R&D Intensity and Finance: Are Innovative Firms Financially Constrained?

by

Ward Brown

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Ward Brown is in the Economics Department at the London School of Economics and is also a Research Officer at the Financial Markets Group.

R&D Intensity and Finance: Are Innovative Firms Financially Constrained?

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The assumption of perfect capital markets is least likely to be satisfied for the class of firms which devote resources towards the development of innovative products or processes. Existing tests of the impact of capital market imperfections on innovative firms cannot distinguish between two alternative hypotheses: (i) that capital markets are perfect, and that different factors drive the firm's different expenditures, and (ii) that capital markets are imperfect, and that the different expenditures of the firm repond disproportionately to a common factor, namely shocks to the supply of internal finance. However, an implication of the perfect capital markets assumption is that each of the firm's expenditures should be equally insensitive to fluctuations in internal finance. Therefore, to distinguish between these hypotheses, the sensitivity of physical investment expenditures to internal finance is compared across innovative and non-innovative firms. For robustness, several investment equations are esitmated. The results support the hypothesis that innovative firms are financially constrained.

KEYWORDS: Investment, R&D , Financing Constraints

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[1] The author is affiliated to the Department of Economics and Financial Markets Group, London School of Economics, London WC2A 2AE. The advice and comments of Steve Bond, Martin Evans and Ian Tonks have been most helpful at all stages of this project. The author gratefully acknowledges the financial assistance of the Financial Markets Group.

1 Introduction

Arguably, the class of firms for which the assumption of perfect capital markets is least likely to be satisfied is the class of innovative firms - firms which devote resources towards the production of innovative products or processes. For this reason economists have long thought that a firm's supply of internal finance will be one of the main determinants of its R&D expenditures. However, there is little empirical support for this belief. R&D expenditures are far less sensitive to fluctuations in internal finance than are physical investment expenditures. Moreover, changes in R&D are highly persistent, and have been found to be correlated with highly persistent changes in cash flow and investment, as well as with large movements in the firm's market value. In their survey of the R&D literature, Kamien and Schwartz (1982) concluded that "the empirical evidence that either liquidity or profitability are conducive to innovative effort or output appears slim".

These findings are consistent with the assumption of perfect capital markets, together with the hypothesis that different expenditures are driven by different factors. However, they is also consistent with the alternative hypothesis that financially constrained firms adjust different expenditures disproportionately in response to a common factor, namely changes in supply of internal finance. Innovative firms may choose to smooth R&D expenditures by using other expenditures as a buffer against fluctuations in internal finance, either because the costs of adjusting R&D are higher or because the elasticity of the marginal benefit to R&D is higher than that of other factors of production.

Simply by comparing the statistical properties of the R&D and investment processes, it is not possible to distinguish between these hypotheses. However, an implication of the perfect capital markets assumption is that each of the firm's expenditures should be equally insensitive to fluctuations in the firm's supply of internal finance. Therefore, a possible test is to compare the sensitivities to internal finance of all investment expenditures of innovative firms with those of non-innovative firms.

In this paper only the physical capital investment expenditures of a panel of UK firms are examined.[1] To split the sample into innovative and non-innovative classes, a measure of firm R&D intensity is used. Then empirical investment equations are fit to the data on physical investment for each sub-sample separately. For robustness, three investment equations are estimated. Two of these are derived from the Adjustment Costs model of investment, Tobin's Q equation and the Euler equation corresponding to the model, and the third is an Accelerator investment equation.

The results are consistent with the alternative hypothesis that innovative firms are financially constrained. Both the results from the Q model and from the Accelerator model show that the sensitivity of investment expenditures to internal finance is much higher for innovative firms than non-innovative firms. The Euler equation results show that the Adjustment Costs model is rejected for both sub-samples. However, there is evidence that the model does fit the data of non-innovative firms better than that of innovative firms.

The rest of the paper is organised as follows. Theoretical issues regarding capital market imperfections and the determinants of R&D expenditures and physical capital investment are addressed in section two. The empirical models and estimators are discussed in section three. A description of the sample selection criteria and the results are given in section four. The final section concludes.

2 Theoretical Issues

2.1 Capital Market Imperfections

One of the main assumptions upon which rest many of the results in the literature on capital market imperfections is the assumption of asymmetric information. When

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[1] In my sample the number of observations on R&D across time is insufficient. A new accounting standard, SSAP 13, obligating large firms to disclose their R&D expenditures in their company accounts, came into effect in the UK only in 1989.

firms possess more information about the quality of an investment than do potential investors, or when the firm can control variables which are not observable to the investor but which affect the return to the investment, capital markets will be inefficient. Arguably, such conditions are most likely to be satisfied by firms which devote resources to innovating. The production of an innovation is more difficult to predict from observable inputs than is the production of most other types of output. There is greater scope for inputs which are not observable to all parties, such as a researcher's skill level or the choice of research agenda, to affect the returns to an investment in the development of an innovation. Moreover, given that many innovations are produced in very technologically advanced industries, there are potentially large differences in the information sets of the different parties to a financial contract. This will limit the extent to which monitoring can reduce possible agency problems.

Under the assumption that managers have an informational advantage over investors regarding the quality of the potential investment projects the firms may undertake, Myers and Majluf (1984) show that equity markets will be inefficient. Given its informational disadvantage, the market requires all firms to issue equity at a discount. The discount can imply such a heavy dilution of the existing shareholders stake in the existing assets of the firm that it is not in their interest to undertake a positive NPV project. Stiglitz and Weiss (1981) show that asymmetric information leads to similar outcomes in debt markets. Again the key assumption in this model is that the market is at an informational disadvantage vis-à-vis the firm regarding the quality of the investment project for which debt finance is being sought (specifically, projects differ according to the variance of their returns). Creditors react to excess demand by rationing some borrowers rather than by raising interest rates. Raising interest rates increases the riskiness of the average investment project in the pool of credit applicants, because applicants with "safe" projects drop out. Again in equilibrium positive NPV projects will be forgone.

An inherent part of an R&D project is the accumulation of knowledge. Knowledge can be viewed as a type of capital asset, and modelled as a factor in the innovation production function. Knowledge is a public good, and the existence of patent systems is typically justified as a mechanism whereby firms which invest in knowledge capital can protect their investment (in legal parlance, the firm's intellectual property). However, patents work only imperfectly. In a survey of R&D investing firms in the U.S., Levin, Klevorick, Nelson, and Winter (1987) report that managers believed non-patent methods of protecting knowledge capital to be more important than patents. Those methods include the lead time a firm has over its rivals (i.e. differences in their knowledge capital), and the speed with which they accumulate knowledge. According to their study, innovative firms clearly possess intellectual property (though not in the legal sense) which has an important impact on the value of its investment projects. It is equally true that such property cannot be appropriated by another party; it is the inalienable property of the firm.[2]

More recently, Hart and Moore (1994) have shown that, even in a model of debt with full information, positive NPV projects may still be forgone. The results of this model rest upon two assumptions: first, that the entrepreneur possess an asset which a creditor is unable to appropriate, and second, that this "inalienable" asset affect the value of assets that can be appropriated (i.e the firm's collateralisable assets). The threat that the entrepreneur may withdraw the inalienable asset from the production process can limit the debt capacity of the firm below the cost of the investment project.[3] Therefore, whether or not such an investment project is undertaken depends upon the amount of internal finance available to the entrepreneur.

Even if innovative firms could mitigate the effect of capital market imperfections by, for example, revealing some of their knowledge capital to parties outside the

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[2] Strictly speaking, this type of intellectual property is the asset of the research staff within the firm. For simplicity, I assume that the researchers are also owner-managers of the firm.

[3] The strength of the threat to withdraw the inalienable asset depends upon the outside options available to the two parties. Levin, Klevorick, Nelson, and Winter (1987) report that one of the main channels of information spillover is through the hiring of rival firms R&D staff. This would indicate that the firm's bargaining position viv-à-vis creditors is strong. Other things being equal, such a firm's debt capacity would be low.

firm, doing so may not be optimal. Levin, Klevorick, Nelson, and Winter (1987) report that secrecy is also an important way firms protect their intellectual property, particularly for process innovations. Indeed, the importance of lead time over rivals suggests that revealing information may be very costly. Bhattacharya and Ritter (1983) and Horstmann, MacDonald, and Slivinski (1985) present theoretical models in which it is not optimal for a firm to reveal all of its information, either through a third party such as a financial intermediary, or through patenting its innovations.

It has been argued above that the assumptions underlying theoretical work on capital market imperfections will be satisfied for investment projects which involve the development or discovery of an innovation. Under what conditions will capital market imperfections affect the firm's other expenditures such as physical capital investment? Firms which conduct R&D typically produce the product innovations and implement the process innovations which are the corresponding outputs of the firm's R&D input. Hence, the firm's innovations will affect the returns to its physical capital, and the returns to investment in new physical capital depend upon the firm's future innovations. It is therefore unlikely that firms will be able to separately finance R&D projects and physical capital investment projects. If capital markets are imperfect for R&D projects, those imperfections will impact upon the firm's physical investment projects due to the interdependence of the returns to the two projects.

2.2 Determinants of R&D and Investment

In general, under the null hypothesis that innovative firms are not financially constrained, desired expenditures on R&D and physical capital will respond to different, as well as common, factors. For example, the theoretical literature on innovation has emphasised that information spillover will be a unique determinant of desired R&D expenditures (referred to as the "technology push" factor). It is unlikely that this factor would also affect investment, at least contemporaneously. The empirical support that R&D and investment are driven by different factor is strong. For example, Lach and Schankerman (1989) show that while both R&D and investment respond to a shock which is permanent (in the sense that its impact is highly persistent), investment is influenced strongly by an idiosyncratic shock as well.[4]

However, the observation that highly persistent shocks affect both R&D and investment while less persistent shocks affect only investment is also consistent with the alternative hypothesis of capital market imperfections. Under the alternative hypothesis, the responses of actual expenditures on R&D and physical capital to shocks to the firm's internal finance will be proportionate only in the restricted case where the functions governing the firm's production and its costs of adjusting inputs are homothetic. If innovative firms' production functions were homothetic, the ratio of R&D to output would be a constant function of firm size. However, as Pakes and Schankerman (1984) note, a stylised fact in the empirical literature is the "observation that the coefficient of variation of research intensity [R&D to sales ratio] is an order of magnitude larger than those of traditional inputs."

Moreover, given the importance firms place on secrecy and lead time over competitors, the implicit costs of laying of R&D staff may be much higher than the costs of adjusting physical investment. Researchers who are laid off may transmit valuable knowledge about firm's research programs to its competitors. Levin, Klevorick, Nelson, and Winter (1987) report that hiring a competitor's R&D personnel is viewed by many firms as one of the most effective channels of information spillover. In addition to possessing knowledge valued by competitors, it is likely that researchers acquire a great deal of firm specific knowledge which would imply substantial training costs associated with hiring new staff. A widely reported fact which which is consistent with these observations is that within-firm variance of R&D is much lower than that of investment (see, for example, Lach and Schankerman (1989), Himmelberg and

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[4] Similar evidence has been reported by other authors. Pakes (1985) found that changes in R&D were associated with large changes in the market value of the firm, indicating the market expected a persistant change in profits. Himmelberg and Petersen (1994) found evidence that R&D expenditures were sensitive to permanent (i.e highly persistent) changes in cash flow, not transitory changes. They interpreted this as evidence of higher costs of adjustment for R&D, although it is also consistent with the above null hypothesis.

Petersen (1994), Hall (1992)).

In conclusion, the observed stochastic properties of investment and R&D are consistent with both hypotheses: (i) capital markets are perfect, but the determinants of desired R&D and investment expenditures differ (as do the properties of the stochastic processes governing the respective determinants), and (ii) capital markets are imperfect, but actual R&D and investment expenditures respond differently to the common determinant of internal finance shocks. Therefore, an appropriate test to distinguish between them is to examine the sensitivity of the expenditures to changes in the firm's supply of internal finance. In view of the lower within-firm variability of R&D, performing this test on investment will be more powerful.

3 Empirical Specification

3.1 Model Specification

To distinguish between the alternative and null hypotheses, this paper examines how different empirical models of investment fit the data of different subsamples of firms. Since investment decisions are forward looking, these models should be structural in the sense of Lucas. Otherwise it is not theoretically possible to isolate the effect of shocks to the supply of internal finance from the effect of new information contained in changes in internal finance regarding the future marginal profitability of capital (demand shocks). In common with much of the empirical investment literature, two of the empirical models used in this are derived from the Adjustment Costs model of investment (expositions of this model are given in Eisner and Strotz (1963), Lucas (1967), and Gould (1968)): the Q model, and the Euler equation corresponding to the costs-of-adjustment model.

The Q model of investment is a test of the first-order condition of the Adjustment Costs model under two assumptions: (i) linear homogeneity of the profit and cost of adjustment functions, and (ii), perfect capital markets.[5] Under the second assumption the market value of the firm equals its fundamental value (the expected present discounted value of future cash flows), while under the first condition the average and marginal products of capital are equal (see Lucas and Prescott (1971), Hayashi (1982)). The following quadratic form for the cost of adjustment function is commonly assumed, $G(I, K; \varepsilon) = \frac{\varphi}{2}(\frac{I}{K} - \alpha - \epsilon)^2 K$, where I is investment, K the existing stock of capital, α a firm specific constant, and ϵ a random variable. With this functional form, the first order condition can be written as,

$$\left(\frac{I}{K}\right)_{it} = \alpha_i + \beta Q_{it} + \epsilon_t, \tag{3.1}$$

where β is the inverse of the marginal cost of adjustment, φ, and Q_{it} is the ratio of the market value of the firm to the replacement cost of its existing assets.

Under the null, the theory predicts that Q_{it} is a sufficient statistic for the firm's investment rate. Under the alternative hypothesis, capital markets will still be weak-form efficient. In this case it is not generally true that the market value of the firm will equal the fundamental value. However, Q_{it} will represent expected marginal value of capital conditional on all public information.[6] Therefore, under the alternative, the reported cash flow variable reflects the effect of shocks to the firm's supply of internal finance. Moreover, instrumenting cash flow with its own lagged values will ensure that any possible informational affect is eliminated.[7]

An advantage of the Q model is the existence of a well specified alternative. However,

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[5] These functions are defined in the appendix, where both the first-order condition and the Euler equation are derived. Sufficient conditions for the linear homogeneity of the profit function are constant returns to scale and perfect competition in all input and output markets. An assumption in this particular derivation of the model is that newly installed capital becomes producive immediately.

[6] Under the alternative hypothesis, Q_{it} can be thought of as measuring with error the fundamental value of the firm. Valid instruments will depend on the degree of serial correlation in both the measurement error and ϵ.

[7] In theory, there will be no such effect if all variables are dated under according to the same convention. However, in the empirical work in this paper, Q_{it} refers to the beginning-of-period whereas all other variable dated t refer to end-of-period values.

in practice the measurement error under the alternative hypothesis may be very large. Factor analytic empirical studies show that the factor common to the stock price and investment accounts for only a small percentage to the total variation in the stock price. The vast majority of price variation is accounted for by an idiosyncratic factor (see Blanchard, Rhee, and Summers (1990) and Lach and Schankerman (1989)). An advantage of estimating the Euler equation is that it can be done without using observations on the firm's stock price.

To make the Euler equation estimable, either a functional form for the profit function can be assumed (as in Abel (1980)), or the linear homogeneity assumption made above can be maintained (as in Bond and Meghir (1994)). In fact, the linear homogeneity of the profit function can be relaxed to allow for imperfect competition.[8] Using the same functional form for the costs of adjustment function, the Euler equation can be written as,

$$\begin{aligned} \left(\frac{I}{K}\right)_{it} &= \beta_1\left(\frac{I}{K}\right)_{it-1} + \beta_2\left(\frac{I}{K}\right)^2_{it-1} + \beta_3\left(\frac{C}{K}\right)_{it-1} \\ &\quad +\beta_4\left(\frac{Y}{K}\right)_{it-1} + \alpha_i + d_t + v_t, \end{aligned} \tag{3.2}$$

where I represents investment, C cash flow, and Y output. All variables are weighted by the firm's capital stock, K. The term α_i picks up firm specific effects, while d_t is a time dummy to control for fluctuations in the omitted price and user cost of capital terms (see Appendix). One interpretation for the error term, v_t, is that it is an expectational error (i.e it represents the effect of new information acquired in period t). As such v_t should be i.i.d. However, v_t may also summarise the effects of random variables such as the error term in the costs of adjustment function, and therefore may not be i.i.d.

The theoretical model places the following restrictions on the signs of the coefficients in the above equation: (i) the coefficient on the lagged investment rate, β_1, is positive and greater than one; (ii) the coefficient on the square of the lagged investment rate,

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[8] Both the production function and the costs of adjustment functions are still assumed to be linear homogeneous, and input markets perfectly competitive.

β_2, is negative and greater that one in absolute value; (iii) the coefficient on cash flow, β_3, is negative, and (iv) the coefficent on output, β_4, is positive if there is imperfect competition (otherwise it is zero). A disadvantage of the Euler equation test is that the model is not well specified under the alternative. In other words, if the restrictions are not satisfied it is not possible to determine which assumption, linear homogeneity or perfect capital markets, has been violated.

As a check on the results of the regressions based on the Adjustment Costs model, a third and simpler model of investment is estimated: the Sales Accelerator model. A theoretical justification for this model can be derived under similar assumptions above, but without the assumption of adjustment costs (a good reference for this and other investment models is Nickell (1978)). Dropping that assumption eliminates the need to deal with expectations since the capital stock can be costlessly adjusted instantaneously. The factors driving investment are then the exogenous processes driving prices, the user cost of capital, and demand for the firm's output. Moreover, with no adjustment costs and under the null,changes in ouput are driven entirely by exogenous shocks to demand. The empirical model can be written as,

$$\left(\frac{I}{K}\right)_{it} = \alpha_i + d_t + \left(\frac{\Delta Y}{Y}\right)_{it} + \mu_t \tag{3.3}$$

where again α_i picks up a firm specific effect, d_t picks up fluctuations in prices and the user cost of capital, and the growth rate of sales, $\Delta Y/Y$, captures exogenous demand shocks. Under the null hypothesis, cash flow contains the same information as the growth rate of sales and therefore should not enter significantly. However, under the alternative hypothesis cash flow will enter significantly if financing constraints are binding.

3.2 Estimators

An instrumental variables estimator is required for both of the empirical models derived from the Adjustment Costs model. In the Q model, if ϵ_t is realised at the beginning of the period (i.e. is in the firm's information set in period t), then Q_{it} will be endogenous through the effect ϵ_t has on the actual amount of capital installed.[9] Valid instruments for Q_{it} will be variables with a lag or lead of j or greater, where j is the lowest lag for which $cov(\epsilon_t, \epsilon_{t-j}) = 0$. The theory places no restrictions on serial correlation in the ϵ process.

Similarly in the Euler equation, the standard within-groups estimator is biased due to the presence of the lagged dependent variable. Differencing the model to remove the fixed effect necessitates the use of instruments for the lagged dependent variable terms. As in the estimation of the Q model, lagged values can be used as instruments. The validity of the instruments will depend on the degree of serial correlation in the error term.

Unlike the first two models, an instrumental variables estimator is not theoretically required for the Sales Accelerator model, since sales growth in that model is strictly exogenous. However in this model, as in the previous two models, under the alternative hypothesis the cash flow terms may be endogenous. These terms are instrumented in all regressions, and can therefore be interpreted as the effect *predictable* cash flow has on investment.

All of the above models are differenced to remove the firm-specific effect, α_i, and an Anderson-Hsiao estimator is used (Anderson and Hsiao (1982))(except for the basic Sales Accelerator model, which is estimated by OLS). While this estimator is not efficient, it is consistent. However, Monte Carlo experiments done by Arellano and Bond (1991) show that in dynamic models the loss of efficiency is not great if the coefficient on the lagged dependent variable is not too close to one.

The Anderson-Hsiao estimator differs from the efficient estimator in two ways. First, the GMM estimator which imposes the moment condition for each available instrument *in each time period* is the efficient estimator in the class of instrumental variable estimators which use only linear combiations of instrumental variables (see Holtz-

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[9] The error term, ϵ_t, is interpreted as factors which are observable to the firm, but not to the econometrician. Alternatively, it can be assumed that ϵ_{t-1} is in the firm's information set and that ϵ is serially correlated.

Eakin, Newey, and Rosen (1988) and Arellano and Bond (1991)).[10] In contrast, the the moment conditions imposed by the Anderson-Hsiao estimator are the sum of the individual time period moment conditions corresponding to a particular lagged value of the instrument (i.e. there is one moment condition per instrument, as opposed to one moment condition for each year in which the instrument is available).

Second, the efficient GMM estimator uses an estimate of the optimal weighting matrix based on the residuals generated by an initial consistent estimator. The (arbitrarily chosen) weighting matrix for the Anderson-Hsiao estimator has two's on the principal diagonal, and one's on the main off-diagonals.[11] The standard errors of this estimator are White-corrected for heteroscedasticity.

The choice of the less efficient Anderson-Hsiao estimator was made for two reasons. First, the standard errors of the efficient GMM estimator produced by the estimation routine employed in this paper are biased downwards.[12] Second, in practice the large set of valid instruments typically available to the efficient estimator can raise difficulties. One of the problems encountered in this paper was the unreliability of test statistics, such as the Sargan statistic, when a large set of instruments were used. For this reason, Anderson-Hsiao instruments were used.

One of the specification tests reported is the Sargan statistic (referred to as the J-statistic in Hansen (1982)). However, because the validity for the instruments depends crucially on serial correlation in the error term, two estimates of this serial

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[10] For example, if there were five observations per firm, and instruments of lag two or greater were valid then this estimator would impose six moment conditions: there is one valid instrument for the observation in period 3 (lag 2), two for the observation in period 4 (lags 2 and 3), and three for the observation in period 5 (lags 2, 3 and 4). If the instrument set were restricted to only the second lag, there would be three moment conditions.

[11] If the models are exactly identified, then the orthogonality conditions are set exactly to zero and the weighting matrix is the idendtity matrix.

[12] Estimation was performed using the DPD routine developed by Manuel Arellano and Stephen Bond (Arellano and Bond (1988)). The bias in the standard errors of the two-step GMM estimator is reported in Arellano and Bond (1991).

correlation are also reported: a test for first-order serial correlation, the $m1$ statistic, and a test for second-order serial correlation, the $m2$ statistic (see Arellano and Bond (1991)). If the error term in the undifferenced model is white noise, then the error term in the differenced model should exhibit first-order, but not second-order, serial correlation.

4 Data and Results

4.1 Sample Selection

In January 1989 a new standard of accounting practice was introduced in the United Kingdom, the Statement of Standard Accounting Practice (SSAP 13), which requires large firms to report their R&D expenditures. The standard applies "in effect to companies which are public limited companies, or special category companies, or subsidiaries of such companies, or which exceed by a multiple of ten the criteria for defining a medium-sized company under the Companies Act 1985". In practice this has meant that roughly the largest 300 companies conducting research and development have been obligated to disclose this expenditure each year since 1989. Disclosure of R&D expenditure of firms outside this category, or prior to 1989 for the firms in this category, has been done at the discretion of the firm.[13]

The data used is from the published accounts of UK listed firms and was collected from Datastream. A full description of the individual variables is given in the Data Appendix. From the universe of UK listed firms a primary sample of firms was identified with the following criterion: the firms chosen for the sample were required to have at least one positive recorded R&D expenditure between the years 1990–1993. This criterion does not distinguish between those firms which were required to report their R&D expenditures, and those which reported voluntarily. The initial sample

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[13] SSAP 13 did not alter the conditions under which R&D may be capitalised rather than expensed. Few firms in the sample reported capitalised R&D expenditures.

consisted of approximately 340 firms, the vast majority of which had fewer than four positive observations on R&D .

Two further selection criteria were applied to this primary sample. First, all firms with fewer than seven consecutive positive observations on all of the main variables were deleted. Data on firms which have been acquired, or which have gone out of business, are not readily available from Datastream. Consequently, all firms have seven or more observations leading up to 1993 (the final observation for each firm is 1993). Second, firms with large one period changes in their capital stock were also deleted.[14] The final sample is an unbalanced panel consisting of 144 firms with observations ranging between seven and twenty-two. Approximately half of the sample had observations available for the full sample period.

This sample was divided into high and low R&D intensity classes according to a measure of R&D intensity: the ratio of R&D expenditures to total investment (physical investment plus R&D expenditures). High intensity firms were defined to be those firms whose R&D intensity was above its corresponding industry mean for each year in which the firm reported a positive R&D expenditure.[15] Tables 1a–1c show the breakdown of observations for the entire sample, and for the two sub-samples.

4.2 The Q model

Tables 2 and 3 show the results for the Q regression (equation (3.1)) for the high intensive and low intensive industries respectively. Comparing the first column of the two tables we see that the point estimates of Q are very similar for the two classes of firms. However, the test statistics for the class of low intensive firms clearly reject the instrument set. The Sargan statistic rejects at the 1% level. The $m2$

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[14] This was done to exclude firms with major mergers or acquisitions. Firms whose change in their book value of lay outside three times the interquartile range above and below the median were removed.

[15] The classification used was Datastream's level 6 industrial classification. This is their most detailed classification.

statistic narrowly fails to reject at the 5% level. To deal with the potential serial correlation, it is assumed that the error term in equation (3.1) follows an AR(1) process, $\epsilon_t = \rho\epsilon_{t-1} + \nu_t$, and a Cochrane-Orcutt transformation is performed. Using equation (3.1) to solve for ϵ gives,

$$\left(\frac{I}{K}\right)_{it} = (1-\rho)\alpha_i + \beta Q_{it} + \rho\left(\frac{I}{K}\right)_{it-1} - \rho\beta Q_{it-1} + \nu_t. \tag{4.4}$$

This specification is used in column 2 of Table 3. Although the $m2$ statistic now gives no indication of second order serial correlation, the Sargan statistic still rejects the validity of the instrument set. In column 3 the second lag is dropped from the instrument set, and in column 4 the fourth lag is dropped. The Sargan statistic fails to reject either of these two new instrument sets. However, the $m1$ statistic fails to reject first-order serial correlation for the specification of column 3. Since the model is estimated in first-differences, this indicates misspecification. In addition, the $m2$ rejects at the 5% level. Therefore, the preferred specification for the class of low intensity firms is that of column 4. Although the common factor restriction on the coefficients in equation (4.4) is not tested, it seems likely that it would not be rejected since the product of the coefficients on Q_t and $(I/K)_{t-1}$ is 0.0039.

The point estimate of the cost-of-adjustment parameter is close to the estimate for high intensity firms. Though these estimates imply that the response of investment to shocks to the marginal value of capital is unreasonably sluggish, they are similar to estimates reported in other studies.[16] To test the null hypothesis against the alternative, free cash flow was included in the regression. A comparison of columns 5 to 7 in table 3 with columns 2 to 4, or columns 5 to 7 (in those specifications the second lag has been dropped from the instrument set), in table 2 show that, while the null hypothesis can be rejected for both classes of firms, the effect of free cash flow on the investment of high intensity R&D firms is quantitatively larger. This is consistent with the alternative hypothesis that high intensity R&D firms are financially constrained.

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[16] For example, they are very close to the estimates reported for a larger set of UK manufacturing firms studied by Blundell, Bond, Devereux, and Schiantarelli (1992).

4.3 Euler Equation

The results for the Euler equation regression are given in Table 4.[17] Looking at the first and fourth columns, it can be seen that the Adjustment Costs model appears not to fit the data well for either class of firm. None of the estimated coefficients are within two standard errors of the range predicted by the theory. Moreover, the coefficient on the cash flow term has the wrong sign. The Adjustment Costs model appears to be clearly rejected for both classes of firms.

However, there is some evidence that the model fits the data for low intensity firms somewhat better than that for high intensity firms. In the second and fifth columns, the second lag is removed from the set of instruments. Although the specification tests do not reject the validity of instruments dated $t-2$, dropping these instruments changes the point estimates of the two lagged endogenous variable terms for the low intensity class.[18] The point estimates are now within the range predicted by the theory, though less precisely estimated (both coefficients are still significant at the 5% level). By comparison, in column 5 the coefficents estimated from the data on high intensity firms remain well outside the range predicted by the theory. Moreover, for the class of high intensity firms the only coefficient which is statistically significant is that of cash flow.

It is not possible to deduce from this evidence which of the assumptions underlying the model is violated.[19] However, there is some evidence that the difference in the

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[17] In their paper on firm investment, Bond and Meghir (1994) show that the firm's debt policy can be incorporated into the Euler equation by including the term $(B/K)^2_{t-1}$. All the regressions reported in Table 4 were run with this term included, but its coefficient was never statistically significant.

[18] If the error term were an MA(1) process, values of the the regressors in period $t-2$ would be invalid, but higher order lags would remain valid. Most of the bias arising from using the invalid $t-2$ instruments is likely to be manifested in the coefficients on the lagged endogenous terms. However, the Hausman test statistic also fails to reject the validity of these instruments, taking a value of 3.118 with 2 degrees of freedom.

[19] Note that because the (Y/K) controls for either imperfect competition or departures from a

model's fit to the data of the different classes of firms is due to the greater impact of financing constraints on high intensity firms. First, in columns 3 and 6, the cash flow term is replaced by free cash flow (the difference being interest payments and taxes). This has no affect on the estimates for low intensity firms, but increases the value of the estimate of the cash flow coefficient of high intensity firms, indicating that the revenue lost to taxes and interest payments affect the investment expenditures of these firms. Second, while it is plausible that the costs of adjusting physical capital may be associated with R&D intensity, it is more likely that much of the variation in adjustment costs in between industries. Yet not only were industry dummies included in the estimation, the nature of the sample splitting criterion is such that most industries are represented in both subsamples.

4.4 The Accelerator Model

The results for the Accelerator Model, presented in Table 5, tell much the same story as the Q model results. The model fits the data fairly well. Columns 1 and 4 show the results for the basic model, estimated using ordinary least squares. The sales growth term is positive and significant in both regressions. The results with free cash flow included in the specification are in columns 2 and 5.[20] As with the Q model results, the effect of free cash flow on the investment of high intensity firms is quantitatively much larger. Although this is not a forward looking model, by instrumenting free cash flow any information about the future marginal productivity of capital has been purged from the contemporaneous free cash flow terms. The results in columns 3 and

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constant returns to scale production function, the only remaining assumptions are the assumed form of the cost of adjustment function, and perfect capital markets.

[20] Unlike the Q model, there is no theoretical argument that the sales growth term is endogenous. The free cash flow terms, however, may still be endogenous. Therefore, cash flow is instrumented with its lagged values in the subsequent regressions. The $m2$ statistic indicates that these instruments may not be valid for low intensity firms. A Cochrane-Orcutt transformation was performed. This eliminated the second order serial correlation. The point estimates of the coefficients on the free cash flow and sales growth terms were unaltered.

6 show that lagged free cash flow is also significant, although it has a negative sign for high intensity firms. In conclusion, these results are consistent with the hypothesis the high intensity firms are financially constrained.

5 Conclusions

The assumption of perfect capital markets is least likely to be satisfied for the class of firms which devote resources towards the development of innovative products or processes. An implication of this assumption is that each of the firm's expenditures should be insensitive to fluctuations in internal finance. To test this hypothesis existing empirical work either has examined the sensitivity of R&D expenditures to internal finance or has compared the properties of the statistical process of R&D with those of the processes of other expenditures such as physical capital investment. Neither of these procedures can distinguish between the two hypotheses: (i) that capital markets are perfect, and that different factors drive the firm's different expenditures, and (ii) that capital markets are imperfect, and that the different expenditures of the firm repond disproportionately to a common factor, namely shocks to the supply of internal finance.

To distinguish between these hypotheses, the sensitivity of physical investment expenditures to internal finance is compared across innovative and non-innovative firms. For robustness, several investment equations are estimated. The results from the Q model and the Accelerator model show that the sensitivity of the investment of innovative firms to internal finance is much higher than that of non-innovative firms. The Euler equation results show that, although the Adjustment Costs model is rejected for both classes of firms, it fits the data of non-innovative firms better than that of innvoative firms. There is evidence that the difference in the fit across the different classes of firm is due to the impact of financing constraints on innovative firms.

Tables 1a - 1c

Table 1a - Full Sample

No. of obs	7	8	9	10	11	12	13	15	16	18	19	21	22
No. of companies	9	10	7	4	4	5	3	2	2	4	2	5	87

Table 1b - High Intensity Firms

No. of obs	7	8	9	10	11	12	15	18	19	21	22
No. of companies	4	3	2	1	2	1	1	2	2	1	21

Table 1c - Low Intensity Firms

No. of obs	7	8	9	10	11	12	13	15	16	18	21	22
No. of companies	5	7	5	3	2	4	3	1	2	2	4	66

Table 2

Q Equation - High Intensity Firms

	1	2	3	4	5	6	7
Q_t	0.0161	0.0066	0.0093	0.0086	0.0076	0.0038	0.0032
	(0.0064)	(0.0081)	(0.0044)	(0.0054)	(0.0107)	(0.0077)	(0.0079)
FCF_t	-	0.5712	-	0.1306	0.6174	-	-0.2545
	-	(0.1506)	-	(0.4791)	(0.1763)	-	(0.6389)
FCF_{t-1}	-	-	0.3707	0.2958	-	0.5684	0.7478
	-	-	(0.0832)	(0.2897)	-	(0.1385)	(0.437)
m1	-3.652	-3.53	-3.772	-3.296	-3.676	-3.815	-4.326
m2	0.614	0.902	0.187	0.321	0.933	-0.171	-0.356
Sargan	2.773	1.664	2.894	2.471	1.543	0.656	0.269
prob	(0.25)	(0.797)	(0.576)	(0.481)	(0.462)	(0.72)	(0.604)

(i) The dependent variable is $(I/K)_t$. Sample period is 1972-1993. There are 686 observations.

(ii) Time and Industry dummies included in estimation. White-corrected standard errors are in brackets.

(iii) Lags 2,3, and 4 of the regressor are used in columns 1 to 4. Lags 3 and 4 in columns 5 to 7.

(iv) The $m1$ and $m2$ test statistics are normally distributed around zero.

(v) The Wald test statistic for the joint significance of the two cash flow terms in column 4 is 19.627, and in column 7 is 13.131.

Table 3

Q equation - Low Intensity Firms

	1	2	3	4	5	6	7
Q_t	0.0193	0.0221	0.129	0.0223	0.0177	0.0171	0.0136
	(0.0071)	(0.008)	(0.1446)	(0.0077)	(0.0065)	(0.0064)	(0.0107)
$(I/K)_{t-1}$	-	0.2011	-0.2331	0.1751	0.1674	0.1717	0.1985
	-	(0.036)	(0.2102)	(0.0414)	(0.0414)	(0.0387)	(0.0444)
Q_{t-1}	-	-0.0092	-0.0746	-0.005	-0.004	-0.0054	-0.0159
	-	(0.0042)	(0.0925)	(0.0042)	(0.0042)	(0.0041)	(0.0118)
FCF_t	-	-	-	-	0.1502	-	-1.2373
	-	-	-	-	(0.0778)	-	(1.1255)
FCF_{t-1}	-	-	-	-	-	0.1061	0.9045
	-	-	-	-	-	(0.0486)	(0.7542)
m1	-6.393	-7.575	-1.165	-7.459	-7.281	-7.236	-1.807
m2	-1.838	-0.589	-1.967	-0.777	-0.867	-0.812	0.9
Sargan	9.261	11.01	0.045	2.875	5.777	5.57	0.706
prob	(0.01)	(0.012)	(0.831)	(0.09)	(0.123)	(0.135)	(0.703)

(i) The dependent variable is $(I/K)_t$. Sample period is 1972-1993. There are 1894 observations.

(ii) Time and Industry dummies included in estimation. White-corrected standard errors are in brackets.

(iii) Lags 2,3, and 4 of the regressors are used in columns 1 and 2, lags 3 and 4 in columns 3, and lags 2 and 3 in columns 4 to 7.

(iv) The $m1$ and $m2$ test statistics are normally distributed around zero.

(v) The Wald test statistic for the joint significance of the two cash flow terms in column 7 is 1.834.

Table 4

Euler Equation

	Low Intensity			High Intensity		
$(I/K)_{t-1}$	0.5554	1.2064	0.5864	0.0818	0.3659	0.1055
	(0.134)	(0.5387)	(0.1386)	(0.2112)	(0.9165)	(0.2182)
$(I/K)^2_{t-1}$	-0.5192	-1.919	-0.5577	-0.0224	-0.0956	-0.0243
	(0.2127)	(0.9493)	(0.2205)	(0.2836)	(1.3172)	(0.2928)
$(C/K)_{t-1}$	0.2198	0.3232	0.2195	0.2475	0.1839	0.3363
	(0.056)	(0.1084)	(0.0726)	(0.0714)	(0.2155)	(0.078)
$(Y/K)_{t-1}$	-0.0067	-0.0165	0.0001	0.0105	0.0015	0.0199
	(0.0055)	(0.0098)	(0.0048)	(0.0114)	(0.0151)	(0.0078)
m1	-7.443	-2.215	-7.604	-4.522	-1.726	-4.479
m2	-0.749	-1.875	-0.826	1.259	0.699	1.177
Sargan	5.441	0.708	7.284	2.816	2.976	3.47
prob	(0.71)	(0.95)	(0.506)	(0.945)	(0.562)	(0.902)

(i) The dependent variable is $(I/K)_t$. Sample period is 1972-1993. There are 686 observations for high intensity firms and 1894 observations for low intensity firms.

(ii) Time and Industry dummies included in estimation. White-corrected standard errors are in brackets.

(iii) Lags 2,3, and 4 of the regressors are used in columns 1,3,4 and 6. Lags 3 and 4 in columns 2 and 5.

(iv) The $m1$ and $m2$ test statistics are normally distributed around zero.

(v) The Hausman test statistic for the validity of the lag 2 instruments is 3.118 (2) for low intensity firms and 0.557 (2) for high intensity firms.

Table 5

Sales Accelerator Model

	Low Intensity			High Intensity		
$(\Delta Y/Y)_t$	0.0608	0.037	0.0541	0.1245	0.0442	0.1381
	(0.0264)	(0.0251)	(0.0258)	(0.0408)	(0.0448)	(0.0415)
$(FCF/K)_t$	-	0.2996	-	-	0.676	-
	-	(0.0871)	-	-	(0.154)	-
$(FCF/K)_{t-1}$	-	-	0.2116	-	-	-0.0706
	-	-	(0.0598)	-	-	(0.0224)
m1	-6.267	-6.209	-6.219	-3.549	-3.614	-3.529
m2	-1.859	-1.955	-1.793	0.634	0.88	0.663
Sargan	-	3.035	4.137	-	0.018	1.029
prob	-	(0.219)	(0.126)	-	(0.991)	(0.598)

(i) The dependent variable is $(I/K)_t$. Sample period is 1972-1993. There are 686 observations for the high intensity firms and 1894 observations for the low intensity firms.

(ii) Time dummies included in estimation. White-corrected standard errors are in brackets.

(iii) Lags 2,3, and 4 of free cash flow are used in columns 2,3,5, and 6. OLS is used in columns 1 and 4.

(iv) The $m1$ and $m2$ test statistics are normally distributed around zero.

A Costs of Adjustment Model

The firm's problem is to maximise,

$$V_t = E_t \sum_{j=0}^{\infty} \beta^{-j} \Pi_{t+j}, \tag{A.5}$$

where β is a discount factor, assumed constant, and

$$\Pi_t = p_t F(K_t, L_t; \mu_t) - p_t G(I_t, K_t; \epsilon_t) - w_t L_t - p_t^I. \tag{A.6}$$

$F(\cdot,\cdot;\cdot)$ is the firm's production function, $G(\cdot,\cdot;\cdot)$ the cost of adjustment function, I investment, K the capital stock, L labour, p output price, p^I the price of new capital, w the wage, and μ and ϵ are random disturbances. The firm's problem can be formulated as the following dynamic programming problem,

$$V(K_{t-1}; \mu_t, \epsilon_t) = \max_{I,L} \{\Pi_t + \beta E_t [V(K_t; \mu_{t+1}, \epsilon_{t+1})]\}, \tag{A.7}$$

subject to (i) (A.6), (ii), the law of motion for capital,

$$K_{t+1} = (1-\delta) K_t + I_t, \tag{A.8}$$

and (iii), the stochastic processes governing the two disturbance terms. Assuming that capital invested in period t also becomes productive in period t, the first-order condition for investment is,

$$\left(\frac{\partial \Pi}{\partial I}\right)_t + \left(\frac{\partial \Pi}{\partial K}\right)_t + \beta E_t \left(\frac{\partial V}{\partial K}\right)_{t+1} = 0, \tag{A.9}$$

and the Euler equation is,

$$\left(\frac{\partial V}{\partial K}\right)_t = (1-\delta)\left(\frac{\partial \Pi}{\partial K}\right)_t + \beta(1-\delta) E_t \left(\frac{\partial V}{\partial K}\right)_{t+1}. \tag{A.10}$$

Using equation (A.10), the first-order condition can be re-written as,

$$-(1-\delta)\left(\frac{\partial \Pi}{\partial I}\right)_t = \left(\frac{\partial V}{\partial K}\right)_t. \tag{A.11}$$

This is the equation tested by the empirical Q model equation. To derive the latter from equation (A.11), assume that both the production function and the costs of adjustment function are linearly homogenous in their arguments. This implies that the profit function $\Pi(I, K, L)$ is also homogeneous of degree one. Under this assumption it is straightforward to show that the value function is also homogeneous of degree one in K (see Stokey, Lucas, and Prescott (1989)). From Euler's theorem it follows that the marginal value of capital, $\partial V/\partial K$, equals the average value of capital, V/K. Assuming efficient capital markets allows market prices to be used to construct the average value of capital. Finally, assuming the functional form for $G(\cdot,\cdot;\cdot)$ gives equation (3.1).

To derive the Euler equation used in the text, substitute equation (A.11) into equation (A.10) to get,

$$(1-\delta)E_t\left(\frac{\partial\Pi}{\partial I}\right)_{t+1} = \left(\frac{\partial\Pi}{\partial I}\right)_t + \left(\frac{\partial\Pi}{\partial K}\right)_t . \tag{A.12}$$

Under the same linear homogeneity assumptions, the assumption of a perfectly competitive labour market and a monopolistic output market, and the assumed functional form for $G(\cdot,\cdot;\cdot)$ equation (3.2) in the text is derived.

B Data Appendix

The definitions of the data used in the construction of the variables is as follows (Datastream codes are in square brackets).

Tobin's Q (Q): The market value of ordinary shares [HMV] plus the book value of total loan capital [321] less deferred tax [301] divided by the book value of capital [339].

Investment (I) : Total new fixed assets [435].

Cash Flow (CF) : Provision for depreciation of fixed assets [136], plus operating profit before tax, interest and preference dividends [137].

Free Cash Flow (FCF) : Cash Flow less total interest charges [153] and total tax charge [172].

Output (Y) : Total sales [104].

R&D : Research and Development (expensed) [119].

Capital Stock (K) : Book value of net total fixed assets [339].

Market value of ordinary shares (V) : Historic market value of the firm [HMV].

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