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# Do Liquidity Constraints Matter For R&D in the Pharmaceutical Industry?

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*This paper expands previous country focused studies of liquidity constraints for R&D within firms by considering several hundred firms in eleven OECD countries, using dynamic panel specification, and controlling for country specific institutional and financial environments. Cash flow has a positive effect on firms R&D: the estimated elasticity of R&D to cash flow is 0.36 at median values and this effect is more significant for young firms and firms with less than 500 employees. Firms with low investment prospects have lower sensitivity of their R&D to cash flow.*

**Field of Research:** Economics

**Keywords:** liquidity constraints, R&D, investment, pharmaceutical industry

**JEL classification:** O32, L65

## 1. Introduction

The Pharmaceutical industry is an important component of the health sector and the modern economy. Within the industry, innovation was recognised as the single most important factor of global competitiveness (Agrawal, 1999). However, the costs of discovery and development of new drugs is rapidly increasing. According to the US industrial association data (PhRMA, 2008, p.2), R&D costs per drug averaged $138 million in 1975; $318 million in 1987; $802 million in 2001; and US$1,318 million in 2005. According to an estimation of Bartfai and Lees (2006, pp.14,71), only 12.5% of all disease entities generate enough return on the investments of pharmaceutical firms and less then 6% of these diseases have blockbuster sales over one billion dollars.

Some researchers worry about decreasing productivity in the industry, leading to the coining of the phrase; 'innovation productivity paradox' in which rapidly growing R&D spending in the industry has little effect on the number of innovative drugs developed (Gassmann et al, 2008). Hall (2002) concluded that small and new innovative firms experience high costs of capital and even large firms prefer internal funds for the financing of R&D. Pisano (2006) points out that new biotech firms are financially constrained and a few unsuccessful drug candidates can lead to bankruptcy.

The next section reviews the literature on liquidity constraints for investment in general and as applied to the pharmaceutical industry. Section 3 explains the

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econometric approach, section 4 describes the data and reports estimated impacts of liquidity constraints on R&D, followed by a conclusion.

## 2. Literature Review

Hall (2002) summarizes several important features of R&D that can make the cost of external capital for an R&D project higher than the cost of cash generated through a firm's revenue:

- Asymmetric information between inventor and investor
- Moral hazard on the part of the inventor
- Tax deduction legislation that affects costs of servicing external debts
- Incomplete markets as debt-holders prefer physical assets as collateral to secure loans: sunk costs of R&D are usually higher than of physical investment.

Asymmetry of information is quite high in pharmaceuticals as the quality of a drug candidate can remain uncertain for several years until clinical trials are mostly completed. Moral hazard problems also naturally arise due to secrecy of information and incomplete disclosure of the relative efficacy of one drug versus another. Pharmaceutical R&D costs are often sunk, patented drugs markets are segmented and often have oligopolistic characteristics, and tacit knowledge and skills of scientists make it difficult to fire them. These disable the classical Hayashi's (1982) assumption that the average Tobin's Q sufficiently characterizes firm's investment opportunities and the importance of cash flow naturally emerges.

The seminal paper of Fazzari, Hubbard et al. (1988) points out the key role of cash flow in investment decisions of firms. Almeida, Campello et al. (2004) find that financially constrained firms save more cash from their own cash flow. Himmelberg and Petersen (1994) found a significant relationship between R&D and internal finance in a panel of 179 American small technological firms. They used fixed effect regression and estimated cash flow elasticities for R&D at 0.67.

However, determination of cash constrained firms is tricky. Hubbard (1998) warns that financially distressed firms can be presented as cash constrained ones. Allayannis and Mozumdar (2004) find that the regression results can be affected by a few influential observations of negative cash flow. The interpretation of a positive cash flow relationship with investment is also not clear as was evident in Gomes (2001), who argues that this relationship can be explained by expected profitability of investment. Cooper and Ejarque (2003) through a model with numerical simulations demonstrate that market power rather than capital market imperfections explain the positive relationship between investment and internal funds of firms.

Gomes (2001) argues that the significance of internal funds in investment regressions may reflect measurement error in Tobin's Q. Alti (2003) proposes a model to explain sensitivity of investment to cash flow for small and young firms through learning about their cash flow realizations. Bond, Klemm et al.

(2004) find that cash flow does not explain the investment decisions of firms if expected profitability predicted by securities analysts is used. The only problem of using securities analysts' forecasts is that we do not know how the original forecasts are obtained and also because analysts could use cash flow analysis in their forecasts.

Another important parameter affecting investment and R&D decisions is leverage; a ratio of liabilities to total assets. Modigliani and Miller (1963) show corporate taxes bring a positive relationship between leverage and the value of the firm due to tax deductions on debt repayment. However, high leverage can increase the risk of bankruptcy and increases risks for the return on equity. Carpenter and Petersen (2002, p.f59) argue that "for high-tech firms, the limited collateral value of assets, together with adverse selection, moral hazard, and financial distress should cause the marginal cost of debt to increase rapidly with leverage".

Szewczyk, Tsetsekos et al. (1996) find that average approximation for Tobin's Q is statistically significant in explaining abnormal returns connected to R&D projects, and that these returns are higher for leveraged firms. Because marginal Tobin's Q is unobservable, the average Q is proxied by price to book ratio. McConnell and Servaes (1995) detect the leverage has a negative impact on corporate value of the US firms with high Tobin's Q, but a positive impact on the value of firms with low Tobin's Q. Aivazian, Geb et al. (2005) find that leverage is negatively related to investment of Canadian firms. Ahn, Denis et al. (2006) find a negative impact of leverage on investment for diversified firms with high Tobin's Q.

Competition in pharmaceutical markets is often dynamic due to the introduction of new technology, imitation or generic products. Scherer (2007, p.39-40) noticed that in times of high abnormal profits, pharmaceutical firms increase R&D, but competition eventually reduces the profits with a subsequent decrease in R&D. A patent does not fully protect the profit of the innovator from imitative destruction. Philipson and Dai (2003, p.46) estimated that competition with newly patented drugs in the US reduces net present value of the original drug sales similarly or even greater than entry of drugs after patent expiration. According to Gassmann et al, (2008, p.16), the first entrant in respect to a class of drug usually takes a market share of 40-60%, the second entrant captures around 15%, whilst a third might not even recover its costs.

Several empirical studies have been devoted to R&D in the pharmaceutical industry. Hsieh, Mishra et al. (2003) used an IV regression technique and found positive associations between R&D intensity (R&D to firm's revenue) and performance indicators such as net margin, operating margin, sales growth, and Tobin's Q in respect to pharmaceutical and chemical industries.

Grabowski and Vernon (2000) using data on 11 firms specify an OLS regression of R&D divided by sales as a linear function of a contemporaneous index of expected returns to R&D, one year lagged cash flow divided by sales, and a dummy variable for each firm. Their estimations generate a coefficient before cash flow that is between 0.12 and 0.31. Vernon (2005) later criticized

this approach by pointing to the fact that firms have sustainably heterogeneous profit expectations. He proposed to replace the industry profit margin with the current period pre-tax profit margin. Vernon obtained statistically significant result for 14 US firms on a panel dataset over four years using OLS, fixed and random effects panel regressions.

The specification of Grabowski and Vernon might not provide a consistent estimate. Corrections are needed in case of persistence of R&D as OLS estimators are likely to be biased in this case. Hall and Hayashi (1989) empirically found persistency in R&D investment across a number of industries. As pharmaceutical R&D projects usually continue between 8 and 15 years, some persistency of R&D in the industry should be expected. In this regard, Mahlich and Roediger-Schluga (2006) consider a dynamic model that is estimated with systems GMM in regression of R&D intensity on cash flow. Their estimations for a panel dataset of Japanese pharmaceutical firms indicate little impact on sales with a positive coefficient for cash flow in the range of 0.027-0.062.

## 3. Empirical Methods and Expected Results

The GMM estimators for dynamic panel regressions are used in the following functional form:

$$Y_{it} = \alpha i + Y_{it-1}\beta_0 + (CF/K)_{it-1}\beta_1 + (Cash/K)_{it-1}\beta_2 + Q_{it-1}\beta_3 + (Sales/K)_{it-1}\beta_4 + (Debt/Assets)_{it-1}\beta_5 + Risk_{it}\beta_6 + log(Size)_{it}\beta_7 + M_{it}\mu_1 + Y_t\mu_2 + C_c\mu_2 + \varepsilon_{it}$$

where $Y_{it}$ is either the ratio of R&D to the total assets of firm $i$ at time $t$; $K$ – total assets of a firm; $CF$ – cash flow; $Q$ – Tobin's Q as proxied by market-to-book ratio; *Sales* are total sales; *Debt* - total liabilities; *Size* – a variable to control for a firm's size as proxied by logarithm of the number of employees, which could control for economies of scale and greater market information available on larger firms; $C_c$ – country dummies; $Y_t$ – year dummies; $\varepsilon_{it}$ - white noise. *Risk* is logarithm of ratio of a firm's highest stock price to its lowest stock price in a year, which is used as a proxy for market volatility; *Cash* – cash and cash equivalent holdings.

The $M_{it}$ term includes country specific time varying macroeconomic factors based on the World Bank World Development Indicators:

- *regquality* – regulatory quality in a country, percentile rank of the country from the World Bank Governance Indicators for 1996-2007, available at <www.govindicators.org>.
- *crtoprivate* - domestic credit to private sector, percent of GDP, which reflects availability of external capital.
- *population* – total population to account for the market size, million.

Based on the literature review, I expect the coefficients for cash flow to be positive, and the coefficients for debt and risk must be negative. A consistent estimation of the coefficients in this dynamic panel specification can be performed with an Arellano and Bond (1991) difference GMM method and the

system GMM method of Blundell and Bond (1998). The system GMM combines the moment conditions for the first difference model with level moments and has less bias if the series are close to a random walk. The key assumption is that $\varepsilon_{it}$ are independent across firms.

Implementation of the estimations is performed with Stata software using the xtabond2 program developed by Roodman (2006). Bond (2002) explains that a within group estimator is often biased downwards in panel data with small time periods, whereas the OLS levels estimator is biased upwards in large samples and this can be used to estimate the possible range for a parameter. I use both difference and system GMM and the dependent variable lagged at *t-2, t-3* and further lags as the GMM instrument, and year dummies as IV instruments.

## 4. The Data and Estimations

Firm level indicators have been extracted from an Orbis$^{TM}$ dataset of financial indicators for pharmaceutical companies in eleven OECD countries (Table 1). I use an unbalanced panel data of quoted pharmaceutical firms from eleven countries for the period 1997-2007. The value variables are in Euros adjusted by annual exchange rates into Euros.

**Table 1. Percent of observations in the dataset by countries**

| Country | Frequency | Share, percent | Cumulative |
|---|---|---|---|
| Belgium | 7 | 0.97 | 0.99 |
| Denmark | 20 | 2.78 | 3.80 |
| France | 14 | 1.95 | 5.77 |
| Germany | 73 | 10.15 | 16.06 |
| Ireland | 7 | 0.97 | 17.04 |
| Japan | 164 | 22.81 | 40.14 |
| Netherlands | 9 | 1.25 | 41.41 |
| Sweden | 14 | 1.95 | 43.38 |
| Switzerland | 16 | 2.23 | 45.63 |
| United Kingdom | 69 | 9.6 | 55.35 |
| USA | 317 | 44.09 | 100.00 |

The majority of data come from German, Japanese and American companies. The median share of R&D and investment in cash flows of firms is 0.464, i.e. roughly half of a firm's cash flows were spent on R&D and investment. The R&D data have some persistency and most of the variance comes between groups (Table 2). Correlation between cash flow and R&D expenditures scaled by total assets is 0.78 across all firms in the sample.

**Table 2. Descriptive statistics of firms' indicators**

| Variable | Panel | Mean | Std. dev. | Minimum | Maximum | Observations |
|---|---|---|---|---|---|---|
| *cashta* | overall | .184 | .244 | 0 | .971 | 16313 |
| | between | | .227 | 0 | .969 | 2465 |
| | within | | .104 | -.439 | .929 | 6.617 |
| *cashflta* | overall | .005 | .224 | -1.238 | .451 | 14532 |
| | between | | .211 | -1.116 | .408 | 2215 |
| | within | | .119 | -1.013 | .838 | 6.5607 |
| *saleta* | overall | 1.169 | 1.082 | 0 | 6.267 | 13678 |
| | between | | 1.054 | .00007 | 5.905 | 2135 |
| | within | | .341 | -2.332 | 4.889 | 6.406 |
| *lemp* | overall | 5.896 | 1.949 | 0 | 12.737 | 12722 |
| | between | | 1.904 | 0 | 12.641 | 2224 |
| | within | | .464 | -1.097 | 9.958 | 5.723 |
| *debta* | overall | .451 | .339 | .00008 | 3.538 | 8032 |
| | between | | .285 | .0007 | 2.965 | 1166 |
| | within | | .222 | -1.172 | 2.853 | 6.888 |
| *rdasn* | overall | .183 | .254 | -1.865 | -.00002 | 4924 |
| | between | | .216 | -1.753 | -.00005 | 751 |
| | within | | .156 | -1.535 | .654 | 6.556 |
| *risk* | overall | .644 | 1.314 | -9.791 | 11.239 | 5699 |
| | between | | 1.181 | -7.762 | 5.444 | 1053 |
| | within | | .508 | -2.987 | 8.797 | 5.412 |
| *employs* | overall | 2888 | 13642 | 1 | 340000 | 12722 |
| | between | | 10629 | 1 | 309400 | 2224 |
| | within | | 2014 | 0 | 63480 | 5.722 |
| *pbookr* | overall | 3.707 | 4.207 | .14 | 33.08 | 5007 |
| | between | | 3.504 | .17 | 28.01 | 965 |
| | within | | 2.650 | 0 | 25.351 | 5.188 |
| *regquality* | overall | 77.727 | 23.291 | 14.15 | 100 | 29190 |
| | between | | 22.877 | 20.927 | 99.334 | 2656 |
| | within | | 4.365 | 39.551 | 112.262 | 10.992 |
| *crtoprivate* | overall | 111.962 | 53.984 | 2.457 | 326.983 | 25648 |
| | between | | 51.196 | 12.972 | 199.645 | 2607 |
| | within | | 16.308 | 24.848 | 301.062 | 9.838 |
| *population,* | overall | 126 | 111 | 3.673 | 299 | 26220 |
| million | between | | 111 | 3.923 | 286 | 2631 |
| | within | | 4.73 | 112 | 139 | 9.968 |

*Note: cashta* – ratio of cash and cash equivalent holdings to total assets; *cashflta*– ratio of cash flow to total assets; *saleta* – ratio of sales to total assets; *debta* – ratio of total liabilities and debt to total assets; *rdasn* – ratio of R&D expenditures to total assets, which characterizes R&D intensity; *risk* – logarithm of ratio of a firm's highest stock price to its lowest stock price in a year; employs – number of employees in a firm; *lemp* – logarithm of the number of employees in a firm; *pbookr* – price-to-book ratio of a firm's assets, a proxy for the average Tobin's Q.

The same specification was used to estimate the coefficients with robust standard deviations by four methods: pooled cluster OLS, panel within estimator, difference and system GMM (Table 3). Both Sargan and Hansen tests for overidentified restrictions indicate the orthogonality conditions of the difference GMM estimator failed to be rejected, which implies that the instruments are likely to be valid and not correlated with the errors. The Sargan test for the system GMM rejects the null, but coefficients for the regressors are quite close to the difference GMM estimations. Wald and F statistics reject the null hypothesis of joint insignificance of the coefficients.

Given the test statistics for the Arellano-Bond test AR(1) in first differences, I reject the null of no serial correlations in errors, but failed to reject it for the

second order AR(2) correlations, which confirms validity of the used instruments and suggests in favour of a proper specification.

**Table 3. Regression results for R&D intensity in the global industry**

| | Pooled cluster OLS | Panel within estimator | Difference GMM | System GMM |
|---|---|---|---|---|
| R&D to assets, *rdasn* at *t-1* | .145*** | .048 | -.022 | -.005 |
| | (.031) | (.033) | (.046) | (.044) |
| Cash flow to assets, *cashflta* | .374*** | .339*** | .557*** | .559*** |
| | (.030) | (.028) | (.149) | (.143) |
| Cash to assets, *cashta* | -.066*** | .006 | .6894* | .713* |
| | (.020) | (.024) | (.379) | (.378) |
| Sales to assets, *saleta* | -.071*** | -.136 | -.203 | -.151 |
| | (.019) | (.021) | (.198) | (.184) |
| Price-to-book ratio, *pbookr* | -.003*** | -.0025** | .008 | .013 |
| | (.001) | (.001) | (.008) | (.009) |
| Debt to assets, *debta* | -.004 | -.031 | -.131 | -.101 |
| | (.021) | (.025) | (.201) | (.246) |
| Logarithm of number of employs, *lemp* | -.002 | -.0135* | .132 | .1363** |
| | (.003) | (.008) | (.119) | (.067) |
| *Risk* | -.007* | -.008 | .049 | .039 |
| | (.004) | (.004) | (.048) | (.046) |
| Regulatory quality, *regquality* | -.001 | -.001* | -.034* | -.022* |
| | (.001) | (.0004) | (.019) | (.012) |
| Credit to private sector, *crtoprivate* at *t-1* | -.0001 | .0001 | .0002 | .0002 |
| | (.0003) | (.0003) | (.005) | (.003) |
| *Population*, at *t-1* | -0.001 | -0.001 | -0.004 | -0.001 |
| | (0.001) | (0.001) | (0.016) | (0.001) |
| Intercept | .1762*** | .409*** | | 1.031 |
| | (.0604) | (.152) | | (.779) |
| Year and country dummies are included | | | | |
| Arellano-Bond test AR(1) | | | 0.018 | 0.008 |
| Arellano-Bond test AR(2) | | | 0.868 | 0.513 |
| Sargan test of overidentified restrictions, p-value | | | 0.591 | 0.056 |
| Hansen test of overidentified restrictions, p-value | | | 0.966 | 0.995 |
| Difference-in-Hansen tests of exogeneity of instrument subsets, p-value | | | 0.870 | 0.955 |
| Difference test of exogenous instruments | | | 0.953 | 0.995 |
| Wald $chi^2$ or F-test | 29697.66 | 15.68 | 95.89 | 137.7 |
| $R^2$ (within) | 0.32 | 0.38 | | |
| Number of firms | 482 | 482 | 415 | 482 |
| Number of observations | 2125 | 2125 | 1555 | 2125 |

Note: t-statistics are shown in parentheses. Significance levels in a two-tailed test:
*** at the 1%, 0.01 level, ** - 5%, * - 10%.

Cash flow to assets shows positive and significant coefficients in all four estimations, which herald the cash sensitivity of R&D. The elasticity point estimation at the median value of the R&D expenditures, cash flows, and assets in the sample shows that 10% growth of cash flow leads to 3.6% growth in R&D expenditures. The positive coefficients for cash holdings suggest that the companies with higher cash are likely to spend more on R&D too. However, the causality might be reversed: companies planning significant

R&D projects tend to accumulate larger cash holding. Coefficients for regulatory quality suggest negative relationship with R&D to assets, which can be explained by the stringency of government regulations.

Because it is empirically hard to identify firms with liquidity constraints (Moyen 2004), I use several criteria for such identification and estimate the cash flow coefficients for several definitions of cash constraint firms. I check cash flow sensitivity of R&D for the following indications of likely financially constraint firms using difference GMM estimations (Table 4):

**Table 4. Difference GMM estimations for different subsets of firm-years**

| | Indications of the liquidity constraints | | | | | |
|---|---|---|---|---|---|---|
| | (1) | (2) | (3) | (4) | (5) | (6) |
| R&D to assets, *rdasn* at *t-1* | .029<br>(.079) | -.100<br>(.079) | -.008<br>(.060) | -.053<br>(.105) | .435***<br>(.062) | -.039<br>(.182) |
| Cash flow to assets, *cashflta* | .748***<br>(.194) | .141<br>(.117) | .275***<br>(.055) | .373*<br>(.197) | .705***<br>(.109) | .094*<br>(.055) |
| Cash to assets, *cashta* | .786<br>(.4906) | -.063<br>(.0927) | .095<br>(.073) | .013<br>(.144) | -.206***<br>(.054) | -.108<br>(.116) |
| Sales to assets, *saleta* | -.564<br>(.357) | -.145<br>(.108) | .010<br>(.078) | -.189<br>(.192) | -.546***<br>(.103) | -.049<br>(.044) |
| Price-to-book ratio, *pbookr* | .018<br>(.017) | -.005<br>(.003) | -.003<br>(.003) | .021<br>(.018) | .023***<br>(.005) | -.001<br>(.002) |
| Debt to assets, *debta* | -.243<br>(.379) | -.152**<br>(.065) | .031<br>(.054) | -.347<br>(.395) | .242***<br>(.085) | -.019<br>(.045) |
| Logarithm of number of employees, *lemp* | .148<br>(.164) | .002<br>(.037) | -.001<br>(.053) | .118<br>(.178) | -.352***<br>(.119) | .034*<br>(.019) |
| *Risk* | .028<br>(.064) | -.008<br>(.019) | .016<br>(.019) | .011<br>(.029) | -.014<br>(.009) | -.021<br>(.015) |
| Regulatory quality, *regquality* | .0234<br>(.0806) | -.0017<br>(.0049) | .0005<br>(.0023) | .0172<br>(.0136) | .004<br>(.004) | -.001<br>(.002) |
| Credit to private sector, *crtoprivate* at *t-1* | .007<br>(.017) | -.0001<br>(.001) | -.0005<br>(.001) | .004<br>(.005) | .002<br>(.002) | .0003<br>(.001) |
| *Population*, at *t-1* | -0.041<br>(0.054) | -0.002<br>(0.004) | 0.001<br>(0.006) | -0.011<br>(0.027) | 0.004***<br>(0.001) | -0.002<br>(0.004) |
| Arellano-Bond test AR(1) | 0.088 | 0.051 | 0.073 | 0.246 | 0.243 | 0.246 |
| Arellano-Bond test AR(2) | 0.302 | 0.822 | 0.332 | 0.248 | 0.500 | 0.958 |
| Sargan test of overidentified restrictions, p-value | 0.982 | 0.000 | 0.408 | 0.575 | 0.937 | 0.167 |
| Hansen test of overidentified restrictions, p-value | 0.927 | 0.775 | 0.736 | 0.577 | 1.000 | 0.329 |
| Difference-in-Hansen tests of exogeneity of instruments, p-value | 0.934 | 0.599 | 0.590 | 0.454 | 1.000 | 0.278 |
| Difference test of exogenous instruments | 0.573 | 0.836 | 0.713 | 0.616 | 0.999 | 0.445 |
| Wald $chi^2$ or F-test | 89.84 | 34.61 | 63.14 | 86.78 | 7537 | 337.7 |
| Number of firms | 125 | 171 | 258 | 131 | 19 | 34 |
| Number of observations | 308 | 678 | 871 | 243 | 37 | 95 |

Note: R&D to assets is the dependent variable. Numbers at the top heading of the table corresponds to the liquidity constraint definitions.
t-statistics are shown in parentheses. Significance levels in a two-tailed test:
*** at the 1%, 0.01 level, ** - 5%, * - 10%.

(1) for small firms with a maximum of100 employees
(2) for large firms with a minimum of 500 employees

(3) excluding firm-years with negative cash flows as negative cash flows could be a sign of accelerating expenditures or financial distress
(4) firms with Tobin's Q less than one as proxied by price-to-book ratio, which implies firm-years with low investment opportunities
(5) for young firms with established fifteen or less years ago
(6) for firms with bottom half of the dividends to after tax income payout ratio, which is less than 0.144.

The sensitivity of R&D to cash flow is higher for smaller firms (0.75) than for all firms - 0.56, whereas the cash flow sensitivity for large firms is becoming statistically insignificant. For larger firms debt burden appears to play a more negative role in their R&D decisions. If we exclude firms with negative cash flows, the sensitivity of R&D to cash flow is still statistically significant, but much smaller - 0.27.

Firms with low investment prospects as proxied by less than one price-to-book ratio also have reduced sensitivity of their R&D to cash flow. Young firms have higher sensitivity of R&D to cash flow. Young firms have significant sensitivity of their R&D to price-to-book ratio and they seem to finance their R&D with debt while having a negative relationship of R&D with the number of employees, sales, and cash holdings. This is a typical situation for biotech start ups. Cash constraint firms with a lower dividend payout ratio tend to spend much less out of cash flow on R&D, which suggests that such firms have a poorer business performance.

## 5. Conclusion

Cash flow has a positive effect of firms R&D in the sample and across several subsamples of definitions for the likely financially constrained firms. The estimated point of elasticity of R&D to cash flow is 0.36 at median values and this effect is more significant for young firms and firms with less than 500 employees. Firms with low investment prospects as proxied by less than one price-to-book ratio or by lower dividend payout ratio have lower sensitivity of their R&D to cash flow.

Pharmaceutical companies with higher cash holdings are likely to spend more on R&D too, but causality might be reversed: companies planning significant R&D projects tend to accumulate larger cash holding. The uncovered negative relationship of regulatory quality with R&D to assets ratio is likely to be explained by higher risks of R&D due to the stringency of the government cost-containment controls.

## References

Agrawal, M 1999, *Global competitiveness in the pharmaceutical industry: The effect of national regulatory, economic, and market factors*, Pharmacuetical Products Press, New York.

Ahn, S, Denis, D and Denis, DK 2006, 'Leverage and investment in diversified firms', *Journal of Financial Economics*, vol. 79, pp. 317–337.

Aivazian, V, Geb, Y and Qiu, J 2005, 'The impact of leverage on firm investment: Canadian evidence', *Journal of Corporate Finance*, vol. 11, pp. 277– 291.

Allayannis, G and Mozumdar, A 2004, 'The impact of negative cash flow and influential observations on investment–cash flow sensitivity estimates', *Journal of Banking & Finance*, vol. 28, pp. 901–930.

Almeida, H and Campello, M 2007, 'Financial constraints, asset tangibility, and corporate investment', *The Review of Financial Studies*, vol. 20, no. 5, pp. 1429-1460.

Alti, A 2003, 'How sensitive is investment to cash flow when financing is frictionless?', *Journal of Finance*, vol. 58, pp. 707–722.

Arellano, M and Bond, S 1991, 'Some tests of specification for panel data: Monte Carlo evidence and an application to employment equations', *Review of Economic Studies*, vol. 58, pp. 277-297.

Bartfai, T and Lees, G 2006, *Drug discovery: from bedside to Wall Street*, Elsevier Academic Press, London.

Blundell, R and Bond, S 1998, 'Initial conditions and moment restrictions in dynamic panel data models', *Journal of Econometrics*, vol. 87, pp. 115-143.

Bond, S 2002, *Dynamic panel data models: a guide to micro data methods and practice*, Working Paper CWP09/02, Centre For Microdata Methods And Practice, London.

Bond, S, Klemm, A, Newton-Smith, R, Syed, M, and Vlieghe, G 2004, The roles *of expected profitability, Tobin's Q and cash flow in econometric models of company investment*, Working Paper no. 222, Bank of England, London.

Carpenter, R and Petersen, B 2002, 'Capital market imperfections, high-tech investment, and new equity financing', *The Economic Journal*, vol. 112, no. 477, pp. F54-F72.

Cooper, R and Ejarque, J 2003, 'Financial frictions and investment: requiem in Q', *Review of Economic Dynamics*, vol. 6, pp. 710-728.

Fazzari, S, Hubbard, G, and Petersen, B 1988, 'Financing constraints and corporate investment', *Brookings Papers on Economic Activity*, no.1, pp. 141-206.

Gassmann, O, Reepmeyer, G and von Zedtwitz, M 2008, *Leading pharmaceutical innovation,* Springer-Verlag, Berlin.

Grabowski, H and Vernon, J 2000, 'The determinants of pharmaceutical research and development expenditures', *Journal of Evolutionary Economics,* vol. 10, pp. 201-215.

Gomes, J 2001, 'Financing investment', *American Economic Review*, vol. 91, no. 5, pp. 1263–1285.

Hall, B 2002, 'The financing of research and development', *Oxford Review of Economic Policy*, vol. 18, no.1, pp. 35-51.

Hall, B and Hayashi, F 1989, Research and development as an investment, NBER Working Paper no. 2973, National Bureau of Economic Research, Cambridge.

Hayashi, F 1982, 'Tobin's average Q and marginal Q: a neoclassical interpretation', *Econometrica*, vol. 50, pp. 213-224.

Himmelberg, C and Petersen, B 1994, 'R & D and internal finance: a panel study of small firms in high-tech industries', *The Review of Economics and Statistics*, vol. 76, no.1, pp. 38-51.

Hsieh, PH, Mishra, C, and Gobeli, D 2003, 'The return on R&D versus capital expenditures in pharmaceutical and chemical industries', *IEEE Transactions on Engineering Management*, vol. 50, no. 2, pp. 141-149.

Hubbard, G 1998, 'Capital-market imperfections and investment', *Journal of Economic Literature*, vol. 36, no.1, pp. 193-225.

Kaplan, S and Zingales, L 1997, 'Do financing constraints explain why investment is correlated with cash flow?', *Quarterly Journal of Economics*, vol. 112, pp. 169-215.

Mahlich, J and Roediger-Schluga, T 2006, 'The determinants of pharmaceutical R&D expenditures: evidence from Japan', *Review of Industrial Organization*, vol. 28, pp. 145-164.

McConnell, J and Servaes, H 1995, 'Equity ownership and the two faces of debt', *Journal of Financial Economics*, vol. 39, pp. 131-157.

Modigliani, F and Miller, M 1963, 'Corporate income taxes and the cost of capital - a correction', *American Economic Review*, vol. 53, no.3, pp. 433-43.

Philipson, T and Dai, C 2003, 'Between- vs. within-patent competition', *Regulation*, vol. 26, no. 3, pp. 42-48.

PhRMA, 2008, *Pharmaceutical industry: profile 2008,* The Pharmaceutical Research and Manufacturers of America, Washington, D.C.

Pisano, G 2006, *Science business: the promise, the reality, and the future of biotech*, Harvard Business School Press, Boston.

Roodman, D 2006, '*How to do xtabond2: an introduction to "Difference" and "System" GMM in Stata'*, Working Paper Number no.103, Center for Global Development, Washington, D.C.

Scherer, F 2007, *The political economy of patent policy reform in the United States*, Working Paper no. RWP07-042, Kennedy School of Government, Harvard University, Cambridge.

Szewczyk, S, Tsetsekos, G, and Zantout, Z 1996, 'The valuation of corporate R&D expenditures: evidence from investment opportunities and free cash flow', *Financial Management*, vol. 25, no.1, pp.105-110.

Vernon, J 2005, 'Examining the link between price regulation and pharmaceutical R&D investment', *Health Economics*, vol. 14, pp. 1-16.