ESSAYS IN UNDERSTANDING INVESTMENT

Gavin Wallis

UCL

PhD in Economics

I, Gavin Wallis confirm that the work presented in this thesis is my own. Where information has been derived from other sources, I confirm that this has been indicated in the thesis.

Abstract

Business investment accounts for around 10 per cent of GDP, but is one of the most volatile components of demand. Despite a large volume of work developing investment theories and testing them, their empirical performance is generally poor and the effectiveness of tax policy remains unclear.

Chapter 1 relaxes the common assumption of capital homogeneity by estimating a Q model with multiple assets. This is done using a detailed establishment level panel. The main findings are: (a) the dataset shows clear evidence of inaction, irreversibility and heterogeneity; (b) the Q model assuming quadratic adjustment costs performs slightly better than in most previous literature; (c) the performance of the Q model is significantly improved when applied asset-by-asset; (d) asset-by-asset estimation avoids autocorrelation problems; and (e) for most asset-by-asset regressions Q is found to be a sufficient statistic.

Chapter 2 investigates whether the poor empirical performance of the aggregate Q model can be explained by the exclusion of intangibles. The inclusion of intangibles improves the empirical performance of the Q model in a number of ways: (a) estimated adjustment costs are lower; (b) explanatory power is greater; (c) predictive power and parameter stability is improved; and (d) average q remains significant in a Q model with intangibles that has additional regressors but not in a standard Q model.

Chapter 3 considers whether tax policy can be used to boost the long-run level of investment. The main findings are: (a) tax changes have had large impacts on the user cost of capital; (b) aggregate regressions give estimates of the user cost elasticity in the range -0.14 to -0.27; (c) tax policy can have significant impacts on the long-run level of the capital stock and investment; and (d) a natural experiment approach supports this finding by showing strong impacts of taxation following major reforms.

Table of Contents

List of Tables and Figures

Introduction

Business investment accounts for around 10 per cent of UK GDP, but is one of the most volatile components of demand. Because of this, the impact of economic factors, including tax policy, on the long-run level of investment or on the volatility of investment are age-old questions. As such, there has been a large volume of work on developing investment theories and testing them empirically. Despite this, the empirical performance of investment models is generally very poor and as noted by Hall and Jorgenson (1967) "The effectiveness of tax policy in altering investment behaviour is an article of faith among both policy makers and economists". This is still true more than 40 years on. This thesis firstly explores some alternative explanations for the empirical failure of the Q model of investment and then considers the impact of tax policy on investment. While this thesis is obviously not going to provide a complete answer to the numerous issues in the investment literature where 40 years of research has failed, they do provide some useful insights.

Chapter 1 relaxes the common assumption in the investment literature of capital homogeneity by estimating a Q model with multiple capital goods. This is done using a marginal q approach and a detailed establishment level panel with over 20,000 observations and covering over 25 years. The main findings are: (a) the dataset shows clear evidence of inaction, irreversibility and heterogeneity between assets; (b) despite evidence of non-convexities, the Q model assuming quadratic adjustment costs performs slightly better than in much of the past literature; (c) the performance of the Q model is significantly improved when applied asset-by-asset, with adjustment cost estimates at least twice as large as for total investment; (d) estimation of the Q model asset-by-asset also appears to get rid of autocorrelation problems; and (e) for most asset-by-asset regressions Q is found to be a sufficient statistic, with variables such as cash-flow and uncertainty not statistically significant. These empirical results highlight the importance of allowing for multiple capital goods and point to the importance of detailed disaggregated data on investment to be able to perform sound microeconometric analysis of investment models.

The basic Q model estimated on aggregate data and using average q has failed miserably. However, traditional measures of investment do not include spending on intangible assets, such as research and development, product design, training and organisational capital, even though such assets are expected to yield future profits. Chapter 2 investigates whether the poor empirical performance of the aggregate Q model of investment can be explained by the exclusion of intangible assets. It uses, for the first time in empirical work, comprehensive measures of intangible investment and capital, as well as a measure of average q for the UK business sector. The inclusion of intangible assets improves the empirical performance of the Q model in a number of ways: (a) estimated adjustment costs are lower; (b) explanatory power is greater; (c) predictive power is better and, unlike the standard Q model, a Q model with intangibles does not suffer from parameter instability; and (d) while average q is still not a sufficient statistic to explain investment, it remains significant in a Q model with intangibles that has additional regressors but not in a standard Q model with additional regressors.

Chapter 3 considers whether tax policy can be used to boost the long-run level of investment. After documenting how tax policy has changed since 1980 and the impact of these changes on the cost of capital this chapter investigates this question using a UK dataset. The main findings are: (a) tax changes have had large impacts on the user cost of capital; (b) aggregate time series regressions give new estimates of the user cost elasticity in the range -0.14 to -0.27; (c) on the basis of (a) and (b) tax policy can have significant impacts on the long-run level of the capital stock and hence on investment; and (d) results from a natural experiment approach support this finding by showing strong impacts of taxation on investment in periods following the announcement of major reforms.

Taken together, the results in this thesis highlight the importance of considering different types of assets as distinct, including a broader range of assets than traditional tangible investment. They also highlight the importance of taking into account tax policy when conducting investment analysis.

This thesis is a subset of a broader research agenda looking at the contribution of investment in different assets to growth. For example, Giorgio Marrano, Haskel and Wallis (2009) and Goodridge, Haskel and Wallis (2012a) consider the contribution of intangible investment to growth in the UK market sector. Goodridge, Haskel and Wallis (2012b) considers the amount of telecommunications investment in the UK and its contribution to productivity growth. Chapter 3 highlights the importance of public policy in terms of the corporation tax regime while recent work in Haskel and Wallis (2010) highlights the importance of public investment in science in driving market sector productivity growth.

References

Giorgio Marrano, M., Haskel, J. and Wallis, G. (2009). "What Happened to the Knowledge Economy? ICT, Intangible Investment and Britain's Productivity Record Revisited". *Review of Income and Wealth*, Volume 55, Issue 3, 686-716.

Goodridge, P., Haskel, J. and Wallis, G. (2012a). "UK Innovation Index: Productivity and Growth in UK Industries". *CEPR Discussion Paper*, No. 9063.

Goodridge, P., Haskel, J. and Wallis, G. (2012b). "The Contribution of the Internet and Telecommunications Capital to UK Market Sector Growth". *Forthcoming*.

Hall, R. E. and Jorgenson, D. W. (1967). "Tax Policy and Investment Behaviour". *American Economic Review*, Volume 50, No. 3, 391-414.

Haskel, J. and Wallis, G. (2010). "Public Support for Innovation, Intangible Investment and Productivity Growth in the UK Market Sector". *CEPR Discussion Paper*, No. 7725.

Chapter 1: A Q Model with Multiple Capital Goods

1. Introduction

Despite the theoretical appeal of the Q model of investment, its empirical performance has been disappointing. Studies based on both aggregate time-series and microeconomic data have generally found a very low coefficient on the Q variable. This low coefficient is suggestive of implausibly high marginal cost of adjustment and implausibly slow adjustment of the capital stock. Q has also not been found to be a sufficient statistic for investment with variables such as cash flow, profits, and sales found to be strongly associated with investment after controlling for Q.[1]

One common feature of most of the Q model literature is the assumption of capital homogeneity. A typical firm will use many types of capital goods, ranging from buildings to computer software. Clearly, these different capital goods provide very different capital services flows into production (see Wallis, 2009), have very different deprecation patterns, and also command different prices. Tax treatment also differs substantially over capital goods as shown in Chapter 3. Combining the multiple capital inputs of a firm into a single aggregate requires the restrictive assumption that these capital goods are perfectly substitutable in the firms' production function, as shown by Blackorby and Schworm (1983). This is not only an unintuitive assumption, especially in light of the increasing use of short-lived Information and Communication Technology (ICT) assets, but has also been rejected in empirical studies of static production, such as those by Berndt and Christensen (1973) and Denny and May (1978).

A multiple capital input Q model was first formulated theoretically by Wildasin (1984). Wildasin showed that, in general, total investment in many capital inputs cannot be expressed as a monotonic function of Q. With more than one capital input there will be a variety of marginal Qs, one for each capital good, and in general these will not be

[1] There are of course some exceptions and in general more plausible estimates have been found when particular attention is paid to potential measurement error. See for example Erikson and Whited (2000) and Bond and Cummins (2001).

equal to observable average Q.[2] Chirinko (1986) formulated a multiple capital input Q model, showing that the conventional formulations of the empirical Q model are misspecified if a firm uses two or more capital inputs with different adjustment cost technologies. Using U.S. aggregate data, Chirinko finds that the econometric evidence rejects the conventional model in favour of the multiple capital inputs specification. A hypothesis test of equality between the adjustment costs parameters for the different capital inputs is also rejected.[3]

In many cases there has been a reliance on the assumption of capital homogeneity in empirical work due to a lack of suitable data to allow for multiple capital inputs. As such, there is a very limited amount of work on Q models with multiple capital inputs. In general, however, empirical applications of investment models with multiple capital goods have been more successful than applications using aggregated data. For example, Hayashi and Inoue (1991) estimate a Q model with a Divisa index of capital goods and find that estimated adjustment costs are less than half of gross profits. However, such a capital index still requires capital goods to be perfect substitutes which Cummins and Dey (1998) find is rejected by the data. Goolsbee and Gross (1997) use data on 16 types of capital in the US airline industry and their results strongly support the use of detailed asset specific data. Bontempi, Del Boca, Franzosi, Galeotti, and Rota (2004), using Italian data, find much more plausible estimates of adjustment costs when using disaggregated data.

There are two distinct empirical approaches in the Q model literature. The first relies on assumptions underlying equality of average and marginal q as set out by Hayashi (1982). This allows researchers to uses stock market data to estimate average q which is generally observable if imprecisely measured. Use of average q requires that financial markets are efficient. The second attempts to measure marginal q directly, such as Abel and Blanchard (1986) and Grilchrist and Himmelberg (1995). This allows relaxation of equality between average and marginal q and the associated assumptions but requires the construction of marginal q, which is not directly observable like average q is. A

[2] Hayashi (1982) showed that marginal and average Q are equivalent when: (i) firms are price takers; (ii) production and adjustment cost technologies are linear homogenous; and (iii) capital is homogenous.

[3] Cummins and Dey (1998) argue that because Chirinko (1983) restricts the adjustment cost parameters of different capital goods to be equal and assumes adjustment cost functions are linear quadratic the method amounts to assuming that there is only one capital good.

simple example, based on Abel (1980), is useful in understanding why movements in the two might differ. Consider a firm that has a large amount of energy-intensive capital. If the price of energy rises sharply, then the value of the firm would fall as the quasi-rents available on existing energy-intensive capital would fall. Average q would therefore also fall. However, while the marginal q of energy-intensive capital will also fall, the marginal q of energy-saving capital will actually increase. If the firm undertakes substantial investment in energy-saving capital as a result of the increase in marginal q an observer who only has aggregate investment data would see a drop in average q coinciding with an increase in investment and reject the Q model of investment.

This chapter uses a marginal q approach to investigate the importance of accounting for the presence of multiple capital goods when estimating a Q model on microeconomic data. It uses a detailed establishment level panel with over 20,000 observations and covering over 25 years. It starts by estimating a standard Q model with a homogenous capital good then goes on to estimate a multiple capital good model. This is the first time such an approach has been adopted using UK data reflecting the difficulties in compiling an appropriate dataset with the required level of asset detail.

The main findings are: (a) the dataset shows clear evidence of inaction, irreversibility and heterogeneity between assets; (b) despite evidence of non-convexities, the Q model assuming quadratic adjustment costs performs slightly better than in much of the past literature; (c) the performance of the Q model is significantly improved when applied asset-by-asset, with adjustment cost estimates at least twice as large as for total investment; (d) estimation of the Q model asset-by-asset also appears to get rid of autocorrelation problems; and (e) for most asset-by-asset regressions Q is found to be a sufficient statistic with variables such as cash-flow and uncertainty not statistically significant. These empirical results highlight the importance of allowing for multiple capital goods and point to the importance of detailed disaggregated data on investment to be able to perform sound microeconometric analysis of investment models.

Section 2 discussed the dataset and presents some initial empirical findings. Section 3 outlines a Q model generalised to multiple capital goods. Section 4 discusses the estimation of marginal q used in the analysis with the econometric specification in

Section 5. Section 6 presents the empirical results. Section 7 concludes. The Appendix describes in more detail the construction of the data used in the analysis.

2. Data

2.1. Data and sample

The empirical analysis uses a panel of establishments in the UK manufacturing sector taken from the Annual Respondents Database (ARD) supplemented with industry level data based on Wallis (2009) and from the UK National Accounts.[4] The ARD provides a good source for estimates of firm level investment in various assets types and can also be used to calculate estimates of establishment level capital stock as well as the estimates of fundamental Q needed to estimate an empirical Q model. The discussion here will focus on measurement issues. For a detailed overview of the ARD see Robjohns (2006).

The empirical analysis focuses on establishments with more than 250 employees. This is because only establishments of this size are continually sampled in compulsory business surveys and a near continuous time-series of investment is needed in order to calculate reliable capital stock estimates. The time period covered is 1980 to 2007. Sample details, including the cleaning criteria used prior to the empirical analysis, are provided in the Appendix. After cleaning the total sample is 3,398 establishments with a total of 20,745 observations.[5]

2.2. Measurement issues

Establishment level capital stocks are calculated as described in detail in the Appendix. A number of measurement issues associated with the calculation of establishment level capital stocks are worthy of discussion here and additional discussion of such issues can

[4] The Annual Respondents Database (ARD) is constructed from compulsory business surveys. Until 1997 it was created out of the Annual Censuses of Production and Construction (ACOP and ACOC); these were combined into the Annual Business Inquiry (ABI) in 1998. The ABI was replaced in 2009 with the Business Register and Employment Survey (BRES).

[5] The empirical analysis in Section 6 has 13,521 observations due to the number of lags used in the analysis.

be found in Attanasio, Pacelli and Reduto dos Reis (2003), Martin (2002) and Harris and Drinkwater (2000).

The first issue is how to deal with missing values for establishments in certain years as a continuous time series is needed to calculate capital stock using the Perpetual Inventory Method (PIM). The approach here is to interpolate missing values. The problem with doing this is that it generates an investment series that is smoother than would normally be found empirically. This is less of an issue for the capital stock which is empirically found to be quite smooth. For this reason the empirical analysis ignores investment rates where the numerator is interpolated and just uses the interpolated investment values to generate the capital stock.

The second issue is the so-called initial conditions problem. Application of the PIM requires a long time-series of investment but only a limited time series of investment is available for each establishment. The method used here is to use estimates of industry capital stocks from Wallis (2009) and allocate these to establishments based on employment shares. This means that the first time an establishment appears in the sample it gets a share of the industry capital stock based on its share of industry employment. From then on its capital stock is determined by its level of investment and the depreciation rate. An alternative is to treat new establishments in the sample as having initial capital stock equal to their level of investment in their first year. Doing so has a minimal impact on the results in Section 6 and the main conclusions hold.

The final issue is the appropriate depreciation rate. Asset specific depreciation rates are set at 2.5 per cent for buildings, 13 per cent for plant, and 25 per cent for vehicles, and are based on Fraumeni (1997). For aggregate capital 8 per cent is used as this is the standard assumption in the literature. These depreciation rates are held constant over time, meaning no allowance is made for increased plant closures of multi-plant establishments during recessions. As shown by Harris and Drinkwater (2000), this could lead to overestimation of the capital stock with the PIM. No suitable method for allowing for such plant closures is available using the dataset here.

Two additional assumptions are required for the analysis. Firstly, the discount rate is assumed to be 7 per cent per annum. Secondly, the real cost of finance, used in estimating the marginal product of capital, is estimated as a weighted average of the cost of equity and the cost of debt finance. Estimation of the real cost of finance is described in more detail in Chapter 3.

2.3. Summary statistics

It is useful to look at some of the characteristic of the dataset before describing the empirical method. A number of previous studies have documented the lumpiness of investment, including Doms and Dunne (1998), Attanasio, Pacelli and Reduto dos Reis (2003) and Cooper and Haltiwanger (2006). Some empirical studies find zero annual investment for a low percentage of observations. One explanation for this is aggregation over heterogeneous capital goods.

Table 1 shows the average investment rate, inaction rate, fraction of observations with negative investment and the spike rate for total investment and broken down by asset. Following Power (1998), Cooper and Haltiwanger (2006) and Nilsen and Schiantarelli (2003) an investment spike is defined as an investment rate that exceeds 20 per cent. Table 1 shows clear evidence of inaction, irreversibility and heterogeneity between assets.[6] For example, the inaction rate for total investment is just 0.6 per cent but it is 28.2 per cent for buildings investment. Aggregation over assets can be seen to hide much of the inactivity and lumpiness that takes place at asset level.

Table 1: Investment rate summary statistics

	Total investment	Buildings	Plant	Vehicles
Average investment rate (I/K)	5.4	2.2	8.6	14.3
Inaction rate (I/K=0)	0.6	28.2	1.0	17.2
Fraction of observations with negative	3.3	8.8	1.9	11.7
Spike rate: positive investment	3.4	2.1	9.3	29.5
Skewness	71.6	98.7	93.8	99.9
Total observations	20745	20745	20745	20745
Number of reporting units	3398	3398	3398	3398

Notes: Percentages except for total observations and number of reporting units. An investment spike is defined as an investment rate that exceeds 20 per cent.

[6] Section A5 outlines the cleaning criteria for the analysis. The summary statistics shown here impose the same criteria for comparison purposes. Imposing less stringent cleaning criteria shows more pronounced evidence of inaction, irreversibility and lumpiness.

Figure 1 shows histograms of the investment rate for total investment and also by asset type. Once again, there is strong evidence of non-convexity and irreversibility. The high incidence of zero investment can be seen together with limited observation where the investment rate is negative. As in Table 1, aggregation over assets hides these patterns to a large extent.

Figure 1: Histograms of the investment rate

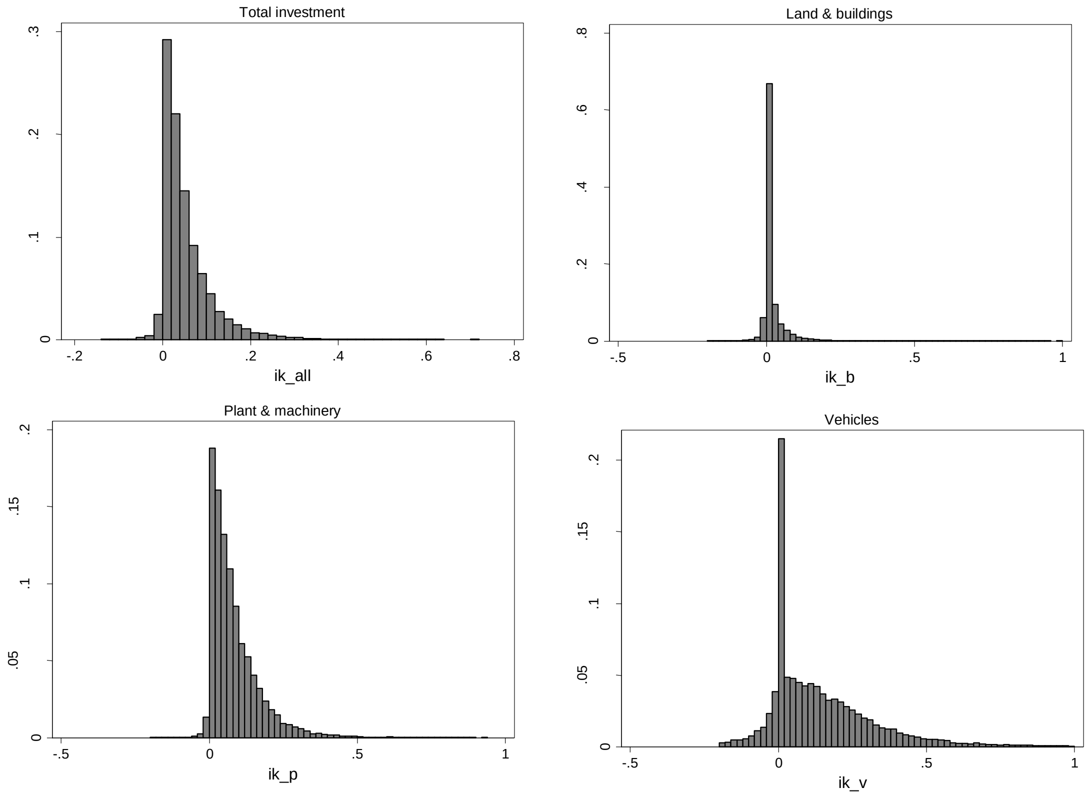


Table 2 shows summary statistics by industry for total investment. It can be seen that while there is some variation across industries it is not as large as the variation across assets. The asset specific variation within industries is not shown to save space, but shows a similar picture to Table 1 with aggregation over assets hiding much of the inaction and lumpiness that takes place at the asset level.

Table 2: Investment statistics by industry

sic92_2digit	Industry	Average investment rate (I/K)	Inaction rate (I/K=0)	Percentage of observations with negative investment
15-16	Manufacture of food products, beverages and tobacco products	6.7	0.6	1.4
17	Manufacture of textiles	3.8	0.6	6.1
18	Manufacture of wearing apparel; Dressing and dyeing of fur	3.5	1.6	4.8
19	Tanning and dressing of leather; manufacturing of leather products	7.6	3.9	5.9
20	Manufacture of wood and wood products	5.7	0.3	4.6
21	Manufacture of pulp, paper and paper products	10.5	0.2	2.6
22	Publishing, printing and reproduction of recorded media	4.8	1.1	3.8
23	Manufacture of coke, refined petroleum products and nuclear fuel	4.9	4.4	1.6
24	Manufacture of chemicals and chemical products	5.4	0.1	1.6
25	Manufacture of rubber and plastic products	7.2	0.4	1.7
26	Manufacture of other non-metallic mineral products	5.2	0.4	3.5
27	Manufacture of basic metals	3.9	0.5	2.9
28	Manufacture of fabricated metal products, except machinery and equipment	3.7	1.2	6.2
29	Manufacture of machinery and equipment not elsewhere classified	3.5	0.7	5.8
30-31	Manufacture of office machinery, computers and other electrical equipment n.e.c.	4.2	1.0	2.7
32	Manufacture of radio, television and communication equipment and apparatus	9.6	0.0	1.6
33	Manufacture of medical, precisions and optical instruments, watches and clocks	7.9	0.0	2.3
34	Manufacture of motor vehicles, trailers and semi-trailers	5.2	0.6	3.5
35	Manufacture of other transport equipment	4.9	1.7	3.6
36	Manufacture of furniture; Manufacturing not elsewhere classified	5.9	1.0	3.2
37	Recycling	8.2	0.0	8.0
	Total	5.4	0.6	3.3

Notes: Sub-sectors 15 and 16 and 30 and 31 are combined to avoid small sample. n.e.c. is not elsewhere classified.

Overall, summary statistics suggest that there may be asymmetries and non-convexities in the adjustment cost technology and also highlight the importance of asset specific treatment. Here we focus on the asset specific issues, not the non-convexities, and we continue to assume quadratic adjustment costs.

3. Model

The model considered is a generalisation to multiple capital goods of the standard model in the investment literature and follows most closely Gilchrist and Himmelberg (1998) and Bontempi, Del Boca, Franzosi, Galeotti and Rota (2004). The value of firm *i* at time *t* is given by

$$V\left(K_{i,t-1},\theta_{i,t}\right)=\max_{\{I_{i,t}\}_{t=0}^{\infty}} E\left\{\sum_{t=0}^{\infty}\beta^{t}\left[\Pi\left(K_{i,t},\theta_{i,t}\right)-G\left(I_{i,t},K_{i,t},\xi_{i,t}\right)-p_{i,t}I_{i,t}\right]|\Omega_{\mathrm{i,t}}\right\} \quad (1)$$

Where $E[.\,|\Omega_{i,t}]$ is the expectations operator conditional on the information set $\Omega_{i,t}$. $K_{i,t}=(K_{i,1,t},\ldots,K_{i,A,t})$ is a vector of A types of capital input available for production in period *t*. $I_{i,t}=(I_{i,1,t},\ldots,I_{i,A,t})$ is a vector of gross investment expenditure on the A types of capital. p is a vector of prices of different capital goods. β^{t} is the firms discount factor. $\Pi(.)$ is the profit function and θ_t is an exogenous profit shock. $G(.)$ is the adjustment cost function. $G(.)$ is vector of adjustment cost functions, one for each type of capital. Under the assumption that $G(.)$ is additively separable this can be written as

$$G(I_{i,t}, K_{i,t}, \xi_{i,t}) = \left(G_1(I_{i,1,t}, K_{i,1,t}, \xi_{i,1,t}), \dots, G_A(I_{i,A,t}, K_{i,A,t}, \xi_{i,A,t})\right) \tag{2}$$

where $\xi_{i,a,t}$ are exogenous shocks to the adjustment cost function.

The law of motion for the capital inputs is given by

$$K_{i,a,t} = K_{i,a,t-1}(1-\delta_a) + I_{i,a,t} \qquad For\ a = 1, \dots, A \tag{3}$$

δ_a is the rate of depreciation for capital of type a, assumed to be fixed over time and common to all firms. Equation (3) implies no time to build with investment in period *t* adding to the capital stock in period *t*.

The first-order conditions for maximising the value of the firm (equation 1) subject to the law of motion for the capital inputs (equation 3) is given by

$$p_{i,a,t} + \frac{\partial G_a(I_{i,a,t}, K_{i,a,t}, \xi_{i,a,t})}{\partial I_{i,a,t}} = E[q_{i,a,t} | \Omega_{i,t}] \qquad For\ a = 1, \dots, A \tag{4}$$

where

$$q_{i,a,t} = \sum_{s=0}^{\infty} \beta^s (1-\delta_a)^s E\left[\frac{\partial \Pi(K_{i,t+s}, \theta_{i,t+s})}{\partial K_{i,a,t+s}} + \frac{\partial G_a(I_{i,a,t+s}, K_{i,a,t+s}, \xi_{i,a,t+s})}{\partial K_{i,a,t+s}}\right] \tag{5}$$

Equation (5) is marginal q and is the same as in Gilchrist and Himmelberg (1995) but generalised to *A* capital inputs and making the assumption that the adjustment costs are additively separable.

3.1. Quadratic adjustment costs

The standard assumption in the investment literature is that the adjustment cost function is quadratic as this greatly simplifies the analysis

$$G_a\left(I_{i,a,t}, K_{i,a,t}, \xi_{i,a,t}\right) = \frac{\alpha_a}{2}\left(\frac{I_{i,a,t}}{K_{i,a,t}} - \gamma_{i,a} - \xi_{i,a,t}\right)^2 K_{i,a,t} \quad For\ a = 1, \dots, A \tag{6}$$

Therefore

$$\frac{\partial G_a(I_{i,a,t}, K_{i,a,t}, \xi_{i,a,t})}{\partial I_{i,a,t}} = \alpha_a\left(\frac{I_{i,a,t}}{K_{i,a,t}} - \gamma_{i,a} - \xi_{i,a,t}\right) \quad For\ a = 1, \dots, A \tag{7}$$

Substituting (7) into (4) and rearranging gives

$$\frac{I_{i,a,t}}{K_{i,a,t}} = \gamma_{i,a} + \frac{1}{\alpha_a}E\left[q_{i,a,t}\middle|\Omega_{i,t}\right] - \frac{1}{\alpha_a}p_{i,a,t} + \xi_{i,a,t} \quad For\ a = 1, \dots, A \tag{8}$$

Equation (8) expresses investment in each type of capital good as a function of its marginal q (shadow price of capital) and also of the price of the capital good.[7] The greater the number of assets the more demands on the data. The advantage of allowing for more assets is that it allows for different adjustment costs, depreciation rates, and deflators for each separate asset.

There are a number of weaknesses with assuming the standard quadratic adjustment cost function. Firstly, both previous literature and the dataset used here show clear evidence of inaction and irreversibility which would suggest something other than quadratic adjustment costs. Bontempi, Del Boca, Franzosi, Galeotti and Rota (2004) assume that the adjustment cost function has both a quadratic and fixed cost component, but estimate the model under the null of no fixed costs. Hence, equation (8) is the same as they estimate using a panel of Italian firms. The assumption of no fixed costs is unlikely to hold for assets such as buildings and is one potential weakness of the approach. The final weakness of the standard quadratic adjustment cost function is that the adjustment cost function for each asset only depends on investment in that asset. To the extent that different assets are complements rather than substitutes, it might be expected that there would be some link between adjustment costs for different assets.

[7] In empirical applications prices are often not included, with time dummies used instead. Asset specific prices are used in the empirical analysis here.

4. Estimating marginal q (the shadow value of capital)

In order to estimate equation (8) empirically we need estimates of the shadow value of capital for each asset, $E\left[q_{i,a,t}\middle|\Omega_{i,t}\right]$. It is usually assumed that $\partial G/\partial K = 0$ (marginal effect on adjustment costs of changes in capital stocks) to leave marginal q as a discounted sum of marginal products of capital. As noted by Letterie and Pfann (2007), this assumption implies that the intensive margin for investment is not affected by the size of the firm (or more accurately by the size of the capital stock). Assuming $\partial G/\partial K = 0$ gives

$$E\left[q_{i,a,t}\middle|\Omega_{i,t}\right] = \sum_{s=0}^{\infty} \beta^s (1-\delta_a)^s E\left[\frac{\partial \Pi_{i,t+s}}{\partial K_{i,a,t+s}} |\Omega_{\mathrm{i,t}}\right] \tag{9}$$

Direct estimation of equation (9) was first proposed by Abel and Blanchard (1986) who measured marginal q by forecasting future marginal revenue products of capital and future discount rates. This was extended to panel data by Grilchrist and Himmelberg (1995) and then to multiple capital goods by Bontempi, Del Boca, Franzosi, Galeotti and Rota (2004).

We can make assumptions about the discount rate β and the rate of depreciation δ but the marginal profitability of capital is not observable. Grilchrist and Himmelberg (1998) show that for a firm with a Cobb-Douglas production function facing perfect competition in the output market, facing a profits tax, and with no fixed costs, the marginal profitability of capital (MPK) is related to (potentially) observable variables as follows

$$MPK_{i,a,t}^{\Pi} = \frac{\partial \Pi_{i,t}}{\partial K_{i,a,t}} = (1-u)\rho_{i,a}\left(\frac{\Pi_{i,t}}{K_{i,a,t}}\right) \tag{10}$$

where u is the corporation tax rate on profits and $\rho_{i,a}$ is the output elasticity of capital. Allowing for imperfect competition and relaxing the assumption of no fixed costs Grilchrist and Himmelberg (1998) show that the marginal profitability of capital is then proportional to the sales to capital ratio

$$MPK_{i,a,t}^{S} = \frac{\partial \Pi_{i,t}}{\partial K_{i,a,t}} = (1-u)(1+\eta_i^{-1})\rho_{i,a}\left(\frac{S_{i,t}}{K_{i,a,t}}\right) = (1-u)\theta_{i,a}\left(\frac{S_{i,t}}{K_{i,a,t}}\right) \tag{11}$$

Where $S_{i,t}$ are firm sales and $\eta_i = (\partial y_i / \partial p_i) \cdot p_i / y_i < -1$ is the (firm-level) price elasticity of demand.

Grilchrist and Himmelberg (1998) express a clear preference for MPK^S over MPK^Π because the latter requires the added assumptions of zero fixed costs and perfect competition. As expected MPK^Π is a noisier measure of the marginal profitability of capital (see Table A3).

The calculation of demand parameters $\rho_{i,a}$ and $\theta_{i,a}$ is described in the Appendix and estimated demand parameters are shown in Table A2.

Following Abel and Blanchard (1986) a proxy for the right hand side of equation (9) is calculated by specifying a linear forcing process for a vector $x_{i,a,t}$ containing variables useful for forecasting the future marginal profitability of capital. In this case the variables $MPK_{i,a,t}^{\Pi}$ and $MPK_{i,a,t}^{S}$. $x_{i,a,t}$ are assumed to follow a stationary stochastic process.

$$x_{i,a,t} = B_a x_{i,a,t-1} + f_i + d_t + u_{i,t} \tag{12}$$

Where B is a matrix of capital-specific coefficients. Following Grilchrist and Himmelberg (1998), cross-sectional heterogeneity is captured by f_i and aggregate shocks (common to all firms) by d_t. $u_{i,t}$ is a vector of innovations in $x_{i,a,t}$ assumed to be orthogonal to lags of $x_{i,a,t}$.

Assuming that d_t also has a finite order autoregressive representation we can derive the expectation of $x_{i,a,t+s}$ given $x_{i,a,t}$ as

$$E\left[x_{i,a,t+s} \middle| x_{i,a,t}\right] = B_a^s x_{i,a,t} \tag{13}$$

Where the terms involving f_i and d_t have been omitted as they are nuisance parameters.

From equation (10) the marginal profitability of capital is proportional to the ratio of realised profits to existing capital, $\Pi_{i,a,t}/K_{i,a,t}$. If $\Pi_{i,a,t}/K_{i,a,t}$ is included as the *j*th element of $x_{i,a,t}$ then $\Pi_{i,a,t}/K_{i,a,t} = c'x_{i,a,t}$, where c is a conformable vector of zeros with a one in the *j*th row. Using this notation and assuming that $x_{i,a,t} \in \Omega_{i,t}$ we can rewrite equation (9) as follows[8]

$$E\left[q_{i,a,t}\middle|\Omega_{i,t}\right] = \sum_{s=0}^{\infty} \beta^s (1-\delta_a)^s E[c'x_{i,a,t+s}|x_{i,a,t}] \tag{14}$$

Now using equation (13) and setting $\lambda_a = \beta(1-\delta_a)$ to simplify the notation

$$E\left[q_{i,a,t}\middle|\Omega_{i,t}\right] = \sum_{s=0}^{\infty} \lambda_a^s c` B_a^s x_{i,a,t} = c'(I - \lambda_a B_a)^{-1} x_{i,a,t} \tag{15}$$

Where I is an identity matrix. Combining with equation (8) gives the following empirical specification for investment

$$\frac{I_{i,a,t}}{K_{i,a,t}} = \gamma_{i,a} + \frac{1}{\alpha_a} \cdot c'(1 - \lambda_a B_a)^{-1} x_{i,a,t} - \frac{1}{\alpha_a} \cdot p_{i,a,t} + \xi_{i,a,t} \quad For\ a = 1, \dots, A \tag{16}$$

Assuming a discount rate of 7 per cent ($\beta = 0.93$) and together with depreciation assumptions outlined in section 2.2 implies that λ is 0.856 for total investment, 0.907 for buildings, 0.809 for plant, and 0.698 for vehicles.

4.1. Estimates of marginal q

Table 3 shows marginal q estimates using the methodology described above. Details of the estimation method and associated regression results can be found in Section 5 and the Appendix. The table shows estimates based on both the profit based and sales based measures of the marginal profitability of capital. The first thing to note is that the mean value of marginal q is below 1 for all but the sales based measure for vehicles. Importantly the total investment estimates hide a large difference between the asset specific estimates of marginal q. Marginal q is low for buildings and has a low standard deviation in contrast to marginal q for vehicles which is much closer to 1 and has a very large standard deviation. Using a sales based measure of the marginal profitability of capital gives higher estimates of marginal q on average with a lower standard deviation.

[8] Using the sales based measure of the marginal profitability of capital leads to a slightly different formulation, which is not shown to save space.

Table 3: Marginal q summary statistics

	Total investment	Buildings	Plant	Vehicles
Profit based				
Mean	0.596	0.480	0.896	0.935
Standard Deviation	0.804	0.200	0.986	1.592
Min	0.017	-0.109	-0.250	0.010
25th percentile	0.270	0.397	0.265	0.294
75th percentile	1.023	0.604	1.289	1.427
Max	1.953	1.426	1.958	2.179
Skewness	2.409	8.087	1.875	3.249
Sales based				
Mean	0.605	0.511	0.929	1.044
Standard Deviation	0.627	0.152	0.736	1.390
Min	0.096	0.209	0.288	0.104
25th percentile	0.197	0.289	0.478	0.296
75th percentile	0.901	0.702	1.219	1.659
Max	1.425	1.361	1.638	3.420
Skewness	2.874	7.648	2.797	3.688

Notes: Mean values for all firms.

5. Econometric specification

Equation (16) is estimated using a two-stage procedure. The matrix B is estimated in the first stage using a bivariate VAR model. This is done for total investment and then for the specific assets (buildings, plant and vehicles). The two variables used in the bivariate VAR are the measures of the marginal profitability of capital under perfect and imperfect competition (equations (10) and (11)). The VAR is estimated using GMM following Holtz-Eakin, Newey and Rosen (1988). Two measure of marginal q are then calculated following the approach above (equation (15)). The first estimate being a profit based estimate of marginal q and the second a sales based estimate. The VAR results are shown in the Appendix.

In the second stage, equation (16) is estimated using the marginal q estimates from the first stage. As we have large N and small T the Arellano and Bover (1995) / Blundell and Bond (1998) system estimator is used. This GMM estimator uses the moment conditions in which lags of the dependent variable and first differences of the exogenous variables are instruments for the first-differenced equation plus the moment conditions in which lagged first differences of the dependent variable are instruments for the level equation.

We test for serial correlation in the first-differenced residuals and test the validity of the overidentifying restrictions. The moment conditions of the GMM estimate are only valid if there is no serial correlation in the idiosyncratic errors. As the first difference of white noise is necessarily autocorrelated we need only concern ourselves with second and higher order autocorrelation.

The standard errors of the second stage estimation need to be corrected to take into account the generated regressors problem. The method set out in Bontempi, Del Boca, Franzosi, Galeotti and Rota (2004) is followed here.[9]

6. Empirical results

Tables 4 and 5 present GMM estimates of equation (16). Firstly for total investment and then by asset type. Table 4 uses a measure of marginal q that is forecast using the profit based measure of the marginal profitability of capital while Table 5 uses marginal q based on the sales based measure of the marginal profitability of capital. All regressions use asset specific prices as instruments. Estimates using time dummies were very similar.

Column 1 of Table 4 shows the regression for total investment. As in previous literature, the performance of the Q model is disappointing. The estimated coefficient on marginal q is significant but quite low at 0.147 and the model suffers from second order autocorrelation. The Sargan test does not reject the over-identifying restrictions. It is useful to compare the result to existing estimates in the literature. In terms of broadly comparable estimates of the coefficient on marginal q the largest estimate in Abel and Eberly (2002) is 0.101. Estimates in Whited (1994) range from 0.003 to 0.05. Grilchrist and Himmelberg (1995) estimate the coefficient to be 0.18. Behr and Bellgardt (2002) estimate it to be 0.299 using a panel of German firms. In Bontempi, Del Boca, Franzosi, Galeotti and Rota (2004) their estimate for total investment is 0.174. So the result here is towards the upper end of previous literature. Column 1 of Table 5 shows the regression for total investment using the sales based measure of marginal q. Again, the estimated coefficient is significant but the estimate is very low. This model also appears

[9] This correction is based on Gauss code kindly provided by Paola Rota.

to suffer from second order autocorrelation and the Sargan test rejects the over-identifying restrictions.

Turning now to the asset specific results using the profit based measure of marginal q. The regression for buildings (column 2) is disappointing with a low estimated coefficient (though not that different from Bontempi, Del Boca, Franzosi, Galeotti, and Rota (2004) whose estimate for buildings is 0.101). The Sargan test also rejects the over-identifying restrictions. A potential problem here is the existence of large fixed costs of adjustment for buildings. The model is estimated under the null of no fixed costs but this is less likely to hold for buildings than for other assets. The results for plant and vehicles are much better with higher estimated coefficients on the marginal q term and neither appears to suffer from autocorrelation.

Table 4: Q model results (profit based marginal q)

	(1) Total investment	(2) Buildings	(3) Plant	(4) Vehicles
Coefficient on marginal q	0.147**	0.092**	0.306***	0.159***
Standard error	0.073	0.039	0.088	0.019
Adjustment cost parameter	6.80	10.87	3.27	6.29
Adjustment costs evaluated at mean investment rate:				
Mean investment rate (per cent)	5.4	2.2	8.6	14.3
Marginal adjustment cost (£1 of investment)	0.37	0.24	0.28	0.90
Mean(I^2/K)	5.19	1.84	8.28	12.89
Total adjustment costs as percentage of investment	17.7	10.0	13.5	40.5
Sargan Chi2(65)	61.21	80.76**	40.72	54.04
AR(1)	-14.12***	-9.19***	-15.56***	-21.60***
AR(2)	-2.01**	0.27	0.07	-0.28
Observations	13521	13521	13521	13521

Notes: *** indicates significance at 1 per cent level. ** indicates significance at the 5 per cent level. * indicates significance at the 10 per cent level. Marginal adjustment cost and total adjustment cost are calculated at the mean investment rate as $b(\bar{I}/\bar{K})$ and $(b/2)(\bar{I}^2/\bar{K})$.

Marginal adjustment costs at the mean investment can be calculated as the adjustment cost parameter multiplied by the mean investment rate, $b(\bar{I}/\bar{K})$. Total adjustment costs as a percentage of investment can be calculated as $(b/2)(\bar{I}^2/\bar{K})$. As shown by Whited (1994), backing out adjustment costs in this way requires a set of arbitrary identifying assumptions because the marginal adjustment cost function in equation (3) does not integrate uniquely back to the adjustment cost function in equation (5) but to a larger class of functions. Despite this, it is useful to consider what the coefficient estimates imply using this method. Table 4 shows that the estimated coefficient on marginal q for total investment together with the required moment estimates suggests a marginal adjustment cost of 37 pence. This is obviously quite high. The estimates for buildings and plant are more realistic at 24 and 28 pence respectively. The marginal adjustment cost for vehicles is very high at 90 pence.

Table 5 shows the same regressions as in table 4, but using a sales based estimate of marginal q. As noted above, these results may be preferable as they do not rely on the assumption of perfect competition and avoid spurious noise in marginal q attributable to cash-flow fluctuations. The results do appear to be better and the value of allowing for multiple capital goods is much clearer. The performance of the Q model run on total investment is very poor with very high estimated adjustment costs. The asset specific regressions are better with the individual coefficients at least twice as large for each asset. Treatment asset-by-asset also appears to get rid of the autocorrelation problems of the total investment regression and the rejection of the over-identifying restrictions.

Table 5: Q model results (sales based marginal q)

	(1) Total investment	(2) Buildings	(3) Plant	(4) Vehicles
Coefficient on marginal q	0.063***	0.176**	0.235***	0.157***
Standard error	0.021	0.075	0.026	0.017
Adjustment cost parameter	15.87	5.68	4.26	6.37
Adjustment costs evaluated at mean investment rate:				
Mean investment rate (per cent)	5.4	2.2	8.6	14.3
Marginal adjustment cost (£1 of investment)	0.86	0.13	0.37	0.91
Mean(I^2/K)	5.19	1.84	8.28	12.89
Total adjustment costs as percentage of investment	41.2	5.2	17.6	41.0
Sargan Chi2(65)	84.93**	63.35	53.18	58.3
AR(1)	-14.22***	-9.17***	-15.23***	-21.55***
AR(2)	-1.76*	0.21	1.71*	-0.94
Observations	13521	13521	13521	13521

Notes: *** indicates significance at 1 per cent level. ** indicates significance at the 5 per cent level. * indicates significance at the 10 per cent level. Marginal adjustment cost and total adjustment cost are calculated at the mean investment rate as $b(\bar{I}/\bar{K})$ and $(b/2)(\bar{I}^2/\bar{K})$.

Column 4 shows some signs of second order autocorrelation for the plant regression. However, the inclusion of an additional lag of the instruments removes this problem. The estimated coefficient on marginal q hardly changes so the directly comparable results are presented in Table 5. Overall, the results in Tables 4 and 5 suggest that it is important to treat different assets separately.

6.1. Sufficiency of marginal q

Is marginal q a sufficient statistic to explain investment at the establishment level? This is usually rejected in the empirical investment literature because additional regressors designed to measure additional factors, such as financial constraints or uncertainty, are found to be significant. For example, early work by Fazzari, Hubbard, and Petersen (1988) found that cash flow tends to have a bigger effect on the investment of firms that they defined as being more likely to face financial constraints. Blundell, Bond, Devereux, and Schiantarelli (1992), using data for 532 quoted UK manufacturing firms over the period 1971–86, finds that a measure of cash flow has a positive and highly significant effect on company investment, in addition to measured Q. Bond, Elston, Mairesse, and Mulkay (2003) finds that cash flow and profits terms appear to be both statistically and quantitatively more significant in the United Kingdom than in three other European countries (Belgium, France and Germany). This finding is consistent with the suggestion that financial constraints on investment may be relatively severe in the more market-oriented U.K. financial system. Gilchrist and Himmelberg (1995) find that the neoclassical model of investment (without cash flow) only holds for firms less likely to face financial constraints, whereas cash flow significantly enters the regressions of constrained firms. The literature on the impact of uncertainty on investment is extensive and a number of papers, including Ghosal and Loungani (2000), Bloom, Bond, and Van Reenen (2001), and Bond and Cummins (2004) find a significant and negative impact of uncertainty on investment.

Table 6 shows a number of additional regressions to look at the significance of other variables.[10] Each entry shows a single regression (i.e. the first entry shows the regression with the additional cash flow variable estimated for total investment). These regressions all use a sales based measure of marginal q for the reasons explained above.

[10] It would be good to also add a measure of debt to the regressions but this data is not available in the ARD.

The first row includes a measure of cash flow as a proxy for financial constraints. Cash flow is defined in the usual way, as profit minus depreciation, and is normalised by total firm capital stock. For total investment and plant (columns 1 and 2) cash flow is not found to be significant and the significance is very marginal for buildings. Cash flow is significant for vehicles. This may reflect the high spike rate for vehicles with close to 30 per cent of observations having investment rates in excess of 20 per cent. Overall, the result would suggest that cash flow is not an important determinant of investment rates at establishment level. This conclusion is different from past literature such as Bond, Elston, Mairesse and Mulkay (2003). However, the sample here does not include small firms and it is more likely that small firms would be credit constrained.

Table 6: Sufficiency of marginal q

	(1) Total investmen	(2) Buildings	(3) Plant	(4) Vehicles
Cash flow (profit-depeciation/K)	0.003	0.011*	0.014	0.050***
Standard error	0.005	0.006	0.009	0.018
Uncertainty (volatility of turnover)	-0.030**	-0.012	-0.051**	-0.005
Standard error	0.014	0.021	0.022	0.056
Uncertainty (volatility of profits/K)	0.004	-0.003	-0.011	-0.009
Standard error	0.006	0.008	0.009	0.022

Notes: *** indicates significance at 1 per cent level. ** indicates significance at the 5 per cent level. * indicates significance at the 10 per cent level. Each entry is a single regression. Profit is normalised using total capital stock. Sample is 13,521 for cash flow regression and 8,833 for uncertainty regressions.

The second and third rows include two different measures of uncertainty. Uncertainty is measured as the volatility of either turnover or the profit rate. Establishment level measures of volatility are generated as set out in Comin and Mulani (2004). The growth rate of variable *x* (turnover or profit rate in this case) for establishment *i* is

$$\omega_{i,t} = \frac{x_{i,t} - x_{i,t-1}}{(x_{i,t} + x_{i,t-1})/2} \tag{17}$$

A five-year measure of volatility is given by

$$Vol_{i,t} = \left[\frac{1}{5}\sum_{\tau=-2}^{2}(\omega_{i,t+\tau} - \overline{\omega}_{i,t})^2\right]^{1/2} \tag{18}$$

where $\overline{\omega}_{i,t}$ is the simple average growth rate from t-2 to t+2. Estimated coefficients are negative as expected (i.e. increased volatility implies lower investment). The results in Table 6 show that uncertainty measured using profits is not significant in any regressions. Uncertainty measured using turnover is significant at the 5 per cent level in the regressions for total investment and plant but not significant in the regressions for buildings and vehicles. Again, the difference with previous literature could be the exclusion of small firms. For example, Ghosal and Loungani (2000) find that the quantitative negative impact of uncertainty is substantially greater in industries dominated by small firms. Turnover volatility could be important for plant and not other assets because of the more continuous nature of plant investment, as can be seen from the low inaction rate for plant investment in Table 1 relative to other assets. Empirically, a high proportion of investment is funded from retained earnings meaning that turnover volatility will be important for total investment.

In summary, while some measures of cash-flow and uncertainty have additional explanatory power for some assets, for most regressions these additional regressors are not significant. This represents an improvement over much of the existing literature.

7. Conclusions

This chapter relaxes the common assumption in the investment literature of capital homogeneity by estimating a Q model with multiple capital goods. This is done using a marginal q approach and a detailed establishment level panel with over 20,000 observations and covering over 25 years. The results highlight the importance of considering different types of assets as distinct, with the Q model performing much better when applied asset-by-asset than when applied to total investment.

A couple of limitations and possible extensions are worthy of discussion. Firstly, while the assumption of quadratic adjustment costs appears to be a good assumption for plant and machinery it is not for other assets. Establishment level data shows clear evidence of inaction and irreversibility. Allowing for a more general adjustment cost function would strengthen the analysis though greatly complicates the approach. Secondly, as highlighted by Bond and Cummins (2001), the approach here assumes that the profit function is homogenous of degree one in capital alone which will lead to an omitted variable bias if the profit function is homogenous of degree one in capital and other inputs. Unfortunately it is not possible to link the dataset here to analysts' earnings forecasts for comparison with their approach.

It would also be useful to extend the analysis to include intangible assets, as is done in Chapter 2 for the aggregate Q model. The problem here is the availability of firm-level intangible investment data. The ARD does contain some information on advertising expenditure but there are too many gaps in the data series to conduct robust analysis. New surveys of intangible investment would enable future analysis.

These limitations aside, the empirical results highlight the importance of allowing for multiple capital goods and point to the importance of detailed disaggregated data on investment to be able to perform sound microeconometric analysis of investment models.

Appendix

Four-letter identifiers are Office for National Statistics (ONS) codes.

A1. Data

The empirical analysis uses a panel of establishment level data on UK manufacturing firms from the Annual Respondents Database (ARD) supplemented with industry data based on Wallis (2009) and the UK National Accounts. The empirical analysis is limited to establishments with more than 250 employees and covers the period 1980 to 2007. Table A1 provides details of the sample by manufacturing sub-sector.

Table A1: Sample details (by manufacturing sub-sector)

sic92_2digit	Industry	No. of reporting units	Observations
15-16	Manufacture of food products, beverages and tobacco products	567	3580
17	Manufacture of textiles	209	1241
18	Manufacture of wearing apparel; Dressing and dyeing of fur	153	770
19	Tanning and dressing of leather; manufacturing of leather products	20	51
20	Manufacture of wood and wood products	72	349
21	Manufacture of pulp, paper and paper products	113	457
22	Publishing, printing and reproduction of recorded media	266	1753
23	Manufacture of coke, refined petroleum products and nuclear fuel	34	182
24	Manufacture of chemicals and chemical products	294	2123
25	Manufacture of rubber and plastic products	202	1141
26	Manufacture of other non-metallic mineral products	113	691
27	Manufacture of basic metals	219	1221
28	Manufacture of fabricated metal products, except machinery and equipment	177	903
29	Manufacture of machinery and equipment not elsewhere classified	402	2251
30-31	Manufacture of office machinery, computers and other electrical equipment n.e.c.	134	588
32	Manufacture of radio, television and communication equipment and apparatus	110	486
33	Manufacture of medical, precisions and optical instruments, watches and clocks	133	642
34	Manufacture of motor vehicles, trailers and semi-trailers	186	1016
35	Manufacture of other transport equipment	123	645
36	Manufacture of furniture; Manufacturing not elsewhere classified	112	630
37	Recycling	11	25
	Total	3650	20745

Notes: The empirical analysis actually covers 3,398 establishments. Some of these establishments appear in more than one manufacturing sub-sector over the sample period. Sub-sectors 15 and 16 and 30 and 31 are combined to avoid small sample.

A2. Investment and other ARD variables

Investment is available in the ARD in current prices and for total investment, buildings, vehicles and plant. Estimates of real investment are calculated by deflating using implied manufacturing investment deflators available from the National Accounts. Everything is done in 2005 prices. The STATA command “ipolate” is used to fill gaps in the investment series. These values are only used to generate establishment level capital stocks and are dropped for the empirical analysis. Other ARD variables used include employment, which is used to allocate initial capital stocks (see below). Profit is measured as gross value added (GVA) minus the ARD variable total labour costs. GVA at market prices is used and this is deflated using the relevant manufacturing output deflator (done as 2 digit level). The ARD measure of turnover is taken as establishment level sales. Cash flow is measured as profit (defined above) minus depreciation and is normalised by total capital stock. Depreciation is calculated by applying depreciation rates to the establishment level capital stock estimates.

A3. Establishment level capital stock

Establishment level estimates of capital stock are not available from the ARD so have to be constructed. This is done using a Perpetual Inventory Method (PIM) to calculate establishment level capital stock series from a history of constant price investment series. The ARD contains current price investment series for buildings, plant and vehicles.

A total capital stock series by establishment, treating capital as homogenous, is calculated as follows

$$I_{i,t} = \frac{\sum_a I_{i,a,t}^A}{P_t} \tag{A1}$$

$$K_{i,t} = K_{i,t-1}(1-\delta) + I_{i,t} \tag{A2}$$

The first expression shows that establishment level investment is summed over assets and then deflated using a deflators for total investment, P_t. The deflator used is the implied deflator for manufacturing investment (INJJ / INKL * 100). A depreciation rate of 8 per cent is used in the second expression when constructing estimates of capital stock.

There are two issues when applying the above method to data from the ARD. Firstly, the investment series by establishment are not always complete. Missing value of investment are interpolated in order to calculate establishment level capital stock estimates. However, the empirical analysis ignores investment rates where the numerator is interpolated.

The second issue is the initial conditions problem. For each establishment a full history of investment data is not available. This means a method is needed of estimating initial capital stocks. This is done by taking sic 2 digit level industry capital stock estimates and allocating this industry capital stock to each establishment using its share in industry employment. This means that the first time an establishment appears in the sample it gets a share of the industry capital stock based on its share of industry employment. From then on its capital stock is determined by its level of investment and the depreciation rate. Sic 2 digit level industry capital stocks are taken from Wallis (2009).

Asset specific establishment level capital stock estimates are calculated as follows

$$I_{i,a,t} = \frac{I_{i,a,t}}{P_{a,t}} \tag{A3}$$

$$K_{i,a,t} = K_{i,a,t-1}(1 - \delta_a) + I_{i,a,t} \tag{A4}$$

The first expression shows that investment is deflated at the asset level. The deflators used are the implied deflator for manufacturing investment in buildings, plant and vehicles (IMDA / IMGV * 100, IMZW / INDR * 100, and IMOL / IMSG * 100).

Asset specific depreciation rates are set at 2.5 per cent for buildings, 13 per cent for plant, and 25 per cent for vehicles and are based on Fraumeni (1997). The initial condition problem is dealt with as above but using asset specific industry level estimates of capital stock from Wallis (2009).

A4. Marginal product of capital and demand parameters

Two estimates of the marginal product of capital are used as described in the main text.

$$MPK^{\Pi}_{i,a,t} = \frac{\partial \Pi_{i,t}}{\partial K_{i,a,t}} = (1 - u)\rho_{i,a}\left(\frac{\Pi_{i,t}}{K_{i,a,t}}\right) \tag{A5}$$

$$MPK^{S}_{i,a,t} = \frac{\partial \Pi_{i,t}}{\partial K_{i,a,t}} = (1-u)(1+\eta_i^{-1})\rho_{i,a}\left(\frac{S_{i,t}}{K_{i,a,t}}\right) = (1-u)\theta_{i,a}\left(\frac{S_{i,t}}{K_{i,a,t}}\right) \tag{A6}$$

Where Π is establishment profits, u is the corporation tax rate on profits, $\rho_{i,a}$ is the output elasticity of capital, S is firm sales and $\eta_i = (\partial y_i/\partial p_i) \cdot p_i/y_i < -1$ is the (establishment level) price elasticity of demand. The establishment level profit and sales measure are ARD variables. Profit, Π, is measured as gross value added minus total labour costs and is deflated using industry specific manufacturing output deflators (sic92 2 digit). Capital stock, K, is measured as described above. Sales, S, are measures as turnover deflated using manufacturing sub-sector output deflators (sic92 2 digit).

The demand parameters used in the empirical analysis are calculated at sub-sector level (sic92 2 digit) following the approach in Gilchrist and Himmelberg (1998). The output elasticity of capital is estimated asset-by-asset as

$$\hat{\rho}_{j,a} = \left(\frac{1}{N_j}\sum_{i\in I(j)}\sum_{t\in T(i)}\left(\frac{\Pi_{i,t}}{K_{i,a,t}}\right)\right)^{-1}\frac{1}{N_j}\sum_{i\in I(j)}\sum_{t\in T(i)}(r_{i,t}+\delta_{i,a,t}) \tag{A7}$$

Where N_j is the number of establishment-year observations for sub-sector j. $r_{i,t}$ is the real cost of finance and is measured as a weighted sum of the cost of equity finance and the cost of debt finance. See Chapter 3 for full details of how the real cost of finance is calculated. The real cost of finance varies over time but not by establishment. Assumptions about asset depreciation rates are as above.

The asset specific scale parameters for the sales to capital ratio are estimated as

$$\hat{\theta}_{j,a} = \left(\frac{1}{N_j}\sum_{i\in I(j)}\sum_{t\in T(i)}\left(\frac{S_{i,t}}{K_{i,a,t}}\right)\right)^{-1}\frac{1}{N_j}\sum_{i\in I(j)}\sum_{t\in T(i)}(r_{i,t}+\delta_{i,a,t}) \tag{A8}$$

All variables are measured as described above. Estimated demand parameters by manufacturing sub-sector are shown in Table A2.

Table A2: Demand parameters by manufacturing sub-sector

Industry	sic92_2digit	oec_all	oec_b	oec_p	oec_v	dp_all	dp_b	dp_p	dp_v
Manufacture of food products, beverages and tobacco products	15-16	0.3272	0.0605	0.2219	0.0019	0.0528	0.0095	0.0354	0.0003
Manufacture of textiles	17	0.7618	0.0727	0.4903	0.0104	0.0923	0.0080	0.0603	0.0014
Manufacture of wearing apparel; Dressing and dyeing of fur	18	0.4486	0.0168	0.2668	0.0103	0.0608	0.0021	0.0344	0.0020
Tanning and dressing of leather; manufacturing of leather products	19	0.1170	0.0054	0.0939	0.0131	0.0123	0.0006	0.0100	0.0016
Manufacture of wood and wood products	20	0.6503	0.0867	0.4005	0.0290	0.0690	0.0118	0.0402	0.0032
Manufacture of pulp, paper and paper products	21	0.2168	0.0085	0.2109	0.0024	0.0235	0.0010	0.0233	0.0004
Publishing, printing and reproduction of recorded media	22	0.3264	0.0245	0.2247	0.0094	0.0662	0.0041	0.0462	0.0016
Manufacture of coke, refined petroleum products and nuclear fuel	23	0.0916	0.0115	0.0770	0.0002	0.0261	0.0031	0.0226	0.0001
Manufacture of chemicals and chemical products	24	0.4661	0.0354	0.3621	0.0056	0.0880	0.0078	0.0664	0.0009
Manufacture of rubber and plastic products	25	0.5061	0.0537	0.3985	0.0060	0.0736	0.0056	0.0580	0.0010
Manufacture of other non-metallic mineral products	26	0.4385	0.0641	0.3373	0.0088	0.0811	0.0116	0.0617	0.0019
Manufacture of basic metals	27	0.6790	0.0397	0.5273	0.0048	0.0631	0.0033	0.0482	0.0004
Manufacture of fabricated metal products, except machinery and equipment	28	0.5451	0.0317	0.3799	0.0047	0.0698	0.0052	0.0468	0.0007
Manufacture of machinery and equipment not elsewhere classified	29	0.5517	0.0120	0.3658	0.0160	0.0629	0.0020	0.0417	0.0017
Manufacture of office machinery, computers and other electrical equipment n.e.c.	30-31	0.5787	0.0659	0.4348	0.0088	0.0709	0.0087	0.0530	0.0010
Manufacture of radio, television and communication equipment and apparatus	32	0.5471	0.0425	0.4354	0.0047	0.0620	0.0037	0.0509	0.0003
Manufacture of medical, precisions and optical instruments, watches and clocks	33	0.2420	0.0187	0.1928	0.0060	0.0380	0.0033	0.0298	0.0009
Manufacture of motor vehicles, trailers and semi-trailers	34	0.7333	0.0275	0.5325	0.0076	0.0613	0.0030	0.0435	0.0007
Manufacture of other transport equipment	35	0.4040	0.0524	0.2604	0.0058	0.0390	0.0039	0.0244	0.0006
Manufacture of furniture; Manufacturing not elsewhere classified	36	0.3713	0.0547	0.2404	0.0152	0.0380	0.0058	0.0246	0.0015
Recycling	37	0.1347	0.0062	0.1187	0.0057	0.0179	0.0008	0.0152	0.0012

Notes: Sub-sectors 15 and 16 and 30 and 31 are combined to avoid small sample. oec is the parameter $\rho_{j,a}$ and dp is the parameter $\theta_{j,a}$. ‘all’ is total investment, ‘p’ is plant, ‘b’ is buildings and ‘v’ is vehicles.

A5. Cleaning criteria for analysis

The following cleaning criteria are applied before running the empirical analysis:

i. Drop firms with less than 250 employees.
ii. Drop all interpolated values of investment.
iii. Drop if investment rate missing for any asset type (to ensure sample is the same for each regression).
iv. Drop observations with investment rates greater than 1 and less than -0.2.
v. Drop negative or zero incidences of capital stock.
vi. Drop if the profit to capital ratio or sales to capital ratio is missing (as need for marginal q estimation).
vii. Drop if the profit to capital ratio, Π/K, is less than -0.5 or greater than 1.
viii. Drop if MPK^{Π} is less than -0.25 or greater than 1.25.
ix. Drop if MPK^{S} is less than -0.25 or greater than 1.25.

A6. Additional summary statistics

Table A3: Additional summary statistics

	Asset	N	Mean	Standard deviation	Min	25th percentile	75th percentile	Max	Skewness
I/K	Total	20745	5.392	6.282	-13.323	1.457	7.219	71.607	2.735
	Buildings	20745	2.155	6.595	-19.950	0.000	1.913	98.717	6.053
	Plant	20745	8.608	9.331	-19.955	2.495	11.734	93.750	2.595
	Vehicles	20745	14.263	18.574	-19.962	0.000	22.923	99.928	1.472
Profit/K	Total	20745	0.202	0.214	-0.497	0.058	0.306	1.000	0.977
	Buildings	20745	0.728	1.810	-10.079	0.134	0.856	73.401	16.741
	Plant	20745	0.410	0.444	-1.201	0.119	0.608	3.656	1.194
	Vehicles	20745	22.190	55.577	-323.766	3.183	24.465	3478.096	20.975
Sales/K	Total	20745	1.669	1.284	0.000	0.825	2.108	19.040	2.570
	Buildings	20745	6.170	15.655	0.000	1.965	5.862	598.864	14.925
	Plant	20745	3.427	2.739	0.000	1.658	4.365	39.268	2.949
	Vehicles	20745	185.409	326.200	0.000	42.562	199.180	9861.357	8.092
MPK (Profit)	Total	20745	0.059	0.065	-0.188	0.016	0.087	0.493	1.406
	Buildings	20745	0.017	0.030	-0.180	0.002	0.022	0.889	7.090
	Plant	20745	0.084	0.096	-0.222	0.023	0.124	1.221	1.634
	Vehicles	20745	0.090	0.157	-0.250	0.010	0.109	1.246	3.041
MPK (Sales)	Total	20745	0.065	0.049	0.000	0.032	0.083	0.592	2.240
	Buildings	20745	0.019	0.029	0.000	0.005	0.022	0.880	7.688
	Plant	20745	0.094	0.074	0.000	0.046	0.120	1.192	2.682
	Vehicles	20745	0.100	0.137	0.000	0.023	0.120	1.245	3.284

Notes: MPK is marginal profitability of capital.

A7. First-stage VAR estimates

Table A4: VAR estimates (profit based)

	Total investment	Buildings	Plant	Vehicles
MPK (Profit)				
L1	0.395***	0.107***	0.346***	-0.061***
	0.019	0.014	0.019	0.023
L2	0.065***	0.032***	0.041***	-0.079***
	0.011	0.008	0.012	0.013
MPK (Sales)				
L1	-0.869***	-0.073***	-0.746***	0.070**
	0.039	0.023	0.037	0.029
L2	-0.122***	0.044***	-0.119***	0.156***
	0.025	0.011	0.024	0.018
Sargan Chi2(77)	63.97	46.59	32.34	102.45**
AR(1)	-9.43***	-18.13***	-13.21***	-20.12***
AR(2)	1.01	0.86	0.21	-0.93
Observations	20745	20745	20745	20745

Table A5: VAR estimates (sales based)

	Total investment	Buildings	Plant	Vehicles
MPK (Profit)				
L1	-0.063***	-0.039***	-0.064***	-0.184***
	0.005	0.004	0.005	0.007
L2	-0.033***	-0.058***	-0.037***	-0.070***
	0.003	0.004	0.003	0.006
MPK (Sales)				
L1	0.540***	0.523***	0.518***	1.083***
	0.028	0.013	0.029	0.021
L2	-0.019**	0.012**	-0.015**	0.086***
	0.007	0.005	0.007	0.009
Sargan Chi2(77)	113.76***	91.6*	31.89	51.32
AR(1)	16.44***	-11.64***	-8.87***	-12.63***
AR(2)	-0.39	-0.27	0.92	-1.84*
Observations	20745	20745	20745	20745

Notes: *** indicates significance at 1 per cent level. ** indicates significance at the 5 per cent level. * indicates significance at the 10 per cent level. Instruments are lagged values and time dummies. MPK is marginal profitability of capital. L1 and L2 are first and second lags.

References

Abel, A. B. (1980). "Consumption and Investment". In Friedman, B. M. and Hahn, F. H. (eds.), *Handbook of Monetary Economics*, Volume 2, Chapter 14.

Abel, A. B. and Blanchard, O. J. (1986). "The Present Value of Profits and Cyclical Movements in Investment". *Econometrica*, Volume 54, No. 2, 249-274.

Abel, A. B. and Eberly, J. C. (2002). "Investment and q with Fixed Costs: An Empirical Analysis". mimeo www.kellogg.northwestern.edu/faculty/eberly/htm/research/invest13.pdf

Arellano, M. and Bond, S. R. (1991). "Some Tests of Specification for Panel Data: Monte Carlo Evidence and An Application to Employment Equations". *Review of Economic Studies*, Volume 58, 277-297.

Arellano, M. and Bover, O. (1995). "Another Look at the Instrumental Variable Estimation of Error-Components Models". *Journal of Econometrics*, Volume 68, 29-51.

Attanasio, O. P., Pacelli, L. and Reduto dos Reis, I. (2003). "Investment Patterns in UK Manufacturing Establishments". mimeo web.econ.unito.it/prato/papers/qr67.pdf

Behr, A. and Bellgardt, E. (2002). "Dynamic Q-investment functions for Germany using panel data balance sheet data and a new algorithm for the capital stock at replacement values". Economic Research Centre of the Deutsche Bundesbank, Discussion Paper 23/02.

Berndt, E. R. and Christensen, L. R. (1973). "The Translog Function and Substitution of Equipment, Structures, and Labor in U.S. Manufacturing". *Journal of Econometrics*, Volume 1, 81-113.

Blackorby, C. and Schworm, W. (1983). "Aggregate Heterogeneous Capital Goods in Adjustment-cost Technologies". *Scandinavian Journal of Economics*, Volume 85, No.2, 207-222.

Bloom, N., Bond, S. and Van Reenen, J. (2001). “The dynamics of investment under uncertainty”. *IFS Working Paper*, No. W01/05.

Blundell, R., Bond, S., Devereux, M. and Schiantarelli, F. (1992). “Investment and Tobin’s Q: Evidence from Company Panel Data”. *Journal of Econometrics,* Volume 51, 233-57.

Blundell, R. and Bond, S. (1998). “Initial Conditions and Moment Restrictions in Dynamic Panel Data Models”. *Journal of Econometrics*, Volume 87, 115-143.

Bond, S. and Cummins, J. (2001). “Noisy Share Prices and the Q Model of Investment”. *IFS Working Paper*, No. W01/22.

Bond, S. and Cummins, J. (2004). “Uncertainty and Investment: An Empirical Investigation Using Data on Analysts' Profits Forecasts”. mimeo www.federalreserve.gov/pubs/feds/2004/200420/200420pap.pdf

Bond, S., Elston, J., Mairesse, J. and Mulkay, B. (2003). “Financial factors and Investment in Belgium, France, Germany, and the United Kingdom: A Comparison Using Company Panel Data”. *Review of Economics and Statistics*, Volume 85, 153-65.

Bond, S., Moessner, R., Mumtaz, H. and Syed, M. (2005). “Microeconometric Evidence on Uncertainty and Investment”. mimeo www.ifs.org.uk/docs/wpinvunc.pdf

Bontempi, E., Del Boca, A., Franzosi, A., Galeotti, M. and Rota, P. (2004). “Capital Heterogeneity: Does It Matter? Fundamental Q and Investment on a Panel of Italian Firms”. *Rand Journal of Economics*, Volume 35, No. 4, 674-690.

Chirinko, R. S. (1986). “Investment, Tobin’s Q, and Multiple Capital Inputs”. *NBER Working Paper*, No. 2033.

Comin, D. and Mulani, S. (2004). “Diverging Trends in Macro and Micro Volatility: Facts”. *NBER Working Paper*, No. 10922.

Cooper, R. W. and Haltiwanger, J. C. (2006). “On the Nature of Capital Adjustment Costs”. *The Review of Economics Studies*, Volume 73, No. 3, 611-633.

Cummins, J. G. and Dey, M. (1998). “Taxation, Investment, and Firm Growth with Heterogeneous Capital”. mimeo www.econ.nyu.edu/cvstarr/working/1998/RR98-07.PDF

Del Boca, A., Galeotti, M. and Rota, P. (2003). “Non-convexities in the Adjustment of Different Capital Inputs: A Firm-Level Investigation”. *Fondazione Eni Enrico Mattei Research Paper*, No. 35.

Denny, M. and May, J. D. (1978). “Homotheticity and Real Value Added in Canadian Manufacturing”. In Fuss, M. and McFadden, D. (eds.), *Production Economics: A Dual Approach to Theory and Applications*, Volume 2, 53-57.

Doms, M. and Dunne, T. (1998). “Capital Adjustment Patterns in Manufacturing Plants”. *Review of Economic Dynamics*, Volume 1, 409-429.

Epstein, L. (1983). “Aggregating Quasi-Fixed Factors”. *Scandinavian Journal of Economics*, Volume 85, No.2, 191-205.

Erickson, T. and Whited, T. M. (2000). “Measurement Error and the Relationship between Investment and “q””. *The Journal of Political Economy*, Volume 108, No. 5, 1027-1057.

Fazzari, S., Hubbard, G. and Petersen, B. (1988). “Financing Constraints and Corporate Investment”. *NBER Working Paper*, No. 2387.

Gilchrist, S. and Himmelberg, C. (1995). “Evidence on the role of cash flow for investment”. *Journal of Monetary Economics*, Volume 36, 541-572.

Gilchrist, S. and Himmelberg, C. (1998). “Investment, Fundamentals and Finance”. *NBER Working Paper*, No. 6652.

Goolsbee, A. and Gross, D. B. (1997). "Estimating Adjustment Costs with Data on Heterogeneous Capital Goods". *NBER Working Paper*, No. 6342.

Ghosal, V., Loungani, P. (2000). "The differential impact of uncertainty on investment in small and large businesses". *The Review of Economics and Statistics*, Volume 82, No. 2, 338-349.

Harris, R. and Drinkwater, S. (2000). "UK plant and machinery capital stocks and plant closures". *Oxford Bulletin of Economics and Statistics*, Volume 62, No.2, 239-261.

Hayashi, F. (1982). "Tobin's Marginal q and Average q: A Neoclassical Interpretation". *Econometrica*, Volume 50, No.1, 213-224.

Hayashi, F. and Inoue, T. (1991). "The Relation Between Firm Growth and Q with Multiple Capital Goods: Theory and Evidence from Panel Data on Japanese Firms". *Econometrica*, Volume 59, No. 3, 731-753.

Holtz-Eakin, D., Newey, W. and Rosen, H. S. (1988). "Estimating Vector Autoregressions with Panel Data". *Econometrica*, Volume 56, No. 6, 1371-1395.

Letterie, W. A. and Pfann, G. A. (2007). "Structural Identification of high and low investment regimes". *Journal of Monetary Economics*, Volume 54, No. 3, 797-819.

Martin, R. (2002). "Building the Capital Stock". Ceriba mimeo www.ceriba.org.uk/pub/CERIBA/BuildCapStock/Martin2002.pdf

Nilsen, Ø. A., Schiantarelli, F. (2003). "Zeroes and lumps in investment: empirical evidence on irreversibilities and non-convexities". *The Review of Economics and Statistics*, Volume 85, No. 4, 1021-1037.

Power, L. (1998). "The missing link: technology, investment, and productivity". *The Review of Economics and Statistics*, Volume 80, No. 2, 300-313.

Robjohns, J. (2006). "ADR2: the new Annual Respondents Database". *Economic Trends*, No. 630, 43-51.

Tobin, J. (1969). “A General Equilibrium Approach to Monetary Theory”. *Journal of Money, Credit and Banking*, Volume 1, No. 1, 15-29.

Wallis, G. (2009). “Capital Services Growth in the UK: 1950 to 2006”. *Oxford Bulletin of Economics & Statistics*, Volume 71, Issue 6, 799-819.

Whited, T. M. (1994). “Problems with Identifying Adjustment Costs from Regressions of Investment on q”. *Economic Letters*, Volume 46, Issue 4, 327-332.

Wildasin, D. E. (1984). “The q Theory of Investment with Many Capital Goods”. *American Economic Review*, Volume 74, No. 1, 203-210.

Chapter 2: How Tangible is the Failure of the Q Model?

1. Introduction

The basic Q model estimated on aggregate data and using average q has failed miserably. Typically, investment has been found to be only weakly related to average q, estimated capital adjustment costs to be implausibly high, and the sufficient statistic prediction of the basic model to be rejected. This has led many researchers to argue that disaggregated data is needed to conduct sound empirical analysis of investment. This chapter is an attempt to revive the aggregate Q model by including comprehensive estimates of a broad range of intangible investment and capital.

Given the availability of good microeconomic datasets with which to study investment, why should we care about the aggregate Q model? The appeal of the Q model at aggregate level is its simplicity. Given an estimate of average q, the Q model prediction is simple. If average q is above one, the aggregate level of capital stock should expand to bring average q back to one. If average q is below one, the aggregate level of capital stock should fall to increase average q back to one.[11] The speed of this adjustment will depend on the size of adjustment costs. The main advantage the model is that average q is, in principle, observable while other variables used in investment models, such as the marginal efficiency of capital or the user cost of capital, are not and have to be estimated. Furthermore, market value data is available in real time, while investment data are only available with a considerable lag.[12] This means that the Q model is potentially useful for both nowcasting and forecasting investment.

Estimating an aggregate Q model with the inclusion of intangible assets is not a new idea, but one common feature of previous empirical work is that it uses proxies for intangible investment that are not comprehensive. For example, both Bond and Cummins (2000) and Klock, Baum and Thies (1996) use data on research and development (R&D) and advertising expenditure, which is a narrower definition of intangible investment than used here. Hall (2000) estimates the value of intangible

[11] This of course assumes that investment is perfectly reversible.

[12] For example, provisional estimates of quarterly UK business investment are usually released around eight weeks after the end of the quarter and these are often subject to large revisions. Microeconomic dataset of investment are typically available with a lag of at least two years.

capital stock, or 'e-capital' as he calls it, as the difference between the observed total market value of firms and the market value of their traditionally measured capital stock. Under certain assumptions this should provide a good measure of total intangible capital. In more recent work Hulten and Hao (2008) investigate whether intangible investment can explain the large difference between the market value of shareholder equity and the reported book value of six large companies in the U.S. pharmaceuticals industry. For these firms they find that the inclusion of intangibles reduces average q in 2006 from 3.85 to 1.26.

This chapter investigates whether the poor empirical performance of the Q model of investment can be explained by the exclusion of intangible assets. It uses for the first time in empirical testing of an aggregate Q model direct estimates of a broad range of intangible investment and capital. This chapter also uses a measure of average q for the UK business sector for the first time. Oulton (1981) and Price and Schleicher (2006) estimate average q for UK private non-financial corporations, but not for the UK business sector as a whole.

A broad range of intangible assets are included, under three main intangible asset classes, based on the definitions first developed in Corrado, Hulten and Sichel (2006). Firstly, computerised information (mainly software), secondly, innovative property (covering scientific and non-scientific R&D) and finally firm-specific resources (company spending on reputation, human and organisational capital). The intangible investment and capital estimates are taken from previous work investigating the importance of intangible investment for UK macroeconomic performance (Giorgio Marrano, Haskel and Wallis, 2009). A traditional Q model of investment using the standard definition of capital is estimated as a benchmark followed by a Q model with the inclusion of intangible investment and capital. The two models are then compared in the following ways: (i) size and significance of estimated adjustment costs; (ii) explanatory power; (iii) predictive power and parameter stability; and (iv) sufficiency of average q and the significance of other regressors.

The inclusion of intangible assets improves the empirical performance of the Q model in a number of ways. Estimated adjustment costs are lower but still somewhat high. Explanatory power of the Q model is greater with the inclusion of intangibles. Predictive power is better and unlike the standard Q model a Q model with intangibles does not suffer from parameter instability. Even with the inclusion of intangibles, average q is not a sufficient statistic to explain investment. However, average q remains significant in a Q model with intangibles that has the additional regressors cash-flow, net debt and the lagged investment rate, but not in a standard Q model with these additional regressors.

The remainder of this chapter is organised as follows. In Section 2, the investment model is set out, including the extension of the basic model to include intangible investment and capital. Section 3 describes the data and some of its key features. Section 4 presents the empirical specification used in estimation. Section 5 presents the empirical results and interpretation, and Section 6 concludes. The Appendix describes the construction of the data in more detail.

2. The Q model of investment and average q

The model used is standard in the investment literature so is set out briefly below. Most important are the assumptions that allow investment to be expressed as a function of average Q. Hayashi (1982) showed that marginal q is a sufficient statistic for investment in a value-maximising model of investment with convex adjustment costs and set out the formal conditions under which average and marginal q are equivalent. These conditions are: (i) firms are price takers; (ii) production and adjustment cost technologies are linear homogenous; and (iii) capital is homogenous.

The objective of a representative firm is to decide how much to invest in order to maximise its value, measured as the present value of a stream of current and expected future net revenues. The value of a representative firm is given by

$$V(K_{t-1},\xi_t) = \max_{\{I_t\}_{t=0}^{\infty}} E\left\{\sum_{t=0}^{\infty}\beta^t\left[\Pi(K_t,\xi_t) - G(I_t,K_t,\xi_t) - p_t I_t\right]\right\} \qquad (19)$$

Subject to the capital accumulation constraint

$$K_t = K_{t-1}(1-\delta) + I_t \qquad (20)$$

Where K_t is the replacement value of the capital stock, Π is the representative firm's profit function, ξ_t is an exogenous shock to the profit function, β_t is the firm's discount factor, $G(.)$ is the adjustment cost function, I_t is gross investment, p_t is the relative price of capital goods, and δ is the constant rate of depreciation of capital.[13]

The first-order condition yields the familiar marginal q specification

$$p_t + \frac{\partial G(I_t, K_t, \xi_t)}{\partial I_t} = E[q_t] \tag{21}$$

Where

$$q_t = \sum_{s=0}^{\infty} \beta^s (1-\delta)^s \left[\frac{\partial \Pi(K_{t+s}, \xi_{t+s})}{\partial K_{t+s}} - \frac{\partial G(I_{t+s}, K_{t+s}, \xi_{t+s})}{\partial K_{t+s}} \right] \tag{22}$$

q_t is marginal q and is expressed in equation (22) as the discounted sum of marginal revenue products of capital.

To obtain an investment specification that can be estimated empirically, we need to assume a functional form for the adjustment cost function $G(.)$. It is somewhat traditional in the literature to define a functional form that is linear homogenous in capital and investment and the most common assumption is quadratic adjustment costs

$$G(I_t, K_t, \xi_t) = \frac{\alpha}{2} \left(\frac{I_t}{K_t} - \gamma - \xi_t \right)^2 K_t \tag{23}$$

Substituting equation (23) into equation (21) yield a familiar investment specification

$$\frac{I_t}{K_t} = \gamma + \frac{1}{\alpha} \left(E[q_t] - p_t \right) + \xi_t \tag{24}$$

[13] See Section 3.4 for a discussion of how appropriate the assumption of a constant rate of depreciation is.

Equation (24) is still expressed in terms of marginal q (minus the price of capital goods). Here we will be using a measure of average q, constructed from financial data, as a proxy for marginal q. Under the assumption that the Hayashi (1982) conditions hold, equation (24) can be expressed in terms of average q as follows

$$\frac{I_t}{K_t} = \gamma + \frac{1}{\alpha} Q_t + \xi_t \tag{25}$$

Where Q_t is average q.

Following Tobin (1956), Hall (1999) and others, average q is defined as

$$Q_t = \frac{V_t}{K_t} = \frac{V_t^e + V_t^d}{K_t} \tag{26}$$

Where V_t is the net financial value of the business sector made up of the value of equity V_t^e and the value of total debt V_t^d. In the standard empirical application K_t mainly consists of tangible capital, such as plant, buildings, vehicles and computer hardware. Based on existing National Accounts definitions K_t only includes the intangibles software, mineral exploration, and copyright and license costs for artistic and literary originals. Here an alternative measure of average q is considered as follows

$$Q_t^R = \frac{V_t^e + V_t^d}{K_t^R} \tag{27}$$

Where the superscript R refers to the fact that a wider definition of intangible capital is being used. The inclusion of intangibles does not alter the value of equity or debt, but simply increases the replacement value of the capital stock. The wider definition of intangible capital used is the same as that developed in Corrado, Hulten and Sichel (2006) and employed in Giorgio Marrano, Haskel and Wallis (2009). It includes R&D, product design, branding, training and organisational capital.

2.1. Tax-adjusted average q

Past literature, such as Summers (1981) and Poterba and Summers (1983), has emphasised the importance of using a tax-adjusted measure of average q. Following Summers (1981) and Cummins, Hassett, and Hubbard (1994) tax-adjusted average q excluding intangible assets is calculated as

$$Q_{Taxadj,t} = \frac{Q_t - p_t^K / p_t^Y (1 - D_t)}{1 - u_t} + 1 \tag{28}$$

Where p_t^K is the price of tangible capital goods, p_t^Y is the price of all goods (market sector GVA deflator), and u_t is the main corporation tax rate. D_t is the present value of depreciation allowances at time t as a proportion of the price of assets. For tangible assets D_t is calculated as described in Chapter 3.

Tax-adjusted average q with the inclusion of intangible assets is calculated as

$$Q^R_{Taxadj,t} = \frac{Q_t^R - p_t^{K^R} / p_t^Y (1 - D_t)}{1 - u_t} + 1 \tag{29}$$

Where $p_t^{K^R}$ is the price of all capital goods (tangible and intangible) and as in equation (28) p_t^Y is the price of all goods (market sector GVA deflator adjusted for the inclusion of intangibles). u_t is the main corporation tax rate. D_t is now defined as the weighted average of the net present value of depreciation allowances for tangible assets and the net present value of depreciation allowances for intangible assets. The weights used are the shares of tangible and intangible investment in total investment.

For most intangible assets, the net present value of depreciation allowances is one because such expenditure can be expensed from taxable profits. The exceptions are scientific R&D, mineral exploration and purchased software. Purchased software cannot be expensed but qualifies for the plant and machinery capital allowance. The calculation of the present value of plant and machinery capital allowance is described in detail in

Chapter 3. Investment in mineral exploration has been subject to various capital allowances since 1970.

Scientific Research Allowances (SRA), now called Research & Development Allowances, were introduced after the Second World War and are a 100 per cent first-year allowance on capital expenditure for R&D purposes. However, given the narrow coverage of the SRA and following Bloom, Griffith and Van Reenen (2002) it is assumed that expensing was not available until 2002 and prior to that capital expenditure was subject to the general plant and machinery allowances. The R&D Corporate Tax Relief, which most people call the R&D Tax Credit, was introduced in 2002 to provide an allowance for 'revenue expenditure'. In essence this tax relief is a 125 per cent first-year allowance (130 per cent from April 2008 onwards) on revenue expenditure for R&D purposes. The net present value of depreciation allowances for R&D is then a weighted average of the present value of these two different allowances where the weights are given by the shares of capital and revenue expenditure in total R&D spending. The net present value of depreciation allowances for R&D and the associated tax-adjustment factor, defined in Chapter 3, is shown in Figure A1 in the Appendix.

3. Data

The analysis focuses on the UK business sector. Past UK analysis, such as Oulton (1979) and Price and Schleicher (2006), has focused on the non-financial business sector. However, given the financial sector's prominence in the stock market and the extent to which the sector has invested in intangibles, including in software and product development, it is important to include it. Key features of the data are discussed here with a fuller description of the data provided in the Appendix.

3.1. Tangible and intangible investment

Traditional measures of investment by the UK business sector are readily available from the UK National Accounts. Here National Accounts measures of business investment are used and are referred to as tangible investment. Strictly speaking this is not correct because the existing National Account definition of investment includes the intangibles software, mineral exploration, and copyright and license costs for artistic and literary originals (see Table 1). Business investment data consistent with the Blue Book 2010 are used in order to ensure consistency with the intangible investment data.

The wider definition of intangible capital used for estimating a Q model including intangibles is the same as that developed by Corrado, Hulten and Sichel (2006) and used in Giorgio Marrano, Haskel and Wallis (2009). Table 1 shows the intangibles included. The first column shows the three broad categories of intangible assets, while the second column provides a more detailed breakdown. The final column is important as it identifies which of these types of investment are currently included in the standard definition of capital. That is, if you download an official investment series which ones would be included. All investment in computer software is included as is mineral exploration and copyright and licence costs. Everything else is currently treated as intermediate consumption and so will not be included in official investment or capital stock series.

Table 1: Intangible assets and current treatment in the National Accounts

Type of intangible investment	*Includes the following intangibles*	*Current treatment in the National Accounts*
Computerised information	(1) Computer software (2) Computer databases	Both treated as investment
Innovative property	(1) Scientific R&D (2) Mineral exploration (3) Copyright and license costs (4) New product development costs in the financial industry (5) New architectural and engineering designs (6) R&D in social science and humanities	Only (2) and (3) treated as investment
Economic competencies	(1) Brand Equity (2) Firm-specific human capital (3) Organisational structure	None of these treated as investment

The construction of the intangible investment estimates are explained in detail in Giorgio Marrano, Haskel and Wallis (2009), but a few important points are worth noting here. Firstly, the estimates cover both purchased intangible assets and intangible assets produced in-house, termed ‘own-account’. In general, the former is measured using data on intermediate purchases of intangible assets or from estimates of turnover from intangible producing industries. The data sources are mostly the National Accounts with the main exceptions being brand equity and organisational structure, where data from the Advertising Association and Management Consulting Association are used. Where possible, own-account intangible investment is estimated by identifying workers in specific occupations whose time is devoted to creating intangible assets and estimating intangible investment based on their wages.

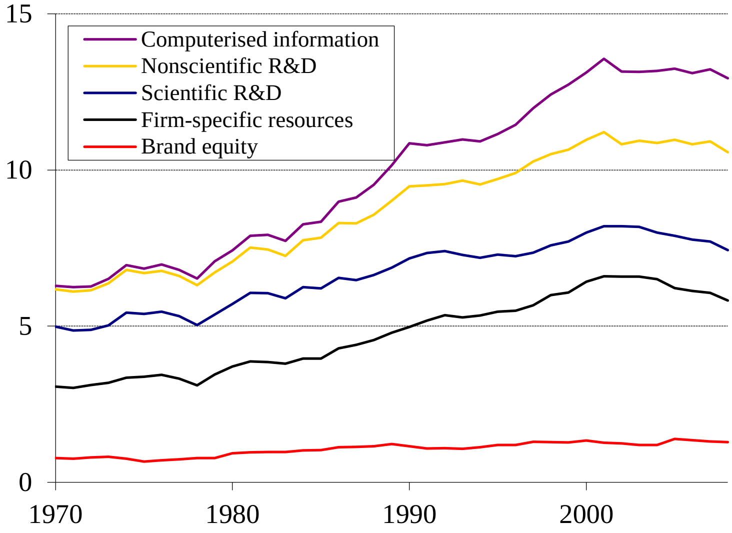
Secondly, not all of the spending identified is considered to be investment. For example, only 60 per cent of expenditure on advertising is considered to be for brand building. The assumption of the proportion of spending considered as investment is relatively arbitrary and is based on a limited amount of research for most intangible assets but follows the assumptions in Corrado, Hulten and Sichel (2006) and Giorgio Marrano, Haskel and Wallis (2009).

Finally, initial estimates of intangible investment are calculated in nominal terms. In order to estimate capital stock, real investment series are needed. For all assets except software, an implied market sector gross value added (GVA) deflator is used. For software, a National Accounts deflator exists and this is used.

The short discussion above highlights some of the uncertainties with measuring intangible investment. Importantly, the inclusion of intangibles has the potential to introduce measurement error into an expanded Q model. Section 4.2 discusses the implications of this in more detail.

Intangible investment data is only available for the period 1970 to 2008 so the analysis is limited to this period when including intangibles in a Q model. Figure 1 shows nominal intangible investment as a percentage of market sector output over the period 1970 to 2008 by the UK business sector. Total intangible investment in 1970 was less than £3 billion, or just over 6 per cent of output. By 2008 this had increased dramatically to nearly £120 billion, around 13 per cent of output. Intangible investment has also grown in importance relative to tangible investment. In 1970 tangible investment was twice the level of intangible investment. Since around 2000 intangible investment is estimated to be larger than tangible investment.

Figure 1: Business sector intangible investment, nominal, percentage of output



Source: Giorgio Marrano, Haskel and Wallis (2009) and Haskel, Goodridge, Pesole, Awano, Franklin, and Kastrinaki (2011).

Notes: The figure shows the time series for intangible investment for aggregated categories as a percentage of market sector output. It is a cumulative graph so that the top line shows total intangible investment. The lowest line shows brand equity and the line above that shows brand equity plus firm specific resources. Thus the gap between the lines is investment in each intangible asset. Brand equity includes advertising and market research. Firm-specific resources includes firm specific human capital and organisational structure. Scientific R&D includes scientific R&D and mineral exploration. Non-scientific R&D includes copyright and licences costs, new product development costs in the financial industry, new architectural and engineering design and R&D in social science and humanities. Computerised information is basically software, which as shown in Table 1 is already treated as investment in the National Accounts.

3.2. Average q

Two measures of average q are calculated following equations (26) and (27).[14] For both equations the numerator is the net financial value of the business sector. As highlighted by Oulton (1981), net financial value as measured in the UK National Accounts refers to UK-based firms, many of which generate a part of their profits from capital in other countries. The counterpart to this is that UK capital stock measures include the capital stock of firms operating in the UK but generating profits for residents in other countries. As is standard in the literature, it is assumed that these two effects cancel each other out.

[14] Further details are provided in the Appendix.

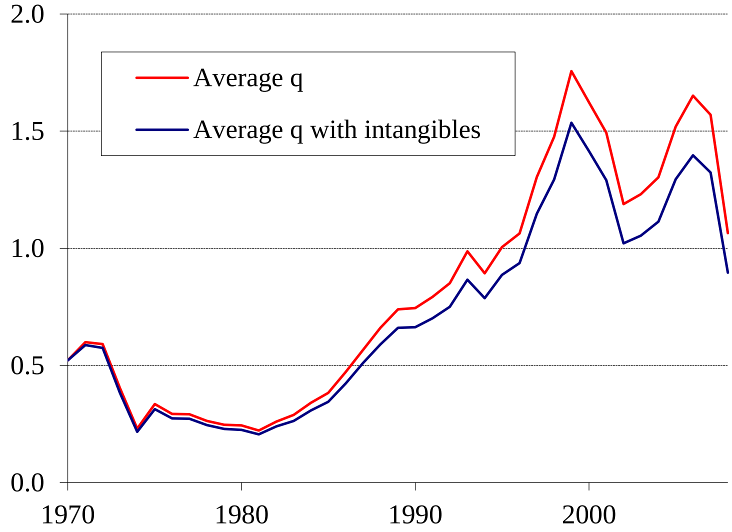
Estimates of the capital stock for the business sector are problematic. Estimates of tangible (existing National Account) capital stock for the UK business sector are not available directly from the National Accounts so are based on updated estimates from Wallis (2009). The capital stock estimates are constructed using a perpetual inventory method and using a National Accounts dataset consisting of a long time series of constant price investment data, depreciation rates and price deflators. The estimates are constructed so as to be fully consistent with the National Accounts and are therefore also consistent with the measures of business investment being used.

Estimates of intangible capital stocks are taken from Giorgio Marrano, Haskel and Wallis (2009) and Haskel, Goodridge, Pesole, Awano, Franklin and Kastrinaki (2011) and are also estimated using a perpetual inventory method. Intangible capital stock estimates present an even more difficult measurement challenge than intangible investment due to uncertainty over the appropriate rate of depreciation to use. R&D is one of the few intangible assets that has been studied extensively. Even so, as shown recently by Hall (2007), even the standard assumption of a 15 per cent depreciation rate used in the R&D literature is open to question. The measurement of depreciation of other intangible assets is very much in its infancy. The depreciation rates used in Giorgio Marrano, Haskel and Wallis (2009) range from 20 per cent for R&D to as much as 60 per cent for brand equity and are based on Corrado, Hulten and Sichel (2006). In essence, the assumptions are simply best guesses with the exception of brand equity, which is based on Landes and Rosenfield (1994). Awano, Franklin, Haskel and Kastrinaki (2010) reports on a recent UK survey to measure the amount of investment by firms in intangible assets and the expected life length of such investment. The survey results would suggest slightly higher rates of depreciation than assumed in Giorgio Marrano, Haskel and Wallis (2009).[15]

Figure 2 shows the two measures of average q over the period 1970 to 2008. The first is based on the standard definition of capital (average q) and the second with a broader definition of intangible capital in the denominator of average q (average q with intangibles).

[15] The date of the survey should be borne in mind, being conducted during a deep recession in the UK. However, the conclusions of this chapter are not affected by assuming the depreciation rates from the latest survey.

Figure 2: Measures of average q for the UK business sector



If the stock market is strongly efficient and there is perfect competition, average q should only deviate from one due to adjustment costs. As can be seen from Figure 2, average q was consistently below one up until 1995 and since then has been consistently above one, reaching almost 1.8 in 1999. The deviation of q from one is too sustained to be explained by adjustment costs alone. Indeed, this is partly why empirical estimates of adjustment costs are usually implausibly high and why average q is not found to be a sufficient statistic for investment, with variables such as cash flow, debt and lagged investment found to be strongly associated with investment after controlling for average q. As noted by Hall (2000), "two tasks face the researcher who invokes the hypothesis of stock market rationality: understanding the high valuations of the 1990s and understanding the low valuations of the 1970s and 1980s." This is now three tasks, with the third being understanding the sharp fall in average q at the start of the 21st Century.

There are two competing explanations for the consistent deviations of average q from one. The first is that the stock market is not strongly efficient but that stock market valuations deviate significantly from fundamental values.[16] Under this explanation the high valuations of the 1990s simply reflect a share price bubble. The second is that the traditional measures of capital used to calculate average q do not include spending on intangible assets, such as research and development, product design, branding, training

[16] See for example Bond and Cummins (2000).

and organisational capital, even though such assets are expected to yield future profits.[17] In essence, measured capital is underestimated due to the exclusion of intangible assets. Of course, these two explanations are not mutually exclusive and are also only two of many possible explanations for the poor empirical performance of the Q model of investment.

Under the second explanation, the sustained increase in the market values of firms since the early 1990s is due to strong investment in intangible assets and much of this investment not being captured in traditional measures of average q. The low valuations of the 1970s and 1980s are more difficult to explain. However, this period of 'negative intangibles' could be driven by three factors.[18] The first is that firms in the early 1970s were ill-equipped to exploit the benefits of the information technology (IT) revolution and so lost value. The second is that the oil price shocks that hit the global economy in 1973 and 1979 made much of the existing capital stock obsolete. The third is that shareholders have the last claim on corporate revenue and may have lost to other stakeholders during the early 1970s.

The second explanation for the sustained deviation of average q from one has been investigated in the context of the Q model. In this context, the explanation is that the inclusion of intangible assets should give more reasonable estimates of adjustment costs and improve the empirical performance of the Q model.

Based on the standard definition of capital, average q has a very strong upward trend in the late 1990s, peaking at 1.76 in 1999. The sample mean is 0.81 and there is clearly a sustained period in the late 1990s when average q exceeds one. Unsurprisingly, the inclusion of intangibles shifts the line down. This is because we have simply added intangible capital to the denominator and not changed the numerator. The upward trend in the late 1990s is now a little less pronounced, as this was a period when intangible capital grew rapidly. The peak is still in 1999 but is slightly lower at 1.54. The sample mean for the period 1970 to 2008 falls to 0.71. Notice that the problem of low valuations in the 1970s and high valuations in the 1990s still exists, suggesting that intangibles, as measured, do not completely explain these valuations. Looking at the period from 1990 onwards, the sample mean for the standard measure of average q is

[17] See for example, Hall (2000), Bond and Cummins (2000), and McGrattan and Prescott (2001).

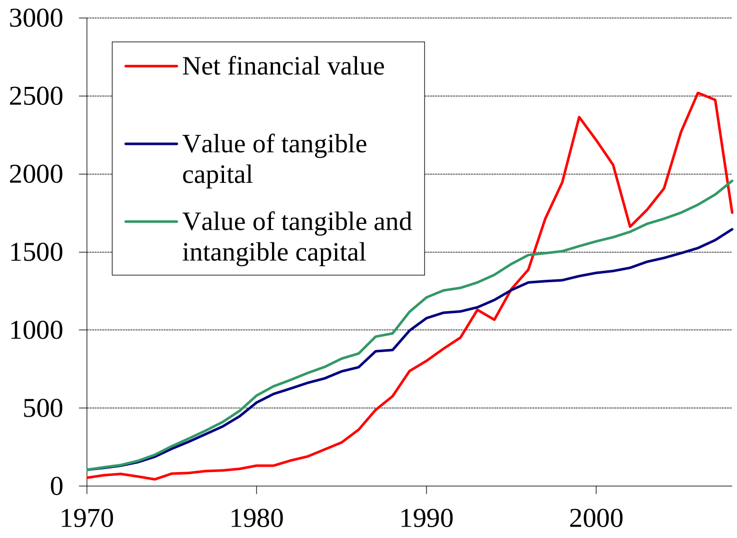
[18] The discussion here draws on Price and Schleicher (2006).

1.24 while that for intangible adjusted average q is 1.07, so closer to the theoretical prediction.

3.3. Net financial value

It is interesting to consider a decomposition of net financial value (total stock market capitalisation) along the lines of Hall (2000). The difference here is that the value of intangible assets is not being estimated as the difference between the observed total market value of firms and the market value of their traditionally measured capital stock. Instead, intangible capital is being measured directly. Figure 3 shows the net financial value of the UK business sector in pound billions against the value of tangible capital and also the value of both tangible and intangible capital. The relationship to Figure 2 should be noted here. Net financial value divided by the two different measures of total capital would give the two different measures of average q in Figure 2. The other way to think of this is that the fraction of stock market value explained by the book value of capital is the inverse of average q. For example, peak stock market value occurred in 2006 at over £2.5 trillion. Even if intangible capital is included, only 71.5 per cent of this valuation can be explained by the value of capital. This corresponds to an average q of 1.40 (1/0.715). Without intangible capital, only 61 per cent of total stock market value can be explained by the value of the capital stock.

Figure 3: Decomposition of net financial value of UK business sector, £ billion



Hall (1993) estimates a market value equation for U.S. manufacturing firms regressing market value on both physical and intangible capital (R&D and brand equity). Such a regression is a way of testing if intangible capital has explanatory power for market value. Hall finds that R&D does have explanatory power.

Hulten and Hao (2008) do a decomposition of net financial value for six large companies in the U.S. pharmaceuticals industry and find that intangible assets do not explain the entire price-to-book gap. They conclude that some part of the remaining gap may reflect the volatility of the stock market, with its episodes of exuberance and pessimism. Another part of the gap may reflect what they call "a Schumpeterian gap" between the *ex ante* cost-based estimates of the paper value and the *ex post* innovation rents earned. They argue that large pharmaceutical companies are able to generate *ex post* super-normal profits. As shown by Abel and Eberly (2002) average q will exceed one for a firm that earns rents from monopoly power, even in the absence of adjustment costs. Mismeasurement of balance sheet items is the third possible explanation Hulten and Hao (2008) offer for the persistence of the gap.

3.4. The investment rate

The investment rate is calculated as I_t / K_{t-1} where I_t is gross investment. Figures 4 and 5 show the two measures of average q against the corresponding investment rate. The unconditional correlations between average q and the investment rate are 0.892 and 0.895 respectively. These are both quite high, in part due to both average q and the investment rate exhibiting upward trends. One explanation for the upwards trend in the investment rate is an increase in the average rate of depreciation over time as firms have shifted towards investment goods with higher depreciation rates, such as ICT capital.[19] See, for example, Tevlin and Whelan (2003) and Bakhshi, Oulton and Thompson (2003). However, the net investment rate, both with and without intangibles, still shows a strong upwards trend.[20]

[19] Based on the assumptions about depreciation rates in Giorgio Marrano, Haskel and Wallis (2009) and using net stock value weights, the average rate of depreciation for all capital (tangible and intangible) increases from 9 per cent in 1970 to 12.5 per cent in 2004. Using estimates of depreciation calculated from Awano, Franklin, Haskel, and Kastrinaki (2010) and using a double-declining balance, the average rate of depreciation increases to 16 per cent in 2004. The equivalent figures for the standard National Accounts measure of capital are 9 per cent in 1970 rising to around 10 per cent. Using weights based on profit shares rather than values, the rate of depreciation increases more, from 11 per cent to 14 per cent.

[20] The results in Section 5 are very similar when using measures of net investment rather than gross investment and the improvements in the empirical performance when including intangibles remain.

Figure 4: Average q and the investment rate without intangibles

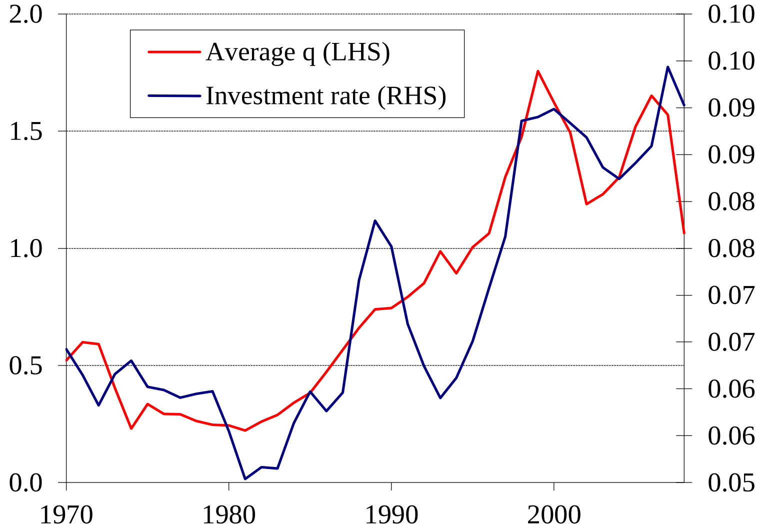
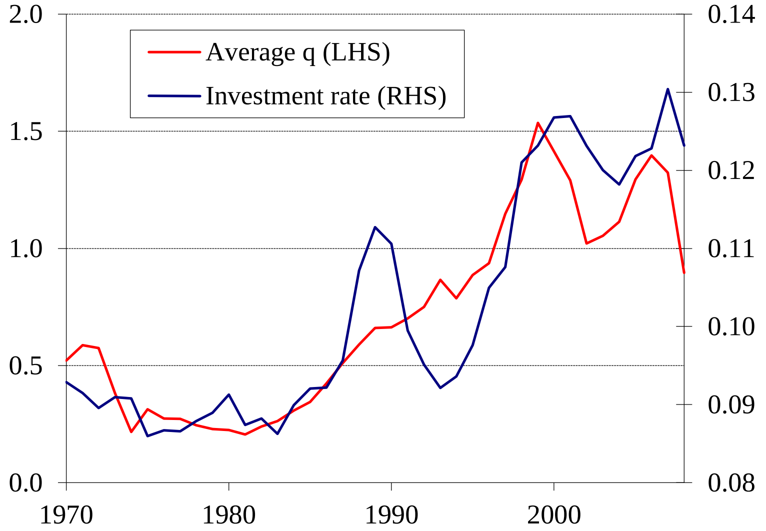


Figure 5: Average q and the investment rate with intangibles

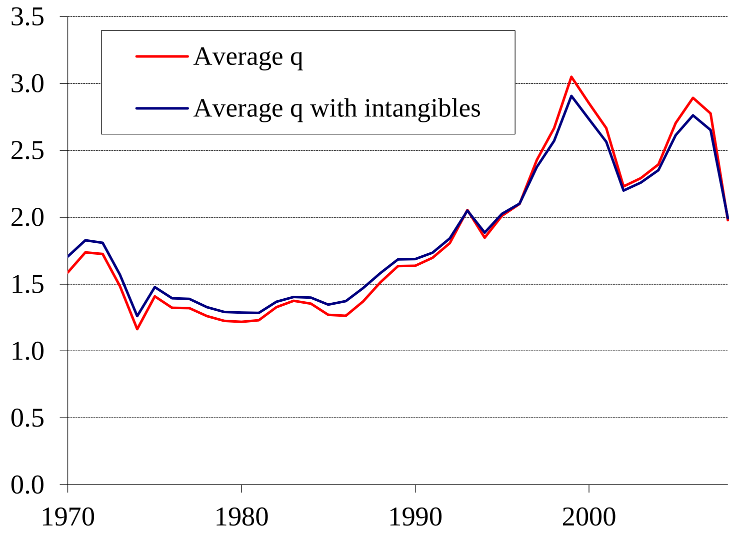


A couple of points are worthy of note here. Firstly, and as noted above, the inclusion of intangible assets leads to a fall in average q because we have simply added intangible capital to the denominator and not changed the numerator. Secondly, the investment rate increases when we include intangibles. This is because, although the inclusion of intangibles increases the numerator, investment, and the denominator, capital stock, intangibles are assumed to depreciate more quickly than tangibles, so the proportional increase in investment is larger than the proportional increase in the capital stock. Finally, from a visual inspection it would appear that the inclusion of intangibles might help the empirical performance of the Q model. This is tested more formally below.

3.5. Tax adjusted average q

Figure 6 shows a tax-adjusted standard measure of average q together with a tax-adjusted average q with the inclusion of intangible assets. Relative to Figure 2, the inclusion of intangibles can be seen to flatten tax-adjusted average q rather than cause a downwards shift. The mean of both series is similar at around 1.85. However, the flattening of average q does reduce the 'high' valuations of the late 1990s and increase the 'low' valuations of the 1970s and 1980s.

Figure 6: Tax-adjusted measures of average q for the UK business sector



4. Empirical specification

Following the standard empirical application of the Q model using average q, the basic equation estimated is

$$\frac{I_t}{K_{t-1}} = a + \frac{1}{b} Q_t + \varepsilon_t \tag{30}$$

The parameter of interest is 1/b. Econometric estimates of I_t / K_{t-1} on Q_t have empirically tended to yield a small coefficient on Q_t. These estimates imply implausibly large adjustment costs. A Q model with the inclusion of intangibles is estimated as

$$\frac{I_t^R}{K_{t-1}^R} = a + \frac{1}{b} Q_t^R + \varepsilon_t \tag{31}$$

where the superscript R refers to the fact that intangibles are being included in measures of investment, capital and average q. The significance of the additional variables net debt, cash-flow, and the lagged investment rate I_{t-1} / K_{t-2} is also tested. Both net debt and cash-flow are normalised by dividing them by the capital stock. If the Q model of investment is correct, average q should be a sufficient statistic to explain investment and so these additional explanatory variables should not be significant. Versions of (30) and (31) are also estimated using tax-adjusted measures of average q.

4.1. Estimation

Equations (30) and (31) are estimated by both ordinary least squares (OLS) and by instrumental variables (IV). Although we are essentially arguing that one of the main reasons for measurement error in average q is the exclusion of intangible capital in the denominator, there is still likely to be measurement error remaining (see next section). An appropriate instrument must be correlated with average q but not correlated with the error terms in the explanatory equation. Here the standard approach in the literature is used and lagged values of average q are used as instruments. These are valid instruments so long as the measurement error in average q is not serially correlated.

4.2. Measurement error

Given the difficulties in measuring intangibles, it is important to recognise that by estimating a Q model with intangibles we are removing one type of measurement error but introducing new measurement error. The inclusion of intangibles will remove the conceptual measurement error but will introduce new measurement error due to the difficulties with measuring intangible capital. A very simplified model is presented in the Appendix and shows that estimating with the inclusion of intangibles will be better so long as the variance of the adjustment made to average q for the inclusion of intangibles is greater the variance of the measurement error introduced by the inclusion of intangibles.

5. Empirical results

5.1. OLS and IV estimation

Table 2 shows both OLS and IV estimates of a standard Q model, using the standard definition of capital, alongside equivalent estimates of a Q model with the inclusion of intangibles. The sample is restricted to the period 1970 to 2008 due to the availability of intangible investment and intangible capital series.

Table 2: Regression results

	(1)	*(2)*	*(3)*	*(4)*
	Standard Q model	*Q model with intangibles*	*Standard Q model*	*Q model with intangibles*
	OLS	*OLS*	*IV*	*IV*
Coefficient on average q (1/b)	0.024***	0.032***	0.026***	0.034***
Standard error	0.002	0.003	0.002	0.003
t-value	12.00	12.18	12.52	12.45
R-squared	0.795	0.800	0.792	0.804
Generalized R-squared	-	-	0.836	0.843
Adjustment cost parameter (b)	41.7	31.3	38.5	29.4
Pagan-Hall	-	-	2.52	4.00
Sargan	-	-	3.81	2.79
Sample	1970-2008	1970-2008	1970-2008	1970-2008

Notes: Three lagged values of average q used as instruments, *** denotes statistical significance at the 1 per cent level.

Column (1) is a standard Q model estimated using OLS. The estimated coefficient (1/b) is strongly significant, but as in much past empirical work, the estimated coefficient is much lower than would be expected. The implied adjustment cost parameter (b) is 41.7. Estimating the same model with intangibles (column (2)) increases the estimated coefficient on average q and gives a smaller estimated adjustment parameter. The inclusion of intangibles can be seen to increase the explanatory power of the model only marginally, as reflected in the small increase in the R-squared.

Columns (3) and (4) show IV estimation results to take into account remaining measurement error in average q. Once again, the inclusion of intangibles increases the estimated coefficient on average q. Three lags of average q are used as instruments in the regressions and the Sargan tests fail to reject the validity of the instruments in both regressions. The R-squared increases very marginally with the inclusion of intangibles. However, as shown by Pesaran and Smith (1994), standard R-squared measures are inappropriate as a measure of fit and for model selection in the IV context. Therefore Table 2 also reports a generalized R-squared for both models, estimated following Pesaran and Smith (2004). This measure of goodness-of-fit shows a larger improvement from the inclusion of intangibles, although the improvement is still small. One might expect both equations to suffer from serial correlation as a number of previous studies have found the lagged investment rate to have very strong explanatory power for the current investment rate. However, the Pagan and Hall (1983) test for heteroscedasticity suggests that neither model suffers from serial correlation.

Marginal adjustment costs at the mean investment rate can be calculated as the adjustment cost parameter multiplied by the mean investment rate, $b(\bar{I}/\bar{K})$. As shown by Whited (1994), backing out adjustment costs in this way requires a set of arbitrary identifying assumptions because the marginal adjustment cost function does not integrate uniquely back to the adjustment cost function but to a larger class of functions. Despite this, it is useful to consider what the coefficient estimates imply using this method. For the tangible model the average investment rate is 6.9 per cent, making the marginal adjustment cost of £1 of additional investment £2.65. This is obviously implausibly high but is in the region found in the investment literature (see Table 3). Including intangibles actually increases the marginal adjustment cost to £3.00, because although the adjustment parameter is lower the mean investment rate is higher at 10.2 per cent.

A comparison with existing literature is useful. There are no comparable UK studies for the period covered. Indeed, most comparable macroeconomic studies are based on US data and on an earlier time period when intangibles are less likely to have been so important. However, Table 3 presents four other studies that are directly comparable in that they estimate a traditional Q model (without the inclusion of intangible assets) equivalent to equation (30). As can be seen, a typical value for the adjustment cost coefficient in a standard Q model applied at the aggregate level is similar to the model estimated here. The average of the four studies is 0.025.

Table 3: Comparison of adjustment cost estimates

Study	*Country*	*Sample*	*1/b*	*b*
Standard Q model	UK	1970-2008	0.026	38.5
Q model with intangibles	UK	1970-2008	0.034	29.4
Hayashi (1982)	US	1952-1978	0.042	23.6
Clark (1979)	US	1954-1973	0.029	34.5
Summers (1981)	US	1948-1978	0.016	62.5
Chirinko (1986)	US	1950-1978	0.013	76.9

Notes: Restricted to literature estimating an equivalent to equation (30), without lagged values of average q, highest estimate of 1/b shown.

Recent work by Gourio and Rudanko (2011) investigates the role of 'customer capital' in explaining investment dynamics. They expand the neoclassical adjustment cost model of investment to include a frictional product market that requires firms to spend money on sales efforts. This generates a form of intangible capital embodied in the firm's customer base. Their measure of customer capital is somewhat wider than brand equity used here, including not just advertising but all spending related to selling products. However, their results, using Compustat data, look promising in helping to explain the failure of Q model regressions at firm-level, lending some support to the improved performance of the aggregate Q model found here.

5.2. Predictive power

To test the predictive power of the standard Q model against the Q model with intangibles both were estimated over the period 1970 to 1994 with out of sample predictions for the years 1995 to 2000. This choice of forecast period allows an investigation of how well the alternative models predict the sharp increase in the investment rate at the end of the 1990s. Previous literature, such as Tevlin and Whelan (2003) and Bakhshi, Oulton and Thompson (2003), have documented the failure of investment regressions to explain the 1990s investment boom. Table 4 shows both the root mean squared error (RMSE) and following Davidson, Hendry, Srba, and Yeo (1978) and Oulton (1979) the statistic $z(k)$ defined as

$$z(k) = \sum_{t=1}^{k} (f_t / \hat{\sigma})^2 \qquad (32)$$

where f_t is the forecast error, k is the length of the forecast period and $\hat{\sigma}$ is the estimated standard deviation of the residuals from the estimating period. $z(k)$ is a test of parameter stability and is distributed as χ^2 with k degrees of freedom.

Table 4: Tests of predictive power

	RMSE	Z statistic
Standard Q model	0.0076	11.5*
Q model with intangibles	0.0065	7.5

Notes: Z statistic is χ^2 with 6 degrees of freedom. * indicates significance at the 10 per cent level.

Looking first at the RMSE results, the Q model with intangibles has better predictive power than the standard Q model. The Q model with intangibles also has a lower $z(k)$ statistic with no evidence of parameter instability. The Z statistics is significant at the 10 per cent level for the standard Q model suggesting that the model suffers from parameter instability. These finding are robust to different choices of forecast period.

5.3. Split sample estimation

In 1970 intangible investment was quite small relative to tangible investment. By 2008 intangible investment was greater than tangible investment. It is interesting, therefore, to see if the standard Q model of investment performs better on the earlier part of the sample than it does in the latter part of the sample and if the Q model with intangibles performs better on the latter part of the sample. This could help to confirm whether intangibles are important, especially in thinking about more recent investment growth.

Table 5 presents IV regression results for both the standard Q model and a Q model with intangibles for different time periods. The sample break point is taken as 1990 because after this point intangible investment is always at least 50 per cent as large as tangible investment.[21]

[21] The results are robust to choosing any year around 1990.

Table 5: Spilt sample regression results

	(1)	*(2)*	*(3)*	*(4)*	*(5)*
	Standard Q model	*Q model with intangibles*	*Standard Q model*	*Standard Q model*	*Q model with intangibles*
	IV	*IV*	*IV*	*IV*	*IV*
Coefficient on average q (1/b)	0.034***	0.053***	0.032***	0.035***	0.046***
(standard error)	0.006	0.006	0.006	0.006	0.009
t-value	5.39	9.29	5.26	5.56	5.25
R-squared	0.582	0.848	0.580	0.566	0.537
Generalized R-squared	0.579	0.731	0.528	0.705	0.673
Adjustment cost parameter (b)	29.4	18.9	31.3	28.6	21.7
Pagan-Hall	2.89	3.83	2.34	1.11	1.59
Sargan	2.37	1.30	2.59	3.88	5.22*
Sample	1970-1990	1970-1990	1966-1990	1990-2008	1990-2008

Notes: 3 lagged values of average q used as instruments. *** denotes statistical significance at the 1 per cent level and * indicates significance at the 10 per cent level.

Columns (1) and (2) show IV estimates of standard Q model and a Q model with intangibles over the period 1970 to 1990. For this early period the inclusion of intangibles actually improves the performance of the standard Q model. A standard Q model can be estimated back to 1966 and the results are shown in column (3). The results are quite similar to those for the standard Q model over the slightly shorter sample period. Columns (4) and (5) show IV estimates of standard Q model and a Q model with intangibles over the period 1990 to 2008. The inclusion of intangibles does not improve the performance of the model. While the estimated coefficient on average q is higher, the generalized R-squared falls and the Sargan test rejects the overidentifying restrictions, albeit at the 10 per cent level.

5.4. Results with tax-adjusted average q

Table 6 presents IV estimates of a standard Q model and a Q model with intangibles where both measures of average q have been tax-adjusted. Tax adjusting does not appear to make a big difference here, with the empirical improvement from the inclusion of intangibles similar to that in Section 5.1.

Table 6: Regression results with tax-adjusted measures of average q

	(1)	*(2)*
	Standard Q model	*Q model with intangibles*
	IV	*IV*
Coefficient on average q (1/b)	0.022***	0.034***
Standard error	0.002	0.003
t-value	10.72	11.09
R-squared	0.748	0.765
Generalized R-squared	0.798	0.808
Adjustment cost parameter (b)	45.5	29.4
Pagan-Hall	1.76	1.96
Sargan	3.39	2.43
Sample	1970-2008	1970-2008

Notes: Lagged values of average q used as instrument, *** denotes statistical significance at the 1 per cent level.

5.5. Is average q a sufficient statistic

Although it is clear that the inclusion of intangibles improves the performance of the Q model of investment, the question still remains as to whether average q is a sufficient statistic for determining investment. This is usually rejected in the empirical investment literature because variables such as net debt, cash-flow or lagged investment are found to be significant in Q model regressions. Table 7 presents results of estimating both the standard Q model and a Q model with intangibles with the inclusion of net debt, cash-flow and the lagged investment rate to test for significance of these variables and hence the sufficiency of average q in explaining investment.

In all regression, either the standard Q model regressions or the Q model with the inclusion of intangibles, cash-flow is not found to be significant. Net debt is marginally significant in some regressions. This is an improvement over past empirical work, which has often found these variables to be highly significant.

Table 7: Regression results

	(1)	(2)	(3)	(4)	(5)	(6)	(7)
	Standard Q model	*Standard Q model*	*Standard Q model*	*Q model with intangibles*	*Q model with intangibles*	*Q model with intangibles*	*Q model with intangibles*
Average q	0.011***	0.026***	0.008	0.014***	0.028***	0.030***	0.012**
	0.003	0.004	0.005	0.003	0.005	0.003	0.005
	3.93	5.97	1.62	4.08	6.04	11.9	2.55
Net debt	-	0.003***	0.000	-	-	0.002***	0.000
		0.001	0.001			0.001	0.001
		3.15	0.51			2.87	-0.18
Cash-flow	-	-0.081	0.018	-	0.122	-	0.049
		0.085	0.066		0.087		0.079
		-0.96	0.27		1.4		0.62
Lagged investment rate	0.631***	-	0.589***	0.634***	-	-	0.621***
	0.100		0.122	0.092			0.106
	6.36		4.84	6.89			5.85
R-squared	0.918	0.844	0.921	0.934	0.829	0.846	0.936
Generalized R-squared	0.920	0.852	0.926	0.933	0.852	0.854	0.94
Pagan-Hall	3.65	3.41	4.58	2.51	2.13	4.33	3.74
Sargan	1.33	1.93	2.12	2.55	2.13	1.25	3.79
Sample	1970-2008	1970-2008	1970-2008	1970-2008	1970-2008	1970-2008	1970-2008

Notes: 3 lagged values of average q used as instrument. Table shows coefficient, standard error and t-value. Measure of average q are not tax-adjusted. *** denotes statistical significance at the 1 per cent level. ** denotes statistical significance at the 5 per cent level. * denotes statistical significance at the 10 per cent level. Measures of net debt and cash-flow are adjusted for the inclusion of intangible assets. See Appendix for variable definitions and calculations.

Eberly, Rebelo and Vincent (2008) highlight that the significance of cash-flow and net debt in investment regressions may not imply failure of the Q model but could be simply due to measurement error in Q. It could be the case that the measures of average q used in this chapter are better than those that have been used in the past. In a specific UK context, this could be related to the use of average q for the entire business sector rather than just for private non-financial corporations. However, a note of caution is required as net debt becomes difficult to measure when including the financial sector due to the high level of inter-bank lending.[22]

The usual empirical result that average q is not a sufficient statistic for explaining investment is found here. Columns (1), (3), (4) and (6) show that the lagged investment rate is found to be significant in both the standard Q model and the Q model with the inclusion of intangibles and the inclusion of the lagged investment rate leads to average q being less significant. The inclusion of intangibles does improve the performance of

[22] See Section A.5 of the Appendix for more detail.

the q model with regards to other regressors. Average q remains significant in a Q model with intangibles and all additional regressors (column 7) whereas average q is insignificant in a Q model without intangibles and all additional regressors (column 3).

6. Conclusions

This chapter has investigated whether the poor empirical performance of the Q model of investment can be explained by the exclusion of intangible assets. The inclusion of intangible assets improves the empirical performance of the Q model in a number of ways. Estimated adjustment costs are lower but still somewhat high. Explanatory power of the Q model is greater with the inclusion of intangibles. Predictive power is better and, unlike the standard Q model, a Q model with intangibles does not suffer from parameter instability. Even with the inclusion of intangibles, average q is not a sufficient statistic to explain investment. However, average q remains significant in a Q model with intangibles that has the additional regressors cash-flow, net debt and the lagged investment rate, but not in a standard Q model with these additional regressors.

The empirical improvements are marginal in some cases, possibly reflecting measurement error in both models. The fact that estimated adjustment costs remain implausibly high also implies that the stock market is not strongly efficient. The deviation of the standard measure of average q from one in the late 1990s cannot be explained by a combination of intangible assets and adjustment costs. Some of the high valuations of the 1990s must simply reflect a share price bubble.

There are a number of potential reasons for still finding implausibly high adjustment costs and rejecting the sufficient statistic prediction of the theory. Two are worthy of mention. Firstly, further work is needed in developing measures of intangible investment and capital.

Second, is the assumption of capital homogeneity. A typical firm will use many types of capital goods, ranging from buildings to computer software. Clearly, these different capital goods provide very different capital services flows into production (see Wallis, 2009), have very different deprecation patterns, and also command different prices. Tax treatment also differs over capital goods. Combining the multiple capital inputs of a firm into a single aggregate requires the restrictive assumption that these capital goods are perfectly substitutable in the firm's production function. Using aggregate US data Chirinko (1986) finds that the econometric evidence rejects the conventional Q model in favour of the multiple capital inputs specification. The difficulty with relaxing this approach at the aggregate level is that without capital homogeneity the equality of marginal and average q breaks down so you have to move away from the use of stock market value as the basis for your measure of average q. The importance of this assumption is considered in Chapter 1.

These limitations aside, the result in this chapter, and in the rest of the intangibles literature, suggest that intangibles are an important part of understanding investment.

Appendix

Four-letter identifiers are Office for National Statistics (ONS) codes.

A1. Average q

Average q without intangibles is calculated as

$$Q_t = \frac{V_t}{K_t} \tag{A1}$$

Average q with intangibles is calculated as

$$Q_t^R = \frac{V_t}{K_t^R} \tag{A2}$$

A2. Net financial value

The numerator of average q $V_t = V_t^e + V_t^d$ is calculated as the sum of net financial assets (sum of current market values of net debt and equity). This calculation is the same for average q with and without intangibles and is calculated as the sum of net financial assets for private non-financial corporations (NYOT), financial corporations (NYOE), and public corporations (NYOP). All series are available from *Financial Statistics* and series consistent with the Blue Book 2010 are used. The series NYOP goes back to 1966 while NYOT and NYOE only go back to 1987. However, data back to 1962 are available, consistent with Blue Book 1998, for private non-financial corporations (ALCY). To take the series for financial corporations back to 1965 the growth rate of ALCY is applied.

A3. Investment and the capital stock

Tangible investment I_t is available from the existing National Accounts.[23] Real business investment (NPEL) and nominal business investment (NPEK) consistent with the Blue Book 2010 are used.

Intangible investment data is based on Giorgio Marrano, Haskel and Wallis (2009) and Haskel, Goodridge, Pesole, Awano, Franklin, and Kastrinaki (2011). The construction of the data is described in detail in those papers and is consistent with Blue Book 2010. Intangible investment is added to tangible investment to give our estimate of I_t^R.

The denominator of average q is the current (nominal) value of the capital stock, so differs depending on whether intangible assets are included or not. Tangible (existing National Account) capital stock K_t is calculated using a perpetual inventory method as described in Wallis (2009)

$$K_t = \sum_{\tau=0}^{\infty} (1-\delta_{t-\tau})^{\tau} \cdot I_{t-\tau} \tag{A3}$$

where K_t is the replacement value of net stock at the end of period t (start of period t+1). A current price measure is used as the denominator in average q. Estimates of intangible capital stock K_t^R are from Giorgio Marrano, Haskel and Wallis (2009) and are also calculated using a perpetual inventory method as described in that paper.

Investment rates are calculated as I_t / K_{t-1} and I_t^R / K_{t-1}^R.

A4. Tax-adjusted average q

Tax-adjusted average q excluding intangible assets is calculated as

$$Q_{Taxadj,t} = \frac{Q_t - p_t^K / p_t^Y (1-D_t)}{1-u_t} + 1 \tag{A4}$$

[23] Strictly this is not tangible because the existing National Account definition of investment includes software and copyright and license costs.

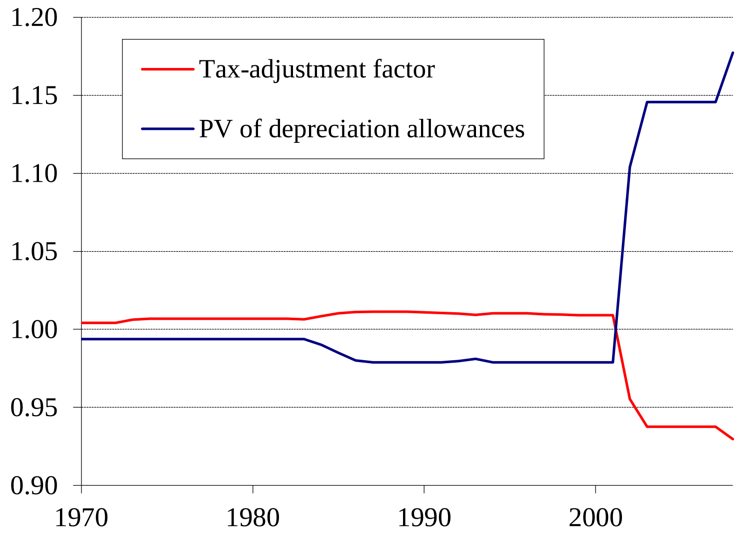
Q_t is calculated as described above. p_t^K is estimated as the implied business investment deflator (NPEK*100/NPEL). p_t^Y, the price of all goods (market sector GVA deflator), is taken from Giorgio Marrano, Haskel and Wallis (2009). u_t, the main corporation tax rate, is available from HM Revenue and Customs. D_t, the present value of depreciation allowances at time t as a proportion of the price of assets, is taken from Chapter 3. A discount factor of 7 per cent is used in the calculation of D_t. This is the average of the weighted cost finance.

Tax-adjusted average q with the inclusion of intangible assets is calculated as

$$Q_{Taxadj,t}^R = \frac{Q_t^R - p_t^{K^R} / p_t^Y (1 - D_t)}{1 - u_t} + 1 \tag{A5}$$

Q_t^R is calculated as described above. $p_t^{K^R}$ and p_t^Y are the implied investment deflator and market sector GVA deflator but now adjusted for the inclusion of intangibles. Both of these are taken from Giorgio Marrano, Haskel and Wallis (2009). D_t is now defined as the weighted average of the net present value of depreciation allowances for tangible assets and the net present value of depreciation allowances for intangible assets. The weights used are the shares of tangible and intangible investment in total investment (estimated using data from Giorgio Marrano, Haskel and Wallis, 2009). See the main text and Chapter 3 for the calculation of D_t for intangible and tangible assets.

Figure A1: Present value of depreciation allowances and tax-adjustment factor for R&D



A5. Net debt

Gross debt is as the sum of domestic bank debt, foreign bank debt and total bonds. For the UK business sector this is the sum of the series NLBC, NLNS, NKIG, NKZA, NLMQ and NKHE. Net debt is calculated by subtracting liquid assets (currency and deposits) from gross debt. However, UK financial corporations have very large levels of currency and deposits on both the asset and liabilities side of their balance sheet due to the financial intermediation role they perform. These deposits are not held for investment purposes and so only the currency and deposits of non-financial corporations (NKJZ) and public corporations (NKDR) are subtracted to give net debt. All series are available from *Financial Statistics* and are consistent with the Blue Book 2010. Net debt is normalised by the relevant capital stock for use in the regression analysis (K_{t-1} or K_{t-1}^{R}).

A6. Cash-flow

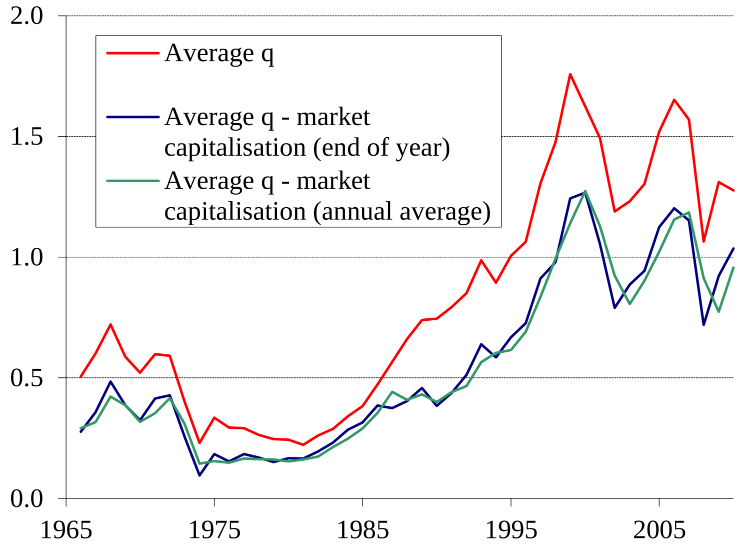
Cash-flow is measured as gross operating surplus less taxes on income and depreciation. Gross operating surplus is available for private non-financial corporations (NRJK), financial corporations (NQNV), and public corporations (NRJT). Gross operating surplus has to be adjusted for the inclusion of intangibles due to the extra rental income generated by intangible capital (See Giorgio Marrano, Haskel and Wallis (2009) for details). Taxes on income series are also available for each sector (FCCP, NHDO and

FCCS). Depreciation for both tangible and intangible capital is calculated by applying the appropriate depreciation rate to the stock of each asset. Therefore, two different estimates of cash-flow are used, one with and the other without the inclusion of intangibles. The inclusion of intangibles increases operating surplus, due to the extra rental income generated by intangible capital, but also increases depreciation, due to the extra intangible capital. Cash-flow is normalised by the relevant capital stock for use in the regression analysis (K_{t-1} or K_{t-1}^{R}).

A7. Alternative measures of average q

Alternative measure of average q can be calculated using alternative measures of financial value of the UK business sector V_t. Figure A2 shows two alternative measures of average q. The first uses end of year stock market capitalisation for the financial value of the business sector, while the second uses the annual average stock market capitalisation. Both measures move in a similar way to the measure of average q being used in the empirical analysis (also shown) but have a slightly lower mean.

Figure A2: Alternative measures of average q



A8. Measurement error

Assume that the true model is given by

$$\frac{I_t^*}{K_t^*} = \alpha + \gamma Q_t^* + \varepsilon_t \tag{A6}$$

where I_t^*, K_t^* and Q_t^* are defined to include intangible assets and the equation conforms to all the assumptions of the classical normal regression model. The least squares estimator of γ is given by

$$\hat{\gamma} = \frac{Cov[Q_t^*, I_t^* / K_t^*]}{Var[Q_t^*]} \tag{A7}$$

For simplicity of the exposition assume that the investment rate I_t^* / K_t^* is the same regardless of whether intangibles are included or not and is observable to the econometrician. In practice of course this is not true but this assumption makes it possible to concentrate on the measurement error of the independent variable Q_t^* and this simplifies the analysis substantially.

Defining Q_t^* as follows (assuming linearity)

$$Q_t^{TANG} = Q_t^* + u_t \text{ with } u_t \sim N[\bar{u}, \sigma_{u,t}^2] \tag{A8}$$

where Q_t^{TANG} is average q calculated without the inclusion in intangibles. For simplicity this is assumed to be perfectly observable to the econometrician. u_t reflects conceptual measurement error and is the adjustment to the standard measure of average q to reflect the inclusion of intangible assets. The error is assumed to be normally distributed with a non-zero mean, empirically $\bar{u} < 0$, and variance $\sigma_{u,t}^2$.

In this setting, the standard Q model of investment is usually estimated empirically as follows

$$\frac{I_t^*}{K_t^*} = \alpha + \gamma Q_t^{TANG} + w_t \tag{A9}$$

However, substituting (A8) into the true model (A6)

$$\frac{I_t^*}{K_t^*} = \alpha + \gamma[Q_t^{TANG} - u_t] + \varepsilon_t \tag{A10}$$

or

$$\frac{I_t^*}{K_t^*} = \alpha + \gamma Q_t^{TANG} + [\varepsilon_t - \gamma u_t] \tag{A11}$$

Therefore, in (A9), since $w_t = \varepsilon_t - \gamma u_t$ and $Q_t^{TANG} = Q_t^* + u_t$, the disturbance is correlated with the regressor.

$$Cov[Q_t^{TANG}, w_t] = Cov[Q_t^* + u_t, \varepsilon_t - \gamma u_t] = -\gamma\sigma_{u,t}^2 \tag{A12}$$

A least squares regression of (A9) will therefore give a biased and inconsistent estimator of γ. Using standard asymptotic results the probability limit of $\hat{\gamma}$ is γ plus the ratio of the covariance between $Q_t^* + u_t$ and $\varepsilon_t - \gamma u_t$ and the variance of $Q_t^* + u_t$.

$$\text{plim}(\hat{\gamma}) = \gamma + \frac{Cov[Q_t^* + u_t, \varepsilon_t - \gamma u_t]}{Var[Q_t^* + u_t]} = \gamma + \frac{-\gamma\sigma_{u,t}^2}{Var[Q_t^* + u_t]} \tag{A13}$$

That the mean of u_t is not equal to zero is not important as only the variance of u_t appears in (A13).

Turning now to the model estimated with the inclusion of intangible assets. Essentially this estimates the true model in (A6) but with measurement error for average q associated with the difficulty of estimating intangible capital.

$$Q_t^R = Q_t^* + v_t \text{ with } v_t \sim N[0, \sigma_{v,t}^2] \tag{A14}$$

The equation estimated is therefore

$$\frac{I_t^*}{K_t^*} = \alpha + \gamma Q_t^R + w_t \tag{A15}$$

where Q_t^R is average q calculated with the inclusion in intangibles and v_t is the measurement error associated with estimating intangible capital. Using the same method as above

$$\text{plim}(\hat{\gamma}) = \gamma + \frac{Cov[Q_t^* + v_t, \varepsilon_t - \gamma v_t]}{Var[Q_t^* + v_t]} = \gamma + \frac{-\gamma\sigma_{v,t}^2}{Var[Q_t^* + v_t]} \tag{A16}$$

The first thing to note is that if intangible capital can be estimated with no measurement error, equation (A15) will give an unbiased estimate of γ if equation (A6) is the true model. If there is measurement error in the estimation of intangible capital both empirical models give biased and inconsistent estimates of γ. But which is best?

Under the classical errors-in-variables assumption that the measurement errors are uncorrelated with the unobserved explanatory variable $Cov[Q_t^*, u_t] = 0$ and $Cov[Q_t^*, v_t] = 0$.[24] This implies that

$$Var[Q_t^*, u_t] = Var[Q_t^*] + Var[u_t] = \sigma_{Q*,t}^2 + \sigma_{u,t}^2 \tag{A17}$$

and

$$Var[Q_t^*, v_t] = Var[Q_t^*] + Var[v_t] = \sigma_{Q*,t}^2 + \sigma_{v,t}^2 \tag{A18}$$

This gives the following bias terms

$$\frac{\gamma\sigma_{u,t}^2}{\sigma_{Q*,t}^2 + \sigma_{u,t}^2} \tag{A19}$$

[24] This might be a good assumption for $Cov[Q_t^*, v_t] = 0$, as v_t is the pure measurement error associated with estimating intangible capital stocks. It will not be a good assumption for $Cov[Q_t^*, u_t] = 0$ as u_t represent the omission of intangible capital and so will be correlated with Q_t^*.

and

$$\frac{\gamma\sigma_{v,t}^{2}}{\sigma_{Q^{*},t}^{2}+\sigma_{v,t}^{2}} \tag{A20}$$

Estimating equation (A15), which includes intangibles, will be better than estimating equation (A9), which does not include intangibles, if the following holds

$$\frac{\gamma\sigma_{u,t}^{2}}{\sigma_{Q^{*},t}^{2}+\sigma_{u,t}^{2}} > \frac{\gamma\sigma_{v,t}^{2}}{\sigma_{Q^{*},t}^{2}+\sigma_{v,t}^{2}} \tag{A21}$$

Multiplying out and cancelling gives the following

$$\sigma_{u,t}^{2} > \sigma_{v,t}^{2} \tag{A22}$$

Equation (A22) is an intuitive result as it states that estimating with the inclusion of intangibles will be better so long as the variance of the adjustment made to average q for the inclusion of intangibles is greater the variance of the measurement error introduced by the inclusion of intangibles.

References

Abel, A. B. and Eberly, J. C. (2002). "Q Theory Without Adjustment Costs & Cash Flow Effects Without Financing Constraints". http://finance.wharton.upenn.edu/~abel/pdf_files_papers/CashFlow-posted.pdf

Attanasio, O. P., Pacelli, L. and Reduto dos Reis, I. (2003). "Investment Patterns in UK Manufacturing Establishments". mimeo web.econ.unito.it/prato/papers/qr67.pdf

Awano, G., Franklin, M., Haskel, J. and Kastrinaki, Z. (2010). "Measuring investment in intangible assets in the UK: results from a new survey". *Economic & Labour Market Review*, Volume 4, No. 7, 66-71.

Bakhshi, H., Oulton, N. and Thompson, J. (2003). "Modelling investment when relative prices are trending: Theory and evidence for the United Kingdom". *Bank of England Working Paper*, No. 189.

Bloom, N., Griffith, R., and Van Reenen, J. (2002). "Do R&D tax credits work? Evidence from a panel of countries 1979-1997". *Journal of Public Economics*, Volume 85, No. 1, 1-31.

Blundell, R., Bond, S., Devereux, M. and Schiantarelli, F. (1992). "Investment and Tobin's Q". *Journal of Econometrics*, Volume 51, 233-257.

Bond, S. R. and Cummins, J. G. (2000). "The Stock Market and Investment in the New Economy: Some Tangible Facts and Intangible Fictions". *Brookings Papers on Economic Activity*, Volume 2000, No. 1, 61-124.

Caballero, R. J. (1999). "Aggregate investment". In Taylor, J.B. and Woodford, M. (eds.), Handbook of Macroeconomics, Vol. 1B, Amsterdam: North-Holland.

Chirinko, R. S. (1986). "Investment, Tobin's Q, and Multiple Capital Inputs". *NBER Working Paper*, No. 2033.

Chirinko, R. S. (1993). “Business Fixed Investment Spending: Modelling Strategies, Empirical Results, and Policy Implications”. *Journal of Economic Literature*, Volume 31, No. 4, 1875-1911.

Clark, P. K. (1979). “Investment in the 1970s: Theory, Performance and Prediction”. *Brookings Papers on Economic Activity*, Volume 1979, No. 1, 73-124.

Corrado, C. Hulten, C. and Sichel, D. (2006). “Intangible Capital and Economic Growth”. *NBER Working Paper*, No. 11948.

Cummins, J. G., Hassett, K. A. and Hubbard, G. (1994). “A Reconsideration of Investment Behaviour Using Tax Reforms as Natural Experiments”. *Brookings Papers on Economic Activity*, Volume 1994, No. 2. 1-74.

Davidson, J. E. H., Hendry, D. F., Srba, F. and Yeo, S. (1978). “Econometric Modelling of the Aggregate Time-Series Relationship Between Consumers’ Expenditure and Income in the United Kingdom”. *Economic Journal*, Volume 88, No. 352, 661-692.

Eberly, J. C., Rebelo, S. and Vincent, N. (2008). “Investment and Value: A Neoclassical Benchmark”. *CEPR Discussion Paper*, No. 6737.

Ellis, C. and Price, S. (2004). “UK Business Investment and the User Cost of Capital”. *The Manchester School*, supplement 2004, 72-93.

Giorgio Marrano, M., Haskel, J. and Wallis, G. (2009). “What Happened to the Knowledge Economy? ICT, Intangible Investment and Britain’s Productivity Record Revisited”. *Review of Income and Wealth*, Volume 55, Issue 3, 686-716.

Gourio, F. and Rudanko, L. (2011). “Customer Capital”. *NBER Working Paper*, No. 17191.

Hall, B. H. (1993). “The Value of Intangible Corporate Assets: An Empirical Study of the Components of Tobin’s Q”. *University of California at Berkeley Economics Working Paper*, No. 93-207.

Hall, B. H. (2007). “Measuring the Returns to R&D: The Depreciation Problem”. *NBER Working Paper*, No. 13473.

Hall, R. E. (1999). “The Stock Market and Capital Accumulation”. *NBER Working Paper*, No. 7180.

Hall, R. E. (2000). “E-Capital: The Link between the Stock Market and the Labour Market in the 1990s”. *Brookings Papers on Economic Activity*, Volume 2000, No. 2, 73-118.

Haskel, J., Goodridge, P., Pesole, A., Awano, G., Franklin, M. and Kastrinaki, Z. (2011). “Driving economic growth: Innovation, knowledge spending and productivity growth in the UK”. mimeo www.nesta.org.uk/library/documents/Driving_Ecc_Growth_Web_v4.pdf

Hayashi, F. (1982). “Tobin’s Marginal q and Average q: A Neoclassical Interpretation”. *Econometrica*, Volume 50, No.1, 213-224.

Hubbard, G. R. (1998). “Capital-Market Imperfections and Investment”. *Journal of Economic Literature*, Volume 36, No. 1, 193-225.

Hulten, C. R. and Hao, X. (2008). “What Is A Company Really Worth? Intangible Capital and the “Market to Book Value” Puzzle”. *NBER working Paper*, No. 14548.

Jovanovic, B. (2007). “Investment Options and the Business Cycle”. *NBER Working Paper*, No. 13307.

Klock, M., Baum, C. F. and Thies, C. F. (1996). “Tobin’s Q, Intangible Capital, and Financial Policy”. *Journal of Economics and Business*, Volume 48, No. 4, 397-400.

Landes, E. M. and Rosenfield, A. M. (1994). “The Durability of Advertising Revisited,” *Journal of Industrial Economics*, Volume 42, 263-276.

McGrattan, E. R. and Prescott, E. C. (2001). “Is The Stock Market Overvalued?” *NBER Working Paper*, No. 8077.

Oulton, N. (1979). “Aggregate Investment and Tobin’s Q: The Evidence from Britain”. *University of Lancaster Discussion Paper*, No. 5.

Oulton, N. (1981). “Aggregate Investment and Tobin’s Q: Evidence from Britain”. *Oxford Economic Papers*, Volume 33, No. 2, 177-202.

Pagan, A. R. and Hall, A. D. (1983). “Diagnostic Tests and Residual Analysis”. *Econometric Review*, Volume 2, 159-218.

Pesaran, M. H. and Smith, R. J. (1994). “A Generalized R^2 Criterion for Regression Models Estimated by the Instrumental Variables Method”. *Econometrica,* Volume 62, No. 3, 705-710.

Poterba, J. M. and Summers, L. H. (1983). “Dividend Taxes, Corporate Investment, and Q”. *Journal of Public Economics*, Volume 22, 135-167.

Price, S. and Schleicher, C. (2006). “Returns to Equity, Investment and Q: Evidence from the United Kingdom”. *Bank of England Working Paper*, No. 310.

Robertson, D. and Wright, S. (2002). “What Does q Predict?” mimeo www.econ.cam.ac.uk/faculty/robertson/whatdoesq.pdf

Summers, L. H. (1981). “Taxation and Corporate Investment: A q-Theory Approach”. *Brookings Papers on Economic Activity*, Volume 1981, No. 1, 67-140.

Tevlin, S. and Whelan, K. (2003). “Explaining the Investment Boom of the 1990s”. *Journal of Money, Credit and Banking*, Volume 35, No. 1, 1-22.

Tobin, J. (1969). “A General Equilibrium Approach to Monetary Theory”. *Journal of Money, Credit and Banking*, Volume 1, No. 1, 15-29.

Wallis, G. (2009). “Capital Services Growth in the UK: 1950 to 2006”. *Oxford Bulletin of Economics & Statistics*, Volume 71, Issue 6, 799-819.

Whited, T. M. (1994). “Problems with Identifying Adjustment Costs from Regressions of Investment on q”. *Economic Letters*, Volume 46, Issue 4, 327-332.

Chapter 3: Tax Incentives and Investment in the UK

1. Introduction

Business investment accounts for around 10 per cent of UK GDP but is one of the most volatile components of demand. Whether or not tax policy can be used to boost the long-run level of investment or smooth the volatility of investment are age-old policy questions.

Despite the large volume of investment literature focusing on the impact of taxation, the evidence is far from conclusive. Much of the early investment literature found very small impacts of tax policy on investment. For example, Bosworth (1985), Clark (1993), and the survey in Gravelle (1992) find small effects of tax policy. Bosworth (1985) finds that taxes are often outweighed as a determinant of the rental price of capital by changes in purchase prices and the cost of funds, meaning they have little effect on investment. Clark (1993) finds that changes in investment tax credits have had only a limited and delayed impact on equipment investment.

More recent literature has made use of the natural experiments provided by periods of major tax reform and found higher estimates of the elasticity of investment with respect to tax changes. For example, Auerbach and Hassett (1991) find that tax policy is important in explaining the cross-section pattern of equipment investment following the U. S. Tax Refom Act of 1986. Cummins, Hassett and Hubbard (1994, 1996) isolate periods of major tax reforms and find that the coefficient on structural variables, such as the user cost of capital, are much larger in those periods and larger than those obtained in previous studies. Cummins, Hassett and Hubbard (1996) using firm-level data for 14 developing countries find that including contemporaneous tax reforms as instruments yields a significant increase in the estimated coefficients on average q. For the UK, the estimate of the coefficient of average q jumps from 0.063 to 0.589.

Additional evidence for the UK is limited. One such paper is King (1972) who finds that an increase in the rate of investment grants by 5 percentage points would increase manufacturing plant and machinery investment by 4.4 per cent. His results are found to be quite sensitive to the assumed discount rate of firms. Bond, Denny and Devereux (1993) focus on the episode around the 1984 corporate tax reform and estimate that a tax system that leaves the cost of capital permanently higher by 1-2 percentage points is likely to depress the level of company investment by up to 5 per cent. Ellis and Price (2004), Barnes, Price and Sebastia-Barriel (2008), and Smith (2008) all estimate the elasticity of the capital stock with respect to the user cost of capital. Although they do not specifically consider the impact of taxation on business investment, they do find a significant user cost elasticity, suggesting that if tax policy can be shown to have a significant impact on the user cost of capital, it will also have a significant impact on the capital stock and hence on investment.

Different approaches are needed for temporary tax changes and permanent tax changes because they have somewhat different implications for investment. A permanent tax change has a permanent effect on the cost of capital and so will have an impact on the desired long-run capital stock, while a temporary tax change has no impact on the long-run desired capital stock and will simply affect the timing of adjustment to the desired level of capital stock. The focus of this chapter is permanent tax changes.

The UK presents a good opportunity to study the impact of tax policy on investment because since the 1980s there has been a general trend towards low rates of corporation tax but also less generous investment allowances. It has also been common in the UK for these tax changes to be preannounced and phased in over a number of years.

This chapter investigates the effectiveness of UK tax policy in boosting the long-run level of investment. It makes use of an extended UK dataset that incorporates a number of permanent tax changes. It presents new estimates of the user cost elasticity using a variety of techniques and describes how these estimates might be used in forecasting. It then investigates the impact of tax changes on investment using an experimental approach focusing on three major tax reform periods in the UK.

The main findings are: (a) tax changes have had large impacts on the user cost of capital. The largest impact came from the 1984 corporation tax reform, which is estimated to have increased the user cost of capital by 6.7 per cent. (b) Aggregate time series regressions give estimates of the user cost elasticity in the range -0.14 to -0.27. These estimates are not out of line with those in previous literature, especially given the downwards bias expected to be present in macro estimates. (c) on the basis of (a) and (b), tax policy can have significant impacts on the long-run level of the capital stock and hence on investment. For example, the 2010 Emergency Budget corporation tax reform could increase market sector capital stock by as much as 1.2 per cent and this could lead to an additional £13 billion of investment over a six year forecast horizon. (d) Results from a natural experiment approach show strong impacts of taxation on investment with the 1984 Corporation Tax Reform, 1997 and 1998 Budgets, and 2007 Budget business tax reforms all exerting a considerable impact on investment in the period following the announcement of these major tax changes. For example, investment in plant and machinery following the 2007 Budget business tax reform was higher than predicted by a reduced-form equation. This under-prediction can be explained by the 1.1 per cent fall in the user cost of capital for plant and machinery caused by the tax reform.

Section 2 presents an overview of changes to investment tax policy since 1980. Section 3 outlines the link between tax policy and the cost of capital and presents evidence on the impact of tax policy since 1980 on the cost of capital. Section 4 presents evidence on the impact of permanent tax changes and Section 5 present the experimental approach. Section 6 concludes. The Appendix describes in more detail the construction of the data used in the analysis.

2. Investment tax policy in the UK

This section presents a brief history of investment tax changes in the UK since 1980. The focus is on the main rates as only a small proportion of investment is done by firms who are eligible for the small companies' rate of corporation tax or whose investment is below the Annual Investment Allowance maximum.[25] For completeness, changes to the small companies' rate of corporation tax and capital allowances aimed at supporting investment by small firms are discussed in Section 2.3. The focus is also on tangible (plant and machinery, vehicles and buildings) investment. The introduction of the R&D tax credit in the UK in 2000 is a significant change to the tax system but this will not be discussed here. See Figure A1 in Chapter 2 for the impact of the R&D tax credit on the tax-adjustment factor for R&D.

[25] Small and medium sized enterprises account for less than 20 per cent of total plant and machinery investment.

2.1. Permanent tax changes

In 1980 the main rate of corporation tax was 52 per cent. There was a first-year allowance of 100 per cent for plant and machinery and an initial allowance of 50 per cent for industrial buildings (increased to 75 per cent in 1981Q2). The difference between a first-year allowance and an initial allowance being that the first-year allowance is applied in place of the writing down allowance, while an initial allowance is applied on top of the writing down allowance. The annual writing down allowances were 25 per cent for plant and machinery, applied on a reducing balance basis, and 4 per cent for industrial buildings, applied on a straight-line basis. Table 1 shows changes to the main rate of corporation tax and capital allowances.

Table 1: Permanent tax changes

Tax change	Changes to main rate of corporation tax	Changes to capital allowances	Phased
1984 Corporation Tax Reform	Reduction from 52 to 35%	Withdrawal of initial-year allowance for buildings from 75%, Withdrawal of first-year allowance for plant and machinery from 100%.	Yes
1990 and 1991 corporation tax cuts	Reduction from 35 to 33%	None	Yes
1997 and 1998 Budgets	Reduction from 33 to 30%	None	Yes
2007 Budget business tax reforms	Reduction from 30 to 28%	Reducton in annual writing down allowance for plant a machinery from 25 to 20%, Phased withdrawal of annual writing down allowance for buildings from 4%.	Yes
2010 Emergency Budget Corporation Tax Reform	Reduction from 28 to 24%	Reduction in annual writing down allowance for plant and machinery from 20 to 18%.	Yes
2011 and 2012 Budgets	Reduction to 22%	None	Yes

In his 1984 Budget, Lawson announced major reforms to business tax that were designed to lower tax rates and provide a broader tax base. In practice this meant reductions in the main rate of corporation tax accompanied by large cuts in depreciation allowance and in some case complete withdrawal of existing allowances. Edwards (1984) provides a detailed discussion of the 1984 corporation tax reform.

The main rate of corporation tax was cut again in April 1990 from 35 per cent to 34 and then to 33 per cent from April 1991. The 1997 Budget announced a reduction in the main rate of corporation tax from 33 per cent to 31 per cent from April 1997. The 1998 Budget announced a further reduction in the main rate of corporation tax from 31 per cent to 30 per cent from April 1999.

The rationale for the 2007 Budget business tax reforms was to "promote growth by enhancing international competitiveness, encouraging investment and promoting innovation". Essentially this meant a reduction in main rate of corporation tax, a reduction in the annual writing down allowance for plant and machinery, and the phased withdrawal of the annual writing down allowance for buildings.

The 2010 Emergency Budget announced major reforms to the corporate tax system including a reduction in the main rate of corporation tax over the course of four financial years and a reduction in the annual writing down allowance for plant and machinery.[26] The rationale for these tax reforms was to increase the international competitiveness of the UK corporate tax system. Further reductions in corporation tax were announced in the 2011 and 2012 Budgets.

2.2. Temporary tax changes

For completeness it is worth briefly mentioning the temporary tax changes that have taken place over the same period. The 1992 Autumn Statement introduced a 20 per cent initial-year allowance for buildings between November 1992 and October 1993 and a 40 per cent first-year allowance for plant and machinery over the same period. The rationale for this policy was to "bring forward private sector investment". The 2009 Budget introduced a 40 per cent first-year capital allowance for plant and machinery for the 2009/10 financial year. This policy was designed to "support business investment and help the economic recovery".

[26] Additional changes included a reduction in the small profits rate (formerly known as the small companies' rate) of corporation tax to 20 per cent, a reduction in the special rate of capital allowances, and a reduction in the Annual Investment Allowance.

2.3. Small companies' rate and investment allowances

The small companies' rate was introduced in April 1973. The main rate of corporation tax increased from 40 per cent to 52 per cent while the small companies' rate was set at 42 per cent. Table 2 shows subsequent changes to the small companies' rate and changes to investment allowances.

Table 2: Small companies' tax changes and investment allowances

Tax change	Changes to small companies' rate of corporation tax	Changes to investment allowances
1979 Budget	Reduction from 42 to 40%	None
1982 Budget	Reduction from 40 to 38%	None
1984 Corporation Tax Reform	Reduction from 38 to 30%	None
1986, 1987 and 1988 Budgets	Cut to 29, then 27, then 25%	None
1996 Budget	Reduction from 25 to 24%	None
1997 Budget	Reduction from 24 to 21%	Small and medium enterprises (SME) first-year allowance for plant and machinery introduced (50%)
1998 Budget	Reduction from 21 to 19%	SME first-year allowance reduced to 40%
Budget 2004	None	First-year allowance increased to 50% for small enterprises only
2007 Budget business tax reforms	Increase from 19 to 21%*	SME first year allowance replaced by an Annual Investment Allowance (AIA) - 100% allowance for first £50,000
2010 Budget	None	AIA increases to £100,000
2010 Emergency Budget Corporation Tax Reform	Reduced from 21 to 20%**	AIA reduced to £25,000

Notes: *One further increase was planned as part of the 2007 Budget business tax reform, 22 per cent from April 2009, but this was postponed to April 2010 in the 2008 Pre-Budget Report to provide recession support. In the 2009 Pre-Budget Report the increase was postponed again to April 2011. However, this was superseded by the announcement in the 2010 Emergency Budget to reduce the small companies' rate to 20 per cent from April 2011. ** The name of the tax was also changed from 'small companies' rate' to 'small profits rate'.

Prior to 1997 there were no special capital allowances for small companies. A Small and medium enterprises (SME) first-year allowance for plant and machinery was introduced in the 1997 Budget. Originally planned to last for one year, this allowance remained in place, at various rates, until the introduction of the annual investment allowance (AIA). The AIA is an annual 100 per cent allowance for a set amount of investment in plant and machinery (other than cars) to all businesses regardless of size and regardless of legal form.

Despite the large number of investment incentives targeted at small and medium size companies there is no evidence that it is desirable to distort investment incentives towards small companies. There are also two problems with the measures described above. Firstly, the small companies' rate is better described as a small profits rate. Indeed, its name was changed in the 2010 Emergency Budget to the small profits rate. This is because the rate applies to all firms with taxable profits below a certain threshold. This means that in practice it will apply to unprofitable large firms but not necessarily small firms that are profitable. Secondly, the AIA applies to all firms. For firms that invest much larger amounts that the annual investment allowance limit there will be almost no impact on the cost of capital. This means that there will be a deadweight fiscal cost and no impact on investment.

2.4. Debt and equity taxation

The tax treatment of different sources of finance can have important implications for how investment is financed. For many years in the UK debt finance has had a tax advantage over finance from retained profits. While interest payments are deductible there is no tax relief for the opportunity cost of financing investment from retained profits. This means that the cost of capital is higher for investment financed by retained profits than for investment financed with debt. This issue will not be considered further here.[27]

[27] Such is the volume of literature in this area that it would not be possible to present a full list of relevant papers on this topic. However, King (1972), Stiglitz (1973), King (1974), Auerbach (1983), Bond, Devereux, and Gammie (1996), Devereux and Griffith (2003) and Auerbach, Devereux and Simpson (2010) are a good starting point.

3. Taxes and the cost of capital

The neoclassical approach offers a structural link between tax policy parameters, such as the rate of corporation tax and investment allowances, and investment through the user cost of capital. As such, analysis of tax policy often uses the user cost of capital approach.[28]

The rental price of a capital asset, or user cost of capital as it is commonly known, is the unit cost for the use of that asset for one period. The real user cost of capital, *r*, for a particular asset *a* is defined using the Hall-Jorgenson (1967) formula

$$r_t^a = \frac{p_t^a}{p_t^Y}\left[\delta^a + R_t - E\left(\frac{\dot{p}_t^a}{p_t^a} - \frac{\dot{p}_t^Y}{p_t^Y}\right)\right] \tag{33}$$

where p^a is the purchase price of the capital good of type a, p^Y is the price of all goods, δ is the rate of depreciation, and *R* is the real cost of finance. See the Appendix for detail description of how the real user cost of capital is constructed. In order to account for the impact of the tax system on the real user cost of capital equation (33) is adjusted as follows:

$$r_t^a = T_t^a \cdot \frac{p_t^a}{p_t^Y}\left[\delta^a + R_t - E\left(\frac{\dot{p}_t^a}{p_t^a} - \frac{\dot{p}_t^Y}{p_t^Y}\right)\right] \tag{34}$$

where T_t^a is the tax-adjustment factor for asset a and following Hall and Jorgenson (1967), Auerbach (1983), and Jorgenson and Landau (1993) among others is defined as

$$T_t^a = \left[\frac{1 - u_t \cdot D_t^a}{1 - u_t}\right] \tag{35}$$

[28] As highlighted by House and Shapiro (2006), the user cost of capital approach is uninformative for analysing the effects of temporary tax changes because temporary tax changes do not change the long-run cost of capital. This means that in the standard neoclassical approach temporary tax changes do not change the long-run supply or demand for capital they just change the timing of when capital is acquired.

where u_t is the corporation tax rate (tax rate on retained profits) and D_t^a is the present value of depreciation allowances as a proportion of the price of asset type *a*.

Firstly, for plant and machinery (*p*) an annual writing down allowance, applied on a reducing balance basis, has always been available and at certain times so has a first-year capital allowance. The present value of capital allowances for plant and machinery is therefore given by

$$D_t^p = [F_t^p/(1+\rho) + A_t^p(1-F_t^p)/(1+\rho)^2 + A_t^p(1-F_t^p - A_t^p(1-F_t^p))/(1+\rho)^3 + \ldots] \qquad (36)$$

Therefore

$$D_t^p = 1/(1+\rho)\cdot[(\rho\cdot F_t^p + A_t^p)/(\rho + A_t^p)] \qquad (37)$$

where ρ is the discount factor, F_t^p is the first-year capital allowance on plant and machinery, and A_t^p is the annual writing down allowance on plant and machinery.[29]

Buildings (*b*) are subject to an annual writing down allowance, applied on a straight line basis, although this was phased out in April 2011. Buildings have never been subject to a first-year allowance but have in the past been subject to initial year allowances. The present value of capital allowances for buildings is therefore given by

$$D_t^b = 1/(1+\rho)\cdot[N_t^b + A_t^b/\rho(1-(1-\rho)^{-(1-N)/A})] \qquad (38)$$

where N_t^b is the initial-year allowance on buildings and A_t^b is the annual writing down allowance.

Finally, vehicles (*v*) are subject to just an annual writing down allowance, applied on a reducing balance basis. The present value of capital allowances for vehicles is therefore given by

[29] Without a different first-year allowance F=A and the equation reduces to equation (39).

$$D_t^v = \frac{1}{1+\rho} \cdot \left[\frac{\rho A_t^v + A_t^v}{\rho + A_t^v}\right] = \frac{A_t^v}{\rho + A_t^v} \tag{39}$$

where A_t^v is the annual writing down allowance on vehicles.

An aggregate (for all assets) present value of capital allowances is estimated as a weighted average of the asset specific variables, where the weights are the shares of each asset in total investment.

3.1. Real cost of finance, discount rate, depreciation rate and sensitivity

Equation (34) requires an estimate of the real cost of finance. Following Ellis and Price (2004) the real cost of finance is estimated as a weighted sum of the cost of equity finance and the cost of debt finance. See the Appendix for details.

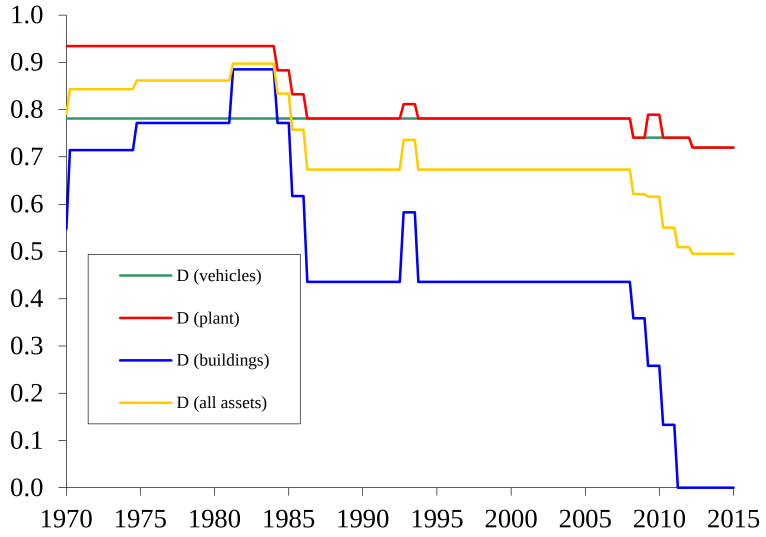
The rate of depreciation for all assets is set at a constant 8 per cent for the empirical analysis below. Sensitivity analysis was conducted using two different time varying aggregate depreciation rates. Both are based on the asset and industry specific depreciation rates in the UK National Accounts (see Wallis (2009)). The first is based on asset value weights and gives a depreciation rate of just under 9 per cent in 1970 rising to around 10 per cent at the end of the sample. The second is based on profit shares giving a depreciation rate that increases from around 11 per cent in 1970 to 14 per cent. The result reported below are not overly sensitive to the depreciation rate and the UCE estimates continue to fall in the range reported below.

Estimation of equations (37) to (39) requires a discount factor. To avoid the estimated tax-adjustment factor being sensitive to changes in the discount factor over time a constant discount factor of 7 per cent is assumed. 7 per cent is used as this is the average real cost of finance over the estimation period. King (1972) argues that the best choice of investment incentives depends on the discount rate assumed to be used by firms. While this is true, the UCE estimates do not appear to be that sensitive to the assumed discount rate. Sensitivity analysis was conducted using a time varying discount rate equal to the real cost of finance and also assuming a discount rate of 10 per cent. Under these differing assumptions the UCE estimates still fall within the range reported below.

3.2. Investment allowances

Figure 1 shows the present discounted value of investment allowances for different types of capital as well as an aggregate measure for all assets over the period 1970 to 2015.

Figure 1: Present discounted value of investment allowances



Notes: To avoid annual variability a constant discount factor of 7 per cent is assumed and for D (all assets) constant weights are assumed for each asset based on long-run averages. The path of the present value of depreciation allowances out to 2015 is based on tax commitments at the time of writing.

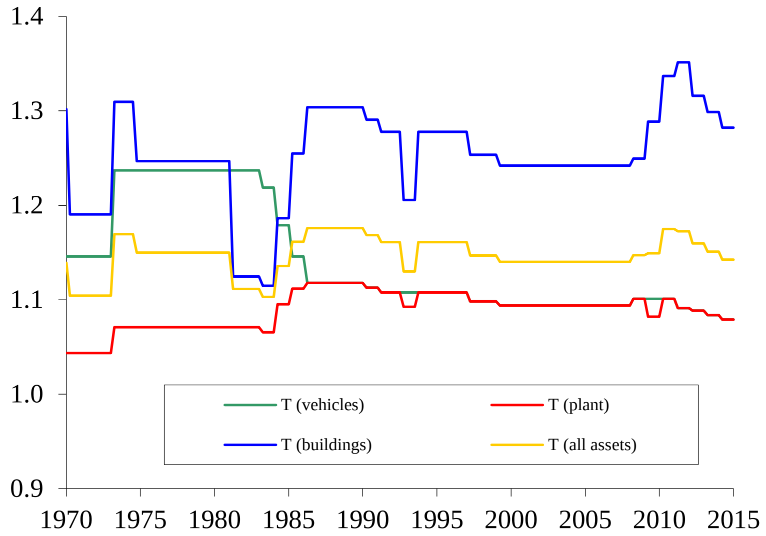
Figure 1 show that over time the net present values of depreciation allowances have in general been falling. Large falls can be seen following the 1984 corporation tax reforms. The falls right at the end are due to the phased withdrawal of the annual writing down allowance for buildings announced in the 2007 Budget and the reduction in the annual writing down allowance for plant and machinery announced in the 2010 Emergency Budget. The temporary enhancements introduced during the 1990s recession and the 2007 recession are also prominent. The aggregate series shows that the 1992 temporary enhancement was larger than the one in 2009. This is because the 2009 Budget enhancement introduced a 40 per cent first-year capital allowance for plant and machinery while the 1992 Autumn Statement introduced a 40 per cent first-year capital allowance for plant and machinery and a 20 per cent initial-year allowance for buildings.

Some of the falls seen in the value of depreciation allowances have been accompanied by falls in the main rate of corporation tax, so for assessing the full impact of tax changes it is better to look at tax-adjustment factors.

3.3. Tax-adjustment factors

Tax-adjustment factors, as defined above, summarise the effect of tax policy on the cost of capital. Figure 2 shows tax-adjustment factors by asset type and a weighted measure for all assets.

Figure 2: Tax-adjustment factors



Notes: To avoid annual variability a constant discount factor of 7 per cent is assumed and for T (all assets) constant weights are assumed for different assets based on long-run averages. The path of tax-adjustment factors out to 2015 is based on tax commitments at the time of writing.

From equation (34) it can be seen that the tax-adjustment factor is a scalar for the user cost of capital. A tax-adjustment factor greater than one implies that the tax system is increasing the cost of capital with a tax-adjustment factor equal to one implying tax neutrality. A cut in the main rate of corporation tax would lead to a fall in the tax-adjustment factor, as does making capital allowances more generous.

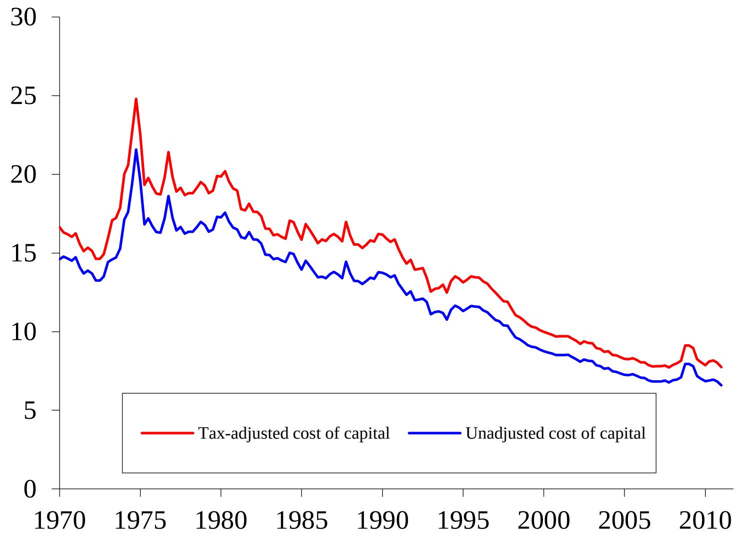
In terms of permanent taxation changes, the 1984 corporation tax reform can be seen to have increased the tax-adjustment factor for all assets from 1.11 to 1.18. The corporation tax cuts made in 1990 and 1991 reduced the tax-adjustment factor slightly as did the corporation tax cuts in 1997 and 1998. This sequence of corporation tax cuts reversed around half of the increase in the tax-adjustment factor due to the 1984 corporation tax reform, leaving the tax adjustment factor at 1.14. The end of the chart captures the 2007 Budget business tax reforms, the 2010 Emergency Budget corporation tax reform and the 2011 and 2012 Budgets. The impact of the 2007 Budget business tax reforms would have been to increase the tax-adjustment factor from 1.14 to 1.19, with the increase being driven by the phased withdrawal of the annual writing down allowance for buildings and the reduction in the annual writing down allowance for plant and machinery, but the impact was limited by tax changes at the 2010 Emergency Budget. The impact of the 2010 Emergency Budget corporation tax reform and the 2011 and 2012 Budgets is to reverse the impact of the 2007 Budget business tax reforms, taking the tax-adjustment factor back down to 1.14.

In terms of temporary tax changes, both the 1990s and 2007 recession measures are visible. The 1990s recession measure reduced the tax-adjustment factor from 1.16 to 1.13, a fall of 2.7 per cent, while the 2007 recession measure reduced the tax-adjustment factor from 1.16 to 1.15, a fall of 0.9 per cent.

3.4. Cost of capital

Figure 3 shows two user cost of capital series. The first is an empirical application of equation (33), so is not adjusted for the impact of the tax system on the cost of capital. The second is a tax-adjusted cost of capital, following equation (34).

Figure 3: User cost of capital



As the tax-adjustment factor is just a scalar the two series follow each other quite closely and both display a strong downwards trend from the mid-1970s to the start of the global financial crisis in 2007. A large part of the downward trend is driven by falling investment goods prices relative to other goods (as measured by the GDP deflator). The rest reflects a downward trend in the cost of finance. From 2007 both series increase as a result of increases in the cost of finance associated with increased risk premia due to the financial crisis.

Table 1 summarises the impact of tax changes on the cost of capital. Column 2 shows the date of the maximum impact on the cost of capital. Column 3 shows the cost of capital in the absence of the tax change while column 4 shows the user cost of capital with the tax changes. Column 5 shows the percentage change in the cost of capital. The final column highlights if the tax change was permanent or temporary.

Table 3: Impact of tax changes on the cost of capital

(1)	(2)	(3)	(4)	(5)	(6)
Tax change	Date of maximum impact on cost of capital	User cost without tax changes	User cost with tax changes	Percentage change in user cost cost of capital	Temporary
1984 Corporation Tax Reform	1986Q2	15.0	15.9	5.8	No
1990 and 1991 corporation tax cuts	1991Q2	14.9	14.7	-1.3	No
1992 Autumn Statement	1992Q4	13.8	13.4	-2.7	Yes
1997 and 1998 Budgets	1999Q2	10.5	10.3	-1.8	No
2007 Budget business tax reforms*	2011Q2	7.8	8.2	4.5	No
2009 Budget temporary capital allowances	2009Q2	9.0	9.0	-0.9	Yes
2010 Emergency Budget Corporation Tax Reform*	2014Q2	8.2	7.9	-2.6	No
2011 and 2012 Budgets	2014Q2	7.9	7.8	-1.5	No

Notes: Maximum incremental impact is shown for each policy in isolation. A constant depreciation rate is assumed for the cost of capital. User cost with tax changes is actual user cost for given period, except for the 2007 Budget business tax reforms onwards.
* The full impact of the 2007 Budget business tax reforms comes in 2011Q2. The full impact of the 2010 Emergency Budget Corporation Tax Reform comes in 2014Q2. The estimates are compiled by applying the pre-reform and post-reform tax-adjustment factors to the unadjusted cost of capital in 2010Q1. The percentage change is indifferent to the cost of capital because the tax-adjustment factor is a scalar. Temporary tax changes shown for completeness.

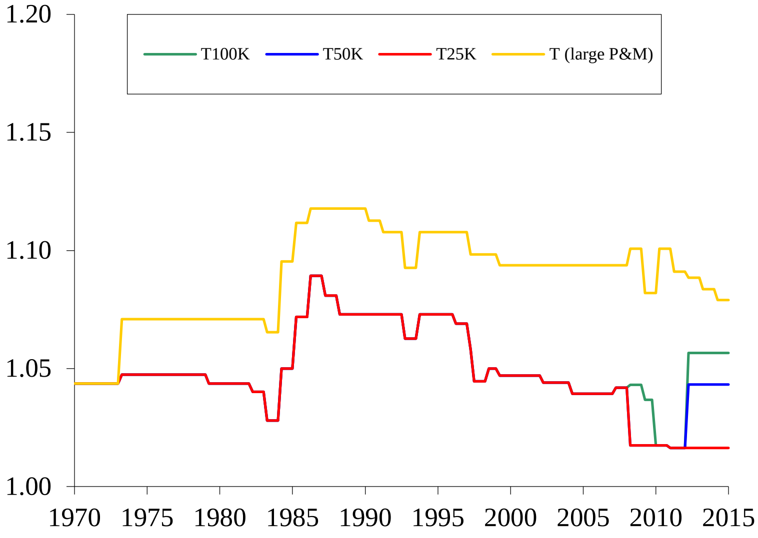
Table 1 shows that both the 1984 Corporation Tax Reform and the 2007 Budget business tax reforms increased the user cost of capital with all other tax changes reducing the cost of capital. The 1984 Corporation Tax Reform had by far the largest impact on the user cost of capital, increasing it by 5.8 per cent. The combined impact of the 2010 Emergency Budget corporation tax reform and the 2011 and 2012 Budgets is to reduce the cost of capital by 4.1 per cent.

In terms of temporary measures, while both reduced the user cost of capital as desired, the tax changes in the 1992 Autumn Statement had a much larger impact on the user cost of capital than the 2009 Budget temporary enhancements to capital allowances.

3.5. Small companies' tax-adjustment factor

The structure of the tax system means that it is not possible to calculate a general tax-adjustment factor for small firms. However, it is possible to calculate a tax-adjustment factor for different representative small firms. To do this we consider a small firm that only invests a certain amount each year and only in plant and machinery and also always falls under the threshold for the small companies' rate of corporation tax. Figure 4 shows tax-adjustment factors for firms that invest £25,000, £50,000, and £100,000 together with the general plant and machinery tax adjustment factor from Figure 2. These levels of investment are chosen because they coincide with the three different thresholds that the annual investment allowance has been set.

Figure 4: Small companies' tax-adjustment factor



Notes: To avoid annual variability a constant discount factor of 7 per cent is assumed. The path of tax-adjustment factors out to 2015 is based on tax commitments at the time of writing.

Figure 4 shows that prior to April 1973 all the tax adjustment factors were equal. This is because prior to that date there were no specific small company allowances and no small companies' rate. Between April 1973 and the middle of 1997 there remained no special capital allowances for small firms but the tax-adjustment factor was always lower due to the small companies' rate of corporation tax being lower than the main rate. After 1997 the tax-adjustment factor for small firms fell relative to that for larger firms with the introduction of first-year allowances for small and medium size enterprises. The introduction of the annual investment allowance, as part of the 2007 Budget business tax reforms, is the point at which the tax-adjustment factors for firms with different levels of investment no longer follow each other. This is because the changing level of the AIA threshold means that a different proportion of each firms' investment is covered by the AIA.

4. The impact of permanent tax changes

4.1. Theoretical long-run impact

A broad range of investment models lead to the following first order condition

$$K^* = f\left(Y^*, r\right) \tag{40}$$

where K^* is the desired long-run capital stock, Y^* is the long-run level of output and r is the user cost of capital. For assessing the impact of tax policy on investment the object of interest is $\partial K^*/\partial r$, the elasticity of capital formation with respect to its price. The user-cost elasticity (UCE) as it is commonly known. This derivative is expected to be negative meaning that a permanently lower cost of capital increases the desired level of capital stock. This is a level effect but adjustment to this new level of capital stock will require investment to be above its equilibrium level for a number of years. In addition, investment remains higher in the long-run as more investment is needed simply to replace depreciated capital stock. With a Cobb-Douglas production function the UCE is set equal to minus one.

4.2. The CES case

Assuming a CES production function

$$Y_t = A_t \left\{ \omega K_t^{\frac{\sigma-1}{\sigma}} + (1-\omega) X_t^{\frac{\sigma-1}{\sigma}} \right\}^{\frac{\eta\sigma}{1-\sigma}} \tag{41}$$

Where Y_t is output, A_t is the stock of technology, K_t is capital stock, and X_t is a composite of other factors of production (including labour). The parameter ω gives the distribution of factor shares. The parameter η characterises returns to scale (the scale parameter). The parameter σ is the negative of the elasticity of substitution between capital and other factors. The advantage of this functional form is that it is strongly separable and can be expanded to include additional factors of production, such as intangible capital, which Chapter 2 suggests is important. Differentiating equation (41) with respect to capital gives the following relationship for the marginal product of capital

$$\frac{\partial Y_t}{\partial K_t} = \eta \omega Y_t^{1+\frac{1-\sigma}{\eta\sigma}} K_t^{-\frac{1}{\sigma}} A^{\frac{\sigma-1}{\eta\sigma}} \tag{42}$$

Profit maximisation implies that the marginal product of capital is set equal to the user cost of capital, defined in equation (34). The equilibrium capital stock is therefore given by

$$K_t = (\eta\omega)^{\sigma} r_t^{-\sigma} Y_t^{\sigma+\frac{1-\sigma}{\eta}} A^{\frac{\sigma-1}{\eta}} \tag{43}$$

Equation (43) implies that, with a CES production function, the elasticity of the capital stock with respect to the user cost of capital is equal to σ, the negative of the elasticity of substitution between capital and other factors.[30]

[30] This is a partial elasticity that holds output fixed. An elasticity that allows output to change in response to a higher capital stock (relying on an assumption of fixed labour) would be higher.

In the presence of adjustment costs the static solution above is usually assumed to approximate the dynamic long-run solution with adjustment of the capital stock taking a number of years. Estimates in the literature of the adjustment period range from five years to over 20 years.[31]

4.3. Existing estimates of σ in the literature

A variety of approaches have been taken in the literature for estimating σ and, as a result, estimates vary greatly. Most work has focused on the US with much of the early work surveyed in Auerbach and Hassett (1992) and Chirinko (1993). More recent examples include Caballero (1994) and Schaller (2006).

There are fewer UK studies and there is more consensus as to what the empirical value of σ is in the UK. UK studies generally point to a UCE of around -0.4. For example, Ellis and Price (2004) estimate the UCE within a vector error correction mechanism (VECM) framework that mimics the dynamics implicit in the neoclassical model of investment, and find an estimate of σ of -0.44. Smith (2008) finds an estimate of close to -0.4 using both aggregate time series methods and dynamic panel data methods. The dynamic panel approach employs a rich industry dataset that allows the UCE to be estimated for different types of capital assets. Barnes, Price and Sebastia-Barriel (2008) use a firm level panel covering over 30 years and using both time averaged and pooled mean group regressions find that there is robust evidence for the UCE being in the region of -0.4.

4.4. New estimates of σ

The UCE is estimated using aggregate data following three different methods.[32] Firstly, the UCE is estimated using a distributed lag model following the approach of Chirinko, Fazzari and Meyer (1996). This is a regression of the investment rate, I_t / K_{t-1}, on lags of changes in the user cost of capital and changes in output. The estimate of the UCE is then given by the sum of the coefficients on the lags of changes in the user cost of capital.

[31] See for example, Shapiro (1986), Chirinko (1993) and Groth (2005).

[32] See the Appendix for details of the regressions discussed in this section.

Secondly, the UCE is estimated using the VECM framework adopted by Ellis and Price (2004). The four variables used in this analysis are investment, capital stock, output and user cost of capital. Under the neoclassical model of investment there should be two cointegrating vectors. The first is the capital accumulation identity and the second is the first order condition from the firms optimisation. The estimate of the UCE is obtained from the second cointegrating vector (the first order condition) once overidentifying restrictions have been imposed.

Finally, the UCE is estimated using dynamic ordinary least squares (DOLS) following Smith (2008). This is a regression of the capital-output ratio on the user cost of capital and sufficient lags and leads of changes in the user cost of capital to make the user cost of capital strictly exogenous. The UCE estimate is obtained from the coefficient on the user cost of capital.

Table 4 shows the main results from each of these three approaches using aggregate data. Further details of each regression are shown in the Appendix. The distributed lag model gives an estimate of the UCE of -0.27.

The VECM estimate of the UCE is -0.21. This is around half that estimated by Ellis and Price (2004). The sample used is longer than in Ellis and Price but this does not account for the difference. Estimating over the same sample as Ellis and Price still gives an estimate of around -0.2. Comparing the two dataset in detail suggests that the difference comes from using different measures of capital stock. Indeed, all the results in Table 2 are somewhat sensitive to using alternative measures of capital stock. However, they do continue to fall in the range reported below.

The DOLS estimate of the UCE is -0.17 when using just lags and -0.14 when using both lags and leads.[33] Again this is a bit lower than found by Smith (2008) when using aggregate data but once again a different measure of the capital stock appears to account for the difference.

[33] The leads are not jointly significance and the regression has a lower adjusted R-squared (see Appendix).

In summary, the three approaches give estimates of the UCE in the range -0.14 to -0.27. These estimates are a bit lower than found in previous UK literature but are not completely inconsistent. The downwards bias of aggregate time-series estimates of the UCE, as noted by, among others, Eisner (1967), Lucas (1969), and Chirinko, Fazzari, and Meyer (2004), should also be borne in mind. Importantly, the results here continue support the rejection of a UCE equal to minus one, which is imposed with a Cobb-Douglas production function, and together with existing literature suggest a UCE in the range of -0.14 to -0.4 for the UK.

Table 4: Regression estimates of the user cost elasticity

Estimation approach	Estimate of UCE	Standard error
Distrubuted lag	-0.271***	0.033
VECM	-0.214***	0.011
DOLS (with lags)	-0.172***	0.015
DOLS (with lags and leads)	-0.141***	0.016

Notes: Sample is 1970Q1 to 2011Q1 for all regressions. *** indicates significance at 1 per cent level. ** indicates significance at the 5 per cent level. Estimate of UCE from distributed lag model is the sum of the coefficients on the lags of the user cost of capital. 24 lags of the user cost and 12 lags of GDP. Robust standard errors. Estimate of UCE from VECM is the coefficient on the user cost of capital in the second cointegrating vector (see Appendix). Estimate of UCE from dynamic ordinary least squares (DOLS) is coefficient on the user cost of capital. 12 lags and 6 leads.

Chapter 1 suggests it is important to take account of capital heterogeneity. It is possible to apply the same three approaches to asset specific data.[34] The results are shown in Table 5.

[34] See the Appendix for details of regression variables. Asset specific data for the business sector is only currently published for the period up to 2010Q1 due to difficulties with the move to the Standard Industrial Classification 2007 (SIC 2007).

Table 5: Asset specific estimates of the user cost elasticity

(1) Estimation approach	(2) Aggregate capital	(3) Buildings	(4) Plant and Machinery	(5) Vehicles
Distrubuted lag	-0.271***	-0.161***	-0.242***	-0.219**
VECM	-0.214***	-0.331***	-0.183***	0.0642
DOLS (with lags)	-0.172***	-0.217***	-0.102***	1.044***
DOLS (with lags and leads)	-0.141***	-0.171***	-0.136*	0.098*

Notes: Sample is 1970Q1 to 2010Q1 for all regressions. Lags and leads range from 4 to 16. *** indicates significance at 1 per cent level. ** indicates significance at the 5 per cent level. * indicates significance at the 10 per cent level.

The asset specific results are somewhat mixed. The results for buildings are similar to those for aggregate capital and give a UCE in the range -0.16 to -0.33 with all estimates significant at the 1 per cent level. The UCE estimates for plant and machinery are slightly lower than for aggregate capital and fall in the range -0.1 to -0.24. The DOLS estimate with both lags and leads is only significant at the 10 per cent level but all other estimates are significant at the 1 per cent level. The vehicle results are poor with a large range of estimates, some of which are not significant. This finding is consistent with the vehicle results in Chapter 1 which are also not as robust as for other assets.

4.5. Implied impact of tax changes on capital stock and investment

Using the aggregate estimates for σ from sections 4.3 and 4.4 and the results from section 3.3 it is possible to estimate the implied impact on the desired level of capital stock of tax changes. The impact on investment will depend on the adjustment period, for which the investment literature presents a wide range of estimates, from five to 25 years.

Table 6 shows the implied impact of major tax changes on the long-run level of capital stock. The second column shows the percentage change in the user cost of capital (as in Table 1) while columns three and four show the implied percentage change in the desired level of capital stock for a UCE of -0.14, the bottom of the range estimated in Section 4.4, and for a UCE of -0.4, the average from previous literature.

Table 6: Impact of tax changes on long-run level of capital stock

Permenant tax change	Percentage change in user cost of capital	Implied impact on long-run capital stock (% level)	
		UCE = -0.14	UCE = -0.4
1984 corportaion tax reform	5.8	-0.8	-2.3
1990 and 1991 corporation tax cuts	-1.3	0.2	0.5
1997 and 1998 Budgets	-1.8	0.3	0.7
2007 Budget business tax reforms	4.5	-0.6	-1.8
2010 Emergency Budget Corporation Tax Reform	-2.6	0.4	1.1
2011 and 2012 Budgets	-1.5	0.2	0.6

Notes: Percentage change in user cost of capital from Table 2. Range of impact based on range of estimates for user cost elasticity (UCE). Implied impact on long-run capital stock is equal to percentage change in user cost of capital times by the UCE.

Table 6 shows that tax policy can have significant impacts on the level of the capital stock. For example, the 2010 Emergency Budget corporation tax reform could increase the long-run level of capital stock by as much as 1.1 per cent and the 1984 corporation tax reform could have reduced it by as much as 2.3 per cent.

4.6. Forecasting using σ

An important advantage of the approach outlined above is it usefulness for forecasting. For example, given a baseline forecast for business investment it is possible to produce a post-tax change forecast as follows. Firstly, estimate the end of forecast corporate sector capital stock implied by the pre-tax changes business investment forecast. This can be done by taking the latest available annual measure of the capital stock and using the perpetual inventory method (PIM) to calculate and end of forecast capital stock. Secondly, estimate the impact of the tax changes on the real user cost of capital via the impact on the tax-adjustment factor (as above). Thirdly, estimate the implied impact on the equilibrium level of the capital using the results from above. The average value for the UCE parameter in the existing UK literature is around -0.4. The impact on the equilibrium level of the capital stock is therefore given by 0.4 times by the percentage change in the user cost of capital. Finally, adjust the pre-tax change business investment forecast to hit the new level of capital stock at some point in the future. The choice of adjustment period is more difficult and is a matter of judgement because of the lack of consensus in the literature on the speed of adjustment and will depend on other factors relevant to the profile for business investment.

The method described above was used to assess the impact of the 2010 Emergency Budget corporation tax reform on the business investment forecast. The 2010 Emergency Budget is estimated to reduce the cost of capital by 2.6 per cent (see Table 3). Assuming a UCE of -0.4 this implies an increase in the equilibrium level of capital stock of around 1.1 per cent. Given the staggered nature of the reductions in the main rate of corporation tax it is assumed that two-thirds of the adjustment to the new level of capital stock takes place by the end of the forecast horizon (2016). This implies an increase in the capital stock in 2016 of around 0.8 per cent. The profile of business investment is kept similar to the pre-tax change forecast. The stronger path of business investment to reach this new level of capital stock implies business investment is 1.9 per cent higher (£3.8 billion) at the end of the forecast horizon. Over the course of the forecast there is an additional £13 billion of business investment.[35] Table 7 below shows the pre-tax change business investment forecast as published by the Office for Budget Responsibility (OBR) prior to the Emergency Budget (2010a) together with a forecast that takes into account the impact of the corporation tax reform.

Table 7: Pre and post corporation tax reform business investment forecasts

	User cost of capital (per cent)	Net capital stock in 2016, £bn	Business investment growth, per cent						
			2010	2011	2012	2013	2014	2015	2016
Pre-measures	8.2	£1,574	1.3	8	9.8	10.6	9.1	8.5	9.1
Post-measures	7.9	£1,586	1.5	8.4	10.1	10.9	9.4	8.8	9.4

Notes: The estimates are compiled by applying the pre-reform and post-reform tax-adjustment factors to the unadjusted cost of capital in 2010Q1. Pre-measures forecast from OBR (2010a). Second row not equal to forecast published by the OBR alongside the Emergency Budget, OBR (2010b), because this represents a partial analysis for a single policy measure. The OBR forecast takes into account all measures announced in the Emergency Budget.

5. A natural experiment approach to major tax reforms

Major tax reforms offer a kind of natural experiment as each tax reform represents a discrete event with a large and, hopefully, identifiable effect on the user cost of capital and investment. Past literature, such as Auerbach and Hassett (1991, 1992) and

[35] Extract from 2010 Emergency Budget statement: “And by increasing the amount of business investment by an additional £13 billion between now and 2016, these reforms will help rebalance the economy away from household debt and government consumption.”

Cummins, Hassett, and Hubbard (1994, 1996,) has been much more successful at finding impacts of tax changes on investment when using an experimental approach and focusing on major tax reforms. Such an approach has not been applied to UK.

The approach here is similar to Cummins, Hassett, and Hubbard (1994). The first step is to estimate a reduced form equation to explain investment rates by asset over pre-reform periods, leaving out tax variables. These equations are used to form predictions for investment in the post-reform period which can then be compared to actual outturns. The second step is to test whether the differences between the predictions and actual outturns can be explained by tax factors. This is tested more formally by running a cross-section of resulting investment residuals against the tax shock.[36]

Three major tax reforms are chosen. The 1984 Corporation tax reform, 1997 and 1998 Budgets and the 2007 Budget business tax reforms. The choice is driven by needing a period of time before each reform, where the tax regime was relatively stable, to estimate a reduced form investment equation. Cummins, Hassett, and Hubbard in their 1996 cross-country study look at the 1990 and 1992 corporation tax cuts in the UK but, as shown in Table 3, this was a small change relative to other reforms and for modelling purposes falls too close to the 1984 reform to get a reasonable sample.

It is important to get timing right as tax change are often preannounced. This means that firms may react before the tax actually changes. The start date is the announcement. For the 1984 Corporation Tax Reform reduced form equations are estimated over the period 1970Q1 to 1984Q1 with a projection for 1984Q2 to 1987Q1. For the 1997 and 1998 Budget reduction in corporation tax the reduced form equations are estimated over the period 1987Q1 to 1997Q1 with a projection for 1997Q2 to 2000Q1. For the 2007 Budget business tax reforms the reduced form equations are estimated over the period 2000Q1 to 2007Q1 with a projection for 2007Q2 to 2010Q1.[37]

The first stage is to estimate 9 reduced-form regressions, by 3 assets for each time period. The aim is not to identify the ‘true’ structural model of investment but to find a model that explains historical investment behaviour reasonably well. The reduced-form

[36] In the language of experimental economics the “control” is the period before the major tax change and the “treatment” is the tax reform.

[37] The temporary enhancement for plant & machinery in 2009 falls in this period.

equations are not constrained to be the same as different explanatory variables have explanatory power in different time periods but in general they include lagged investment rate (lagged dependent variable), the real user cost of capital measures described above, GDP growth, and a measure of cash flow. Cash flow is particularly important for the regression covering the period leading up to the 2007 Budget business tax reform regressions. As can be seen from the Appendix (Figures A4, A5 and A6) the fit of the equations prior to the tax reform episodes is good. As with the results in section 4.4 and in Chapter 1 the vehicle results are not as good as for other assets.

Table 8 shows the average projected investment rates obtained from the reduced-form investment equations for the three years after the announcement together with the actual average investment rate. Detailed charts are shown in the Appendix. Also shown are the asset specific changes to the cost of capital for each tax reform over the same three-year period. The full impact of the 1984 Corporation Tax Reform and 1997 and 1998 Budgets on the cost of capital falls within this 3-year period. Figures for 2007 Budget business tax reform are different from the total impact of the reform as the three-year period includes the temporary allowance for plant and machinery introduced in the 2009 Budget (that is why the impact is positive rather than negative) and the full impact of the reform comes after 4 years. The analysis is constrained to three years for the 2007 Budget business tax reforms because the fourth year overlaps with the 2010 Emergency Budget Corporation Tax Reform.

With the exception of the investment rates for plant following the 1984 corporation tax reform and for buildings following the 2007 Budget business tax reforms, the prediction errors are all of the expected sign. Where tax reform increased the cost of capital the reduced-form equation over-predicts the investment rate. The result for buildings following the 2007 Budget business tax reforms appears to be due to a timing effect. Following the 2007 Budget announcement that the annual writing allowance for buildings would be withdrawn over the course of three years the investment rate rose sharply as firms bought forward investment plans and then fell sharply (see Figure A6). The average error is small and this simple average hides what is happening. The error is actually negative when the cost of capital starts to increase. The 2nd stage regression captures this timing effect better than the simple comparison in the table. The plant result for the 1984 tax reform is more difficult to explain. The investment rate increases dramatically immediately following the reform. This is not surprising due to the phased nature of the reduction in the first year allowance, with firm appearing to bring forward substantial amount of investment. However, from then onwards the investment rate does not appear to fall as much as might be expected given the increase in the plant cost of capital.

Table 8: Projected and actual average investment rates

Reform	Asset	Average 3 year investment rate Actual	Projected	Error	Percentage change in cost of capital*
1984	Buildings	0.024	0.026	-0.002	16.0
	Plant	0.059	0.048	0.011	4.4
	Vehicles	0.161	0.131	0.030	-9.6
1997	Buildings	0.051	0.039	0.013	-2.8
	Plant	0.086	0.075	0.011	-1.3
	Vehicles	0.218	0.188	0.030	-1.3
2007	Buildings	0.046	0.038	0.008	3.8
	Plant	0.089	0.079	0.010	-1.1
	Vehicles	0.159	0.193	-0.033	0.6

Notes: 3 year average annual investment rate. Error is actual minus projection. * Percentage change in cost of capital is change over three year observation period following the announcement of tax changes.

The correlation between the prediction error and the tax shock can be tested more formally by running a cross-section regression of the prediction error against the tax shock following an approach similar to Cummins, Hassett, and Hubbard (1994). With three reforms, three assets and a focus on a three year period post-reform announcement in each case there are 108 quarterly observations. The second-stage regression is of the form

$$w_{at} = \gamma \Psi_{at} + \varepsilon_{at} \tag{44}$$

Where w is the deviation of investment from that predicted by the reduced-form investment equation (i.e. without the exogenous tax shock) and Ψ is the tax shock. Equation (44) is estimated by pooled OLS.

A key issues remains. How to define the tax shock? It is unlikely that the taxation of investment is exogenous at the aggregate level as tax reform is often enacted due to a perception that investment is too low or that the tax regime is too generous. Variation across assets is much more likely to be exogenous. Two different definitions of the tax shock are considered. Firstly, the tax shock defined as the total percentage change in the cost of capital due to the tax reform. Secondly, to take account of the endogeneity issue, the tax shock is defined as the change in the cost of capital relative to the average change for all assets. The intuition here is that the general direction of tax change was predictable but not the asset specific variation.

In the case where the tax shock is defined as the percentage change in the relevant asset specific tax-adjustment factor compared to its pre-reform value the regression yields an estimate of γ equal to -0.149. The estimate is significant at the 1 per cent level (t-value of 3.01). This results shows that the under or over-prediction of investment following periods of major tax reform is related the tax shock caused by the reform. The regression with the tax shock defined as the deviation from the all asset average gives a coefficient of -0.159 and is also significant at the 1 per cent level. For both regressions the R-squared is only in the region of 10% so while the tax-shock has explanatory power for the under or over-prediction of the reduced-from investment equations a significant amount of the under or over-prediction is not explained by the tax shock.

6. Conclusions

This chapter has used a number of different approaches to investigate the impact of tax changes on investment in the UK. A number of different approaches have shown that taxation is important for investment, especially following periods of major tax reform.

The focus has been on how the corporation tax regime can affect the amount of investment focusing on the marginal tax rate for investment decision. However, the corporation tax regime, including the taxation of debt and equity, also has implications for where firms choose to locate their investment. While this topic is beyond the scope of this chapter it has important implications many of which are discussed in detail in Auerbach, Devereux, and Simpson (2010).

Following the 2009 Budget measure to introduce a temporary enhancement to capital allowances there is a natural experiment that can be used to analyse the effects of temporary tax incentives on investment. The 2009 Budget enhancement introduced a 40 per cent first-year capital allowance for plant and machinery while the 1992 Autumn Statement introduced a 40 per cent first-year capital allowance for plant and machinery and a 20 per cent initial-year allowance for buildings. Sufficient data is not currently available to properly exploit this natural experiment. It would also be possible to apply the natural experiment approach used in this chapter to the 2010 Emergency Budget Corporation Tax Reform and subsequent Budget tax changes once a sufficient period since the reform has elapsed. These two areas are left for future work.

Appendix

Four-letter identifiers are Office for National Statistics (ONS) codes.

A1. User cost of capital

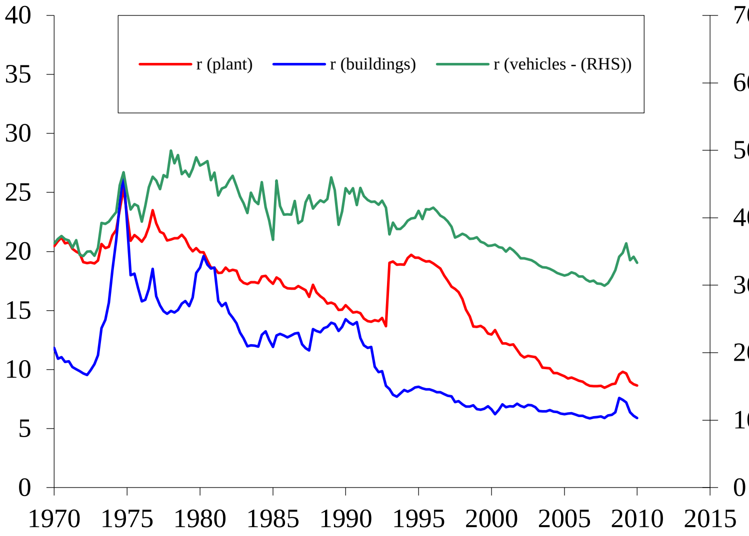
The real user cost of capital is calculated for the market sector as

$$r_t = T_t \cdot \frac{p_t}{p_t^Y}\left[\delta + R_t - E\left(\frac{\dot{p}_t}{p_t} - \frac{\dot{p}_t^Y}{p_t^Y}\right)\right] \qquad \text{(A1)}$$

p_t is the purchase price of the capital goods and is calculated as the implied business investment deflator (NPEK*100/NPEL). p_t^Y, the price of all goods, is taken as the GDP deflator (YBGB). The rate of depreciation δ is set at 8 per cent. The real cost of finance R_t and tax-adjustment factor T_t are calculated as described below. The expected inflation term is unobservable so is ignored.

Asset specific measures of the real user cost of capital are calculated in the same way. This requires asset specific tax-adjustment factors, asset specific depreciation rates and asset specific purchase prices of capital good. The price of all other goods and the real cost of finance are the same for each asset type. Asset specific tax-adjustment factors are calculated as described in the main text. The rates of depreciation for plant and machinery, buildings, and vehicles are set at 13 per cent, 2.5 per cent, and 25 per cent respectively (Based on Fraumeni (1997)). Asset specific purchase prices of capital goods are calculated as the implied deflators of private sector asset specific investment. For plant and machinery EQBW*100/EQCW. For buildings EQBU*100/EQCU. For vehicles EQBV*100/EQCV.

Figure A1: User cost of capital by asset



A2. Real cost of finance

The real cost of finance is calculated using a similar approach to Ellis and Price (2004)

$$R_t = \lambda_t \cdot R_t^d + (1 - \lambda_t) R_t^e \qquad \text{(A2)}$$

The weight on debt finance λ_t is calculated using corporate sector balance sheet data from *Financial Statistics*. The cost of debt finance R_t^d is calculated as the sum of the risk free rate, taken as the ten-year gilt real spot rate, and an option-adjusted spread on non-financial corporate debt. The cost of equity finance R_t^e is calculated using a simple dividend discount model and assuming real dividend growth of 3 per cent per annum.

A3. Tax-adjustment factors

The all asset tax-adjustment factor is calculated as

$$T_t = \left[\frac{1 - u_t \cdot D_t}{1 - u_t} \right] \qquad \text{(A3)}$$

A time series of the main rate of corporation tax u_t is available from the HMRC website. The present value of depreciation allowances D_t is a weighted sum of the asset specific values as defined in the main text where the weights are the shares of each asset in business investment. All of the asset specific present values of depreciation allowances require a discount factor. A constant discount factor of 7 per cent is assumed. The capital allowance data needed to estimate equations (37), (38) and (39) is available covering the period March 1981 to April 2006 on the HMRC website. Data for earlier years is taken from editions of *Inland Revenue Statistics* and later years are put together using Budget and PBR documents.

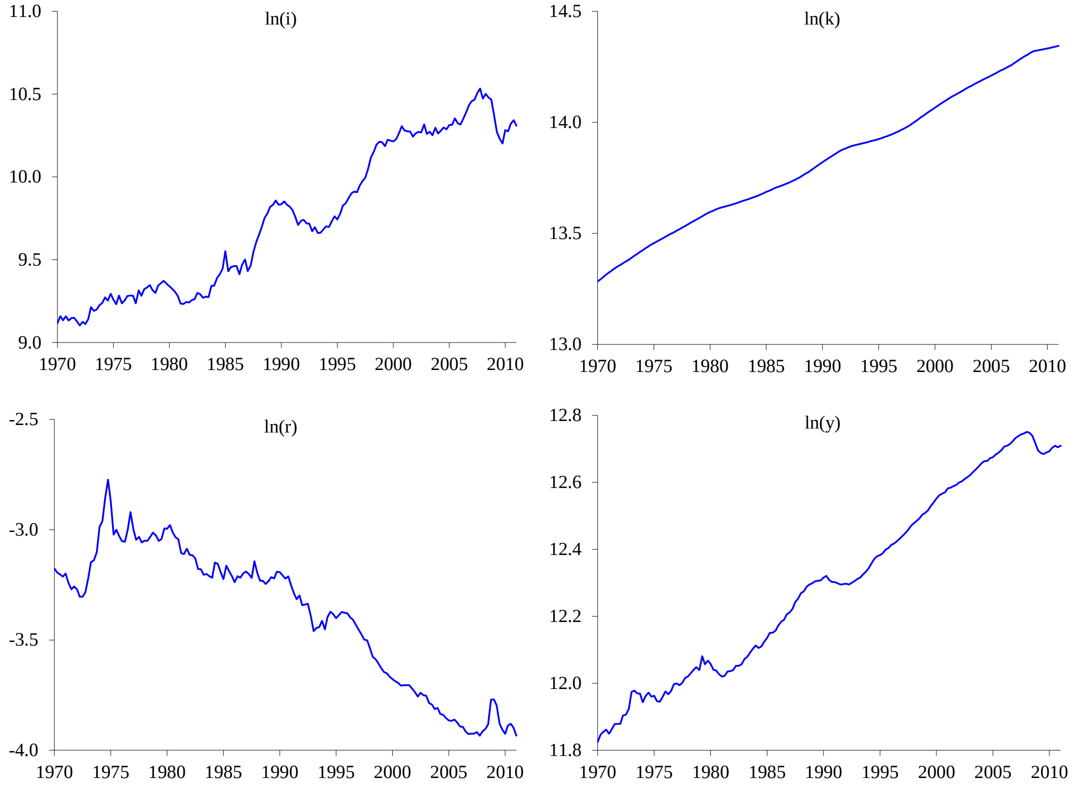
A4. Other data

In addition to the real user cost of capital the regression analysis requires data on market sector investment, capital stock and output. Real business investment (NPEL) is used. Data for market sector net capital stock is based on Wallis (2009).

GDP is used as the measure of output (ABMI). A measure of market sector output would be preferable but a sufficiently long quarterly time series is not available. Figure A1 shows investment i, capital stock k, the user cost of capital r, and output y, all in logs. The investment rate i/k and the capital to output ratio k/y are both shown (in logs) in Figure A2.

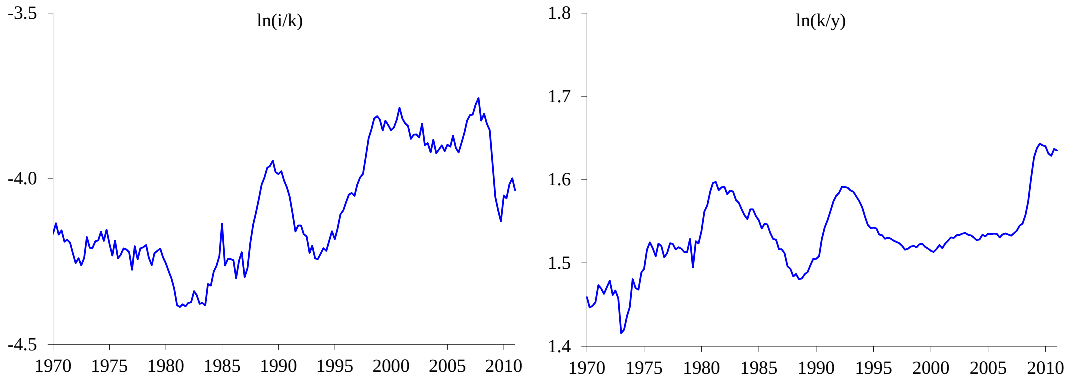
The asset specific regressions in Section 4.4 and Section 5 require data on private sector investment by asset. Real investment for buildings, plant and machinery and vehicles is used (ONS series EQCU, EQCW and EQCV). Asset specific investment data is only available up to 2010Q1. Asset specific net capital stock data is based on Wallis (2009) updated with additional years. The reduced form equations in Section 5 also use before-tax cash flow measured as gross operating surplus (CGBZ) turned into constant prices using the implied GDP deflator (YBGB) and normalised by total capital stock.

Figure A2: Investment, capital stock, the user cost of capital, and output



Notes: All in logs.

Figure A3: Investment rate and capital to output ratio



Notes: Both in logs.

A5. Detailed regression results for Section 4.4.

The regression analysis in Section 4.4 assumes that investment i, capital stock k, the user cost of capital r, and output y are all I(1) variables, while the investment rate i/k and the capital output ratio k/y are both I(0). Table A1 shows that these assumptions are confirmed in practice, although the result is more marginal for the investment rate. The investment rate and capital/output ratio are found to be trend stationary at 10 per cent and 5 per cent respectively. The upwards trend can be explained by an upwards trend in the average rate of depreciation (see footnote 19 in Chapter 2.

Table A1: Augmented Dickey Fuller tests of regression variables

Variable	Level	First difference
Investment (i)	-0.882	-4.632***
Capital stock (k)	-0.794	-3.340***
User cost of capital (r)	-0.015	-5.996***
Output (y)	-1.044	-4.594***
Investment rate (i/k)	-3.263*	-
Capital/output ratio (k/y)	-3.618**	-

Notes: Augmented Dickey Fuller (ADF) test statistic is shown in table. *** indicates significance at 1 per cent level. ** indicates significance at the 5 per cent level. * indicates significance at the 10 per cent level. Investment rate and capital/output ratio with trend.

The distributed lag model estimated is shown below. The results are presented in Table A2.

$$I_t / K_{t-1} = \alpha + \sigma_p(L)\Delta r_t / r_{t-1} + \beta_q(L)\Delta Y_t / Y_{t-1} + \varepsilon_t \qquad \text{(A4)}$$

Table A2: Distributed lag regression results

	Distributed lag model
Sum of r coeffcients	-0.271***
	(0.033)
Sum of y coefficients	0.325***
	(0.073)
Adjusted R^2	0.473

Notes: Estimate of UCE is the sum of the coefficients on the cost of capital (r). Robust standard errors are reported. *** indicates significance at 1 per cent level

Tables A3 and A4 show the cointegration analysis and VECM results. For details of the regression specification see Ellis and Price (2004).

Table A3: Johansen tests for cointegration

Maximum rank (number of cointegrating equations)	Trace statistic	Maximum eigenvalue statistic
One	78.7***	43.8***
Two	34.9**	21.8**
Three	13.1	12.8

Notes: 12 lags. *** indicates significance at 1 per cent level. ** indicates significance at the 5 per cent level.

Table A4: VECM regression results

Variable	Cointegrating relasionship 1	Cointegrating relasionship 2		
Investment (i)	-1	-		
Capital stock (k)	1	-1		
User cost of capital (r)	-	-0.214***		
		(0.011)		
Output (y)	-	1		
Constant	-5.94	1.57		
Error correction	Δi	Δk	Δr	Δy
Loading on cointegrating relationship 1	0.161**	0.003**	0.222***	0.038**
	(0.064)	(0.001)	(0.060)	(0.018)
Loading on cointegrating relationship 2	0.385**	0.007**	0.515***	0.072*
	(0.157)	(0.003)	(0.146)	(0.044)

Notes: *** indicates significance at 1 per cent level. ** indicates significance at the 5 per cent level. * indicates significance at the 10 per cent level. Likelihood ratio test for overidentifying restrictions: $\chi_3^2 = 4.5$ (p value 0.24).

The DOLS regression specification is as follows. Regression results are shown in Table A5.

$$K_t / Y_t = \alpha + \sigma r_t + \beta \Delta r_t + \beta_{-1} \Delta r_{t+1} + \ldots + \beta_{-p} \Delta r_{t+p} + \beta_1 \Delta r_{t-1} + \ldots + \beta_p \Delta r_{t-p} + \varepsilon_t \qquad \text{(A5)}$$

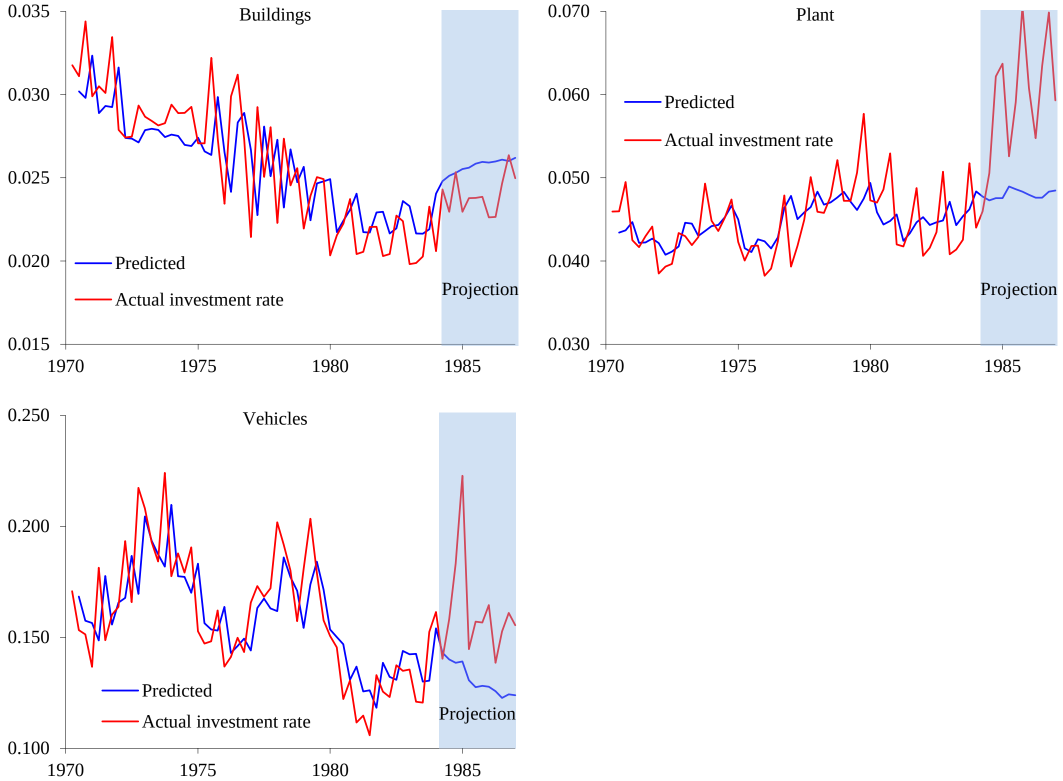
Table A5: Dynamic ordinary least squares (DOLS) regression results

	With lags	With lags and leads
User cost of capital (r)	-0.172***	-0.141***
	(0.015)	(0.016)
SUM (beta)	3.372***	2.821***
	(0.462)	(0.469)
SUM (gamma)	-	0.434
	-	(0.349)
Adjusted R^2	0.460	0.322

Notes: *** indicates significance at 1 per cent level.

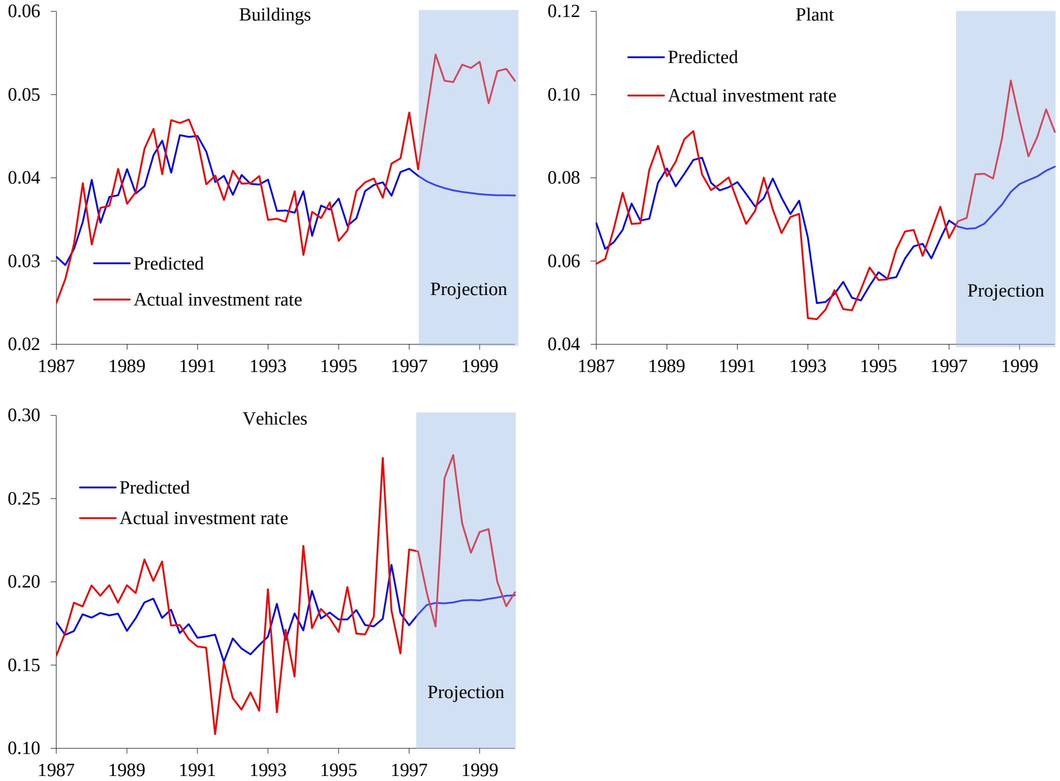
A6. Natural experiment projection graphs

Figure A4: 1984 Corporation tax reform: Predicted versus actual investment rate



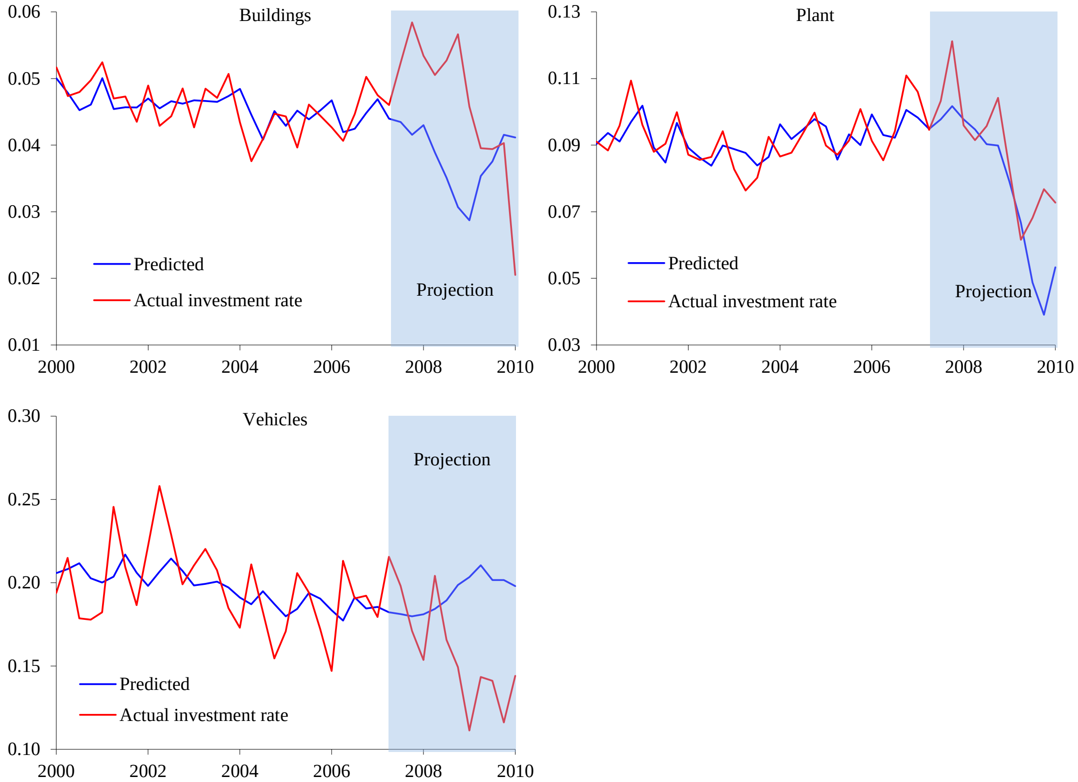
Notes: Annual investment rate. Predicted series is fitted values over period 1970Q1 to 1984Q1 with a projection for 1984Q2 to 1987Q1.

Figure A5: 1997 and 1998 Budgets: Predicted versus actual investment rate



Notes: Annual investment rate. Predicted series is fitted values over period 1987Q1 to 1997Q1 with a projection for 1997Q2 to 2000Q1.

Figure A6: 2007 Budget business tax reforms: Predicted versus actual investment rate



Notes: Annual investment rate. Predicted series is fitted values over period 2000Q1 to 2007Q1 with a projection for 2007Q2 to 2010Q1.

References

Auerbach, A. J. (1983). "Taxation, Corporate Financial Policy and the Cost of Capital". *Journal of Economic Literature*, Volume 21, No. 3, 905-940.

Auerbach, A. J., Devereux, M. P. and Simpson, H. (2010). "Taxing Corporate Income". In *Dimensions of Tax Design: the Mirrlees Review*, Oxford University Press: April 2010.

Auerbach, A. J. and Hassett, K. A. (1991). "Recent U.S. Investment Behaviour and the Tax Reform Act 1986: A Disaggregated View". *NBER Working Paper*, No. 3626.

Auerbach, A. J. and Hassett, K. A. (1992). "Tax policy and business fixed investment in the United States". *Journal of Public Economics*, Volume 47, No. 2, 141-70

Bakhshi, H., Oulton, N. and Thompson, J. (2003). "Modelling investment when relative prices are trending: Theory and evidence for the United Kingdom". *Bank of England Working Paper*, No. 189.

Barnes, S., Price, S. and Sebastia-Barriel, M. (2008). "The elasticity of substitution: evidence from a UK firm-level data set". *Bank of England Working Paper*, No. 348.

Bond, S., Denny, K. and Devereux, M. (1993). "Capital Allowances and the Impact of Corporation Tax on Investment in the UK". *Fiscal Studies*, Volume 14, No. 2, 1-14.

Bond, S., Devereux, M. and Gammie, M. (1996). "Tax Reform to Promote Investment". *Oxford Review of Economic Policy*, Volume 12, No. 2, 109-117.

Bosworth, B. P. (1985). "Taxes and the Investment Recovery". *Brookings Papers on Economic Activity*, Volume 1985, No. 1, 1-45.

Caballero, R. J. (1994). "Small sample bias and adjustment costs". *The Review of Economics and Statistics*, Volume 76, No. 1, 52-58.

Chirinko, R. S. (1993). “Business Fixed Investment Spending: Modelling Strategies, Empirical Results, and Policy Implications”. *Journal of Economic Literature*, Volume 31, No. 4, 1875-1911.

Chirinko, R. S., Fazzari, S. M. and Meyer, A. P. (1996). “What Do Micro Data Reveal About the User Cost Elasticity?: New Evidence on the Responsiveness of Business Capital Formation”. *Levy Economics Institute Working Paper*, No. 175.

Chirinko, R. S., Fazzari, S. M. and Meyer, A. P. (2004). “That Elusive Elasticity: A Long-Panel Approach to Estimating the Capital-Labor Substitution Elasticity”. *CESifo Working Paper*, No. 1240.

Clark, P. K. (1993). “Tax Incentives and Equipment Investment”. *Brookings Papers on Economic Activity*, Volume 1993, No. 1, 317-347.

Cummins, J. G., Hassett, K. A. and Hubbard, G. (1994). “A Reconsideration of Investment Behaviour Using Tax Reforms as Natural Experiments”. *Brookings Papers on Economic Activity*, Volume 1994, No. 2. 1-74.

Cummins, J. G., Hassett, K. A. and Hubbard, G. (1996). “Tax Reforms and Investment: A Cross-Country Comparison”. *Journal of Public Economics*, Volume 62, No. 2. 237-273.

Devereux, M. P. and Griffith, R. (2003). “Evaluating Tax Policy for Location Decisions”. *International Tax and Public Finance*, Volume 10, 107-126.

Edwards, J. (1984). “The 1984 Corporation Tax Reform”. *Fiscal Studies*, Volume 5, No. 2, 30-40.

Eisner, R. (1967). “A Permanent Income Theory for Investment: Some Empirical Explorations”. *American Economic Review*, Volume 57, June, 363-390.

Ellis, C. and Price, S. (2004). “UK Business Investment and the User Cost of Capital”. *The Manchester School*, supplement 2004, 72-93.

Fraumeni, B. M. (1997). “The measurement of depreciation in the U.S. national income and product accounts”. *Survey of Current Business*, July, 7-23.

Giorgio Marrano, M., Haskel, J. and Wallis, G. (2009). “What Happened to the Knowledge Economy? ICT, Intangible Investment and Britain’s Productivity Record Revisited”. *Review of Income and Wealth*, Volume 55, Issue 3, 686-716.

Goolsbee, A. (1998). “Investment Tax Incentives, Prices, and the Supply of Capital Goods”. *The Quarterly Journal of Economics*, Volume 113, No. 1, 121-148.

Gravelle, J. G. (1992). “Tax subsidies for Investment: Issues and Proposals”, *Congressional Research Service Report* 93-209.

Groth, C. (2005). “Estimating UK Capital Adjustment Costs”. *Bank of England Working Paper*, No. 258.

Hall, R. E. and Jorgenson, D. W. (1967). “Tax Policy and Investment Behaviour”. *American Economic Review*, Volume 50, No. 3, 391-414.

HM Treasury. (2007). *Business tax reform: capital allowance changes*.

House, C. and Shapiro, M. D. (2006). “Temporary Investment Tax Incentives: Theory and Evidence from Bonus Deprecation”. *NBER Working Paper*, No. 12514.

King, M. A. (1972). “Taxation and Investment Incentives in a Vintage Investment Model”. *Journal of Public Economics*, Volume 1, 121-147.

King, M. A. (1974). “Taxation and the Cost of Capital”. *The Review of Economic Studies*, Volume 41, No. 1, 21-35.

Lucas, R. E., Jr. (1969). “Labor-Capital Substitution in U.S. Manufacturing”. In Arnold C. Harberger (ed.), *The Taxation of Income from Capital*, Washington: Brookings Institution, 223-274.

Mayes, D. G. and Young, G. (1993). “Industrial investment and economic policy”. *National Institute Discussion Paper*, No. 56.

Office for Budget Responsibility. (2010a). *Pre-Budget forecast*.

Office for Budget Responsibility. (2010b). *Budget forecast*.

Schaller, H. (2006). “Estimating the long-run user cost elasticity”. *Journal of Monetary Economics*, Volume 53, No. 4, 725-736.

Shapiro, M. D. (1986). “The Dynamic Demand for Capital and Labor”. *The Quarterly Journal of Economics,* Volume 101, No. 3, 513-542.

Smith, J. (2008). “That elusive elasticity and the ubiquitous bias: is panel data a panacea?”. *Bank of England Working Paper,* No. 342.

Stiglitz, J. E. (1973). “Taxation, Corporate Financial Policy, and the Cost of Capital”. *Journal of Public Economics,* Volume 2, 1-34.

Wallis, G. (2009). “Capital Services Growth in the UK: 1950 to 2006”. *Oxford Bulletin of Economics & Statistics*, Volume 71, Issue 6, 799-819.