms only for the latter specification. No conclusion for R&D could be drawn from the Euler equation model, probably because the sample was too small for a precise estimation.

Results from Bond et al. (1999) lead one to conclude that financial constraints are significant in the UK economy while no effect is found for German firms, which can be explained by the institutional differences across the financial systems in the two countries. Furthermore cash flow has an impact on the decision to engage in R&D rather than on the levels of R&D expenditures.

Bougheas et al. (2001) tested the effect of liquidity constraints on the R&D investments of Irish companies. They also concluded that R&D investments in these companies are subject to liquidity constraints. This result is in line with the findings of previous studies examining UK and US companies.

Based on a sample of about 10,000 Belgian manufacturing firms over the last decade, Cincera (2003) compared financing constraints on both fixed tangible capital and R&D. The analysis was founded on two reduced form equations for investment: an accelerator and an ECM. Although the results indicated the presence of financial constraints on tangible as well as R&D investment, this effect was unexpectedly found to be smaller for R&D. The estimates also indicated that young firms, small firms, firms that are not part of a multinational company, firms that do not perform R&D on a permanent basis, firms that benefit from public funds to support R&D activities, and firms located in the Walloon region face higher financial constraints.

Czarnitzki (2006) used a modified price–cost margin as a proxy for internal funds of German small- and medium-sized enterprises (SMEs), while external financing constraints were measured by a lagged credit rating index. R&D expenditures of West German firms were found to be sensitive to internal and external resources while there was no evidence of financial constraints for East German firms. The role of public funding was shown to be relevant for R&D expenditures in both regions, with a greater relevance for East Germany.

Finally, Savignac (2008) used data on 1,940 French firms and provides evidence about the role of financing constraints in the decision to undertake innovative activities. A direct measure for financing constraints was obtained from the Financement de l’Innovation Technologique (FIT) survey. The author considers the decision to innovate and the likelihood to be financially constrained as two simultaneous issues. In order to address this endogeneity of
financing constraints to innovation decisions, a recursive bivariate probit model is estimated. Results show that the likelihood for a firm undertaking innovative activities decreases by more than 20% when the firm faces financial constraints.

Data

Appendix 2 presents the framework implemented for the econometric analysis. In order to estimate an ECM for R&D investments, we use data on net sales and R&D from the five EU R&D Investment Scoreboards editions issued every year between 2004 and 2008 by the JRC-IPTS. R&D data from the Scoreboards represent all R&D financed by the companies, regardless of the geographical localisation of R&D activities. Scoreboard data were collected from audited financial accounts and reports.8

Combining the Scoreboards resulted in a raw unbalanced panel of 16,553 observations for 2,696 firms (706 US firms and 1438 EU firms). Based on this sample, a matching procedure was conducted with the Compustat database in order to gather information about the cash flow of the companies.9 The cash flow variable is equal to the income before extraordinary items, which represents the income of a company after all expenses except provisions for common and or preferred dividends, plus depreciation and amortisation, i.e. the non-cash charges for obsolescence and wear and tear on property.10 The methodology for the matching between both data sources is documented in Cincera and Ravet (2010). The procedure involved matching 1,962 firms. Each monetary observation was converted into constant currency (in euros) and prices.11

The R&D stock was constructed by using a perpetual inventory method (Griliches, 1979). For each firm, the R&D stock at time \( t \) is defined by:

\[
C_t = (1 - \delta)C_{t-1} + R_t
\]

where \( \delta \) represents the depreciation rate of R&D capital and \( R \) is the deflated amount of R&D expenditures. The depreciation rate was set to 0.15, which is usually assumed in the literature.12 The initial value of \( C \) can be computed by using the following formula:

\[
C_0 = \frac{R_0}{g + \delta}
\]

where \( g \) is the growth rate of \( R \) and is assumed to be constant. The growth rates that are used in this study are the sample average13 growth rates of R&D expenditures in each two-digit industry classification benchmark.

In order to compare R&D investment liquidity constraints between Europe and the US, two samples of similar companies have been constructed for the EU and the US. Following Moncada-Paternò-Castello et al. (2009), size as measured by the amount of R&D investment in the firm is used as the criterion for matching similar firms. It turns out that the sample of the 1,962 firms among which 942 are from the EU and 525 from the US includes firms with different volumes of R&D investment. For the 2008 edition of the Scoreboard, the R&D investment threshold for the EU sub-sample is €4.35 million and that for the non-EU sub-sample €24.21 million. In order to construct sub-samples of comparable EU and non-EU companies, it is preferable to consider only companies with R&D investments above the US threshold. Finally, a trimming procedure was implemented to remove outliers (see Cincera and Ravet (2010)).

Table 1 presents some descriptive statistics for the variables used in the regression analyses with comparisons between the 27 Member States of the EU (EU-27) and the US. The global sample refers to the sample including both EU and US firms.

The average number of employees is large due to the nature of the R&D Scoreboards. The median number of employees is about 6,000 employees. We assume that this is a limitation in our analysis of financing constraints as large firms are expected to be less constrained compared to SMEs. However, this bias concerns both the European and US samples. The effect of having comparable samples in terms of size is shown in Table 1 and Table A1 (see Appendix 1). The companies in the matched samples look much more similar in terms of the distribution of quartiles and standard errors of the main variables used in the regression calculations.

Empirical findings

Basic results

Table 2 presents the system GMM results as regards the R&D investment ECM when all firms in the sample are considered. These estimates are obtained from a two-step procedure and different sets of instruments. Column 2 for instance uses as instruments two lagged and higher values of regressors while column 3 only consider three lagged and higher values. The validity of these additional instrumental variables when we move from column 3 to column 2 can be tested through the difference between Sargan or Hansen over-identification tests. Another strategy is to compare the results for these tests across models, i.e. columns. The null hypothesis is that the instruments are valid, i.e. they are uncorrelated with the error terms. Under the null hypothesis, the test statistic follows a chi-squared distribution with a number of degrees-of-freedom being equal to the number of over-identifying restrictions. Rejection of the null hypothesis casts a doubt on the validity of the set of instruments. This appears to always be the case for the Sargan test and only for the model in the second column for the
Hansen test. The second-order correlation test statistics do not suggest any problems with the time structure of the sets of instruments except again in column 2. With the exception of column 4, the error-correction term has the expected negative sign and is statistically significant at the 1% level. The coefficient of output lagged by two periods is negative and significant, albeit only slightly. This suggests the presence of slightly decreasing returns to scale. Cash flow effects have a positive and significant effect on investment (the long-term coefficient is about 0.489) and this indicates the presence of liquidity constraints. Finally, the positive and significant coefficients associated with the changes in output suggest positive expectations of future profitability to the extent that these variables are a proxy of the investment opportunities of a firm.

Table 3 compares the presence and extent of R&D financing constraints of EU and US firms. It should be noted that the different test statistics vindicate the use of the specification of column 3 for EU firms and columns 2–4 for US firms. The coefficients associated with the cash flow variables are positive and significant for the EU while for the US no evidence of liquidity constraints is found. Interestingly, these results are not in line with those found in previous studies that examined the R&D internal financing relationship.

**Discussion**

The main finding of this paper is that large European firms are subject to liquidity constraints in the financing of their R&D investments, whereas US ones do not appear to be financially constrained. This result is robust to different specifications of the R&D investment model, sub-samples of data, outliers, and econometric methods that address the heterogeneity and possible endogeneity of the variables of interest of the firms, i.e. cash flow and R&D. These different robustness checks are presented and discussed in Appendix 3.

These findings differ from those usually reported in the literature: that US firms appear more financially constrained (Hall et al., 1999; Mulkay et al., 2001; Bond et al., 1999). Many authors conclude that the impact of financial factors on investment and R&D differs across countries and not so much within a given country, hence suggesting that the financial market environment specific to a country, as well as institutional differences in financial systems, is important in explaining the impact of financial factors on R&D investments.15

Different factors may explain the difference between our findings and those in the literature. We now briefly discuss them. In sum, in our view, the main explanation for the divergence in results between this paper and previous studies is the period investigated. Our study is actually the only one which uses data after 2000; a period in which the world’s financial systems have undergone fundamental changes that may have affected the EU and the US differently.

Since the beginning of this decade, within the framework of the Lisbon process to transform the EU into a knowledge-based and more dynamic and

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**Table 1. Descriptive statistics**

<table>
<thead>
<tr>
<th>Variables</th>
<th>Region</th>
<th>Mean</th>
<th>Std.dev.</th>
<th>Quantile 25%</th>
<th>Quantile 50%</th>
<th>Quantile 75%</th>
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</thead>
<tbody>
<tr>
<td>$R_t / C_{t-1}$</td>
<td>Global</td>
<td>0.237</td>
<td>0.101</td>
<td>0.175</td>
<td>0.213</td>
<td>0.270</td>
</tr>
<tr>
<td></td>
<td>EU-27</td>
<td>0.229</td>
<td>0.103</td>
<td>0.169</td>
<td>0.206</td>
<td>0.257</td>
</tr>
<tr>
<td></td>
<td>US</td>
<td>0.245</td>
<td>0.099</td>
<td>0.182</td>
<td>0.221</td>
<td>0.283</td>
</tr>
<tr>
<td>$CF_t / C_{t-1}$</td>
<td>Global</td>
<td>0.835</td>
<td>1.277</td>
<td>0.236</td>
<td>0.454</td>
<td>0.932</td>
</tr>
<tr>
<td></td>
<td>EU-27</td>
<td>0.994</td>
<td>1.552</td>
<td>0.262</td>
<td>0.494</td>
<td>1.038</td>
</tr>
<tr>
<td></td>
<td>US</td>
<td>0.693</td>
<td>0.945</td>
<td>0.210</td>
<td>0.430</td>
<td>0.823</td>
</tr>
<tr>
<td>$y_t$</td>
<td>Global</td>
<td>7.248</td>
<td>1.693</td>
<td>5.971</td>
<td>7.183</td>
<td>8.435</td>
</tr>
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<td></td>
<td>EU-27</td>
<td>7.310</td>
<td>1.780</td>
<td>6.082</td>
<td>7.276</td>
<td>8.597</td>
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<tr>
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<td>7.186</td>
<td>1.599</td>
<td>5.909</td>
<td>7.089</td>
<td>8.310</td>
</tr>
<tr>
<td>$c_t$</td>
<td>Global</td>
<td>5.879</td>
<td>1.391</td>
<td>4.845</td>
<td>5.572</td>
<td>6.630</td>
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<td>EU-27</td>
<td>5.697</td>
<td>1.456</td>
<td>4.602</td>
<td>5.329</td>
<td>6.434</td>
</tr>
<tr>
<td></td>
<td>US</td>
<td>6.059</td>
<td>1.300</td>
<td>5.123</td>
<td>5.727</td>
<td>6.777</td>
</tr>
<tr>
<td>$\Delta y_t$</td>
<td>Global</td>
<td>0.074</td>
<td>0.221</td>
<td>-0.019</td>
<td>0.052</td>
<td>0.138</td>
</tr>
<tr>
<td></td>
<td>EU-27</td>
<td>0.056</td>
<td>0.214</td>
<td>-0.029</td>
<td>0.035</td>
<td>0.110</td>
</tr>
<tr>
<td></td>
<td>US</td>
<td>0.092</td>
<td>0.226</td>
<td>-0.008</td>
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<td>Employees</td>
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<tr>
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<td>US</td>
<td>19899</td>
<td>40924</td>
<td>1634</td>
<td>5600</td>
<td>18803</td>
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</table>

Large European firms are subject to liquidity constraints in the financing of their R&D investments, whereas US ones do not appear to be financially constrained.
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Table 2. System GMM two step estimates - all firms

<table>
<thead>
<tr>
<th>Instruments set</th>
<th>lag(2,.)</th>
<th>lag(3,.)</th>
<th>lag(4,.)</th>
</tr>
</thead>
<tbody>
<tr>
<td>$R_{t-1} / C_{t-2}$</td>
<td>-0.059 (0.108)</td>
<td>0.175 (0.071)**</td>
<td>0.400 (0.153)**</td>
</tr>
<tr>
<td>$\Delta y_t$</td>
<td>0.009 (0.112)</td>
<td>0.228 (0.115)**</td>
<td>0.111 (0.119)</td>
</tr>
<tr>
<td>$\Delta y_{t-1}$</td>
<td>0.019 (0.031)</td>
<td>0.037 (0.062)</td>
<td>0.018 (0.084)</td>
</tr>
<tr>
<td>$c_{t-2} - y_{t-2}$</td>
<td>-0.093 (0.034)***</td>
<td>-0.053 (0.02)***</td>
<td>0.002 (0.032)</td>
</tr>
<tr>
<td>$CF_t / C_{t-1}$</td>
<td>0.074 (0.033)**</td>
<td>0.061 (0.028)**</td>
<td>0.030 (0.020)</td>
</tr>
<tr>
<td>$CF_{t-1} / C_{t-2}$</td>
<td>0.013 (0.011)</td>
<td>-0.009 (0.010)</td>
<td>0.011 (0.019)</td>
</tr>
<tr>
<td>$y_{t-2}$</td>
<td>-0.078 (0.014)***</td>
<td>-0.048 (0.012)***</td>
<td>-0.025 (0.020)</td>
</tr>
</tbody>
</table>

Notes: *** statistically significant at 1% level
** statistically significant at 5% level
* statistically significant at 10% level

Estimation performed using xtabond2 (Roodman, 2006); all equations include time dummies, heteroskedastically-consistent standard errors in brackets, P values in square brackets

AR(1)’s and AR(2): tests for first-order and second-order serial correlation in first-difference residuals; two-step estimates; instruments used in column s ($s = 2, 3, 4$): observations dated $t - s$ to $t - 5$ for $X_t$ (transformed equation) and $t - s + 1$ for $\Delta X_t$ (equation in level)

competitive economy, several product market reforms have been put in place in the EU to catch up with the US, especially in the capital market (Cincera and Galgau, 2005). As a result, financial institutions face stronger competition and the conditions for borrowing money for investments, in particular for intangibles such as R&D, are more difficult.

The first decade of the 21st century has been a period with a lack of regulation in lending. This was one of the root causes of the recent burst of the financial bubble in the US and the ensuing worldwide financial and economic turmoil. This lack of regulation and the risks taken by banks may have alleviated the constraints on obtaining loans for investment projects and therefore firms investing in R&D may have been less concerned by financial constraints to fund their R&D investments, especially in the US.

R&D activities are riskier by nature and generally provide less collateral to lenders as compared to investments in capital goods. As a result, financing constraints may be even more pronounced in the case of such intangible investments. However, given the existence of high adjustment and sunk costs associated with this kind of investment, firms will engage in R&D activities if they do not expect to be seriously affected by financial constraints. As such, cash flow effects tend to matter less for large investors than for smaller companies. Moreover, the provision of public support to R&D may interfere with the investment decision of a firm by alleviating liquidity constraints problems, if they are present at all.

The outcome has been factors hampering R&D and innovation activities, exemplified by a scarcity of venture capital. There are also indications, corroborated by the empirical findings of our study that one of these factors, the difficulty in obtaining access to external sources of financing, has affected the EU more than the US.

Conclusion

Based on two newly constructed and comparable samples of EU and US private companies which represent the largest companies in the world, this paper investigated the impact of financing constraints on R&D investments over the first decade of this century. The results based on an error-correction equation have been obtained by using a system GMM estimator which, compared to the usual first-difference GMM estimator, usually produces more precise estimates and reduces the possible bias arising from the weak explanatory power of the instruments and high values of the autoregressive parameter.

Our main empirical findings indicate a positive impact of cash flow effects on the firms’ R&D investment decisions. However, they also suggest that only large EU R&D companies are facing liquidity constraints, not their large US R&D competitors. This finding is robust to alternative modelling strategies, econometric methods implemented and data subsamples. In terms of policy implications, these results suggest improving conditions in the EU for access to external capital, i.e. debt and equity. Policy-makers would do well to provide direct R&D support for these firms, i.e. tax incentives and R&D subsidies and
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Table 3. System GMM two-step estimates: EU-27 and US samples

<table>
<thead>
<tr>
<th>Instruments set</th>
<th>EU-27</th>
<th>US</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>lag(2,.)</td>
<td>lag(3,.)</td>
</tr>
<tr>
<td>$R_{t-1} / C_{t-2}$</td>
<td>-0.145 (0.065)**</td>
<td>-0.074 (0.159)</td>
</tr>
<tr>
<td>$\Delta y_t$</td>
<td>-0.181 (0.133)</td>
<td>-0.077 (0.071)</td>
</tr>
<tr>
<td>$\Delta y_{t-1}$</td>
<td>0.007 (0.052)</td>
<td>0.156 (0.071)**</td>
</tr>
<tr>
<td>$C_{t-2} / y_{t-2}$</td>
<td>-0.031 (0.044)</td>
<td>-0.083 (0.035)**</td>
</tr>
<tr>
<td>$CF_{t-1} / C_{t-2}$</td>
<td>0.073 (0.019)**</td>
<td>0.042 (0.020)**</td>
</tr>
<tr>
<td>$y_{t-2}$</td>
<td>0.031 (0.013)**</td>
<td>0.018 (0.015)</td>
</tr>
</tbody>
</table>

Notes: *** statistically significant at 1% level  
** statistically significant at 5% level  
* statistically significant at 10% level  
Estimation performed using xtabond2 (Roodman, 2006); all equations include time dummies, heteroskedastically-consistent standard errors in brackets, P values in square brackets  
AR(1) and AR(2): tests for first-order and second-order serial correlation in first-difference residuals; two-step estimates;  
instruments used in column s (s = 2,3,4): observations dated t − s to t − 5 for $X_t$ (transformed equation) and t − s + 1 for $\Delta X_t$ (equation in level)  

Further develop the availability of risk capital. Indirectly, clearer framework conditions in the EU, in particular for private equity should be achieved. However, in terms of direct support, it is not clear whether policy-makers should primarily allocate public resources to support large firms which are top R&D investors and allocate less to smaller companies as the former may be less concerned with financing constraints on funding their R&D investments than the latter. In order to further investigate this question, it would be useful to consider a larger sample which would include, besides large R&D corporations, small- and medium-sized R&D investors.

To some extent, the main results obtained in this paper contradict the findings of the existing literature on the subject. In our view, the main reason lies in the period considered for the regression analyses (the first decade of the 21st century in this study versus data before 2000 in other studies) as well as, possibly, conjectural and structural changes in the financial systems of the EU and the US before and after the passage to the new millennium, which need further investigation. A second explanation lies in the sample used in the present analysis, which consists of the largest R&D companies in the EU and in the US. It is not certain that the main conclusions of the paper will remain applicable when smaller firms are also considered. This question also deserves further investigation.

In order to better understand the relationship between R&D investing behaviours and financing constraints it would also be helpful to know more precisely the share of the different sources for the funding of R&D, i.e. internal financing, debt and issues of shares on the stock markets. Indeed, if firms in the EU are relying less on external sources compared with their US counterparts, then this could explain why EU firms are more sensitive to liquidity constraints.

Another interesting extension of this work would be to investigate which component of R&D investment, i.e. the ‘R’ vs. the ‘D’, is more financially constrained; the outsourced R&D abroad or the research carried out in the home country. Based on a longer history of data, it would be interesting to compare both periods in the EU and the US, i.e. 1990–1999 vs. 2000–2009 and investigate whether or not the importance and existence of liquidity constraints has changed over time and across the two regions.

Finally, while maintaining the important division between European and US companies, which occurs because of the very different business environments for R&D firms in the two regions, it may also be worth investigating groups of firms by sector of economic activity. The differences in financial constraints and management of R&D resources often differ significantly from one sector to another. Generally, differences are larger between sectors than between regions in the same sector of activity, particularly when considering multinational firms.
Appendix 1. Descriptive statistics

Table A1. Descriptive statistics on initial sample

<table>
<thead>
<tr>
<th>Variables</th>
<th>Region</th>
<th>Mean</th>
<th>Std.dev.</th>
<th>Quantile 25%</th>
<th>Quantile 50%</th>
<th>Quantile 75%</th>
</tr>
</thead>
<tbody>
<tr>
<td>$R_{t-1} / C_{t-2}$</td>
<td>Global</td>
<td>0.245</td>
<td>0.112</td>
<td>0.178</td>
<td>0.215</td>
<td>0.277</td>
</tr>
<tr>
<td></td>
<td>EU-27</td>
<td>0.244</td>
<td>0.123</td>
<td>0.172</td>
<td>0.212</td>
<td>0.273</td>
</tr>
<tr>
<td></td>
<td>US</td>
<td>0.247</td>
<td>0.101</td>
<td>0.182</td>
<td>0.222</td>
<td>0.286</td>
</tr>
<tr>
<td>$CF_t / C_{t-1}$</td>
<td>Global</td>
<td>0.907</td>
<td>1.335</td>
<td>0.256</td>
<td>0.478</td>
<td>1.007</td>
</tr>
<tr>
<td></td>
<td>EU-27</td>
<td>1.061</td>
<td>1.639</td>
<td>0.172</td>
<td>0.212</td>
<td>0.273</td>
</tr>
<tr>
<td></td>
<td>US</td>
<td>0.692</td>
<td>0.945</td>
<td>0.209</td>
<td>0.430</td>
<td>0.821</td>
</tr>
<tr>
<td>$y_t$</td>
<td>Global</td>
<td>6.963</td>
<td>1.906</td>
<td>5.707</td>
<td>7.017</td>
<td>8.267</td>
</tr>
<tr>
<td></td>
<td>EU-27</td>
<td>6.430</td>
<td>2.089</td>
<td>5.014</td>
<td>6.452</td>
<td>7.816</td>
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<tr>
<td></td>
<td>US</td>
<td>7.118</td>
<td>1.677</td>
<td>5.852</td>
<td>7.065</td>
<td>8.284</td>
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<tr>
<td>$c_t$</td>
<td>Global</td>
<td>5.462</td>
<td>1.602</td>
<td>4.425</td>
<td>5.362</td>
<td>6.391</td>
</tr>
<tr>
<td></td>
<td>EU-27</td>
<td>4.777</td>
<td>1.674</td>
<td>3.570</td>
<td>4.470</td>
<td>5.704</td>
</tr>
<tr>
<td></td>
<td>US</td>
<td>6.043</td>
<td>1.296</td>
<td>5.115</td>
<td>5.708</td>
<td>6.762</td>
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<tr>
<td>$\Delta y_t$</td>
<td>Global</td>
<td>0.081</td>
<td>0.238</td>
<td>-0.012</td>
<td>0.058</td>
<td>0.145</td>
</tr>
<tr>
<td></td>
<td>EU-27</td>
<td>0.066</td>
<td>0.253</td>
<td>-0.028</td>
<td>0.043</td>
<td>0.133</td>
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<td></td>
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<td>0.094</td>
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<td>Employees</td>
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<td>1324</td>
<td>5087</td>
<td>17725</td>
</tr>
<tr>
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<td>EU-27</td>
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<td>691</td>
<td>3101</td>
<td>11246</td>
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<tr>
<td></td>
<td>US</td>
<td>19576</td>
<td>40663</td>
<td>1556</td>
<td>5400</td>
<td>18100</td>
</tr>
</tbody>
</table>

Appendix 2. Econometric framework

This section presents the investment error-correction equation as well as the econometric methodology to be implemented for estimating the relationship between cash flow and R&D investments. As stressed by Hall and Lerner (2010), this is a standard methodology based on an investment equation. The methodological framework is close to that used by Harhoff (1998), Bond et al. (1999), Mairesse et al. (1999) and Mulkay et al. (2001). Following the neo-classical long-run model (Jorgenson, 1963), the logarithm of the desired (or long run) stock of capital is proportional to the logarithm of output and user cost of capital:

$$C_t = \alpha_t + \beta y_t - \sigma u c_{\alpha t}$$  \hspace{1cm} (1)

where $c$ is the logarithm of the stock of R&D, $y$ is
the logarithm of the sales and \( ucc \) is the logarithm of the user cost of capital. This model can be derived by assuming a profit-maximising firm with a CES production function with elasticity, \( \sigma \).

As noted by Mulkay et al. (2001), the user cost of capital:

\[
UCC_{it} = \left( P_{it}' / P_{it} \right) \left( r_{it} P_{it}' / P_{it} + \delta_{i} - \Delta P_{it}' / P_{it}' \right)
\]

is difficult to measure at the firm level given the absence (in general) of the output price \( P_{it} \) and investment price \( P_{it}' \) at such a disaggregated level. This problem is in general addressed by assuming that the variations in the user costs can be represented by time dummies and the specific fixed (long-term) effects of a firm.

In order to allow dynamic adjustments of R&D capital, we transform Equation (1) in an autoregressive distributed lag model ADL(2,2). This is a standard specification in the literature that is convenient for short period samples as it captures temporal dynamics without abusively dropping data in the estimations because of the lag variables. We obtain the following equation:

\[
c_{it} = \alpha_{i} + \alpha_{t} + \rho_{1} c_{i-1} + \rho_{2} c_{i-2} + \beta_{0} y_{it} + \beta_{1} y_{i,t-1} + \beta_{2} y_{i,t-2} + \epsilon_{it}
\]

Following Bond and Meghir (1994), Harhoff (1998) and Mulkay et al. (2001), this equation can be rewritten in an error-correction framework:

\[
\Delta c_{it} = \alpha_{i} + \alpha_{t} + \delta_{0} \Delta c_{i-1} + \delta_{1} \Delta y_{i,t} + \delta_{2} \Delta y_{i,t-1} + \delta_{3} \Delta y_{i,t-2} + \delta_{4} y_{i,t-2} + \epsilon_{it}
\]

where: \( \delta_{0} = \rho_{1} - 1, \delta_{1} = \beta_{0}, \delta_{2} = \beta_{0} + \beta_{1}, \delta_{3} = \beta_{1} + \beta_{2} + \rho_{2} - 1 \) and \( \delta_{4} = \beta_{2} + \beta_{3} + \rho_{2} - 1 \). \( \delta_{i} \) is the coefficient of the error-correction term and is expected to be negative. \( \delta_{4} \), if non-significant, indicates that returns to scales are constant.

By applying the usual approximation \( \Delta c_{it} \approx R_{it} / C_{it-1} - \delta \), with \( R \) being the R&D expenditures and \( \delta \) the depreciation rate of R&D capital, Equation (3) becomes:

\[
R_{it} / C_{it-1} = \alpha_{i} + \alpha_{t} + \delta_{0} R_{it-1} / C_{it-2} + \delta_{1} \Delta y_{i,t} + \delta_{2} \Delta y_{i,t-1} + \delta_{3} (y_{i,t-2} - y_{i,t-2}) + \epsilon_{it}
\]

Following the seminal work of Fazzari et al. (1988), if we assume that investments of credit-constrained firms are more sensitive to the availability of internal finance, Equation (4) can be augmented with cash flow effects (divided by one period lagged \( C \) for normalisation) to test for the presence of financial constraints. Hence, financial constraints can be assessed by analysing the sensitivity of R&D investments to variations in cash flow available to firms.
to be magnified when applying the first-difference or within-transformations (Griliches and Hausman, 1986). The two other sources of bias refer to the simultaneity between the contemporaneous regressors and the disturbances and the endogeneity of the contemporaneous regressors and the past disturbances. A solution to these three potential sources of biases consists of using an instrumental variable approach by choosing an appropriate set of lagged values of the regressors for the instruments. This approach can be implemented by means of a GMM framework such as the one developed by Arellano and Bond (1991) among others. If the original error term follows a white noise process, then values in levels of these variables lagged two or more periods will be admissible instruments. The validity of the instruments is generally verified by the classical Sargan test and Hansen test of the over-identifying restrictions.

More recently, Arellano and Bover (1995) and Blundell and Bond (1998) developed a system GMM estimator, which combines the instruments of the first-difference equation with additional instruments of the untransformed equation in level. Given the higher number of instruments, the system GMM estimator can lead to dramatic improvements in terms of efficiency compared with the first-difference GMM estimator. The validity of these additional instruments, which consist of past first-difference values of the regressors, can again be tested through difference by the Sargan over-identification tests.

Appendix 3. Robustness of results

This section discusses some alternative regression analyses performed to assess the robustness of the main results. The tables reporting these results available in Cincera and Ravet (2010). When a fixed effects model (within transformation) is estimated, only EU firms are subject to liquidity constraints; as for the US ones, the coefficients associated with the cash flow variables are not significantly different from zero. The Hausman test is statistically significant at the 1% level which rejects the null hypothesis of no correlation between the unobserved specific effects of the firms and the regressors, hence invalidating the random specification.

The results reported in this paper are obtained from two-step GMM estimators. One-step GMM estimators are calculated by weighting the moment conditions with an arbitrarily chosen matrix which does not depend on estimated parameters while two-step estimators use a weight matrix based on the consistent one-step estimation. Arellano and Bond (1991), Arellano and Bond (1998), Windmeijer (2005) and Roodman (2006) have shown that the one-step GMM estimator may be more reliable than the two-step one for statistical inference as the latter provide downward-biased asymptotic standard errors. However, Windmeijer (2005) developed a small-sample correction for the standard errors of two-step estimators that allows for more accurate inference. We used this correction for the reported two-step estimators. When a consistent one-step estimator is implemented for the EU sample, both the Sargan and Hansen tests reject the validity of the different sets of instruments used. Yet a positive coefficient is still observed for the cash flow variables. This is not the case for the US firms which once again do not appear to be financially constrained.

Estimating a simpler accelerator R&D investment specification leads one to the conclusion that only EU firms are sensitive to cash flow variations. We considered alternative specifications where only the current value of the cash flow variable, the one-year lagged value or the current, one-year and two-year lagged values of this variable are considered altogether. These specifications allow one to control for the presence of multi-collinearity which could alter the estimated coefficients of cash flow variables when different periods of this variable are introduced simultaneously in the specification. On the other hand, we also considered an additional lag of the cash flow–R&D capital ratio, i.e. $CF_{t-2}/C_{t-3}$. While the results as regards this specification are not conclusive for the US sample, on the whole, the findings clearly indicate that financing constraints are present for R&D companies in the EU.

As an additional test, we investigated the role played by the size of companies. Indeed, several studies have shown the central role played by the size of a firm in explaining the sensitivity of capital and R&D investment to cash flow variations. Small firms are more dependent upon internal resources since the loan rates charged by commercial banks tend to be higher. Conversely, larger firms can more easily finance capital expenditures from internal resources, issuance of equity or debt. In this study, we measure the size of a firm in two ways. First, a proxy for size is directly introduced in the specification, i.e. the number of employees at time $t$ and at time $t-1$. Secondly, the regression is performed on a subset of the largest companies, i.e. those with more than 1,000 employees. It should be noted that this results in a cut of the sample by about one-half.

For the EU companies, the results appear to be in line with these theoretical predictions as the magnitude of the estimated coefficient associated with the cash flow variables are somewhat smaller as compared with the results when the full sample is considered. For the US firms, again, no effect of liquidity constraints is detected except to some extent for the specification based on the sub-sample with the largest companies. Yet, in this case, the estimated effects appear to be much smaller than those obtained for the EU subset.

As an alternative to the cash flow variable, the operating profit of the firm is also considered to
proxy the internal available financial resources of a firm. This variable is defined as profit (or loss) before taxation, plus net interest cost (or minus interest cost) and government grants, less gains (or plus losses) arising from the sale/disposal of businesses or fixed assets. Here too the main conclusions are not altered when the operating profit is used as an alternative proxy for cash flow.

The last robustness check consists of estimating the R&D investment ECM for the EU-27 sample but without the UK companies. The rationale for this test is that the UK financial system may differ from the European continental one and be more similar to the US one. The results do not change our main conclusion: continental European R&D firms are more likely to be hit by financing constraints for their R&D investments than US ones.

Notes
1. The output of R&D activities consists of new products and processes, which are typically difficult to use as collateral. According to Himmelberg and Petersen (1994) who refer to Ackelof’s (1970) classic example of a car market with asymmetric information and adverse selection problems: ‘A potential buyer of a used car can, at relatively low cost, hire a mechanic to assess the car’s true quality. In contrast, a potential investor might have to hire a team of scientists to make an accurate appraisal of the potential value of a firm’s R&D projects.’
2. Capital market imperfections can prevent firms from accessing these external funds at least at the same costs than the internal resources. As stressed by Harhoff (1998): ‘If providers of finance face greater uncertainty with respect to R&D than to investment projects, they will require a higher lemon’s premium for the former type of investment. Hence, even without rationing behaviour on behalf of banks and other financial institutions, there will be a premium to be paid for obtaining external funding’.
3. As emphasised by Arrow (1962), given the time it takes to succeed, a typical R&D project involves important fixed set-up costs. This ‘indivisible’ aspect of R&D as an input view R&D activities mainly as a fixed factor of production.
4. In Belgium in 1995, the distribution of intramural R&D expenditures by type of costs was as follows: 58% for the R&D personnel, 9% for investment and 33% for the organisation of these activities (Cincera, 2005).
5. Schiantarelli (1996) and Hubbard (1998) provide reviews of the literature regarding the role of financial constraints on the investment activities of a firm on fixed capital. Mairesse et al. (1999) discuss and compare alternative modelling specifications, i.e. simple accelerator and error-correction specifications, as well as panel data econometric methodologies, i.e. traditionally between and within firm estimation versus GMM estimators, for estimating investment equations of a firm.
6. Quoting the authors: ‘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 unquoted, hostile takeovers are extremely rare, and dividend payout ratios tend to be lower and less rigid in German firms than in British firms.’
7. The FIT survey is based upon the technological innovation concept exposed in the Oslo Manual (OECD and EUROSTAT, 1997).
8. See Moncada-Paternò-Castello et al. (2009) for more details.
11. Reference year is 2007. Exchange rates and deflators are taken from EUROSTAT. We used the national gross domestic product deflators.
12. Bosworth (1978) has estimated the depreciation rate of R&D. The estimated range is 0.1–0.15. When testing different values for δ, Hall and Mairesse (1995) found little or no change in the estimation of the R&D capital effect.
13. The average growth rate for an industry is computed as the average of the distribution of individual growth rates inside the range [Q1 – 1.5(Q3 – Q1), Q3 + 1.5(Q3 – Q1)] where Q1 and Q3 are the first and third quartiles, respectively, of the distribution.
14. As pointed out by Roodman (2006), Sargent’s statistic is a special case of Hansen’s J test under the assumption of homoscedasticity. Therefore, for robust GMM estimation, the Sargan test statistic is inconsistent.
15. Another difference of our study is that the sample of EU countries includes almost all EU countries, not only Germany vs. UK or France vs. the US like in the other studies comparing micro-data from different countries. Finally, as pointed out by (Harhoff, 1998), large quoted EU firms are more subject to financing constraints. As a matter of fact, our sample also consists of very large EU companies, i.e. the largest R&D companies investing in the world.
16. See, however, Butzen et al. (2001) for an application that estimates the user cost of capital.
17. Approximation for \( \Delta C_R \):
\[
\Delta C_R \approx \log(C_{t+1}) - \log(C_{t}) = \log\left(\frac{C_{t+1}}{C_{t}}\right)
\]
18. However, for Fazzari et al. (2000), the theoretical model of Kaplan and Zingales fails to capture the approach used in this literature and therefore does not provide a relevant critique.
19. R&D opportunity or managerial skills may also be mentioned.
20. As noted by Bond et al. (1997), if the error term in levels is serially uncorrelated, then the error term in the first difference has a moving average structure of order 1 (MA(1)) and only instruments lagged two periods or more will be valid. If the error term in levels already has a moving average structure, then longer lags will have to be considered.
21. More fundamentally, as shown by Blundell and Bond (1998), when the autoregressive parameter is high and the number of time periods is low, the first-difference GMM estimator will be subject to serious finite sample bias as a result of the weak explanatory power of the instruments.
22. See Schiantarelli (1996) for a survey of the empirical literature on this subject.
23. See, for example, Stoll (1984) for the US credit market.

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