Time irreversible investment: Theory and macroeconomic evidence for the UK manufacturing sector.

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Time Irreversible Investment: Theory and Macroeconomic Evidence for the UK Manufacturing Sector

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Abstract

Using UK manufacturing data, this study attempts to identify the presence of irreversible investment considerations at the industry group level of aggregation, and investment disaggregated by investment good category, and its influence on investment patterns and relationships. A selection of asymmetry tests is utilised in an attempt to identify 'lumpy' patterns induced into the investment series when it is irreversible, before attempting to directly identify investment irreversibility with the use of Ramsey and Rothman's (1996) time reversibility test. A second theme of investigation concentrates on testing for a negative investment-uncertainty relationship, which it is suggested will hold in the presence of irreversible investment. The uncertainty relationship is examined indirectly initially, through the relationship of output growth to output growth uncertainty, as modelled through the application of an Asymmetric Power Autoregressive Conditionally Heteroskedastic in Mean (APARCH-M) model. The uncertainty relationship is then subject to further, more direct scrutiny, through examination of the relationship of investment to output growth uncertainty, effect on investment being modelled using the previously applied APARCH-M models. A final approach utilises a non-linear Self Exciting Threshold Autoregressive (SETAR) model to represent investment to account for 'lumpy' investment patterns. While evidence of asymmetry is relatively weak, a number of industry groups (Engineering, Fuels and Textiles) are found to display time irreversibility. It is found that these industry groups are more likely to display negative investment-uncertainty relationships, especially when modelled directly rather than through the output growth-uncertainty relationship. These investment-uncertainty relationships are also found to hold with the imposition of the SETAR model, which is found to successfully explain much of the neglected non-linearity present when investment is modelled with the use of linear autoregressive models. This study suggests, therefore, that industry groups display investment patterns that are heterogeneous in nature, and where irreversible investment characterises the investment patterns at the industry group level of aggregation for certain groups, but not all groups.

DECLARATION

This work has not previously been accepted in substance for any degree and is not being concurrently submitted in candidature for any degree.

Signed .... (candidate)

Date ......21.2.06......

STATEMENT 1

This work is the result of my own investigations, except where otherwise stated.

Other sources are acknowledged by footnotes giving explicit references. A bibliography is appended.

Signed .... (candidate)

Date ......21.2.06......

STATEMENT 2

I hereby give consent for my work, if accepted, to be available for photocopying and for inter-library loan, and for the title and summary to be made available to outside organisations.

Signed .... (candidate)

Date ......21.2.06......

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Chapter 1 - Introduction

Although important for current income, as a component of output, investment is perhaps more important as the driver of future output by maintaining and augmenting the capital stock. What drives investment therefore also drives future income growth. Although this has generated a large literature devoted to the links between investment and growth, and the causes of growth, this is not the topic of this study. Instead, this study concentrates upon the forces that encourage and discourage firms to make investments, and the patterns produced in these investment series by the economic conditions that firms face.

1.1 – The Desired Capital Stock and How to Get There

Whilst those factors that determine the desired capital stock of firms have produced one branch of literature this is only part of the story in modelling investment. Knowing what a firm's desired capital stock is, is very different from knowing how a firm will plan to move its current capital stock to this new level. If firms could change their capital stocks to a new desired stock immediately the capital stock would move from one level to another in jumps as new information became available, so investment would be characterised by periods of inactivity followed by points in time when firms experienced an infinite rate of investment (divestment).[1]

Obviously this is unrealistic, and in a world of limited resources the decision to invest is a trade off between current and future output. Investment theory can be thought of

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[1] See sub-sections 2.3.3 and 2.3.4 for discussion of infinite investment rates and capital adjustment costs.

in two parts, the determinants of the desired capital stock, and the forces that determine how the capital stock is adjusted towards this new desired level. In some respects these two decisions have been treated separately, but more recent work has begun to cast doubts on this approach. It is one thing to target a new higher desired capital stock only to receive more information at a later date suggesting a lower desired capital stock is actually more appropriate if the newly purchased capital can be resold for its original cost, but it is a very different matter for a firm that cannot resell the capital. This new assumption that investment may be irreversible has implications for not only how firms will adjust their capital stocks, but also what their desired capital stock will be.

Although the implications of irreversible investment have been examined and developed in great depth, the main findings are quite intuitive and can be described quite concisely.[2] Taking the implications for the desired capital stock first, irreversible investment leaves the firm with the danger that it will erroneously end up holding a larger capital stock than it actually wants.[3] This means that firms will tend to hold a lower level of capital to avoid this. The implications for the movement towards a new desired capital stock are even more striking. Rather than smoothly adjusting the capital stock towards the new desired capital stock, firms will only make investments when they are confident that the expected returns will cover the possible downsides. This means that investments are delayed until the returns reach a trigger level and then all investments that would have been made as the returns rose are made in one spike. This gives the investment pattern of a firm a lumpy nature.

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[2] For a review of the irreversible investment literature see Dixit and Pindyck (1994), and Chapter 3 of this study.

[3] This simple view of the world is not always found to hold when firms have either strategic considerations to take into account (see sub-section 3.3.3), or when considering the importance of investment timing and intensity (see sub-section 4.3.2).

The 'new wave' theories, as the investment theories assuming irreversible investment are known, have received much theoretical attention, but less empirical attention. One reason for this is that it is relatively easy to observe one firm making investments spikes, creating a lumpy investment pattern, but when viewing the aggregate it is harder to model the effect of many firms making investments spikes driven by individual and aggregate factors.[4] Whilst the individual firm has a very lumpy investment pattern the aggregate is typically smooth and investment spikes are not observed. Does this mean that irreversible investment is unimportant when modelling the aggregate?[5] It seems unlikely that the microeconomic foundations can be ignored, as policy changes are likely to have very different implications. The aim of this study is to determine whether irreversible investment and the lumpy investment patterns it engenders are visible at industry group aggregation levels. Whilst evidence from aggregate investment has generally found little evidence, this does not means that irreversible investment will not be evident at lower levels of aggregation.[6]

Irreversible investment is found to also have an important affect upon one particular relationship relating to the investment decision, the investment-uncertainty relationship. Without uncertainty the assumption of irreversible investment would have much less impact, as there would be no danger of a firm being left with surplus capacity. However, the greater the uncertainty relating to the world in which the firm operates, the greater the danger that a firm will make a misjudgement of future

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[4] Section 3.4 reviews the empirical studies at the firm and plant level of lumpy investment, whilst Section 3.2 discusses the implications of aggregating the investment patterns of individual firms making lumpy investments in the presence of structural and stochastic heterogeneity.

[5] See Chapter 3 for discussion of the relative successes of traditional and 'new wave' theories in modelling the aggregate investment pattern.

[6] One method of detecting the presence of irreversible investment has been to examine the investment series for evidence of asymmetry, an approach which has met with limited success in not only studying the investment decision but other aspects of the business cycle (see sub-section 3.4.2 for a discussion of the business cycle studies that have attempted to detect asymmetry in the business cycle).

conditions.[7] This implies that there is a negative relationship between investment and uncertainty when investment is irreversible. This is the opposite of the relationship that is traditionally thought to hold.[8]

1.2 – Aims of this Study

This study concentrates upon fixed capital investment within the UK manufacturing sector at the industry group level of aggregation. I do not attempt to build a model for the investment series examined, but rather draw inferences about the nature of these investment patterns and relationships created by the presence of any irreversible investment considerations. The aims of this study are therefore, firstly, to determine whether there is any evidence of irreversible investment decisions within the industry group investment patterns and, secondly, to identify the nature of the relationship that exists between investment and uncertainty. Achievement of the first of these aims is attempted by examining the patterns created within the aggregate investment and industry group level investment series for the UK. If firms are unable to decrease the capital stock as easily as they can increase it, there is likely to be asymmetry present within the investment series as firms make capital purchases in large spikes. Whilst lumpiness in investment is likely to be fairly evident at the firm or plant level, at the aggregate level structural and stochastic heterogeneity will make it harder to identify.[9]

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[7] Section 4.3 covers the literature relating to the investment-uncertainty relationship when investment is irreversible.

[8] The traditional positive investment-uncertainty relationship is discussed in Section 4.2. An extensive empirical literature on the investment-uncertainty relationship has also been produced, which is reviewed in Section 4.4.

[9] Studies discussing the investment patterns likely to be observed with irreversible investment, at the firm or plant level, and the effect of aggregating these investments when firms are heterogeneous is reviewed in Section 3.2.

One effect is that investment patterns are likely to become asymmetric over the business cycle, as well as having important effects upon business cycle timing itself.[10] The investment-uncertainty relationship is examined first indirectly and then directly. The indirect relationship draws on the fact that output growth is driven by the investment decisions made by firms, and therefore by examining the output growth-uncertainty relationship, it is possible to draw inferences about the nature of the investment-uncertainty relationship that is driving it. The second method utilised in an attempt to identify the relationship is to estimate the actual investment-uncertainty relationship directly. The presence or otherwise of irreversible investment considerations should alter this relationship greatly.

The twin aims of this study will determine whether the effects of irreversible investment can be felt and observed at the industry group level of aggregation, and whether certain industry groups are more strongly affected than others. The results of the empirical chapters should give a clear indication as to what, if any, considerations should be taken into account regarding irreversible investment when modelling investment for industry groups, not only in the specification of models used to estimate investment, but also the manner in which uncertainty should be allowed to enter such models.

1.3 – Outline of Study

The influence of investment upon growth and the business cycle has led to a literature that attempts to offer theories and models to understand the patterns and trends seen within aggregate investment. The review of investment literature offered here will

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[10] The effects of irreversibilities for investment patterns over the business cycle are reviewed in sub-section 3.3.4.

cover the main developments in modelling investment patterns, starting with Keynes' explanation of the marginal efficiency of capital and the animal spirits of business optimism in determining whether to invest, and then covering mathematical orientated theories such as the accelerator and neo-classical theories of investment, and Tobin's marginal *Q*. These theories will be explained and discussed in Chapter 2. At the beginning of this chapter I described the literature on investment theory as looking at two different aspects of the investment decision, the determinants of the desired capital stock and the path taken by the capital stock to reach this desired level. In some respects the traditional literature mainly concentrates upon the former with the latter to an extent disregarded, other than through assumptions made regarding costs of capital adjustment to prevent the possibility of an infinite rate of investment. Although the later 'new wave' theories examine the irreversible investment consideration which is the topic of this study, it is often these models that the irreversible investment decision is incorporated into, and therefore these earlier theories are still of considerable relevance.

Chapter 3 will introduce the more recent 'new wave' theories of investment, which have been developed from the late 1970s/early 1980s onwards, and which concentrate more heavily upon the way in which the capital stock is adjusted to the desired capital stock. Section 3.1 will explain why disillusionment began to develop with the investment models that had been created from the neo-classical base. Chapter 3 also looks at the literature that has introduced models explaining how firms adjust their capital stock when faced by non-convex adjustment costs and how this relates to the aggregate investment level. Sections 3.2 and 3.3 examine two particular families of models produced to explain plant level data, namely (S,s) models and theories of irreversible investment. The empirical work relating to the 'new wave theories is presented in Section 3.4.

The emphasis placed on expectations by Keynes was maintained in one way or another in the later models that followed. In a majority of these models there have been extensions that have looked at the impact of uncertainty upon expectations. A number of these models have shown that uncertainty can lead to delay in making investment decisions. Chapter 4 looks at the impact of uncertainty, starting once again with the traditional models and moving through their evolution to the more modern models such as those presented in Chapter 3, focusing on the considerable change in the investment-uncertainty relationship caused by the assumption of irreversible investment. Section 4.4 describes the empirical evidence for the various theoretical investment-uncertainty relationships discussed in the earlier sections of the chapter.

Chapter 5 uses a number of traditional asymmetry tests, which look for either skewness within the series or differences in the distributions of expansions relative to contractions to identify asymmetry. These tests include the Sichel (1993) skewness test and Randles et al. (1980) triples test which look at the skewness of the series in question relative to the series trend.[11] The aggregate and industry investment data used in the empirical work within this study are also presented in Chapter 5.

Chapter 6 introduces the time reversibility test (*TR* test), which determines whether a series has the same probability distribution whether run backwards or forwards in time. If the null of time reversibility is rejected this suggests that capital stocks are not adjusted upwards in the same manner as downwards. One reason as discussed above and expanded upon in Chapter 3 is the presence of fixed capital adjustment costs associated with raising the capital stock due to investment being

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[11] Section 5.6 presents the alternative detrending techniques available for isolating the stationary cyclical component of the investment series.

irreversible or partially irreversible. The *TR* test therefore forms a direct test of where the investment series are irreversible. The *TR* test does also come with an additional advantage, in that the test is able to determine the source of the time irreversibility, in the sense of whether the series has a linear data generating process with non-Gaussian innovations or, as would be most appropriate for irreversible investment, a non-linear data generating process.

As discussed in Section 1.2 another relationship strongly affected by the assumption that investment is irreversible is the investment-uncertainty relationship, with the traditionally positive relationship becoming negative as the 'option value of waiting' causes delays in investment as uncertainty rises. Chapters 7 and 8 model the investment-uncertainty relationship using Generalised Autoregressive Conditional Heteroskedastic in mean models (GARCH-M) to produce an output growth uncertainty measure. In Chapter 7 the relationship between this uncertainty measure and output growth is examined, a topic that has been examined before with mixed results, which may be due to certain industries being more strongly affected by differing considerations relating to each of the proposed investment-uncertainty relationships. The aim of Chapter 7 is therefore is to identify which industries are more affected by irreversible investment, or less so, by examining the data at the industry group level.

The studies in Chapter 7 do, however, have the disadvantage of being influenced by short-run output decisions as well as longer term capacity decisions. With this in mind Chapter 8 models the direct relationship between investment and uncertainty. Using the same output growth uncertainty series estimates as in Chapter 7 in the context of simple AR and accelerator investment equations, the relationship is once again modelled at the industry group level, but without the noise generated by short-run output decisions.

Chapter 9 attempts to draw together the two threads of this study, the identification of asymmetry and non-linearity suggestive of irreversible investment constraints being present, and the investment-uncertainty relationship. A non-linear Self Exciting Threshold Autoregressive (SETAR) process is applied in modelling the investment series, with the intention that this should remove any neglected asymmetry if the presence of irreversible investment has been allowed for. Once estimated using the SETAR specification, the investment-uncertainty relationship is re-examined, so allowing for the possibility that the investment-uncertainty relationship may change between different investment 'regimes'.

The overall aim of this study is therefore to determine whether investment at the industry group level is more or less strongly affected by irreversible investment considerations, and what implications this has for policy, particularly relating to the volatility of the economy. The use of data at the industry group level will allow it to be determined whether all industry groups show evidence of irreversible investment considerations, and, if not, whether those that do are affected in a similar manner.

Chapter 2 – Traditional Theories of Investment

Before looking at the literature relating to irreversible investment it is first necessary to present the traditional theories of investment from which the 'new wave' theories are constructed. The remainder of this chapter is structured as follows; sections 2.1 to 2.4 cover the Keynesian, Accelerator, Neo-classical, and Tobin's Q, theories of investment respectively, with the final section, 2.5 summarising the chapter.

Most of the theories looked at in this chapter were developed from observations of the aggregate level of investment in the economy, and using the representative firm approach for producing models to explain these patterns. In general these theories follow a clear progression and it therefore seems sensible to examine each of the theories in chronological order. The basis of almost all theories of capital accumulation is that there is an optimum profit maximising level of output for all firms, and that in attempting to produce at this level firms select the correct combination of factors of production to minimise the cost of production. This means that there is a desired or optimum capital stock for each firm, and by assuming a representative firm approach, the optimum capital stock for the economy as a whole can be readily derived. The theories differ in the assumptions that are made about the level that is optimum, and how firms adjust their capital towards these levels.

2.1 Keynes' Theory of Investment

Keynes' theory of investment can be found in 'The General Theory of Employment, Interest and Money' (1936). In chapter 11, Keynes explains and clarifies the concept of the MEC (marginal efficiency of capital), which is the discount rate required to equate the NPV (net present value) of a project to the sale price of capital:

(2.1) $$\sum_{j=0}^{N} R_{t+j}(1+\rho)^{-j} = P_t^K$$

where R_{t+j} is the flow of revenue in period $(j + t)$, ρ is the marginal efficiency of capital, and P_t^K is the sale price of capital in period t. This means that firms will choose to invest if the MEC is greater than the interest rate, $(\rho > i)$, as they will be able to get greater returns from investing in the capital rather than in the market.[12]

The demand curve for capital goods is assumed to be downward sloping, as firms will be less willing to purchase more capital at higher prices. In many earlier investment theories it was assumed that the supply curve of capital goods was perfectly elastic, and the price of goods would not increase with the capital stock. Keynes however suggested that the marginal efficiency of capital would fall as the capital stock increased as:

> "If there is an increased investment in any given type of capital during any period of time, the marginal efficiency of that type of capital will diminish as the investment in it is increased, partly because the prospective yield will fall as the supply of that of capital is increased, and partly because, as a rule, pressure on the facilities for producing that type of capital will cause its supply price to increase;"
>
> Keynes (1936) page 136

In equilibrium there will be no net investment as the capital stock will be maintained at the point where the MEC is equal to the interest rate, only replacement investment takes place.[13] If there is a decrease in the interest rate this will lead to positive net investment as the MEC will now be higher than the interest rate. This increase in demand for capital goods will cause the price of the goods to rise. The diagram below shows the impact of a fall in interest rates in these circumstances.

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[12] Domar (1946) feels that Keynes neglects the impact of capital accumulation on productivity. He studies the impact of various rates of investment growth relative to population and income growth. This may have important implications for determining the equilibrium level of capital, as further additions to capital may increase labour productivity, so raising returns above the interest rate.

[13] *Net* investment (I_N) refers to the change in the capital stock, $(I_{Nt} = K_t - K_{t-1})$. This should not be mistaken for purchases of capital, which is referred to as *gross* investment (I_G). The difference between the two values coming from the depreciation of the existing capital stock, (δK_{t-1}), with *net* investment being defined as *gross* investment less the depreciation of the capital already held, $(I_{Nt} = I_{Gt} - \delta K_{t-1})$. Investment to replace the deprecating capital rather than expand the capital stock is described as replacement investment. When the depreciation rate (δ) is assumed to be zero (capital has an infinite life), the *net* and *gross* investment have the same value as one another.

Figure 2.1 – Marginal Efficiency of Capital and Investment

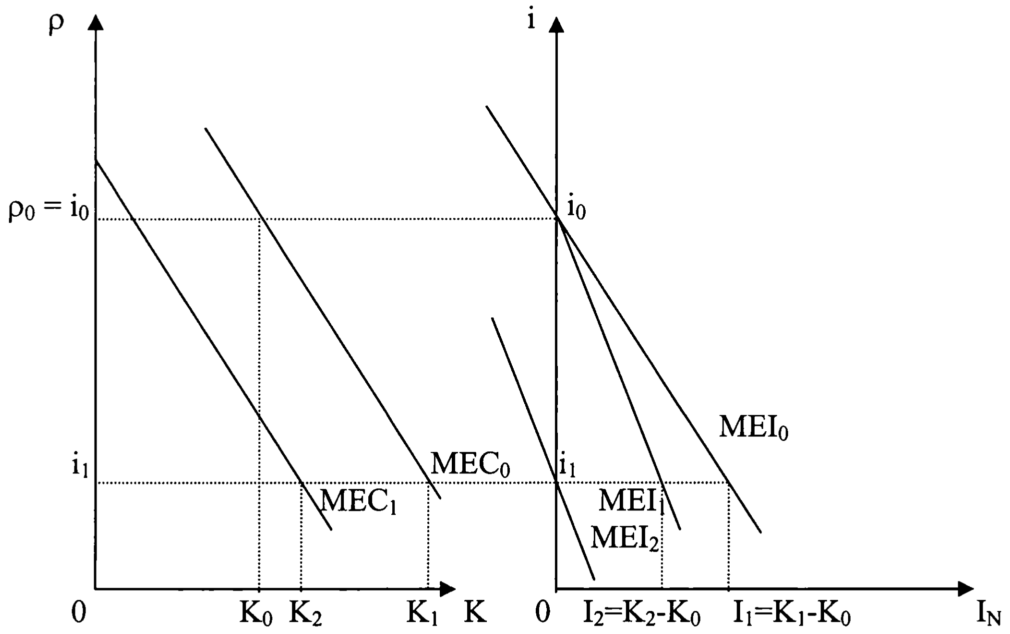

Figure 2.1 shows the MEC curve in the left hand panel, and the MEI (marginal efficiency of investment) in the right hand panel. This is the flow of new investment, as determined by the interest rate. The lowering of interest rates raises the desired stock of capital. However, as investment increases the price of capital rises, which changes the slope of the MEI, so the curve becomes MEI_1 rather than MEI_0, this reflects the fact that the supply price of capital has risen and therefore a larger change in the interest rate is required to produce as large a change in the investment rate, as compared to before the price rise. This sets investment for the period at $I_2=K_2-K_0$ rather than $I_1=K_1-K_0$, whilst I_1 is the investment rate that would have been observed if prices had not increased. The increase in price moves the marginal efficiency of capital curve to MEC_1, so that the optimal capital stock becomes K_2. As this capital

level is approached the MEI moves in to MEI_2. The model has returned to equilibrium at this point so that $\rho = i$.[14]

In Chapter 12 of 'The General Theory of Employment, Interest and Money' Keynes looks more closely at the role that producers' expectations play in the decision about investing. Investors are assumed to be forward looking in that the net present value of a project is based upon the investor's expectations of the demand for the product and the interest rate over this period. Keynes uses the stock market as an example of how returns are difficult to determine, in that there is a large amount of speculation in the markets clouding the picture of what true returns can be expected. Although some of the expectations of returns are based upon sound fundamentals Keynes writes:

> "Even apart from the instability due to speculation, there is the instability due to the characteristic of human nature that a large proportion of our positive activities depend on spontaneous optimism rather than on a mathematical expectation, whether moral or hedonistic or economic. Most probably, of our decisions to do something positive, the full consequences of which will be drawn out over many days to come, can only be taken as a result of animal spirits—of a spontaneous urge to action rather than inaction, and not as the outcome of a weighted average of quantitative benefits multiplied by quantitative probabilities."
>
> Keynes (1936) page 161

The combination of speculation and animal spirits, Keynes concludes, means that it is not possible to control the level of investment within the economy through monetary control of the interest rate alone, and that the government should take a stronger lead in determining the level of investment within the economy directly. Although Keynes does consider, in other chapters of the 'General Theory', that expectations are likely to be affected greatly by the present economic conditions faced by manufacturers,

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[14] Asimakopulos (1971) notes that although the assumption of a rising supply price of capital will result in a downward sloping capital demand schedule, when making investment decisions firms are unlikely to consider the impact of other firms making investment decision at the same time and forcing the price of capital up, as this is likely to be an ex post consideration, whilst the equating of the marginal efficiency of capital to the cost of capital will be made ex ante.

there is no explicit consideration of current profit levels in Keynes's investment decision model.[15]

2.2 Accelerator Theories of Investment

Whilst Keynes (1937) introduces and describes a number of concepts familiar in later investment theory, it is formalised and incorporated into other investment structures by others. An early structure being the accelerator structure presented in this section.

2.2.1 – Simple Accelerator Theories

Accelerator theories of investment became popular after World War 2 and were developed from earlier work on the multiplier and accelerator effects by such writers as Clark (1936) who is credited with drawing attention to the possibilities of the acceleration principle, whilst Harrod (1948) later developed accelerator theory into a model of the business cycle. Although accelerator theories concentrate on the demand side of the investment market, and ignore the supply side to a large degree, they do attempt to endogenise investor's expectations, so that a rate of net investment can be calculated for different conditions. Simple accelerator theories are based upon the assumption that output is proportional to the capital stock. This means that *net* investment (I_{Nt}) is equal to a percentage of the change in the demand for output (Y_t) from this period compared to last:

$$I_{Nt} = K_t - K_{t-1} = v(Y_t - Y_{t-1}) \tag{2.2}$$

---

[15] Asimakopulos (1971) suggests that there is a two way interaction between profit levels and investment. Current profits will produce expectations of higher future returns, increasing the level of investment. Asimakopulos therefore suggests that the level of investment is a factor in determining the level of future returns, and higher investment will result in higher returns.

where v is the constant acceleration coefficient, which tells us what fraction of the change in output is translated into a change in the capital stock.[16]

2.2.2 - Flexible Accelerator Theory

A more complicated version of the accelerator, known as flexible accelerator theory, suggests that changes in the capital stock are not directly related to the change in the output level. Klein (1951) and Kalecki (1943) both produced theories of investment that can be described as flexible accelerator theories, and these theories can both be summarised as follows. Firms have a target level of future output, and add to their capacity base to achieve this. The scale of the addition to capital in order to increase capacity is determined by expectations based upon past experiences of output. Therefore, investment is related to the existing capital stock of a firm, and past output levels. Such flexible accelerator theories can be rationalised through one of two assumptions: either that there are delays in the delivery of capital goods, or that the expectations of producers change only slowly. Delivery lags can then be modelled as the gap between the actual and the desired (or optimal) level of capital not being closed completely in each period:

$$I_{Nt} = K_t - K_{t-1} = \lambda\left(K_t^d - K_{t-1}\right) \tag{2.3}$$

where K_t^d is the level of capital needed to produce the current demand for output. If the desired level of capital stock is assumed to be proportional to output so that $K_t^d = vY_t$ then the above equation can be rewritten as:

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[16] Bennion (1945) includes an accelerator in a model of national income in an attempt to model the economic cycle, but has difficulty in determining a single value to match the cycles seen in the economy. Eckaus (1953), in his assessment of the accelerator theory of investment, notes that although not investigated in most earlier work the existence of a single constant accelerator coefficient is improbable, as the coefficient is likely to change across industries and economic conditions. Tsiang (1951) suggests that, similarly with the velocity of circulation in the quantity theory of money, the accelerator coefficient is likely to be an endogenous part of the model rather than being exogenously determined. This means it cannot be easily calculated and given a single value.

$$(2.4)\qquad I_{Nt} = K_t - K_{t-1} = \lambda\left(vY_t - K_{t-1}\right) = \lambda vY_t - \lambda K_{t-1}$$

or:

$$(2.5)\qquad K_t = \lambda vY_t + (1-\lambda)K_{t-1}$$

or from repeated substitution:

$$(2.6)\qquad K_t = \lambda vY_t + (1-\lambda)v\lambda Y_{t-1} + (1-\lambda)^2 v\lambda Y_{t-2} + \cdots$$

so that investment becomes:

$$(2.7)\qquad I_{Nt} = \Delta K_t = \lambda v\Delta Y_t + (1-\lambda)v\lambda\Delta Y_{t-1} + (1-\lambda)^2 v\lambda\Delta Y_{t-2} + \cdots$$

or more compactly, where there are assumed to have been N previous periods of investment/production before period t:

$$(2.8)\qquad \Delta K_t = \lambda v\sum_{j=0}^{N}(1-\lambda)^j\Delta Y_{t-j}$$

This means that investment is a weighted average of past changes in output. To avoid serial correlation this can be rewritten with the aid of the Koyck transformation as:

$$(2.9)\qquad I_{Nt} = \Delta K_t = \lambda v\Delta Y_t + (1-\lambda)\Delta K_{t-1}$$

This makes investment a combination of this period's output and the level of investment in the last period.

The second explanation of flexible accelerator theories is that of slowly adjusting expectations of output. This is similar to the delivery lag explanation, but where the gap that is only partially closed is between the expectations of output and actual output. If the capital stock in period t is assumed to be equal to the desired capital stock $\left(K_t^d\right)$, which is proportional to the expected output level:

$$(2.10)\qquad K_t = K_t^d = vE\left(Y_t\right)$$

where $E(\bullet)$ represents the expectations of the value of the function or variable in parenthesis, then:

(2.11) $$\Delta K_t = \Delta K_t^d = v\Delta E(Y_t) = v(E(Y_t) - E(Y_{t-1}))$$

If the expectations of investors regarding output change adaptively, then expectations will change by some fraction of last period's difference between the expectation of output and the actual level:

(2.12) $$E(Y_t) - E(Y_{t-1}) = \lambda(Y_{t-1} - E(Y_{t-1}))$$

rearranged to:

(2.13) $$E(Y_t) = \lambda Y_{t-1} + \lambda(1-\lambda)Y_{t-2} + \lambda(1-\lambda)^2 Y_{t-3} + \cdots$$

Assuming N previous periods of investment have taken place this gives investment as:

(2.14) $$\Delta K_t = v\Delta E(Y_t) = \lambda v \sum_{j=0}^{N} (1-\lambda)^j \Delta Y_{t-1-j}$$

or:

(2.15) $$I_{Nt} = v\lambda Y_{t-1} + (1-\lambda)\Delta K_{t-1}$$

Equations (2.9) and (2.15) are very similar apart from the lag in output in (2.15), as the current output level is unknown and expectations are slow to adapt.[17]

2.2.3 - Criticisms of Accelerator Theory

The simplicity of Accelerator Theory makes it attractive. There are however a number of criticisms of the accelerator theory of investment, which are mainly covered by Knox (1952). One of the main assumptions required for the accelerator principle to apply is that the economy must be working at full capacity, otherwise producers will use spare capacity to increase output rather than invest in new capital. The economy will rarely if ever be operating at what strictly classifies as full capacity (where the

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[17] In some of both Klein's (1951) and Kalecki's (1943) investment equations profits replace the previous periods' output. Klein also included the relative value of output in terms of the price of capital goods, which is similar to the neo-classical theory of investment (see section 2.3).

supply curve become vertical). If full capacity is classified as any point beyond the minimum average cost level of output, the accelerator theory may be applicable.[18]

A second difficulty that needs to be addressed is that of observing net investment without confusing it with replacement investment. Knox (1952) suggests that the most important measure of investment may actually be gross investment because as demand slows net investment will decrease but replacement investment will rise. Hicks (1950) suggests that due to different lengths of usage for capital, replacement cycles will be damped. Knox shows that under certain assumptions this need not be true, since capital is replaced when the expected profits that arise from new capital (π_{1t}), less profits from old capital (π_{2t}), are greater than the cost of replacement $\left(P_{1t}^{K}\right)$ minus the scrap value of the old capital (S_{2t}):

(2.16) $$\pi_{1t} - \pi_{2t} > P_{1t}^{K} - S_{2t}$$

Knox rewrites equation (2.16) in terms of operating costs, as below:

(2.17) $$\sum_{j=0}^{N} \frac{Y_{t+j}}{(1+i)^{j}}\left(c_2 - c_1\right) > P_{1t}^{K} - S_{2t}$$

where Y is the anticipated stream of output over future periods to period $t+N$, (assuming that the capital has an expected lifetime of N periods), discounted as appropriate for an interest rate of I, whilst c_1 and c_2 are the average costs of production with new and old machines respectively. When output is high replacement becomes more likely as Y takes a higher value, which suggests that replacement might be delayed until there is an upturn in demand. As time passes, including depressions, ($c_2 - c_1$) will also rise in value as technological advance will lower c_1 whilst

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[18] An alternative to using this definition of full capacity is to use Chenery's (1952) capacity principle, whereby investment, rather than being related to output, is related to the level of utilisation of existing capital.

depreciation of old capital will raise c_2, which means there is likely to be more pressure for gross investment to follow the pattern of output.

A third criticism of accelerator theory, is that expectations of future output are likely to play an important role in investors' decisions as to when to make net and replacement investment. These expectations are likely to be based upon knowledge of demand for their goods rather than consumption as a whole, which means that simple accelerator theory is unlikely to be able to explain patterns of investment for aggregate consumption as a whole.

A final point made by Knox (1952) is that current profit levels may also play a part as higher current profits lift any liquidity constraints faced by firms looking to invest. Knox concludes that due to a number of failings in accelerator theory, net investment cannot be modelled from output movements alone.

2.3 Neo-Classical Theories of Investment

The neo-classical theory of investment was developed by Jorgenson (1963) in an attempt to link together investment theory and the theory of neo-classical capital accumulation. Jorgenson felt that whilst the theories of capital accumulation (in order to maximise utility over time) were well founded, ad hoc theories characterised the area of investment, such as capacity or profit principles (i.e. accelerator theory). These theories, he felt, did not adequately include relative factor prices; although some attempts had been made to introduce interest and factor prices into accelerator theories these were, in Jorgenson's opinion, inadequate.

> "It is difficult to reconcile the steady advance in the acceptance of the neoclassical theory of capital with the steady march of the econometric literature in a direction which appears to be diametrically opposite. It is true that there have been attempts to validate the theory. Both profits and capacity theorists have tried a rate of interest here or a price of investment goods there. By and large these efforts have been unsuccessful; the naïve positivist can only conclude, so much the worse for the theory. I believe that a case can be made that previous attempts to "test" the neoclassical theory of capital have fallen so far short of a correct formulation of this theory that the issue of the validity of the neoclassical theory remains undecided."
>
> Jorgenson (1963) pages 247-248

2.3.1 – Outline of the Neo-Classical Model of Investment

Neo-classical theories of investment are commonly based upon the premise that firms acquire capital up to the point where the marginal product of capital is equal to the user cost of capital. The user cost of capital is the total cost faced by a firm that uses the capital. Pentecost (2000) breaks this down into the opportunity cost, the depreciation cost, and the capital cost. The opportunity cost is the cost to a firm of having some of its liquid assets tied up in capital, and this is therefore the interest that could have been earned by investing the value of the asset at the market rate of interest. The depreciation cost takes into account the fact that as an asset is used it loses value as it wears out, and becomes less efficient. The capital cost is the cost a firm faces if the price of the asset it has bought falls (while if the price of similar assets rises through time then this will lower the user cost of capital). The equations below develop a baseline model for investment, in which the user cost of capital, as described above, is given by the following equation:

$$(2.18) \qquad r_t^K = r_t P_t^K + \delta P_t^K - \Delta P_t^K = \left[r_t + \delta - \Delta P_t^K . \left(P_t^K \right)^{-1} \right] P_t^K$$

where r_t^K is the user cost of capital in period t, r_t is the real rate of interest in period t, P_t^K is the price per unit of capital, δ is the annual rate of depreciation of capital (it is assumed that the depreciation rate of capital remains constant over the lifetime of capital), and ΔP_t^K is the change in the price of capital in period t ($\Delta P_t^K = P_t^K - P_{t-1}^K$).

Tax impacts can also be introduced to the model by observing their impact on the user cost of capital. Romer (1996) uses the example of an investment tax credit being introduced with a credit worth a fraction (*f*) of its investment expenditures. The effective price of a unit of capital is reduced to (1-$f\tau$) P_t^K from P_t^K, where τ is the corporate income tax rate. Equation (2.18) for the user rate of capital can be rewritten as:

$$r_t^K = \left[r_t + \delta - \Delta P_t^K \left(P_t^K\right)^{-1}\right]\left(1 - f\tau\right)P_t^K \tag{2.19}$$

In order to examine the real user cost of capital r_t^K must be observed relative to the price level of output (P_t), so the real user cost of capital is given by r_t^K / P_t. To maximise returns the real user cost of capital is equated with the marginal revenue of capital (MR_K) to give:

$$MR_K = \frac{r_t^K}{P_t} \tag{2.20}$$

It is assumed that production occurs via a Cobb-Douglas production function $\left(Y_t = AK_t^{\alpha} L_t^{1-\alpha}\right)$, giving the following:

$$MR_K = \alpha \frac{Y_t}{K} = \frac{r_t^K}{P_t} \tag{2.21}$$

this gives a desired capital stock $\left(K_t^d\right)$ of:

$$K_t^d = \frac{P_t Y_t}{r_t^K} \tag{2.22}$$

This means that as the user cost of capital increases, the desired stock of capital falls, unless met with an equivalent increase in the price of output. As the market rate of interest determines the opportunity cost portion of the user cost of capital, equation (2.22) above suggests that there is a negative relationship between the interest rate and desired capital stock. As the rate of interest rises the opportunity cost of holding capital rises, raising the user cost of capital, so that the quantity of capital desired falls. The equilibrium capital stock therefore adjusts according to the following equation:

$$(2.23) \qquad \Delta K_t^d = \alpha \Delta\left(\frac{P_t Y_t}{r_t^K}\right)$$

Jorgenson (1963) based his model upon the framework described in the previous sub-section, but with a number of important changes. The model concerned an economy with two factors of production, capital and labour. The model also included a number of lags for the time it takes for the stock of capital to adjust to the required level of capital after a change in some external factor such as the interest rate. Such time lags are required to prevent the rate of investment being infinite, as a discrete change in an external variable will lead to a discrete change in the capital stock held. Jorgenson attributes these time lags to capital having a 'time-to-build' property. This means that the net investment in any time period is a weighted average of past starts of projects in the proceeding periods. The main investment equation produced was:

$$(2.24) \qquad I_t = w(L)\left[K_t^* - K_{t-1}^*\right] + \delta K_t$$

where $w(L)$ is a power series in the lag operator. New projects are initiated until the backlog of uncompleted projects is equal to the difference between the optimum capital stock (K_t^*) and the actual capital stock (K_t).[19] Projects initiated, but not completed could be represented by planned investment spending.[20]

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[19] There have been a number of criticisms of Jorgenson's use of the optimal capital level (K^*), as in the static approach to investment exhibited by Jorgenson's model this is only appropriate under diminishing returns, rather than constant returns, which would produce no optimal capital level in the long run. Jorgenson (1972) defends the use of the optimal capital level by suggesting that it should be thought of as a moving target rather than a long run equilibrium target for capital.

[20] Jorgenson (1963) tested the investment equations produced against data provided by the OBE-SEC survey of US manufacturing. The OBE-SEC survey also provides data on anticipated investment. Jorgenson uses these figures for anticipated data to represent investment projects in intermediate stages of completion. The fitted equations produced models with high levels of explanatory power (high R^2 values of around 0.9) for investment levels between 1949 and 1959 in the survey.

2.3.2 – Criticisms of Jorgenson's Model

As Pentecost (2000) points out, Jorgenson's model does not achieve much of what was theoretically intended, as the relative prices and output enter via a composite term, and an optimally adjusted firm would not face any delivery lags. Looking initially at the first of these criticisms of Jorgenson's neo-classical model of investment, the issue of relative prices of capital and output being contained in a composite term, Jorgenson wished to show that rather than just being based upon changes in output, the relative prices of these goods would also determine the level of investment. By only including these relative prices in a composite term with output, it is impossible to determine the importance of these relative prices. Addressing the second criticism, Jorgenson's model assumes that future conditions are known with perfect certainty. Christ et al. (1963) describe the contradiction of Jorgenson's assumption that firms maximise profits in a two stage process, whereby output is chosen to maximise profits from a given capital stock and then the capital stock is adjusted to maximise profits for the output decision. Christ et al. ask why an efficient management team does not observe that these two objectives will converge in the future and by looking a few periods ahead choose both the optimal output and capital stock simultaneously? Gould (1969) also notes that firms base their valuation of the optimal capital stock on the assumption of immediate delivery, whilst investment is actually lagged. This means, therefore, that the neoclassical investment theory may produce results which are not optimal.

Jorgenson assumes that the time lags of capital deliveries will remain constant over the business cycle. This implicitly assumes that the capital producing industries have enough free capacity to accommodate higher demands of capital stock in some periods to others. Christ et al. (1963) disagrees with this and suggests that capacity will be stretched in booms as investment increases, and capital producing industries will also attempt to smooth production through depressions. Another assumption made by Jorgenson is that the desired capital stock will always be greater than the actual capital stock at any point in time. Mansfield describes this as an 'unlikely assumption', and notes that if the desired capital stock at any point in time is less than the actual capital stock, partially completed projects will be cancelled which will change the distribution of lagged deliveries in the future.

2.3.3 – Interest Rate Changes and the Neo-Classical Theory of Investment

The previous sub-section outlined a number of theoretical criticisms of the neo-classical investment theory. This section concentrates upon a particular problem that arises when the user cost of capital changes, due for example to a change in the interest rate, and the consequent problem of a potentially infinite rate of investment. Jorgenson (1963) notes that differentiating the investment function with respect to the interest rate gives:

$$\frac{\partial I}{\partial r} = z_\tau \frac{\partial K^d}{dr} \tag{2.25}$$

where K^d is the desired capital stock, r is the real interest rate, and z_τ represents the time pattern of the investment response to a change in the desired capital stock, due to a change in interest rates τ periods ago. z_τ evolves through time according to the delivery lag function assumed. As time approaches infinity the time response approaches the depreciation rate (δ), as the desired capital level is approached by the actual level of capital. Once the desired capital stock is reached the only change in the investment rate due to the interest rate change will be the change in the replacement investment level. This means that the long term response of the rate of investment to a change in the interest rate is:

$$\frac{\partial I}{\partial r} = \delta \frac{\partial K^*}{\partial r} \tag{2.26}$$

Thus, the long term change in the rate of investment is the depreciation rate times the change in the desired capital stock induced by the change in the interest rate. In an optimally adjusted economy a discrete change in the interest rate would lead to a discrete change in the cost of capital. This is because part of the cost of capital, the opportunity cost of capital is determined by the interest rate. This will lead to a discrete change in the desired capital stock, so an optimally adjusted firm would experience an infinite rate of investment. As was noted in sub-section 2.3.2 Jorgenson assumes that there are delivery delays between a stimulus taking place, such as a change in the interest rate, and capital stock being adjusted, however Christ et al. (1963) and Gould (1969) note that in an optimally adjusted economy there would be no delays. This leaves open the possibility of an infinite rate of investment, this is not possible in an economy that must choose between consumption and investment with limited resources. This means that in order to avoid an infinite rate of investment an alternative explanation for smoothed investment over time must be found. One explanation of this smoothed pattern of investment is examined in the following sub-section.

2.3.4 – Adjustment Costs of Capital

To solve the problem of the impossible infinite rate of investment the presence of adjustment costs of capital were introduced into the model.[21] Eisner and Strotz (1963)

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[21] The introduction of capital adjustment costs to prevent the possibility of infinite investment rates is one of the first steps towards the 'new wave' theories of investment, as it is shown in Chapter 3 it is the

initially introduced the concept of adjustment costs into the neo-classical model, and other work was then undertaken into the particular forms that these costs might take. These are the costs faced by a firm that is attempting to change its capital stock. Adjustment costs fall into two main categories, those of internal and external adjustment costs. Internal costs were those studied initially by Eisner and Strotz, and are those a firm faces due to problems created within the firm itself. These can include the costs of installing additional capital, training staff, or shutdowns of existing machinery to allow new capital to be installed. External costs are those that impact upon other firms who are considering investment. For example when a firm increases its capital, and given that the stock of capital products is not infinite, the price will increase as demand increases, and so the user cost of capital for all other firms rises (Foley and Sidrauski, 1970).

Adjustment costs are traditionally assumed to be a convex function of investment. This makes sense for both internal and external adjustment costs. Internal adjustment costs are likely to increase the greater is the amount of capital that is installed; for example if one machine is installed it may require the power to other machines to be turned off for a short period of time, but if a hundred new machines are installed the work is more likely to require the entire shutdown of the plant. External costs are also likely to be convex, since as more capital is demanded a greater strain is put on the producers of capital so that production costs rise. Eisner and Strotz (1963) therefore assume that the actual costs of adjustment are in two parts. The first cost of adjustment is proportional to the cost of capital, whilst the second part is assumed to be increasing in the rate of investment, and therefore represents the premium that must be paid if capital is acquired at a faster rate.

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shape of these adjustment costs which is of considerable importance to the patterns observed in aggregate investment.

Lucas (1967) includes adjustment costs in the production decision of the firm, and justifies this through the example of a firm with planning and production departments. In order for investment to be undertaken resources have to directed from the production department to the planning department. This redirection of resources is the form that adjustment costs take in Lucas's model. Whereas Eisner and Strotz, and Lucas, assume that the costs of adjustment are dependent on net investment, Gould (1968) suggests that although internal costs may not be incurred when replacement investment is undertaken, all purchases, no matter for what use, will be influenced by external adjustment costs, and therefore the adjustment cost function should be a function of gross investment rather than net investment.

Mussa (1977) claims that both internal and external costs should be included in the investment model, and shows the approaches taken by proponents of the 'supply function' and 'adjustment cost' theories of investment are just two parts of one model.[22] Capital will be demanded according to the formula:

$$I^i = \tilde{I}\left(\left(q - P^K\right) / P\right) \tag{2.27}$$

Equation (2.27) shows that the investment of firm *i* (I^i) is a function of the inverse of the internal marginal cost function (C'), denoted $\left(\tilde{I}\right)$, which relates the relative prices of the shadow price of capital (q) (the value attached to an additional unit of capital due to the income streams it is expected to generate), the market price of capital goods (P^K), and the price of consumer goods (P). Investment is thus related to the ratio of the difference between the shadow and capital supply prices and the price of consumer goods, so that as the ratio increases then investment increases.

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[22] The 'supply function' theory of investment views the investment function as the supply function of the capital goods producers. The price of capital is determined by the existing stock of capital and demand for capital by asset holders. The price of capital together with the supply function of capital producers then determines the rate of capital accumulation, (Clower, 1954; Witte, 1963; Foley and Sidrauski, 1970).

(2.28) $$d\tilde{I} / d\left(\left(q - P^K\right) / P\right) > 0$$

The second part of the model focuses on the supply side. When the economy is in equilibrium the demand for labour is equal to the supply of labour. It is assumed that those firms producing capital goods use only labour as an input, whilst consumption good producers use capital and labour inputs in a linear homogenous production function (G). This gives labour demand for the capital and consumption good producers of L_J and L_X respectively, and therefore total labour supply $\left(\overline{L}\right)$ and demand in equilibrium of:

(2.29) $$\overline{L} = L_J + L_X = H\left\{\tilde{J}\left(P^K / w\right)\right\} + K \cdot l\left(w / P\right)$$

where the capital producers demand for labour is given by $H(J)$ with J the total production of capital goods, which is a function $\left(\tilde{J}(\bullet)\right)$of the relative price of capital (P^K) and wages (w). Given the nature of the consumption good production function labour demand by the consumption good producers is proportional to the capital stock, with that proportion dependent upon the relative prices of labour and consumption goods. Demand for capital goods must also equal the output of capital goods producers:

(2.30) $$N \cdot \tilde{I}\left\{\left(q - P^K\right)/P\right\} = \tilde{J}\left(P^K / w\right)$$

When these equilibrium conditions hold the real price of capital goods P^K/P, can be calculated from the existing capital stock and shadow price. At any given real shadow price the implicit real supply price results in only one level of capital goods being produced. If more investment goods are demanded the real supply price and therefore the real shadow price must increase to maintain equilibrium in the capital goods market.

Individual firms will maximise the worth of their firms by smoothing the accumulation of capital over time, thus minimising the internal capital adjustment costs that they face. Investment becomes a trade off between higher production of consumer goods and higher capital adjustment costs. If the economy were organised on the basis of a single social planner, capital would be accumulated in a smoothed pattern, as both internal and external costs would be taken into account. Capital would not be acquired too quickly as this would result in the price of capital rising as higher levels of investment can only be achieved at higher prices. Mussa (1977) shows that if investors have rational expectations of future conditions this will internalise the external costs of adjustment as the capital goods consumers will observe that the price of capital will rise in periods of high demand and thus smooth their investment over a number of periods. Mussa uses the example of rented property, whereby landlords will not increase the number of properties they hold when there is a population increase, but will smooth the increase in properties held over a number of years, as production of houses will be limited by the capacity of the construction industry.

2.4 – Tobin's *Q*

The neoclassical theory of investment looks at the effect output and relative prices have upon the rate of investment. Thus firms attempt to maximise returns by investing up to the point where discounted marginal returns are equal to the user cost of capital. Since the value of a firm is equal to the value of future discounted net revenue streams, an alternative method of stating the firms' objective is that it maximises the value of the firm. This means a firm will only undertake an investment if it adds value to the firm of an amount at least equal to the cost of acquiring the capital. This is the basis of Tobin's (1969) *Q* theory of investment. Tobin (1969) suggested that a firm would only add another unit of capital to its capital stock if the cost of this additional capital were less than the value that would be added to the firm from acquiring that marginal unit of capital. Tobin's *Q* in a setting where there is only a single period in the future can be expressed as:

$$(2.31) \qquad Q = \frac{[1/1+i][P_{t+1}MKP_{t+1} + (1-\delta)P_{t+1}^{K}]}{P_t^{K}}$$

where i is the interest rate, P_t is the price of output, MKP_t is the marginal product of capital, δ is the depreciation rate of capital, and P^K is the market price of new capital. The numerator of the equation is simply the value added to the firm from the income stream associated with the additional unit of capital, plus the asset value of the capital less the depreciation rate. This is divided by the market price of capital (P_t^K), to give the ratio of value added to price paid (*Q*). With an infinite time horizon and life of capital, the last term in the numerator would be:

$$(2.32) \qquad P_{t+1}^{K} - \sum_{t=1}^{\infty} P_{t+1}^{K}\delta^{t}$$

and approaches zero. This means that the infinite horizon equation for Tobin's *Q* ratio can be rewritten as:

$$(2.33) \qquad Q_t = \frac{\sum_{t=1}^{\infty}[1/(1+i)^{t}][P_{t+1}MPK_{t+1}]}{P_t^{K}} = \frac{q_t}{P_t^{K}}$$

where q_t defines the shadow price of capital. In order to maximise returns capital will be purchased up to the point where the purchase price of an additional unit of capital

(P^K) is equal to the value added to the firm (q_t),[23] also the shadow price of capital, at which point $Q_t = 1$.[24]

Tobin (1969) shows that the government can use monetary policy to alter the investment rate by changing the *Q* ratio faced by firms.[25] One difficulty that is faced not only by policy makers, but also to some extent by the firms themselves is that the *Q*-theory is based upon the unobservable marginal rate of *Q*. To get round this problem, rather than using Marginal *Q*, applications of the *Q*-theory use the average rate of *Q*, (Average *Q*).[26]

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[23] It should be noted that the change in the value of the firm above is only the change in value associated with the purchase of the marginal unit of capital. The change in adjustment costs is also only the additional cost due to the purchase of the marginal unit of capital, but it should be noted that the size of this change will be determined by the total quantity of capital purchased during the period (I_t). The value of Tobin's *Q* associated with the addition of the marginal unit of capital is referred to as Tobin's Marginal *Q*. When the economy is in equilibrium, Marginal *Q* should be 1 for all firms.

[24] Romer (1996) notes that a firm may also face costs of adjusting the capital stock ($\Delta C(I_t)$), which must also be taken into account when choosing the optimum capital stock, (see subsection 2.3.5 for discussion of capital adjustment costs).

[25] Tobin (1969) shows that monetary policy can be used to change the rate of investment by raising the value of existing assets, so that their value no longer corresponds to the replacement value. In the short term this can ensure that the capital stock does not have a rate of return that corresponds with the marginal efficiency of capital. Tobin explains how all of the rates of return associated with different assets are linked together, the fact that as the return on money is fixed and determined by monetary policy allows the government to determine the returns for all other assets in the short term. In this way the government is able to alter the *Q* ratio of capital, and therefore influence the investment rate. In the long run the quantities of money and capital will be adjusted, so that the returns to capital will return to be equal to the marginal efficiency of capital.

[26] To calculate the marginal rate of *Q* the value to the firm of the additional unit of capital must be calculated by calculating all future returns from the marginal unit of capital. An alternative is to calculate the average rate of *Q* by dividing the value of the firm by the capital stock held by the firm. Average *Q* is therefore often used as an approximation for Marginal *Q*. Using Average *Q* assumes that there are constant returns to scale. Under the normal assumption of diminishing returns to scale Marginal *Q* will be less than Average *Q*. Hayashi (1982) shows that with constant returns to scale in both production and installation functions, Average *Q* will equal Marginal *Q* for a price taking firm. With the above assumptions it does not matter what the initial capital stocks of firms are, all firms will have the same Marginal and Average *Q* if they face the same production and installation functions, as a firm with a capital stock of K_1 will have profits K_1/K_0 times the profits of a firm with a capital stock of K_0. Hayashi suggests that rather than using Marginal or Average *Q* empirical work should be carried out using the variable, Modified *Q*, which takes account of tax credits past (κ) and current investment (z) will earn. Therefore Modified *Q* usually has a higher value than Marginal or Average *Q*. Modified *Q* should therefore contain all expectations of future returns and costs associated with the purchase of capital.

2.5 - Summary

This section covered the origins of investment theory and how it developed to produce a number of models that could be empirically tested. The main difficulty faced by economists trying to produce investment models was how to incorporate the dynamic components of the investment decision (expectations and technological change). This led to the development of two main types of investment theory by the early 1980s, those that implicitly modelled the dynamic components and those which explicitly included them. Although the later implicit models can place values on the influence of certain variables such as user cost of capital and output these models do not help a great deal in understanding the specific relations that exist between the variables and investment. Models that have incorporated dynamic components explicitly, such as Q-theory, have concentrated on trying to use financial market data, which should include expectations of future returns within them. This way there is no need to devise the manner by which expectations enter the investment decision they are already included therefore, the relatively poor performance of the neoclassical and Q theories of investment empirically has lead to other theories being developed to try and explain investment behaviour. Much of the new work has developed from the greater availability of micro level data, which gives a new insight into how firms and even plants make their investment decisions. These new theories are covered in the following chapter.

Chapter 3 Alternatives to Traditional Theories

The neoclassical theories of investment, and the development of Tobin's *Q* from them, as discussed in Chapter 2, appear at first to be sensible models of investment. However since the early 1980s there has been a shift away from using these theories as pre-dominantly, which has been primarily due to the lack of success in modelling both the aggregate and, in particular, the individual firm's investment decisions. Caballero (1999) draws particular attention to the inability of such models to link the user cost of capital to the demand for investment, while the main empirical success has come from the use of quantity variables in accelerator style models, which is opposed to the basic underlying assumption of neoclassical economics where the price mechanism summarises the relative demand and supply positions in existence in the economy.

There a number of explanations as to why models which use a representative firm with convex adjustment costs will not produce predictions that are consistent with the data observed in reality. Firms may not always adjust their capital in exactly the same way and will be impacted upon by not only the overall determinants of the optimal capital level for the economy, but also by a number of different idiosyncratic effects which will affect the optimum level of capital for the specific firm. These idiosyncratic shocks may mean that the representative firm style of model is unable to produce accurate results for the aggregate level of investment. The difficulties that this creates for economists attempting to model investment are further compounded by a number of measurement and data availability problems.

One area of criticism faced by the neo-classical model of investment is the appropriateness of assuming symmetrical convex capital adjustment costs. Once this assumption is dropped expected investment patterns change considerably. This chapter opens with Section 3.1 considering the alternatives to symmetric convex capital adjustment costs, as well as examining other reasons that may have contributed to the failure of traditional theories of investment to model aggregate investment satisfactorily. Section 3.2 looks at the (S,s) adjustment mechanism thought to be utilised by firms attempting to optimise returns when faced with the style of adjustment costs introduced in 3.1. Section 3.3 introduces the literature on irreversible investment, the irreversibility of investment being thought to be a major cause of the adjustment cost structures examined in 3.1. The empirical tests of the 'new wave' investment are presented in Section 3.4, and Section 3.5 summarises the proceeding sections and concludes the chapter.

3.1 – Non-Convex Asymmetric Capital Adjustment Costs

As noted in the proceeding chapter and introduction to this chapter, there were found to be a number of theoretical and empirical failings of the neo-classical investment theory. Whilst the assumption that firms face a capital adjustment cost function that has a symmetrical and convex form avoids the problem of a discrete change in exogenous variables producing an infinite rate of investment, it may not however be completely realistic. Therefore a number of alternative adjustment functions are examined in the following sub-section. Sub-section 3.1.2 looks at the aggregation and measurement problems that exist when modelling investment.

3.1.1 - Alternatives to Symmetric Adjustment Costs

Holt et al. (1960) introduced the convex adjustment cost curve as an approximation for the various costs that are faced by a firm adjusting its number of employees.[27] The ease with which such a convex cost function could be used and manipulated meant that it was adopted by a majority of economists attempting to model investment. For further simplification the cost curve was generally assumed to be symmetrical and have a value of zero when $\Delta K = 0$ (where K is the capital stock). This was not Holt and his co-authors' original intention as the actual example given in their book (page 74) is not centred on zero nor does it have a minimum cost of zero. Minimum capital adjustment costs for *gross* investment are likely to be found when the investment rate is zero and no investment or divestment is taking place, however the minimum cost for adjusting the net capital stock is likely to be found at a *net* investment rate of less than zero, as depreciation of the capital stock should mean that over time the capital stock will decline over time.

The issue of whether adjustment costs are symmetric has also been in debate for a number of years. It does seem unlikely that the costs function of decreasing the capital stock will be identical to that of raising it. As with changing labour demand, there will effectively be different cost functions associated with 'hiring' capital and 'firing' it. As with labour, hiring costs of capital will include search, filter, and training costs, while 'firing' costs for capital take a different form to those for labour. Labour firing costs are normally related to redundancy payments, but with capital some of the main costs will come from the difficulty of finding a buyer willing to pay near to the market value of the capital in question. Thus the sale of capital faces a

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[27] Much of the work on adjustment costs of factor demand has been based upon demand for labour rather than capital, as the data at the firm level is more widely recorded and available for labour compared to capital acquisitions, but many of the labour adjustment cost forms are generally suitable for adaptation to capital accumulation.

lemon style problem (Akerlof, 1970) and also a sunken cost style problem, which reduces the value of capital in the market below the level of worth to the firm that initially acquired the capital. This loss in value of capital once it leaves the firm constitutes an additional adjustment cost, which must be taken into account (see Section 3.3).

Given the different forms of costs in increasing and decreasing the capital stock held by a firm, the cost function is likely to be asymmetric. Where the additional cost of searching for the correct technology (or the loss of value associated with selling the capital) is greater, there is potential for the capital stock to be increased (decreased) more quickly, resulting in longer recoveries (or depressions) in the economic cycle.

An encompassing approach that can be used to represent capital adjustment costs that are convex, but asymmetric, employs the following equation (Pfann and Verspagen, 1989):

$$C(\Delta K) = 0.5b[\Delta K]^2 - c\Delta K + \exp(c\Delta K) - 1 \tag{3.1}$$

The adjustment cost function $C(\Delta K)$ is a convex function of the change in the capital stock. The parameter b determines the convexity of this relationship for both increases and decreases in the capital stock. The parameter c however will determine whether there is any asymmetry in the relationship between changes in the capital stock and the adjustment costs. When $c = 0$ the cost function is symmetric, but when $c > 0$ ($c < 0$) increasing (decreasing) the capital stock is marginally more costly than reducing (increasing) it.[28]

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[28] Pfann and Verspagen (1989) looked at the adjustment costs of labour faced by five large Dutch companies (DSM, Fokker, Hoogovens, Vendex International and Volvo). Hiring costs were found to be higher than firing costs, which means that in equation (3.1) c took a positive value. This meant that during booms the higher costs of adjusting the level of labour upwards meant that the optimum level of

Two further alternatives are linear piecewise costs or lumpy costs, (Hammermesh and Pfann, 1996). Linear piecewise costs are adjustment costs that are proportional to the change in the capital stock. This means that the adjustment cost function can be written as:

$$C(\Delta K_t) = \begin{pmatrix} b_1 \Delta K_t, b_1 > 0 \\ b_2 \Delta K_t, b_2 < 0 \end{pmatrix} \begin{matrix} \mathit{iff}\ \Delta K_t \geq 0 \\ \mathit{iff}\ \Delta K_t < 0 \end{matrix} \tag{3.2}$$

Such that b_1 and b_2 can take differing values if asymmetries are present. The presence of linear piecewise capital adjustment costs mean that even small adjustments in the capital stock will result in relatively high costs. Therefore firms will not alter their capital until their capital stocks are relatively far from the optimum level.[29] This means that there will be periods of time when firms do not adjust their capital stocks, followed by periods of adjustment. Rothschild (1971) also models the impact that linear adjustment costs will have on investment patterns of firms, plus the effect of concave adjustment costs. These arise where it is assumed that there are diminishing costs to scale.[30] With fixed capital, diminishing costs may occur due to discounts on larger orders of equipment. Rothschild (1971) extends his analysis to a cost function which exhibits convex costs for small capital adjustments and concave costs for larger adjustments. This functional form results in small adjustments being spread over a large number of periods and large adjustments being made in a one off investment to benefit from the declining costs of adjustment (per unit of capital) at higher levels of adjustment.

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employment was reached more slowly than in recessions, the opposite is generally thought to be the case with fixed capital.

[29] This is assuming that all factors of production display diminishing returns, and therefore the costs of being away from the optimum capital stock rise at an increasing rate.

[30] The example used for the case of labour adjustment by Rothschild (1971) is that of training, where the cost of training employees declines per employee trained up to a point as one teacher can train more than one employee, but as the number of employees being trained increases the time taken to complete the course will rise, so that it is not a fixed component.

Lumpy costs of adjustment describes the type of cost faced by a firm which, when attempting to adjust their capital stock, contains a fixed element. Examples of this include surveying the site of a new factory. Although the cost will increase with the size of the factory a large proportion of this cost will not change from a factory covering one acre to one covering two acres. When installing new machinery it may be necessary to close a production line. Whilst the line is closed down it may be possible to work on replacing a number of components of the line at once. Therefore the cost will not increase with the number of machines being installed or refitted. As with linear piecewise adjustment costs, lumpy adjustment costs will tend to lead to periods of inaction followed by rapid adjustments back towards the desired level of capital. Abel and Eberly (1994) showed that under certain conditions, three regimes of investment would develop depending upon the value taken by q (the shadow price of capital).[31] Abel and Eberly found that if there was a fixed component of the adjustment costs there would be two threshold values of q, which they notated as q_1 and q_2. Above the higher value (q_2) there would be positive gross investment. Below q_1 there would be negative gross investment. Between the threshold values the fixed component of the adjustment costs prevent firms from changing their capital stocks. The adjustment cost function that Abel and Eberly considered was assumed to be convex with a fixed component dummy variable (v), that took the value of zero if no investment took place and 1 if investment took place. This gives an adjustment cost function of:

(3.3) $$C(I_t, K_t) = v.c(I_t, K_t)$$

As gross investment in any period (I_t) approaches zero the costs of adjustment faced by a firm approach $c(0,K_t)$ which represents the fixed component of the cost of

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[31] For the three regimes to develop investment must be partially irreversible but not completely irreversible, (see Sections 3.2 and 3.3).

adjustment function. This may take different values for capital stock reductions and increases denoted as $c(0,K)^{-}$ and $c(0,K)^{+}$, respectively.[32]

Another model combining both fixed and convex components within the adjustment costs is set out by Le and Jones (2005). It is shown that the size of the variable component has a considerable effect in reducing the lumpiness of the investment process. With purely variable costs firms will make infinitely small incremental investments, whilst the greater the size of the fixed component the lumpier investment becomes with the required trigger rate of return increasing and investments made in larger increments (see Section 3.2 for further discussion of capital stock control techniques).

This subsection has shown that although a majority of traditional investment theory has been based upon the assumption of a convex adjustment cost function this is not necessarily realistic, and there can be implications for investment behaviour if different cost functions are adopted instead. It was noted that the adjustment cost function is likely to asymmetric. This may create a difference in the speed at which firms adjust their capital stocks towards the optimum depending on whether adjustment takes the form of an increase or decrease in the capital stock. In particular the relaxation of the assumption that costs are strictly convex is shown by authors such as Rothschild (1971) and Abel and Eberly (1994) to have large impacts on how firms make their investment decisions. Linear piecewise or lumpy adjustment costs are shown to result in periods of inaction where no capital adjustment is undertaken, which again is likely to have a major impact on the timing of the business cycle.

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[32] Nickell (1978) notes that when using a similar adjustment cost function to that discussed by Abel and Eberly (1994) with initially concave adjustment costs, which become convex beyond a certain degree of adjustment, there will be an optimal rate of investment that minimises the adjustment cost per unit of capital installed (I^{*}). The speed of adjustment to a new higher optimum capital stock will depend upon the relative sizes of I^{*} and replacement investment (δK). When I^{*} is large (small) relative to δK, adjustment will be rapid (slow).

When all of these factors are taken into account it is perhaps not surprising that traditional investment theory has not been empirically successful in modelling aggregate investment.

3.1.2 - Problems of Aggregation

Capital expenditure data are generally highly aggregated, and although government policy is generally concerned with controlling the aggregate level of investment within the economy, as the previous section of work showed, the movements of the aggregate do not always reflect the micro-mechanisms that produce these flows. Therefore, to understand the impact of policy at the aggregate level of investment, it is important to look at the implications at the micro level.

Nickell (1978) notes that there are difficulties with attempting to model the investment decisions of individual firms employing a number of different types of labour and capital through the use of simple production and investment equations, with just the two labour and capital variables. Even assuming that these are accurate, Nickell goes on to note that there is likely to be little resemblance to reality of the estimations produced from the equations when looking at industry data or higher levels of aggregation. The only way round these problems is to assume identical firms operate in the economy making use of homogeneous capital and labour supplies. This becomes more difficult when theories involving piecewise or lumpy adjustment costs are being utilised. If the above assumptions are not relaxed this would imply that there are periods during the economic cycle when there would be no investment at all, as it would not be rational for any firm in the economy to adjust their capital stocks when faced with the relatively large costs of making small adjustments. Dropping the assumption of symmetrical convex adjustment costs has therefore led to a move away from representative firm models for aggregate investment.

A further difficulty that faces economists attempting to model investment flows is another aggregation problem, but rather than the aggregation of a number of firms data during one period it is aggregation of a single firm's or industry's data through time. As disaggregated data have become available a greater understanding of the exact patterns of investment has arisen, but this has been hindered by the problems of temporal aggregation. Increasingly, theory has been concentrated on the phenomenon of lumpy investment, where investment is concentrated into periods of high intensity investment and periods of low investment, or even inactivity in adjusting the capital stock. Hamermesh and Pfann (1996) draw attention to the fact that much of the data available are annual data. It is unlikely that firms will make decisions about factor requirements only once a year, and therefore some of the intuition that might be gained from when firms choose to invest and to what extent this is concentrated into one purchase or sale is lost. Hamermesh and Pfann blame temporal aggregation as a major cause of making it appear that firms smooth investment over time. Investment around the recording period's end for example may be one large investment episode but will be recorded as two smaller episodes spread across two periods.[33]

3.2 – (S,s) Models

In the previous section a number of difficulties and failures of the standard neo-classical investment function with symmetric convex adjustment costs were

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[33] In reality the investment may have been concentrated into two months, for arguments sake December of one year and January of another, but the data will represent this as being spread across two whole years.

identified. This has led to a number of studies which do not involve firms smoothly adjusting their capital stocks towards the optimum capital stock, but rather models in which periods of rapid capital accumulation and periods of investment inactivity characterise a firm's investment pattern. A majority of these theories have included either fixed or linear investment costs or, alternatively, some degree of irreversibility in investment. Modelling these aspects has been approached in two main ways. To model the impact of irreversible investment an approach similar to valuing a financial call option has been developed for the value of waiting for more information to become available, (see Section 3.3). Modelling the impact of fixed or piecewise linear costs has been developed through the use of (S,s) and other threshold models, and it is these models that this section will focus on.

Sub-section 3.2.1 introduces the concept of (S,s) models, whilst 3.2.2 shows the impact of applying (S,s) models at the firm level on the aggregate behaviour. Sub-sections 3.2.3, 3.2.4 and 3.2.5 investigate the impact of a number of different types of shock upon firms operating (S,s) policies.

3.2.1 – Introduction and Explanation of (S,s) Models

(S,s) models were initially developed to attempt to model the behaviour of managers' control over their inventory stocks (Scarf, 1960). Inventories were reduced as sales were made to customers, with no replacement of stock made until a certain low level of inventories was reached (s). The inventory stock was then increased to an upper level of (S). This type of model has been adapted to describe a number of different aspects of the economy, including fixed investment. It should be noted that (S,s) style models are suitable for describing the decision making processes of most adjustment processes that are influenced by piecewise linear or fixed costs and therefore involve a state where adjustment is not optimal, as for example in price setting when facing menu costs (Slade, 1999), or adjustment of portfolios of consumer durables (Grossman and Laroque, 1990).

With fixed investment, it is the capital stock that is the observed state variable. Depreciation of the existing capital stock reduces the capital stock over time, until the capital stock reaches a point (s) at which the firm invests in sufficient quantity to bring the capital stock back to (S). The lower threshold (s) is set such that the cost of adjusting the capital stock back to the optimum (S) is equal to the costs incurred from being away from the optimum due to diminishing factor returns. This means investments will be made in increments of S-s. The lower threshold (s) could also be set as a fraction of (S), allowing the optimum capital stock to evolve through time. Assuming the optimum capital stock increases with time, the trigger point at which it becomes optimal to invest will also increase as will the investment increment (S-s).

Dixit (1991b) looks at two main investment regimes that can be undertaken when firms are faced by adjustment costs with some fixed component of adjustment costs taking the form:

$$\begin{aligned} C_s &= a_s + b_s(S - s) \\ C_r &= a_r + b_r(r - R) \end{aligned} \tag{3.4}$$

where C_s are the costs of adjusting the capital level upwards to S from the lower boundary s, and C_r are the costs of reducing the capital stock from the upper boundary (r) to the target level R. The fixed components of adjustment are a_s and a_r, which may be identical or different in value, depending on whether the adjustment cost function is symmetric or not.

Dixit (1991b) attempts to show how the boundaries and points of adjustment are formed. The model assumed is that of a two-sided (S,s) model with an upper and lower boundary (r and s respectively) which, when reached, trigger the adjustment of the firm's capital stock. Under one regime of capital management (impulse control) the adjustment is to a set value lying somewhere between the two boundaries.[34] When the lower limit is reached the capital stock is adjusted upwards to S, and likewise when the upper boundary is reached the capital stock is adjusted downwards to R.

The alternative control regime is that of instantaneous or 'barrier control', whereby the firm adjusts capital by an infinitesimally small amount to take the capital stock away from the boundary, (Harrison and Taksar, 1983, provide a detailed discussion and explanation of this type of control mechanism). This case does not incur fixed costs of adjustment, giving adjustment costs of:

$$\text{(3.5)} \qquad \begin{aligned} \mathrm{d}c_s &= b_s \mathrm{d}s \\ \mathrm{d}c_r &= b_r \mathrm{d}r \end{aligned}$$

where ds and dr represent the infinitesimally small investment increments, during an investment and divestment respectively under 'barrier control'. The benefit of holding any amount of capital is given by a flow reward function, $F(K)$, of the form:

$$\text{(3.6)} \qquad F(K) = E\left\{ \int_0^\infty e^{-\rho t} f(K) dt - \text{regulation costs} \middle| K_0 = K \right\}$$

where ρ is the discount rate, K is the capital stock, and regulation costs refer to the adjustment costs from which ever control regime is utilised. The initial capital stock is assumed to be $K \in (s, r)$. The boundaries are set in the case of impulse control to equate the flow reward function change to the adjustment costs:

$$\text{(3.7)} \qquad \begin{aligned} F(S) - F(s) &= a_s + b_s(S - s) \\ F(r) - F(R) &= a_r + b_r(r - R) \end{aligned}$$

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[34] Harrison, Sellke and Taylor (1983) provide a rigorous proof for the optimality of impulse control of stocks when fixed components are present within the adjustment cost function.

Barrier control does the same but without having to change the stock by such a large margin, as the fixed component does not need to be overcome:

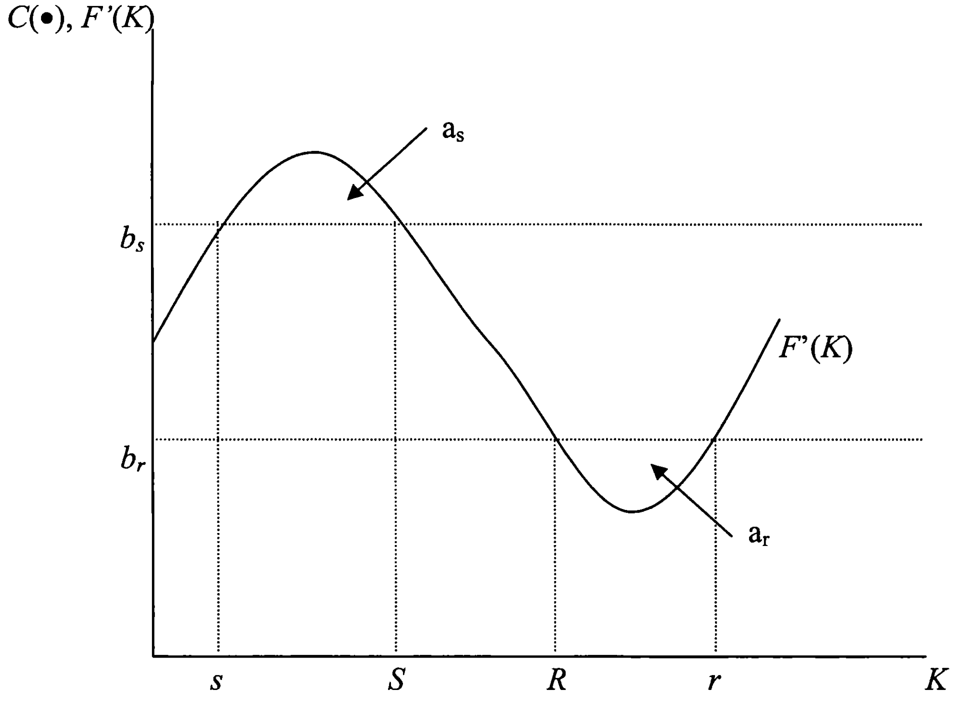
$$F'(s) = b_s \qquad (3.8)$$

$$F'(r) = b_r$$

where $F'(s)$ and $F'(r)$ are the derivative of the flow reward function with respect to a change in capital, at the lower and upper barriers respectively. This matching of costs and benefits is known as the 'value matching condition'.[35]

The figure below taken from Dixit (1991b), shows the points chosen by the above rules. The area captured between the b_s and $F'(K)$ curves and the area between the $-b_r$ and $F'(K)$ curves are equal to the fixed cost component of adjustment costs, (a_s and a_r respectively).[36]

Figure 3.1 – Value Matching Condition



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[35] When, however, the boundary of the flow function $F(K)$ is unknown, Dumas (1991) shows that to achieve optimality the value matching condition is not sufficient, and that the first derivatives of the flow function in the two positions (before and after adjustment) must also be matched, this is known as the smooth pasting condition.

[36] Note that when reducing capacity it is assumed in this diagram that the fixed costs are negative, i.e. there is revenue from selling the capital second hand or as scrap.

If there are no linear costs of adjustment then the target value for both barriers will be the same $S = R$.[37]

The pattern of investment that is created when modelled using (S,s) techniques is useful in that it helps to explain the skewness and kurtosis seen in investment patterns (Caballero et al., 1995). Firms are more willing to make positive rather than negative investments (see Section 3.3 for discussions of irreversible investment and asymmetric investment patterns), leading to the distribution of investment flows being positively skewed. Also it appears that firms are more willing to invest when they are a long way from the optimum capital stock, therefore producing a relatively large number of outlying observations.

Caballero et al. (1995), rather than using a simple (S,s) model to explain plant level investment data from the US Census Bureau, Longitudinal Research Database (LRD), employ an adjustment rate function of the form:

(3.9) $$A = A(x,t)$$

where A is the percentage of mandated investment (x) that is invested each period. Mandated investment is the investment that would occur if there was no cost of adjustment for a period, therefore taking the capital stock back to the optimum level. The adjustment rate function, A, was assumed to be a function of the mandated level of investment (x) and time (t). The adjustment rate function was assumed to be of a quadratic form, which meant that the rate of adjustment (A) increased with the level of adjustment (x) required to achieve the optimum capital stock, which is very much the form taken by an (S,s) function but with varying speeds of adjustment rather than none or complete adjustment.

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[37] Using a model with partially irreversible investment Abel and Eberly (1996) show that the area of activity between the upper and lower trigger values of capital adjustment (r and s) is positively related to the size of the fixed costs of capital adjustment, which in this model are the differences between the purchase price of capital and its resale price.

Caballero and Engel (1999) extend the (S,s) model by looking at a situation where the costs of adjustment are fixed in form, as in the simple (S,s) model, but the value taken by this fixed cost varies across time and firms. In this situation there are no definite threshold values that dictate when the firm will adjust its capital stock, as it is uncertain at which point of imbalance in the capital stock it will be profitable to adjust. To overcome this uncertainty, Caballero and Engel (1999) model the decision to adjust capital as an increasing hazard of the level of imbalance present.[38] This means that as the firms' capital stock moves further from the optimum capital the more likely an adjustment becomes, but is not certain to occur. The exact form that the hazard function takes is dependent on the distribution of the fixed costs of adjustment. It is shown that the traditional (S,s) function is nested within this generalised form of the model as a special case where the variance of adjustment costs is very small, so that less uncertainty is present. This is returned to in Chapter 4 when considering the impacts of uncertainty on the investment decision.

3.2.2 – Heterogeneities and Aggregate Investment

The previous section looked at the literature describing the (S,s) model and its derivatives. This section takes the models introduced in the previous section and looks at how the lumpy patterns observed at the micro level combine to form the smoother patterns of adjustment traditionally modelled at the aggregate level. If firms do adjust their capital stocks in the manner suggested by the (S,s) style of model then it is understandable that the neoclassical theory of investment with convex adjustment costs is not capable of modelling aggregate investment accurately. Equally, it is evident that the assumption of building a model of the aggregate from a representative

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[38] Caballero and Engel (1992) show that a hazard function with a constant probability of adjustment is the equivalent of the traditional partial adjustment model, and is out-performed by an increasing hazard function particularly where shocks are large.

firm using (S,s) decision making tools will not be able to model the patterns seen in the aggregate, as firms are not homogeneous in characteristics and preferences.

Blinder (1981) looks at a similar problem faced in trying to model inventory investment over the economic cycle. The alternative to the (S,s) style of model is the partial adjustment model developed by Lovell (1961), which has similarities to accelerator theories of investment. This assumes that the inventory stock is adjusted towards the optimum level by a fraction of its deviation from that level each period. The main problem that Blinder finds with the partial adjustment model is that the adjustment variable is found to have too low a value in empirical work to be able to explain the large variance of inventory stocks. The (S,s) model is capable of explaining this much more efficiently because for any percentage change in sales this would be expected to move the (S,s) boundaries by the same percentage.[39]

Blinder (1981) looks at the reactions of a four firm economy and the impact of a temporary sales increase. The impact of a temporary increase is to synchronise the timing of adjustments of a number of firms, thus creating a cycle of inventory adjustment. A similar reaction is likely to occur with capital acquisition in an (S,s) environment. When compared to the partial adjustment model, the (S,s) model was generally better at predicting the large movements made in inventory adjustments in recessionary periods that were examined (1979-80), but the performance of the (S,s)

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[39] A percentage change in permanent income would have the same effect upon (S,s) boundaries when considering purchases of durable goods. This increase or decrease in the boundary will result in a larger change in the number of firms (or consumers) reaching the boundary and therefore result in a much larger change in inventory purchases (or consumer purchases) (Bar-Ilan and Blinder, 1992).

According to the permanent income hypothesis, consumption will increase if the permanent income is increased. However, changes in income are unable to explain the large fluctuations observed in the patterns of consumption for consumer durables. Bar-Ilan and Blinder (1992) find that some of these fluctuations can be explained by using an (S,s) adjustment model. As noted by Blinder (1981) movements of the boundaries in an (S,s) model will often result in a large number of firms or consumers being at the adjustment boundary in any one period. Bar-Ilan and Blinder (1992) found that this was the case with purchases of cars in the US. Although the permanent income hypothesis was able to predict the increase in the average value of each car purchased, the (S,s) model was better at predicting the changes in the number of sales that took place.

model was still far from perfect and a number of large adjustments failed to be predicted by the model. The studies by Blinder (1981) and Bar-Ilan and Blinder (1992) both show that greater variance in the number of adjustments due from a movement of the boundaries enforced by a change in some form of demand variable, can help to explain the large movements often seen in the economy in series such as inventory stocks, relative to the explanations given by alternative models such as partial adjustment models (or in the case of investment the accelerator or neo-classical investment models).

Aggregation from the firm level to the aggregate using the (S,s) model would not be too difficult if all firms were homogeneous in preferences and chacteristics. This is not the case however as firms are affected by two types of heterogeneity, structural and stochastic. In the simple setting of the (S,s) model, stochastic heterogeneity comes about from the presence of idiosyncratic shocks to the firms' productivity, or sales, which result in unsynchronised investment decisions. Structural heterogeneity indicates the existence of more then one bandwidth across firms (Caballero and Engel, 1991).

3.2.3 – The Impact of Aggregate Shocks

Caballero and Engel (1991) assume that the firms within an economy are identical in their preferences over capital and labour and follow a one sided (S,s) rule whereby they only consider adjusting their capital stock upwards when it has reached a lower limit or boundary due to depreciation. A steady state is described where the total deviation from the optimum remains constant in the presence of idiosyncratic shocks. This should occur naturally when there are no aggregate shocks, as when aggregated together the number of firms away from their optimum by any fraction of their bands will remain roughly constant. Likewise it will be expected that the number of firms reaching the boundaries of their bands will remain constant, and therefore aggregate investment will remain constant.

Caballero and Engel (1991) found that if aggregate shocks were also included in the model then there would be a major impact upon the patterns seen in aggregate investment. An aggregate shock is likely to bring a large number of firms to, or beyond, the boundaries of their bands, which means that a large number of firms adjust their capital stock to the optimum level. This means that in the period after adjustment has taken place a large number of firms are at their optimum capital stock (*S*). This means that, to some degree, a proportion of the firms have become synchronised in the positions they occupy in their capital replacement cycles. Assuming the same rates of depreciation for different types of capital, and little structural or stochastic heterogeneity, the firms will remain synchronised into the future, with firms continuing to reach the boundary during the same period, therefore creating echoes of the original shock in future periods.

If a more complex adjustment function is assumed, as developed by Caballero and Engel (1999), where there is an increasing probability of adjustment the greater the distance from optimum capital stock, this pattern will be smoothed. This means a single aggregate shock will produce a pattern similar to that associated with the business cycle. This smoothing will be enhanced further if shocks do not impact instantaneously but there is a normal distribution of how quickly firms become aware of the shock, and react to it.

3.2.4 – The Effect of Stochastic Heterogeneity

As noted in the previous section the impact of aggregate shocks in Caballero and Engel's model is to synchronise the position within their cycle of a large number of firms. This means that the shock appears to echo into future periods. If there is no stochastic or structural idiosyncratic heterogeneity of the firms then the shock will remain permanently within the economy unless replaced by a further aggregate shock, which starts another pattern. However if the firms are also vulnerable to idiosyncratic shocks then these individual shocks will gradually break the synchronisation of the economy and the patterns of aggregate investment will return to the steady state seen before the aggregate shock took place.

The greater the number of idiosyncratic shocks the more quickly firms will be moved away from the placement within the bands that the other firms occupy and therefore the more quickly the economy will return to the steady state. Cooper et al. (1999) use a hazard function in a slightly different way to Caballero and Engel (1999), but with similar implications for the patterns of investment seen within the aggregate measure. Rather than using a hazard function that increases with the dispersion from the optimum capital stock, a hazard function increasing in the time since last capital replacement is used (assuming that depreciation is constant both are increasing hazards through time) to model the increasing probability of replacing aging capital with newer more productive capital. Again, the use of a hazard function effectively allows the use of a (S,s) model without having to determine the boundaries or distribution of idiosyncratic shocks hitting the firms explicitly. The simulation created has two states of the economy, high and low. When the economy shifts from one state to another there is either a large drop or increase in the investment rate, which as shown in the above section will echo through time. However due to the use of the hazard function this echo gradually disappears like ripples on a water surface to nothing, as the economy moves back to the steady state.

3.2.5 – The Effect of Structural Heterogeneity

Once an aggregate shock has occurred within the economy a large number of firms will be synchronised in their placement at the beginning of their replacement cycles (they will have adjusted their capital stocks to the optimum level). As noted in the previous subsection the presence of idiosyncratic shocks ensures that the economy gradually dilutes the aggregate shock and returns to the steady state. A similar impact can also be found to occur in the absence of idiosyncratic shocks when structural heterogeneity is present. As firms move towards the lower bounds of their bands the number of firms which reach the boundary at the same time will depend upon the spread of boundaries. For example, consider two groups of firms one with bands of width X and the other with bands of width 1.5X. A very large aggregate shock will push all firms to their boundary and induce them all to undertake investment during the same period. This will mean that at the beginning of the next period assuming that no other shocks take place all firms will be at their optimum capital stock. If capital depreciates at a rate of one unit per period after X periods half of the firms will have reached their lower boundary and another investment spike will take place. This investment spike will be smaller than the spike caused by the initial shock as only half the firms will invest and none are beyond their lower boundary. After 1.5X periods a second investment spike will take place.[40]

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[40] If bandwidths are drawn from a continuum, then the number of firms reaching the boundary at anyone time will gradually decrease over time as the position of firms within their cycles becomes more and more spread over time, until the steady state of investment is reached. The greater the spread of bandwidths the faster the steady state will be achieved. Caballero and Engel (1999) and Cooper et al. (1999) use hazard functions which effectively remove the need to set different bandwidths but assume a large continuum of bandwidths, and therefore see the steady state reached more quickly than under simpler (S,s) models.

3.3 - Irreversible Investment

In the previous two sections it has become evident that if capital adjustment costs are not convex, but contain either a linear or fixed component then it will become optimal for firms to invest in a lumpy fashion rather than adjusting their capital stocks to the optimum capital stock smoothly. Section 3.2 reviewed the different models produced to simulate the decisions made by firms when faced by these non-convex costs, which were then extended to model the effects of aggregate shocks and the heterogeneous responses of firms to shocks using hazard style models.

The questions that remain are what could cause the existence of these large fixed costs of adjustment, and how lumpy is the level of investment observed at the micro-level? One explanation put forward to attempt to rationalise the existence of these apparent large fixed costs of capital adjustment is that of irreversible investment. If disinvestments are not as easily made as positive investments then firms would appear to face the possible danger of over-capacity when deciding to increase the capital stock.

Sub-section 3.3.1 looks at the possible causes of investment irreversibility. Subsection 3.3.2 presents another method of examining the decision to invest with these additional costs of adjustment taken into consideration, namely the 'option value of waiting'. Sub-section 3.3.3 presents the literature regarding irreversible investment decisions in a strategic setting. Sub-section 3.3.4 looks at the implications for investment in relation to the business cycle.

3.3.1 – Irreversible Investment and its Causes

In earlier models of investment it was assumed that investment could be as easily reversed as put in place, which means that investment would follow the path of the optimal capital stock, either adjusting smoothly in the case of the neoclassical model or periodically jumping abruptly to the optimal stock if following a two sided (S,s) model. If, however, investment is deemed to be irreversible so that once capital had been purchased it could not be resold to others, there is a danger that if a firm increased its capital stock to meet current conditions, and conditions then to change so as to suggest that the capital stock should be lowered, this might result in the company paying large costs or keeping a higher stock of capital than it desired. This could lead to companies targeting a lower level of capital in order to avoid this possible cost.

There are two main explanations as to why investment might be irreversible to some degree. Investment will be completely irreversible if the capital purchased cannot be sold once acquired because it is wholly firm specific and non-transferable, as is the case with bespoke machinery or advertising. Whilst this is an extreme case it is more likely that investment will be partially irreversible, which will mean that although a firm will be able to sell capital that it has acquired this will be at a lower price than it was bought for, which still means the investment process involves some sunken costs. Even where capital is industry rather than firm specific capital it is not completely reversible. Firms faced with market conditions leaving them with over-capacity will probably find competitors are in a similar position, and therefore unwilling to purchase spare capacity. Industries that have been studied in particular with this type of irreversible investment are mining (Brennan and Schwartz, 1985), and oil exploration industries (Paddock et al., 1988), as industries concerned with the exploitation of natural resources generally have large fixed start up costs, and industry specific assets.[41] However not all capital goods are firm specific to this degree. There

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[41] Wood (2005) examines investment in the UK brick industry, where investment is found to be lumpy. Although investment irreversibility may be a factor in generating lumpy investment patterns, major investments in the brick industry have to be taken in 'lumps' as the investments are indivisible; a new

are a number of capital goods for which there are well developed secondary markets. It would seem that these goods would not suffer from irreversibility difficulties or the loss would be so small as to have little impact up on the prices paid for the capital second hand.

An alternative explanation for investment irreversibility is that firms suffer from a 'lemons' style asymmetric information problem (Akerlof, 1970). If a firm wishes to sell capital it is difficult to persuade the buyer who has less information that the capital goods in question are not faulty, and that this is not the reason why they are being sold.

3.3.2 – The Option Value of Waiting to Invest

When investment is irreversible for the reasons stated in the previous subsection, how can firms decide when it is advisable for them to invest? Traditionally firms would invest if the net present value (NPV) of the investment was above zero. When investment is partially or fully irreversible, then the decision to invest when the NPV is positive might not be advisable if there is a possibility that in the future certain variables such as the demand for goods, costs of production, or interest rates will change, so that the NPV has the potential to be negative in the long run. The uncertainty of future economic conditions when combined with the irreversibility of investment creates a value in waiting for further information to become available. This value of waiting can be thought of as a call option for the firm to invest, which once the firm undertakes investment is 'called in' or executed. Pindyck (1991) states that the value that these options hold for firms:

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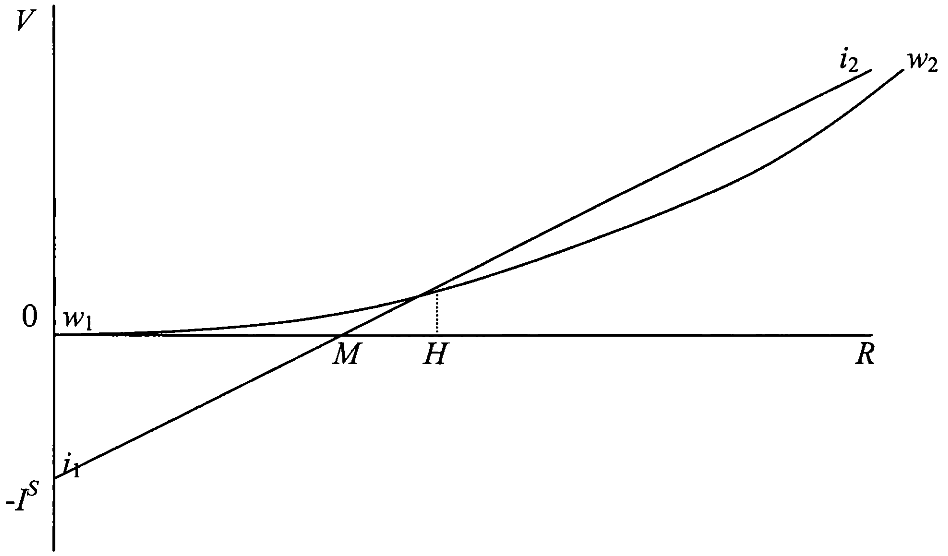
kiln constitutes around 2% of total industry capacity and therefore investments are bound to be made irregularly in large investment spikes.

> " ...result from patents, of ownership of land or natural resources. More generally, they arise from a firm's managerial resources, technological knowledge, reputation, market position, and possible scale, all of which may have been built up over time, and which enable the firm to productively undertake investments that individuals or other firms cannot undertake."
>
> Pindyck (1991) page 1111

This means that the option value of any investment opportunity will vary from firm to firm. When deciding whether to invest or not it is possible to use the positive NPV approach, as long as the value of the option to wait is included in the costs considered.

Dixit (1992) shows that the hurdle rate of return (*H*) that is required for a firm to invest when there is an option to wait is much higher than the Marshallian investment trigger level of returns (*M*), which is the level of returns that gives a zero NPV when discounted to cover the sunk costs of investment (I^S). When investment is completely irreversible this is the whole cost of investment. If investment is partially reversible then I^S is the difference between the purchase and sale prices of capital. The figure below taken from Dixit's paper shows two curves, the NPV of the investment ($i_1 i_2$), and the option value of waiting for more information ($w_1 w_2$).

Figure 3.2 – Option Value of Waiting and the Hurdle Rate of Return



The equation for the line representing the investment project's value is given by:

(3.10) $$i_1 i_2 = R\rho^{-1} - I^S$$

where R is the net operating revenue received by the firm from the project during each period, ρ represents the traditional discount rate of the investment project, and I^S is the sunken cost of investment. The line representing the value of the option to wait is given by:

(3.11) $$w_1 w_2 = AR^\beta$$

where A is a multiplicative constant, which ensures the option to invest and the investment project have the same values at the hurdle rate. The power value β takes the following form and its value is dependent on the discount rate and variance of log(R) given by σ^2:

(3.12) $$\beta = \frac{1}{2}\left[1 + \sqrt{1 + \frac{8\rho}{\sigma^2}}\right] > 1$$

For revenue levels below H the option value of waiting is above the value of the investment as the option always has a positive value and for revenue levels above H the value of the investment is higher than the value of waiting. Investment is undertaken at all revenue levels above this point. This means that the value of the option at any revenue level is given by:

(3.13) $$V(R) = \begin{cases} AR^\beta & \text{if} \quad R < H \\ R\rho^{-1} - K & \text{if} \quad R \geq H \end{cases}$$

In order to maximise the value of the above equation the hurdle rate is set to satisfy the value matching and smooth pasting conditions introduced in section 3.2.1. Dixit and Pindyck (1994) give a general solution to this problem. The conditions that need to be satisfied are as follows:

(3.14) $$F(0) = 0$$

(3.15) $$F(V^*) = V^* - I$$

(3.16) $$F'(V^*) = 1$$

where $F(V)$ is the value of the option to wait to invest in the future when the value of the investment opportunity is V. V^* is the value of the project at which it is optimal to invest, and I represents the direct costs of investment. The interpretations of conditions stated above are as follows. Equation (3.14) is the lower boundary of the stochastic process governing the movement of V: once V falls to 0 it will remain at zero, and therefore the option to wait will have a value of zero. Equation (3.15) is the value matching condition: the option to wait to invest at the optimum value (V^*) must be equal to the value of the project less the direct costs of investing. Equation (3.16) is the smooth pasting condition: the slope of the option to invest in the future must be 1 at the optimum investment point, as this is the value where the value of the investment and the option to wait are tangential to one another, making it the lowest value of the investment which can be obtained where the option to wait is no longer greater than the value of investment. Substituting (3.11) into (3.15), the value matching condition becomes:

(3.17) $$V - I = AV^{\beta}$$

which can be rearranged to give the following expression for A:

(3.18) $$A = \frac{(V - I)}{V^{\beta}}$$

Using the form of solution suggested by equation (3.11), the smooth pasting condition can be rewritten as:

(3.19) $$1 = \beta A V^{\beta - 1}$$

Substituting the solution for A from (3.18) into (3.19) and rearranging gives the optimal value of the investment to invest as:

$$V^{*} = \frac{\beta}{\beta - 1} I \qquad (3.20)$$

which gives a hurdle rate of return of:

$$H = \frac{\beta}{\beta - 1} \rho I^{S} \qquad (3.21)$$

Since the Marshallian investment trigger is ρI^S, and β is known to have a value greater than 1, the hurdle rate which induces investment in Dixit's (1992) model is greater than the traditional investment trigger by a factor of $\beta/(\beta\text{-}1)$.[42,43]

This analysis shows how sunk costs which cause irreversible investment can lead to the lumpy investment patterns such as those produced from (S,s) style investment decision rules. Dixit (1992) shows that sunken costs also lead to firms staying in business when making lower returns than required to pay for the sunken costs of installation, as there is value in waiting to see if conditions become better. This means that irreversibility creates hysteresis in investment markets, so that firms will be slow to react to movements in demand unless they are sufficiently large, and slow to exit markets where small loses are being made.[44]

McDonald and Siegel (1986) look at a situation where the decision to build a plant is irreversible, but the decision to defer building is reversible. The approach used for this situation is to view the decision of choosing whether and when to invest as swapping one risky option for another. Both the value of the investment (V_t) and

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[42] Pindyck (1991) uses a similar model to show that firms will equate the value of waiting with the value of the investment project, where the value of the option to wait varies according to a number of factors including the expected increase in the value of capital through time above the increase in the value of the project. As the difference between the appreciation of capital and value of the project falls the option value of waiting rises. Investment will become less likely to take place, as there is no cost from foregone capital appreciation. Therefore the entire value of the investment is captured in the option value.

[43] Dixit (1991a) considers the effect of price ceilings upon firms faced with irreversible investment decisions. These could be of considerable importance as markets such as those for oil that are associated with irreversibilities are often effected by price ceilings.

[44] Similarly Krugman (1989) notes that sunken costs faced by firms attempting to create export markets, make these firms willing to incur costs due to not changing prices (or not expanding production) even with fairly sizable shifts in the real exchange rate.

the costs of installation (F_t) are assumed to be governed by Brownian motion processes, and the greater the variance of V_t/F_t the higher the value the option will take. Using a variety of different variables to measure the different components of uncertainty in the economy and the investment project, the value of the option when the firm chooses to invest when the net present value of the project is zero is always positive. The lowest option value of waiting per year is around 4% of the projects' value. The optimum values to invest were also calculated and found to be well above 1 for the ratio V_t/F_t. In a large number of cases the value found to be optimum for the ratio was greater than 2, which means that the discounted returns required from the project were required to be double the costs of putting the project in place. If this is an accurate representation of the decisions made by firms it is understandable why the neo-classical and *Q* theories of investment have not been able to accurately model the patterns of aggregate investment observed.

Pindyck (1988) shows that the technique of finding the option value of waiting can also be used to determine the optimum capacity of firms. Pindyck allows capital to be unutilised which means that the firm not only has an option to wait in order to invest, but existing capital also takes an option value, the option to produce in the future. This means that the firm's value (W) is dependent on the value of capital already held, $V(K;\theta)$, and the value of the investment opportunities open to the firm, $F(K;\theta)$, where K is the capital stock held and θ is the demand shift parameter. The value of the firm is therefore:

$$W = V(K;\theta) + F(K;\theta) \tag{3.22}$$

The marginal values of capital and the option to invest ($\Delta V(K;\theta) - P^K$ and $\Delta F(K;\theta)$ respectively where P^K is the price of capital per unit) are both decreasing in the capital stock held. Uncertainty raises the value of both the value of capacity held and the option to invest (see Chapter 4 for more detail). The optimum capital stock, K^* is found to be where the marginal value of capital is equal to the marginal value of the option to invest (i.e. its own opportunity cost):

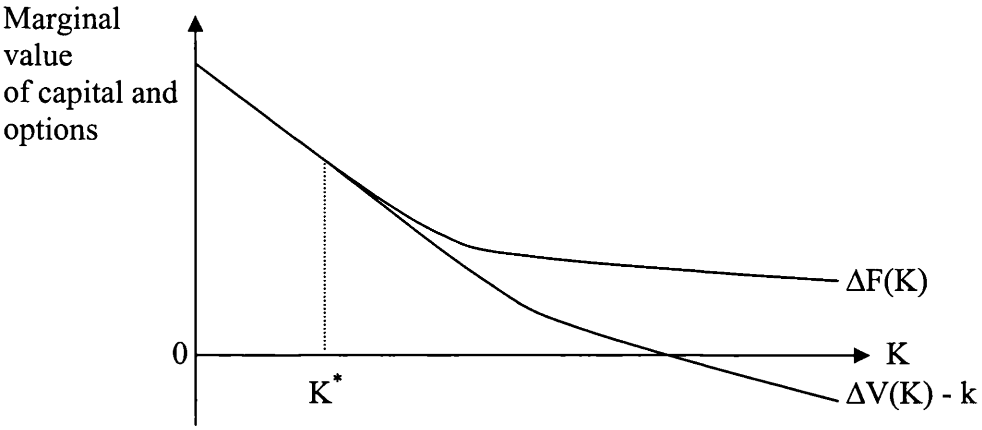
$$(3.23) \qquad \Delta V(K^*;\theta) - P^K = \Delta F(K^*;\theta)$$

or alternatively expressed, so that the marginal revenue earned is equal to the full cost of investing, including foregone opportunities to wait for more information:

$$(3.24) \qquad \Delta V(K^*;\theta) = P^K + \Delta F(K^*;\theta)$$

Figure 3.3 represents the changing values of the marginal value of capital and the marginal option to invest, and how they vary with the capital stock held. The optimum capital stock is found where the slopes of the two marginal option functions are the same. Even at the optimum capital stock firms are not protected from large downturns in investment and therefore it is quite likely that firms will spend a large amount of time operating with less than 100% utilisation of capital.

Figure 3.3 – Marginal Values of Capital and the Option to Invest



Whilst the majority of the literature relating to the 'option value of waiting' assumes investment is completely irreversible, a more realistic assumption is that investment is partially reversible with some scrap value for resale of capital $\left(P_L^K\right)$. Abel et al.

(1996) use a two period model in which the capital stock is chosen in period 1 and adjusted in period 2. Additional capital is purchased at price P_H^K and excess capital is sold at price P_L^K. The result is a three regime model, where firms have a put option to divest and a call option to invest in the future. The capital stock chosen in period 1 maximises the value of returns and the two options combined:

$$V(K_1) = G(K_1) + \gamma P(K_1) - \gamma C(K_1) \tag{3.25}$$

where $G(K_1)$ is the value of the firm assuming that the capital stock remains fixed, $P(K_1)$ is the value of the put option to sell capital in period 2, $C(K_1)$ is the value of the call option to expand the capital stock in period 2, and γ is the discount rate.[45] The existence of these 'option values' within a firm's investment decision, are likely to have considerable influence upon the policies put in place to encourage investment.[46]

This subsection has covered the option approach to investment analysis. The simplest option value that firms must consider is the 'option value of waiting to invest at a later date', when returns are uncertain. This causes the firms to refrain from investing until returns reach a premium above the point where there would be a NPV

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[45] In a similar manner Pindyck (1993a) considers the construction of nuclear power plants where costs of construction are uncertain, but as above the firm has two options, an option to wait for more information before investing and an option to abandon the project. The higher the value of the former the greater is the discouragement to investment, whilst the option to abandon mid-project allows the firm to cut its loses and encourages investment.

[46] Pennings (2005) identifies an important implication for government policy towards foreign firms pondering FDI in a country. Often firms are encouraged to undertake FDI by a potential host government through the offer of financial incentives, which take a number of forms such as grants for investment or training costs. The government in return will receive payoffs in the form of income and corporation tax, and lower benefit payments due to job creation. It is argued that these do not often cover the NPV of the incentives given to investing firms, the remainder of the cost being covered by a halo effect of the FDI upon the surrounding area and businesses. Pennings shows, however, that a government can offer an incentive of nearly the complete cost of the FDI, and then tax away the NPV of all benefits to the foreign firm in making the FDI. This is possible because by issuing incentives the government takes on a share of the uncertainty, which creates the option value of waiting. Firms are therefore willing to undertake investments with a lower threshold rate of return even though much or all of the incentives received will be returned to the host government in the form of tax. It should be remembered that potential host governments face competition from one another in attracting FDI, but in a similar manner firms pondering FDI also face competition from other firms in acquiring incentives for FDI from other firms (see sub-section 3.3.3 for more details on the affects of competition upon the 'option value of waiting' outcomes).

of zero. Other studies have suggested a number of other option values also need to be considered when making an investment, including the option to produce, the option to sell installed capital, and the option to abandon a project. Whether investment will be delayed or not will depend upon the sum of these various options (some of which are negative). However the implication is that irreversible investment will lead to firms investing in a 'lumpy' fashion.[47]

3.3.3 – Strategic Considerations under Irreversible Investment

The literature reviewed in the previous sub-section finds irreversibility to delay investment by varying degrees dependent upon the exact model applied. However in the majority of the literature it is assumed that firms do not face any competition from others in taking advantage of an investment opportunity. In some cases this will be true as, unless the delay is very long, investment opportunities are firm specific and therefore a firm is able to delay investment until it is optimal to undertake it. However in markets that are more mature it is likely that demand increases can be fulfilled by a number of firms. This means that there will be competition to invest first, and therefore create the capacity to gain the additional market share that the increase in demand has created. This subsection examines the work that has looked at the strategic aspects of irreversible investment.[48]

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[47] An alternative explanation for 'lumpy' investment patterns is given by Guo et al. (2005) where firms are faced by irreversible investment, but operate in a world encompassing two regimes of growth rate and volatility of decision variable. Whilst operating within these regimes the firms will utilise a barrier control of the capital stock making small incremental investments. Movement between the regimes will result in large investment spikes, but will return to low levels of investment as barrier control is imposed within the new regime.

[48] A similar consideration might come into affect when firms' behaviour follows that of others, known as herding (Süssmuth, 2003). Signals that encourage investment may not be clear, and therefore firms follow others lead. This will prevent firms from delaying investment, as if one firm invests rather than wait for more information they will assume the other firm has better information and so invest themselves.

The type of strategy adopted by firms varies greatly depending on the type of environment that they operating in. Gilbert and Harris (1984) examine two different types of environment that firms may operate within: a Cournot-Nash equilibrium where investment strategies must be committed to in advance and may not be changed over time; and a pre-emptive equilibrium where firms may attempt to pre-empt competitors' investment decisions. Under the former the standard irreversible investment decision applies, but smaller firms are assumed to invest first as returns to current production are reduced less by increasing capacity, so the smaller the opportunity of expanding capacity the smaller the firm. This results in rent equalisation as smaller firms capital stocks catch up with larger firms. The second environment yielding the pre-emptive equilibrium allows firms the option of trying to pre-empt other firms and gain the first mover advantage. To avoid being beaten to the punch both firms will want to invest in the first time period yielding a NPV of zero. Assuming that one firm has a shorter decision lag than the other, the former firm will invest first gaining a NPV of zero from the investment project. The existence of the competing firm ensures that the firm with the shorter decision lag invests at the first possible opportunity to avoid losing the opportunity to the other firm. Under this model one firm will hold the whole industry capacity, but all rents will be eliminated by the presence of a potential competitor, so unlike the literature studied in the earlier subsections investment will follow the traditional positive NPV rule. Lambrecht and Perraudin (2003) suggest that unless some friction exists in the investment decision, such as incomplete information, the loss of surplus due to pre-emption should result in collusion.

Mills (1988) also finds that all rents will be eliminated when there are sunken costs incurred in the investment process, but finds that this process breaks down when the investment is broken down into two stages, planning and execution, where firms wishing to undertake the planning stage must pay a sunken cost of (ϖ). The firm with the smallest lag between the planning and execution stages, (ι) will undertake the project, as the firm with the shortest decision lag do in the Gilbert and Harris (1984) model. There is however an important further effect associated with the inclusion of a cost from undertaking the planning stage of investment. Without the sunken cost, one firm makes zero profit (the firm with the longer decision lag), whilst the other makes an infinitesimally small profit. The inclusion of the sunken cost means that the firm that loses the investment race will make a negative return from completing the planning stage, and therefore will never undertake this step. The firm that will win the race knows this and therefore delays investment until the period associated with profit maximisation under irreversible investment without strategic considerations.

The strategic situations examined so far have involved cases where there is only the possibility of one firm investing in each investment opportunity. This is not always the case as there is also the possibility that when a new market is forming there is initially only room for one firm to invest but, once the market has formed another firm can enter the market. Dixit and Pindyck (1994) develop a model where two firms invest in a market, with one operating as the 'leader' and the other as the 'follower'. The 'leader' will enter the market at a lower demand level than the 'option value of waiting' implies to be correct, in order to gain the strategic first mover advantage. The second firm will wait to enter the market, entering when the value of investing as the 'follower' is equal to the 'option value of waiting'.[49] Figure 3.4 below depicts this.

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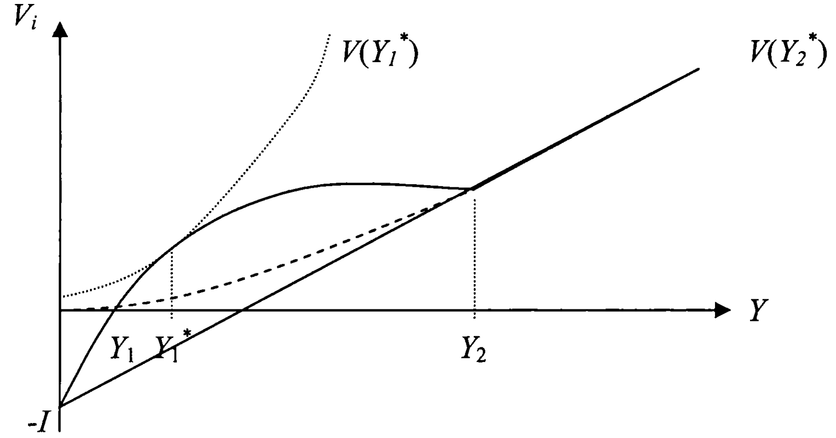
[49] Tvedt (2002) describes a situation in the oil market where OPEC acts as a leader and non-OPEC countries as followers, who invest when oil prices are high and cut back on investment when oil prices are low. Tvedt shows that without perfect information an expansion of OPEC output when prices are

Figure 3.4 – Value of Investing for Leader and Follower Firms



The solid black line represents the value of being the leader in the market, $V_1(Y)$, and the dashed line represents the value of waiting to be the follower, $V_2(Y)$, where Y_1 is the demand level that the leader will enter the market, and Y_2 is the demand level that the follower will enter the market.

Boyer et al. (2001) use a similar model to Dixit and Pindyck (1994) to examine the dynamic investment patterns of firms in oligopolistic conditions. If the firms have identical capacities then the firm that becomes the leader will be the firm with the smaller decision lag, as discussed by Mills (1988). However unlike Mills (1988), Boyer et al. find that, in a similar fashion to Gilbert and Harris's (1984) findings, when the capacities of the firms are unequal the smaller firm will invest first and become the leader. The increase in capacity reduces the returns from existing capital, and therefore the smaller firm has a smaller opportunity cost of investing. Unlike the models presented above, Boyer et al. (2001) show that there is potential in their model for tacit collusion to occur when both firms have the same capacity level, as long as the returns for collusion are greater than the returns from being the leader.

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high may be observed as a fall in demand, so non-OPEC countries do not invest. The knowledge that OPEC will increase output when prices are high results in the trigger price that induces investment by non-OPEC countries being raised, so investment remains in a low rate state for a greater period of time.

Note that the presence of the other firm prevents the leader investing at the optimum demand level for a single firm entering a market with irreversible investment.[50]

The literature reviewed in this sub-section has shown that once the investment opportunity is no longer firm specific, and therefore open to strategic considerations, there is potential for the option value of a waiting rule to break down, and for firms to be forced into investing at the Marshallian demand or price level in order to avoid pre-emption. For this to occur, however, the action of considering a possible investment must involve no sunken costs, and there must be complete information about the other firms in the market. Incomplete information leads to a situation between the two extremes where firms are able to capture some of the value of waiting but not the full rent. When more than one firm can invest in the same market but not at the same time, one firm will be forced into pre-empting the other. The second firm, however, can then wait until the value of the investment is equal to the value of waiting.

3.3.4 – Irreversible Investment and Investment Over the Business Cycle

Nickell (1978) looks at the impact that irreversible investment is likely to have on the patterns of investment observed through the business cycle. In order to avoid over-capacity during recessions, Nickell suggests that firms may start to reduce capital stocks before a downturn in sales in order to reach the new optimum capital stock at the beginning of the recovery phase.[51] The firms will stop investing at period n_0 and

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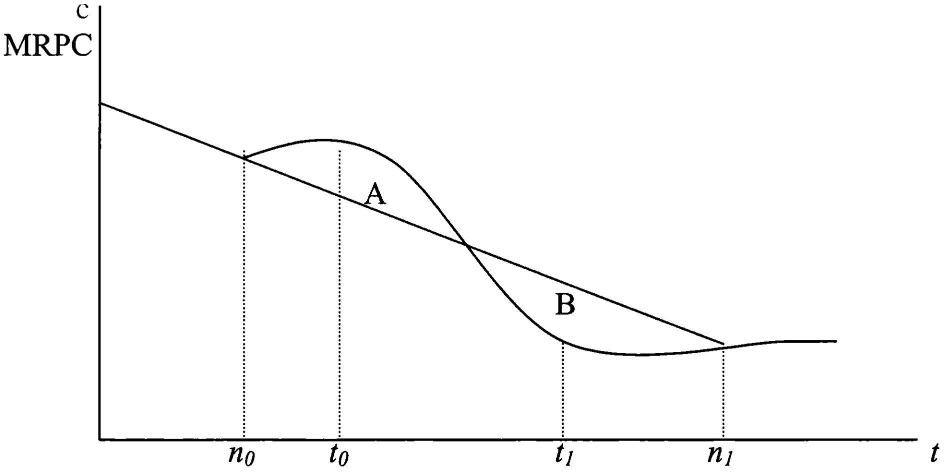
[50] Grenadier (1996) uses a similar approach to Dixit and Pindyck (1994) and Boyer et al. (2001) to model the US real estate market, but finds the initial demand level has an important role to play. When the initial demand level is low then the same results are the same as those found by Dixit and Pindyck (1994), but if initial demand is above the follower trigger value, Y_2, but below the demand level associated with joint investment, Y_J, then both firms will invest if demand either falls to Y_2 (fearing pre-emption), or rises to Y_J. Building booms when demand for property is falling could be explained by this fear of pre-emption when initial demand takes a higher level and falls to Y_2.

[51] Reduction of capital stocks occurs through natural depreciation.

start to invest at period n_1. The downturn in sales will occur at period t_0, and the recovery begins at t_1, (see figure 3.5 below).

Figure 3.5 – Marginal Revenue Product of Capital and Investment



The marginal revenue product of capital (MRPC) initially rises after investment halts, but before sales decrease. After t_0 MRPC falls with sales until the turning point in sales at t_1. Investment is not restarted until the MRPC rises enough to equal the cost of capital, this occurs at n_1. This pattern of investment results in a period when the MRPC is above the cost of capital just before the slump and for the first half of the slump, and then a period when the MRPC is below the cost of capital. In order to achieve an optimum capital policy these two periods should have the same value. Thus areas A and B should have equal area, so that there is no overall gain or loss from the downturn in investment.

Bernanke (1983a) shows that irreversible investment can cause an investment pause when conditions change as firms wait for more information. The example used is the decision whether to purchase energy using or energy saving capital when there is a possibility of an energy supplying cartel forming. Initially this might be observed as temporary and investment in energy using capital will continue. As uncertainty as to the permanence of the cartel increases, investment may stall as firms wait to determine whether the cartel is permanent. Irreversible investment may therefore lead to periods of low investment when uncertainty as to future conditions is high, such as after the oil crises of the 1970s.

As fixed investment is one of the most volatile constituents of output this delay in investment will be an endogenous factor in determining when a recovery will begin after a recession. Gale (1996) gives an example of where this delay may lead to longer slower recoveries than might be expected. Gale's model features N agents, each searching for an innovation, which they have probability w of finding. Once an innovation is found the agent will build a machine to take advantage of the innovation. Every agent either has found an innovation or is searching for an innovation:

(3.26) $$e_t + u_t \equiv N$$

where e_t is the number of agents with a machine (it is assumed that each agent can only hold one machine), and u_t the number of agents searching for an innovation. If a machine is used, it depreciates completely after one period of use. The number of agents searching for an innovation is thus given by:

(3.27) $$u_t = (1 - w)u_{t-1} + x_{t-1}$$

where x_{t-1} is the number of machines being operated in period t-1, (although all agents operating a machine leave the economy after using their machine they are replaced immediately by a new agent). An agent's payoffs from using their machine are assumed to be an increasing function of the level of activity within the economy lagged one period, $f(x_{t-1})$. An agent however has the option of delaying using their machine. Delaying use of the machine one period, to period t+1, allows the agent to receive payoff $\rho f(x_t)$, where $\rho < 1$ is the agents' common discount factor. Therefore all agents will use their machines in the current period if:

(3.28) $$x_t = e_t = N - u_t$$

where e_t is the number of machines present in the economy and because there is no delay is equal to the number of machines being operated in the economy, and:

(3.29) $$f(x_{t-1}) > \rho f(N - u_t)$$

A second regime occurs when economic activity is rising, and agents who own a machine are indifferent between production and delay:

(3.30) $$x_t \le e_t = N - u_t$$

and:

(3.31) $$f(x_{t-1}) = \rho f(N - u_t)$$

In this second regime activity x_t, can be found as:

(3.32) $$x_t = f^{-1}(\rho f(x_{t-1})) \equiv \varphi(x_{t-1})$$

where f^{1} is the inverse of f. Combining the two regimes gives:

(3.33) $$x_t = \min\{N - u_t, \varphi(x_{t-1})\}$$

and:

(3.34) $$u_t = (1 - w)u_{t-1} + x_{t-1}$$

Gale finds that this gives a unique steady state with:

(3.35) $$x^* = \frac{wN}{1+w}$$

and

(3.36) $$u^* = \frac{N}{1+w}$$

In this steady state there will be no delay, as delay can only occur when there is an expectation that activity is rising.

Gale introduces exogenous shocks into the model through the innovation variable w, where the probability of finding an innovation varies between a high state

$w_{H,}$ and a low state w_L. Fluctuations in the innovation variable introduce a cycle into the activity variable, x_t.[52] If there is complete time preference ($\rho = 0$), then activity follows the pattern of the innovation variable completely, but as ρ increases then delay begins to appear. This delay is asymmetric in that it only occurs in the upturn of the cycle, with the recovery being slower and longer.[53] Gale suggests that firms delay production until near the top of cycle when activity may be greater than under a steady state as delay builds up production opportunities that otherwise would not have been present. Activity levels immediately after the recession are lower than would have been the case without delay. This means that delay not only reduces the frequency of a cycle, but also increases its amplitude. Gale shows the results to be robust to relaxing the assumptions relating to complete depreciation, and under various characterisations of the innovation variable's fluctuations.[54] The welfare effects are indeterminate, but the possibility of delay within Gale's model displays considerable influence upon the character of the business cycle.[55]

3.4 – Empirical Work on 'New Wave' Theories

This section of work will survey the empirical work undertaken on the 'new wave' investment theories, described in the proceeding sections. A number of questions need to be answered by empirical work on these theories including, 'how lumpy is

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[52] The innovation variable is assumed to be governed by a Markov process, where initially the states have no persistence, this is later relaxed.

[53] This asymmetry could be described as negative steepness or negative longitudinal asymmetry, (see Chapter 1).

[54] When greater persistence in allowed into the Markov process governing the innovation variable more delay is observed when the low state of the innovation variable has been observed for a longer period beforehand.

[55] In contrast Thomas (2002) argues that with flexible prices, wages and interest rates, lumpy investment will have little impact on aggregate investment patterns, as consumers will still continue to smooth consumption across the business cycle due to the permanent income hypothesis. Flexible prices and interest rates will ensure that if investment spikes are likely to become synchronised, capital goods prices, wages and interest rates will increase, in order to maintain equilibrium, and smooth this effect, thus preventing the distribution affects noted by other studies.

investment', and 'what factors determine how lumpy investment will be'? The empirical assessment of 'new wave' models of investment is more complicated than for traditional models where a representative firm can be realistically assumed. This is mainly due to the aggregation difficulties, where firms have idiosyncratic characteristics and investment is a non-linear function of its determinants. Sub-section 3.4.1 presents the studies utilising plant or firm level data to determine the 'lumpiness' of investment. Sub-section 3.4.2 examines the manner that the plant and firm level 'lumpiness' observed in the studies presented in 3.4.1 create asymmetry within the aggregate investment series. Concentrating upon the cause of the cause of these lumpy investment patterns sub-section 3.4.3 presents empirical evidence of the existence of the 'option value of waiting'. Sub-section 3.4.4 attempts to determine whether irreversible investment has a significant impact upon the patterns of investment through the business cycle.

3.4.1 – How Lumpy is Investment?

The new wave theories suggest that due to a fixed cost of capital adjustment associated with a time value of waiting for additional information, capital adjustments will be undertaken in spikes rather than being smoothed over time. For the 'new wave' theories to be realistic there should therefore be some concrete evidence that investment is not smoothed over time, and this sub-section of work will cover studies that have examined whether there is any evidence for investment to be undertaken in spikes.

Lumpy investment patterns have been identified in individual industries such as the US turbogenerator market (Peck, 1974) and UK brick manufacture (Wood, 2005), but these may be extreme cases because of the indivisibilities and economies of scale prevalent in the individual industries. Doms and Dunne (1998) use the US Census Bureau's Longitudinal Research Database (LRD) of plant level microeconomic data, to examine the patterns of investment for US manufacturing firms. Examination of the data produces interesting results suggesting that firms adjust their capital stocks in a lumpy fashion as would be suggested by irreversible investment. Doms and Dunne (1998) show that the distribution of capital growth rates across the sample, (particularly when weighted by the investment rate) are positively skewed, further over half of the plants were found to adjust more than 37% of their capital stocks in a single year during the sample period (1972-1988). In any single year just over half of the total investment (52%) is attributable to 80% of the firms in the sample that are adjusting capital by less than 10%. Thus, the remaining 48% of investment is attributable to the remaining 20% of firms investing by more than 10% of their existing capital stock. By ranking the each firms' years in the order that investment was greatest for the firm, Doms and Dunne (1998) further found that around half of the investment in the sixteen-year sample period for each firm was attributable to the top three years of investment, which suggests that firms do tend to invest in a lumpy fashion.

Doms and Dunne (1998) also found that the smaller the plant being examined the lumpier investment was likely to be, which could be due to machinery being indivisible, and therefore requiring lumpy investment to replace the capital as it wore out. There was also evidence that although investment is lumpy at the plant level it is less so at the firm level. Where firms were found to have more than one plant in the dataset there was evidence that the firm smoothed investment through time, but did not smooth investment across plants, which could be indicative of some form of fixed cost of capital adjustment at the plant level.[56]

Nilsen and Schiantarelli (1997) find very similar results for the Norwegian manufacturing sector. Their study splits fixed investment into two different categories, plant and equipment (referred to as equipment), and buildings. The data provided by Statistics Norway covers 1866 Norwegian production plants, and clearly shows that the US is not unique in having few gross disinvestments, since only 2% of the observations were found to be negative investment rates in the sample in contrast, 12% of equipment observations are found to be of investment rates greater than 20% of a firms' capital stocks, whilst this figure is found to be 5% of observations for buildings. These investment spikes account for around a third of equipment investment and 50% of building investment which means, as with the US, that investment spikes are an important component of the aggregate investment level. However, Nilsen and Schiantarelli (1997) also found that there was a high frequency of low investment levels (0 – 10%), which would seem to be in contradiction if the existence of fixed costs of adjustment due to irreversible investment. It is suggested that these lower levels of investment are due to replacement investment, which it might be possible to achieve with minimal costs of adjustment, whilst expansion investment results in large costs of adjustment. Nilsen and Schiantarelli's database also gives information on the size of plants and the number and type of plants owned by each firm. The size of plant, as with the evidence for the US, sees more investment spikes for smaller plants, but no more zero investment periods, which means that the possibility of more concentrated investment being due to credit restrictions can be

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[56] This might be particularly the case where investment costs relate to plant closures whilst installation takes place.

discounted. As with the US, Norwegian investment was found to be less lumpy at the firm level.

Gelos and Isgut (2001) follow the technique developed by Caballero et al. (1995) (see Section 3.2), in observing the patterns of actual investment when compared to the rate that would be mandated if the firm were attempting to reach the desired capital level (the level of capital that the firm would wish to hold if adjustment costs were temporarily removed). The desired stock of capital is assumed to be related to the income level, Y_{it}, and the ratio of producer price index for machinery to manufacturing producer price index, P_{mt}/P_t, and a firm specific component, d_i:

$$(3.37) \qquad k_{it}^{d} = \beta_0 + \beta_1 \log(Y_{it}) + \beta_2 \log\left(\frac{P_{mt}}{P_t}\right) + d_i + \varepsilon_{it}$$

whilst mandated investment is found from the estimation of the following equation:

$$(3.38) \qquad \hat{x}_{it} = \hat{\beta}_0 + \hat{\beta}_1 \log(Y_{it}) + \hat{\beta}_2 \log\left(\frac{P_{mt}}{P_t}\right) + \hat{d}_i - k_{it-1}$$

The mandated investment level was calculated for two datasets of firms, one Columbian and the other Mexican. Gelos and Isgut then use a Nadarya-Watson kernel estimator to produce functions of actual investment in terms of mandated investment. The functions derived are increasing with positive investment but when mandated investment is less than zero, where divestment should be taking place, the actual level of investment is found to be positive at a rate between 0.05 and 0.1 for all negative mandated investment rates. The conclusion drawn from this by the authors is that investment is at least partially irreversible and, therefore, when the mandated investment rate is negative firms simply reduce investment to a very low level below the depreciation rate and reduce the capital stock through this slower but less costly process. This was found to be the case for both the Mexican and Colombian firms.

Doms and Dunne (1998), and Gelos and Isgut (1999) also use Herfindahl indicies, which measure the concentration of investment across the firms in the sample. The Herfindahl value is given by the sum of the squared shares of total investment attributable to firms in the sample, therefore the closer the value is to 1 the more concentrated the investment is. The correlations found in the two studies between the aggregate investment rate and the Herfindahl index value, differs, but is always positive, at 0.45 for the US, 0.71 for Colombia and 0.17 for Mexico. This positive relationship suggests that as investment becomes more 'lumpy' and concentrated the aggregate investment rate rises, so higher investment is due to investment spikes rather than an economy wide rise in the investment rate.

3.4.2 – Tests of Asymmetry

The previous sub-section presented studies that have found firms' investment to follow a lumpy pattern rather than smoothly adjusting to an optimal capital stock. Whilst it is relatively easy to identify these lumpy investment patterns at the plant or firm level, this becomes less easy when data are aggregated. The twin effects of stochastic and structural heterogeneity are to increase the speed at which the investment rate returns to the steady state investment rate (see sub-sections 3.2.4 and 3.2.5). This means that investment spikes will tend to be smaller and that their effects disappear rapidly, which will result in difficulty in picking out individual investment spikes. If, the investment rates of firms are being adjusted in a lumpy fashion, however, it should nevertheless result in the aggregate investment series displaying an asymmetric pattern. The issue of asymmetry within the business cycle is not a new subject with economists including Mitchell (1927), Keynes (1936) and Burns and Mitchell (1946) making reference to the tendency for recessions to be shorter and deeper than expansionary periods are long and high. This observation has resulted in a literature devoted to testing for the presence of asymmetry within the business cycle (see Chapters 5 and 6). The tendency for recessions to be deeper than booms are high is described as negative transversal asymmetry (Ramsey and Rothman, 1996), or deepness (Sichel, 1993). In addition to recessions being deeper than booms it has also been noted that economies also display a tendency to contract more quickly than they recover after a recession. Asymmetry in the growth rates of an economy is described as negative longitudinal asymmetry (Ramsey and Rothman, 1996) or 'negative steepness' (Sichel, 1993). Figures 1.1 to 1.3 below show examples of series displaying deepness, negative steepness, and both combined, respectively:

Figure 3.6 - Deepness

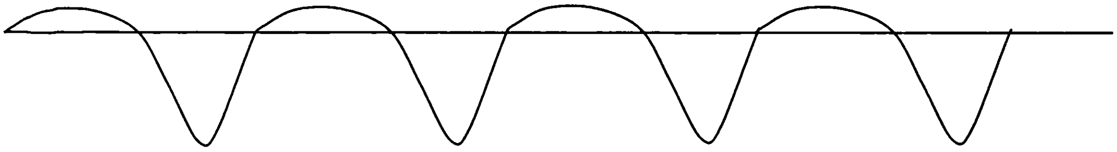

Figure 3.7 – Negative Steepness

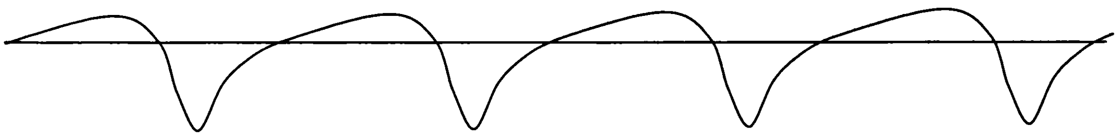

Figure 3.7 – Deepness and Negative Steepness

Any asymmetry present in investment series is likely to follow the opposite pattern to that of the business cycle as a whole, as investment is generally thought to be positively skewed (Caballero et al., 1995). Investment data are therefore likely to display positive transversal asymmetry (highness) and positive longitudinal asymmetry (positive steepness). Some industry groups within UK manufacturing are likely to be more strongly influenced by considerations relating to irreversible investment, and therefore identification of asymmetry of the form dictated by the presence of irreversible investment can be used to isolate those industry groups more strongly affected by irreversible investment considerations.

Neftçi's (1984) paper sparked renewed interest in testing for asymmetry in the business cycle. Much of this work has concentrated upon asymmetry within the business cycle in terms of national output and unemployment (see for example Westlund and Öhlén, 1991, and McQueen and Thorley, 1993). With results for unemployment and industrial production found to vary greatly from country to country, and period studied, however, a limited number of results are also available for investment data. For example Falk (1986) applied Neftçi's procedure to US gross domestic private investment and whilst finding investment recoveries are more persistent than contractions this is not at a statistically significant effect. Speight and McMillan (1998) use the Sichel deepness and steepness test and find no asymmetry in a number of measures of investment.

Rather than testing for asymmetry Stanca (1999) initially tests for non-linearity suggesting that this would be due to asymmetry in the business cycle. The data tested are Italian annual and quarterly data for the periods 1861-1992 and 1960-1995, and covers GDP, consumption, investment, exports and imports. A number of tests for non-linearity are used including McLeod and Li's (1983) portmanteau test, the BDS test (Brock et al., 1996) and a variety of LM-tests. When representing the investment series with an AR process, neglected non-linearity is found for both the annual and quarterly data, and Markov-switching approach was found to eliminate this neglected non-linearity. A similar result is found by Bodman (2001) for the Australian economy where the BDS test finds non-linearity in investment, but no asymmetry can be identified using Randle et al.'s (1980) triples test.

Whilst the plant and firm level data used in the studies in sub-section 3.4.1 suggested considerable lumpiness in the investment patterns of firms, identifying signs of irreversible investment in aggregate investment series is harder to identify. As well as testing for non-linearities directly, a number of authors have adopted the approach of trying to identify asymmetry within the series, which would be symptomatic of irreversible investment and the lumpy investment patterns it causes. The papers presented above in this sub-section show that generally little evidence has been found for asymmetry within investment series, although this may be due to lack of power in the multiple tests applied (Psaradakis and Sola, 2003). The remainder of this section looks at more direct work modelling the option value of waiting and the consequences of irreversible investment for the business cycle as a whole.

3.4.3 – The Option Value of Waiting to Invest

Sub-section 3.4.1 showed that there is considerable evidence that firms choose to invest in a lumpy fashion rather than smoothing investment through time. This answers one of the questions asked in the introduction to this section, but it still remains to be demonstrated that the option value of waiting for more information is important in causing this investment pattern. The studies in this sub-section examine the impact of irreversible investment upon firms' investment decisions through the 'option value of waiting' that it creates, and the hurdle rates of return that are required to accommodate these 'option values of waiting'.

Pindyck (1993a) empirically tests a situation where firms face two kinds of uncertainty, technical uncertainty (β) and input price uncertainty (γ). Technical uncertainty is a lack of information relating to the difficulty in completing the investment project in terms of time and money, which will only diminish as investment is undertaken. Input cost uncertainty, however, be reduced by simply waiting for more information to become available through time. Input price uncertainty therefore has a standard option value of waiting attached to it, but technical uncertainty generates an extra value in undertaking investment, and therefore encourages investment, so raising the hurdle cost.

Pindyck (1993a) uses the example of the construction of a nuclear power station to calibrate his model. As with the normal option value analysis where a hurdle rate of return must be exceeded in order to induce investment, the analysis of variable construction costs requires costs to be less than a critical value. Pindyck investigates how this critical value varies with different values of β and γ. Using time series data from the Tennessee Valley Authority on construction cost, minimum and maximum values of β are estimated (0.24 and 0.59 respectively). The maximum and minimum values of γ were calculated in a similar fashion by fitting the mean expected cost to a geometric random walk, (yielding a minimum γ of 0.07 and a maximum value of 0.2).

Critical values were then calculated for the construction of 1 kilowatt of generating capacity with a value of £2000, a real interest rate of 4.5%, expected construction of 10 years, and the calculated minimum and maximum values of β and γ, as well as for a deterministic environment in which $\gamma = 0$. The mean expected construction cost in 1982 was $1,435 per kilowatt and it is notable that this value exceeds all of the critical values calculated in the presence of input cost uncertainty. Pindyck (1993a) suggests that this is why a large number of projects to construct nuclear power plants were cancelled in this year.[57]

One of the most common examples used in theoretical work relating to the option value of waiting to invest is that of a firm choosing whether to develop an oil reserve with some unknown qualities.[58] Paddock et al. (1988) attempt to empirically test the realism of the theory. They study the sale of 21 oil tracts by the US government, and use two separate methods to value the oil tracts.[59] These estimates of the value of the oil tracts is then compared with the actual bids received in order to determine which valuing method is most similar to those used by the firms in question. The two valuing methods used were a discounted cash flow analysis, and an option value technique, where the second technique is based upon the fact that firm is buying an option to develop the tract if it is the successful bidder. Both techniques use the same geological data provided by the US Geological Survey (USGS). Additional market information is also used under the option valuing method concerning the likely volatility of oil and gas prices and the value of undeveloped oil and gas reserves, as well as two separate valuations of the mean value of gas reserves. The gas valuations were taken from market data, and roughly represent the upper and lower expected values of gas reserves, which means that a mid value would be likely to predict the mean bid quite accurately. When using the lower of these two mean values of gas reserves, both methods yield values below the mean bid value for the tracts. However, using the higher valuation of gas reserves, the option value provides an overestimate

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[57] The 'option value of waiting' is used by Pindyck (1993a) to explain why a number of nuclear power plant construction schemes are cancelled, but on the other hand, Bowe and Lee (2004) show that the Taiwan High-Speed Rail Project would not have been built, without the additional value associated with options to delay, expand or contract various stages of the project.

[58] Slade (2001) uses another natural resource example investigating the decision to temporarily close or reopen Canadian copper mines, and finds considerable additional value associated with this management flexibility relative to the traditional discounted cash flow value of the mine.

[59] The oil tract sale was Federal lease sale No. 62, which was held in 1980. The sale was of central and western tracts in the Gulf of Mexico.

of the average bid made. The winning bids were much higher than the average valuations predicted by each method, and the mean bids. This could be due to a 'winners curse' or different geological information.

The relative success of the option value technique in predicting the average bid shows that it is likely that an option value of waiting to invest may exist for many investment decisions, but unlike the sale of oil tracts, these options to invest in the future are not bought in the same manner, but do exist due to the individual characteristics and expertises of individual firms. The oil industry provides a good example of the option values associated with an investment opportunity, as tangible options can be bought in the form of exploration rites to tracts of land or seafloor, and therefore the option value is more easily given a value, by each firm bidding.

3.4.4 – Investment Spikes and the Business Cycle

If investment is irreversible then the patterns of investment described in sub-section 3.3.4, as suggested by Nickell (1978), are such that there will be a strong correlation between the number of firms adjusting their capital stocks and the rate of output growth. Both Doms and Dunne (1998) and Gelos and Isgut (1999) found that there was a positive correlation between the number of firms experiencing investment spikes and the growth rate. Doms and Dunne (1998) find that there is a positive correlation between the number of plants that have their maximum investment rates in each year and the aggregate investment rate. Nilsen and Schiantarelli (1997) find that the correlation coefficient between the number of firms having their highest equipment investment years and aggregate equipment investment is 0.67, and for buildings the correlation coefficient is found to be 0.86. Gelos and Isgut (1999) similarly find a positive correlation between the number of plants experiencing an investment spike (greater than 20% of current capital stock) in any year and the aggregate investment rate.

Bertola and Caballero (1994) show that the existence of irreversibilities helps to explain the relatively smooth pattern of aggregate investment through time relative to the movements of a desired aggregate investment level calculated using a neo-classical model in which investment is assumed to be reversible and adjustment costless. The desired capital stock was assumed to be a function of market conditions, Z_t, and the price of capital, P_t^K in the following way:

$$(3.39) \qquad K^d\left(Z_t, P_t^K\right) = \left(\frac{c}{\alpha}\frac{P_t^K}{Z_t}\right)^{1/(\alpha-1)}$$

where c is a variable that represents a fixed proportion of capital good prices that the marginal revenue product of capital is not allowed to rise above, which is effectively the hurdle rate of return required to induce investment.

The above model is used to calculate the path of the desired investment rate, and also the path of investment when the irreversibility condition is included. Bertola and Caballero (1994) found that whereas the desired aggregate investment level had a first order serial correlation of 0.25, the fitted model produced incorporating irreversible investment had a first order serial correlation of 0.66. This was compared to the US gross investment to capital stock ratios for the period 1954-86, which was found to have a first order serial correlation of 0.68. The fitted model of irreversible investment was, however, found to only explain 36% of the actual investment series variability. This means that although Bertola and Caballero were able to explain the relative hysteresis observed in investment patterns, the irreversible investment model was only able to explain a relatively small amount of the investment variability.

3.5 – Summary of Chapter

The literature covered in this chapter has examined the alternatives to assuming that investment is subject to symmetric convex adjustment costs. Section 3.1 looked at the problems faced by the standard neoclassical investment function with convex adjustment costs in explaining the patterns of investment observed in the economy. A number of alternative adjustment cost functions were reviewed in sub-section 3.1.1, with asymmetries appearing to have an affect upon the length of time that different phases of the business cycle are likely to take. Costs functions involving piecewise or fixed components were found to be likely to lead to lumpy investment patterns rather than the traditional assumption of investment being smoothed through time. These findings are likely to have large impacts on the policies put in place by governments with the intention of targeting investment.

Sub-section 3.1.2 then considered the difficulties faced by economists in attempting to produce models of lumpy investment due to data availability problems, and measurement difficulties. Although more disaggregated data on fixed capital accumulation has become available in recent years, the problems of measuring the capital stock accurately, and the difficulties that temporal aggregation present in observing firms' investment decisions still persist.

Section 3.2 covered the (Ss) adjustment mechanisms originally developed to model the adjustment of inventory stocks, but modified to model the adjustment of capital stocks by firms facing fixed costs of adjustment. Sub-section 3.2.2 described the benefits in modelling aggregate investment using the (S,s) approach. It was shown by the literature that the presence of aggregate shocks large investment spikes would be apparent within aggregate investment. Sub-sections 3.2.4 and 3.2.5 suggested that the presence of structural and stochastic heterogeneities would smooth these investment spikes when viewing the aggregate. The use of hazard functions effectively creates a continuum of bandwidths that smooth patterns of investment observed (structural heterogeneity is effectively increased).

Section 3.3 introduced the concept of irreversible investment. The inability of firms to reverse investment without incurring some cost means that firms face a fixed cost of investment. When choosing to invest firms must balance the value of the investment project against the value of waiting for further information relating to future prices and demand to become available. Extensions such as strategic considerations were found to have major impacts on the theoretical results of firms' decisions to invest. The impact of the assumption of irreversible investment upon the timing of business cycle phases is also pronounced in that in order to optimise the investment decision through time, investment is found to be delayed beyond the beginning of the recovery.

Section 3.4 covered the empirical studies of the 'new wave' investment theories. Examination of the investment patterns observed for individual firms does appear to suggest that there are fixed components to adjustment costs, as there is strong evidence of lumpy investment patterns. Investigations of data relating to the oil extraction industry which represents one of the best examples of irreversible investment shows that the models have some potential to model investment more accurately than the traditional theories of investment.

The implications of irreversible investment and the (S,s) adjustment mechanism are greatly affected by the level of uncertainty faced by firms. Without some uncertainty regarding future market conditions there is no value in waiting for further information to become available, as all information is already available. Chapter 4 therefore examines the role that uncertainty plays in traditional investment theory, and compares it to the consequences of different forms of uncertainty upon the theories of investment covered in this chapter.

Chapter 4 – Investment under Uncertainty

How the level of uncertainty faced by firms is incorporated into their investment decisions has lead to the creation of a large literature. Each of the main areas of investment theory stretching from the Keynesian theory of investment through Tobin's *Q* to option pricing models of investment have been studied from the perspective of firms operating in more realistic non-deterministic conditions, where the future is not certain and simple to plan for. There has been a large amount of debate about the impact that an increase in the level of uncertainty has on the level of investment spending by firms in the long and the short term, and even what sign the uncertainty-investment relationship takes.

Although a number of sections in chapters 2 and 3 referred to the uncertainty-investment relationship, the sheer scale of the literature, and the conflicting results relating to the relationship contained therein, result in the relationship requiring a dedicated chapter. In order for this to be comprehensive this means going back to the earlier theories and reconsidering each in turn. Section 4.1 examines what is truly meant by uncertainty, and the number of different measures used in theoretical and empirical work on investment. Section 4.2 provides an overview of the literature covering views on the uncertainty-investment relationship derived from traditional theories of investment, whilst the consequences for modern theories of investment are examined in Section 4.3 including the impact of assuming that investment is irreversible, and shows that uncertainty is of particular relevance when this is the case. Empirical work undertaken to determine the sign of the relationship is presented in Section 4.4. Section 4.5 summarises and concludes the chapter.

4.1 – Sources of Uncertainty

When making investment decisions, firms are faced by a number of different forms of uncertainty that have to be accounted for. Firms are faced with uncertainty relating to: the exact cost of its own investment opportunity (Pindyck, 1993a and 1993b); the investment cost of other potential competitors (Lambrecht and Perraudin, 2003); future real interest rates (Ingersoll and Ross, 1992); the price of output in the future (Oi, 1961); production costs in the future; and market demand in the future (Smith 1969).[60,61] These different forms of uncertainty can mainly be consolidated into uncertainty about the cost of capital, and uncertainty about the future revenue stream from the investment project. In order to simplify in analysis, most of the literature relating to uncertainty and investment has concentrated upon only one or other of these sources of uncertainty.

In the same manner that Tobin's Q gives a single measure of all expectations relating to future returns, some studies have attempted to find an overall measure of uncertainty for a firm or the economy through time. The main attraction to using Marginal or Average Q within investment equations is that expectation of future conditions should be implicitly included within the Q variable, via the stock market valuation of the firm. These expectations should be weighted appropriately for their importance to the investing firm (or more accurately the outside world's opinion of their importance). This approach of using market valuations into the investment-uncertainty relationship analysis has led to work looking at the variation in a firm's stock return and either the risk premium carried by the firm's stock relative to the

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[60] Adjustment costs may also be uncertain, which will make the decision of whether to invest or not more complicated.

[61] Where a firm trades internationally, exchange rate uncertainty will also impact upon the investment decision, (Goldberg, 1993; Campa, 1993; Campa and Goldberg, 1995).

market (Craine, 1989), or the risk premium carried by the interest rate of the economy (Ferderer, 1993).

Another area of analysis has focused on the impact of idiosyncratic uncertainty and economy, or industry wide, uncertainty. That is, is there a greater impact arising from uncertainty about the prices received by one firm in particular, or uncertainty from the average price received by the market as a whole? This has motivated work looking at the uncertainty evident in an individual firm's share price, and its impact upon investment relative to the uncertainty of the shares in the entire market, or the firm's market sector (Henley et al., 2003).

The many sources of uncertainty and their possible interactions in a structural model of investment and uncertainty have also led to the search for a single variable that encompasses all information relating to uncertainty. Thus, a final method of measuring uncertainty is to look at variables that are not directly related to an individual firm's future revenue stream from any particular investment opportunity open to them. Examples of this could include the variability of national income or consumption. Although demand for the firm's goods are included in these measures they will generally make up such a small percentage that such measures give an indication of the variability of general market conditions rather than directly measuring the market conditions directly relating to the firm's decision. The reason for using this type of measure is that it may give an indication of where measures specific to the firm might be heading in the future, and these measures are less likely to be affected by one-off large changes.[62]

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[62] One of the more unusual measures of uncertainty is that used by Carruth, Dickerson, and Henley (2000a), where the price of gold is used as the measure. The reasoning behind this is that gold is used as a low risk hedge, so that when market conditions become more volatile, investors will move capital into gold, which is seen as being immune to market volatility. Thus the price of gold is likely to be positively correlated with the level of volatility in the economy.

4.2 – The Traditional View of Uncertainty

Although in the 'General Theory of Employment, Interest and Money', Keynes (1936) does not explicitly model the impact of uncertainty, he does note that the decision to invest should not only be based upon the long term expectations of the returns from the capital, but the confidence with which these predictions are held. A natural assumption to make is that as the returns expected become less certain an investment opportunity will appear less attractive, however, the assumption of risk neutrality makes this initial assessment less strong, where higher returns, associated with higher risks will have no impact upon the level of investment.

The structure of the remainder of the section is as follows. Sub-section 4.2.1 describes how a positive investment-uncertainty relationship is found under traditional investment theory. Sub-sections 4.2.2 and 4.2.3 show that this positive relationship only holds under certain conditions, the first being that the elasticity of substitution relatively low, and the second that form taken by capital adjustment costs must be convex.

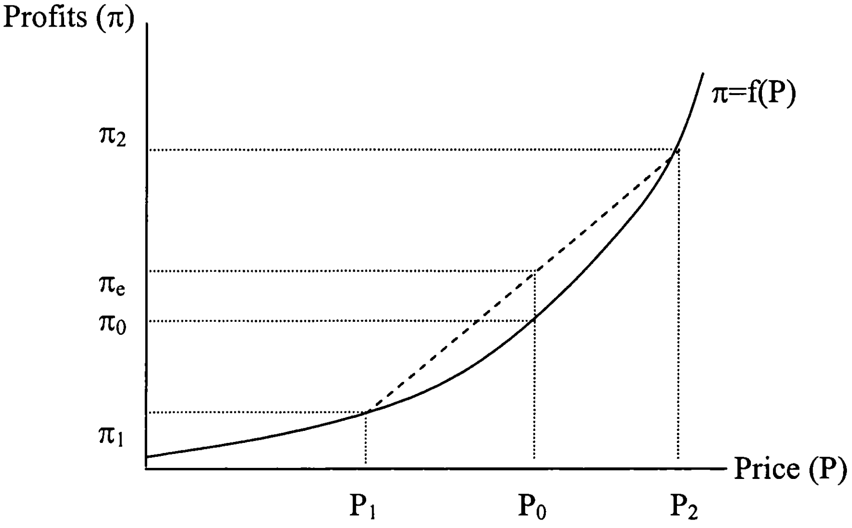
4.2.1 – The Effect of Uncertainty upon Expectations of Future Returns

Oi (1961) investigates the impact of price instability on firms' expectations of profits and utility:

> "Intuitively, it appears as if a competitive firm should always "prefer" stability in prices to instability in prices. This is hardly the case. In fact we shall prove that instability in prices will always result in greater total returns. All this proof requires is that firms maximise short run profits at each point in time."
>
> Oi (1961) page 58

Oi proves that with profits convexly related to prices a greater level of uncertainty of the price of output will result in higher expected profits via the Jenson inequality. A simple example can show this. Consider two situations, one where the price of output is certain at a value of P_0, and a second situation where the price of output can take one of two values, P_1 or P_2, where the mean of these two prices is P_0. If profits (π) are related to the output price via a convex function, ($\pi = f(P)$), the expected profit will be the mean of the two possible profit values, $\pi_e = 0.5(\pi_1 + \pi_2)$. This is shown by figure 4.1 below.

Figure 4.1 – Expected Profits and the Jenson Inequality



The diagram shows that the convexity of the profit function results in the expected profit under uncertainty, π_e, being higher than the profit level associated with a certain price level of π_0. Oi (1961) concludes that this effect will hold as long as firms maximise short run profits each period and the marginal cost curve of each firm is upward sloping throughout the relevant range. These higher expected profits under uncertainty it might be expected would encourage more investment within the market as firms choose higher optimum capital stocks, a theme expanded by others (Hartman, 1972).

Hartman (1972) shows the potential for the existence of a positive relationship between investment and uncertainty. Hartman's model is of a firm that chooses its level of capital, K_t, before production commences in each period. Adjustments to the capital stock are subject to an adjustment cost function:

$$(4.1) \qquad C\left(I_t, P_t^K\right)$$

Such that the cost function $C(\bullet)$ is positively related to the investment level during the period, I_t, and the price of capital, P_t^K, and takes a convex form in relation to the investment level. The firm chooses the capital level in order to maximise profits according to the following function:

$$(4.2) \qquad h\left(K_t, p_t, w_t\right) = K_t g\left(p_t, w_t\right)$$

Both sides of the above equation represent the profit function in different forms. The profit function is assumed to be homogeneous to degree one in capital, and therefore can be expressed as on the right hand side. The profit function is assumed to be convexly related to the price of output (p_t) and the wage rate paid to labour (w_t). A firm therefore has to choose capital to maximise the discounted cash flows represented in the equation below:

$$(4.3) \qquad E\sum_{t=0}^{\infty} \rho^t \left[K_t g(p_t, w_t) - C\left(I_t, P_t^K\right)\right]$$

where ρ^t is a discount factor, and capital is assumed to depreciate at a rate of δ. This means that the marginal unit of capital purchased in period t is expected to add the following level of profit in period $t + s$:

$$(4.4) \qquad E_{(>t)}(1-\delta)^{s-1} g\left(p_{t+s}, w_{t+s}\right)$$

where $E_{(>t)}$ is the expectation of prices after period t conditional on prices up until t. Firms should invest so that the returns from the marginal unit of capital discounted through time are equal to the cost of adjusting the capital stock by this marginal unit of capital:

(4.5) $$C_1\left(I_0, P_0^K\right) = \sum_{t=1}^{\infty} \rho^t (1-\delta)^{t-1} E\left[g\left(p_{t+s}, w_{t+s}\right)\right]$$

As $g(\bullet)$ is convex in both p and w, a mean-preserving spread in either will increase the value of $E[g(\bullet)]$, and in order for the equality to continue to hold in equation (4.5) there will have to be an increase in I_0. This shows how greater uncertainty in this model will lead to higher investment by a profit maximising firm. Hartman also shows that as P^K does not appear on the right hand side of the equation an increase in the uncertainty of capital prices will not affect the level of investment.

4.2.2 - The Investment-Uncertainty Relationship and the Elasticity of Substitution

Rothschild and Stiglitz (1971) show a positive investment-uncertainty relationship is also likely to arise where a firm uses two factors of production, labour and capital. Labour is assumed to be a variable factor of production, and capital is a fixed factor of production, and the firms have to select their desired capital stock, *K*, before the output level, *X*, is known. Once the output level is known, firms choose the quantity of labour required to minimise costs of production, *L*(*X*,*K*), so that the ratio of factor prices (cost of capital, *r*, and wages, *w*), is equal to the marginal rate of substitution:

(4.6) $$\frac{r}{w} = E\left[\frac{\partial L(X,K)}{\partial K}\right]$$

Rothschild and Stiglitz further find that the positive investment-uncertainty relationship holds as long as the elasticity of substitution is equal to, or less than, unity. They consider the extreme opposite case where the elasticity of substitution is infinite, which allows the relationship between investment and uncertainty to be either positive or negative depending on the distribution of the possible values of output, $G(X)$. A production function as shown in equation (4.7) below is assumed:

$$X = bK + aL \qquad (4.7)$$

If the probability of X being greater than bK (the original capacity of the firm) increases then the capital stock will increase. If the probability that the firm will not be able to meet its output level with the old capital stock declines, the optimum capital stock will fall.

Smith (1969) finds the same importance of the elasticity of substitution upon the sign of the investment-uncertainty relationship. Smith develops a model incorporating capital as an imperfectly variable factor of production, so the capital stock is determined before demand is known, but can be utilised at different rates once demand is known. The production function used is Cobb-Douglas with an elasticity of substitution of 1. This ease of substitution means that fear of under-capacity is not a problem as additional labour can always be used. Therefore capital stocks are lowered with uncertainty to prevent the problem of over-capacity. Smith (1969) also shows this would not be the case with alternative production functions with lower elasticities of substitution, such as a linear homogeneous constant elasticity of substitution (CES) production function.

4.2.3 – Uncertainty, Investment and Adjustment Costs

Pindyck (1982) examines the effect of uncertainty over future demand and cost levels. Demand is modelled as evolving stochastically over time, but with current demand levels already known. Pindyck examines the impact that different forms of capital adjustment costs will have on the capital stock firms choose to hold. If adjustment costs are convex (concave) the optimum level of capital will be increased (reduced).

This is because when the marginal cost of capital adjustments are convex it is less costly to reduce the level of investment than to increase it. This means that firms would rather hold more capital than under certainty, so in the event of a demand increase investment does not have to be increased, and firms are instead able to reduce the investment rate in the next period if demand happens to be lower than expected. It is found that firms will produce a higher level of output due to this increased optimum capital stock under uncertainty when adjustment costs are convex, but at higher average costs. This is because in attempting to avoid what Pindyck describes as the 'quasi-fixed cost' of adjustment (the additional cost faced by a firm if it has too low a capital stock and has to increase the capital stock at a faster rate in the future), firms will no longer operate at the optimum factor cost ratio.

Abel (1983) reassesses Pindyck's (1982) model and criticises the fact that in the above model firms do not move towards an optimum capital stock, but rather Pindyck describes them as moving towards a target capital stock where the expected rate of change in the capital stock is zero and the expected rate of change in the investment rate is also zero. In reality this is unlikely to be the long run target of a firm. Abel assumes that firms operate according to a Cobb-Douglas production function, and that capital is adjusted with a convex adjustment function. This means that firms paying a wage of w, and facing a capital adjustment function with a constant elasticity of adjustment of β, will have a cash flow of:

$$p_t L_t^{\alpha} K_t^{1-\alpha} - wL_t - \gamma I_t^{\beta} \tag{4.8}$$

where, p_t is the output price, which follows a stochastic process given by:

$$dp_t / p_t = \sigma dz \tag{4.9}$$

where dz is a Weiner process with mean zero and unit variance. Abel finds that the optimum investment rate under the equation (4.8) is found where the marginal cost of investment is equal to the marginal valuation of capital (V_K):

$$(4.10) \qquad \gamma\beta I_t^{\beta-1} = V_K$$

which gives an optimal rate of adjustment of:

$$(4.11) \qquad I_t = \left({q_t}\big/{\beta\gamma} \right)^{1/(\beta-1)}$$

Since β is constant this means that the investment rate is entirely dependent on q_t, where q_t is the present value of the expected marginal revenue product of capital. Abel therefore suggests that rather than looking at the impact that uncertainty has upon investment, it is possible to look at the impact that uncertainty has on q_t, where q_t is given by the following equation:

$$(4.12) \quad q_t = \frac{hp_t^{1/1-\alpha}}{r+\delta-\dfrac{\alpha\sigma^2}{2(1-\alpha)^2}} = \int_t^{\infty} hp_t^{1/1-\alpha} e\left[\left(\alpha\sigma^2(s-t)/2(1-\alpha)^2\right)-(r-\delta)(s-t)\right]ds$$

where $s > t$, δ is the constant proportional rate of physical depreciation, and:

$$(4.13) \qquad h = (1-\alpha)(\alpha/w)^{\alpha/(1-\alpha)}$$

such that, $hp_t^{1/(1-\alpha)}$, is the marginal revenue product of capital. In equation (4.12) q_t is increasing with uncertainty (σ). This result holds for all shapes of adjustment cost rather than just a convex adjustment cost function as with Pindyck's (1982) model. Abel (1983) also finds the expected rate of change in investment to be:

$$(4.14) \qquad \frac{1}{dt}E_t\left(\frac{dI_t}{I}\right) = \frac{1}{(\beta-1)}\frac{1}{dt}E_t\left(\frac{dq_t}{q_t}\right) + \frac{(2-\beta)\sigma^2}{2(\beta-I)^2(1-\alpha)^2}$$

or:

(4.15) $$\frac{1}{dt}E_t\left(\frac{dI_t}{I_t}\right)=\frac{1}{2(\beta-1)(1-\alpha)^2}\left(a+\frac{2-\beta}{\beta-1}\right)\sigma^2$$

This means that under certainty the expected change in the investment rate will be equal to zero, but when uncertainty is non-zero there will be a positive expected rate of change in investment. Abel (1983) also notes that there is an impact upon the relationship between investment and uncertainty from the shape of the adjustment cost function

> "Under certainty, the growth rate of investment is equal to the growth rate of q, multiplied by the elasticity of investment with respect to q_t, $1/(\beta\text{-}1)$, as may be verified from (19). However under uncertainty, this relation holds only if the marginal adjustment cost function is linear. If the marginal adjustment cost is convex (concave), then, under uncertainty, the expected growth rate of investment is less (greater) than the expected growth rate of q_t multiplied by the elasticity of investment with respect to q_t."
>
> Abel (1983) page 232

This is most clear in equation (4.14) where the final term on the right hand side takes a value of zero under certainty, but where σ, is non-zero and, β not constant, the constant proportional relationship between the growth rates of investment and q would no longer hold.[63]

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[63] The capital asset pricing model (CAPM) suggests that uncertainty will lead to a higher level of investment. The CAPM indicates that, all else being equal, for two projects to be equally attractive when one has a greater level of uncertainty associated with its returns, the project with the greater uncertainty must produce a higher expected rate of return. With the assumption of risk neutrality a firm will desire a higher capital stock for a project with higher returns as the firm attempts to equate the cost of capital with net returns. This would give a similar result to that found by Hartman (1972), described above. However, Craine (1989) shows that although there is likely to be convexity of the firm's indirect profit function in relation to uncertainty in factor and output prices, this may not be the case in equilibrium when using the CAPM as a basis for determining returns and resource allocation. Craine uses risk as a measure of uncertainty, where risk, $\beta(i)_t$, is measured as the covariance between an asset's return, $R(i)_t$, and the discount factor of the market, D_t. Craine finds that whilst a mean-preserving spread in an exogenous variable such as output prices or factor costs affecting one industry sector will increase the expected return to capital from that industry sector, the increase in risk to one particular sector will reallocate resources away from the sector towards other sectors. This means that an increase in risk will have no impact on the level of investment in an industry sector.

4.3 – Uncertainty and Irreversible Investment

The literature covered in the previous section generally suggests that a positive investment-uncertainty relationship will hold, but that the nature of capital adjustment costs and elasticity of substitution will have a major impact upon that relationship (Pindyck, 1982; Abel, 1983; Smith, 1969) as firms balance the potential costs of holding too great or too small a capital stock, and the costly adjustments implied by each. The patterns observed in aggregate investment can therefore be expected to change greatly with the inclusion of the assumption that investment is irreversible, with the potential of holding too large a capital stock becoming much more important and costly.

The assumption that investment is irreversible creates an option value in waiting for further information to become available relating to the decision to invest. This 'option value of waiting' was shown to create the lumpy investment patterns described in sections 3.2 and 3.3, as firms wait for returns to reach a hurdle rate to compensate for the loss of the option to wait. The literature presented in this section explains the effect of uncertainty upon, not only the value of the investment project itself, but also the option value of waiting, and the results that increasing/decreasing uncertainty has upon investment patterns and the optimal capital stock.

4.3.1 – Uncertainty, Investment Irreversibility and Delay

Pindyck (1991) shows how the 'option to wait' to invest becomes more valuable the greater is the uncertainty present in expected demand or price. This is because the firm is able to wait to determine whether conditions will change greatly, and invest in good conditions but avoid investing in bad conditions. Pindyck (1988) examines the capacity choice of firms from a slightly different prospective, where firms do not have to operate at full capacity. This means that firms that hold capital have an option to produce, as well as an option to invest in further capital. This potential to produce if demand warrants has to be balanced against the value of waiting. Pindyck (1988) finds that the 'option value of waiting' is greater under most circumstances. Thus, Pindyck's analysis suggests that the irreversibility of investment can change the positive relationship suggested by traditional theories of investment into a negative relationship as the value of waiting becomes greater, but other considerations can also give a negative relationship, as discussed below.

Leahy and Whited (1996) suggest that irreversible investment produces a concave marginal revenue product of capital, which would again result in a negative relationship between investment and uncertainty, under a mean-preserving spread. This conclusion comes from a competitive environment where poor demand conditions would leave firms stuck with over capacity and therefore poor returns to capital, whilst an upturn in demand will be limited in its benefits as investment will increase capacity and stop returns increasing. This means that irreversibilities will increase the downside of any project, whilst competition limits the upside.

Ingersoll and Ross (1992) examine a simple investment opportunity, where firms make one payment and receive a real return of $1 in the following period, but this project can only be taken once and is indivisible. The form of uncertainty examined is uncertainty about future interest rates. If interest rates are expected to fall in the future the firm will delay making the fixed investment (*I*) as long as possible; conversely, if the interest rate is expected to rise the project will be undertaken immediately. To avoid confusion with these effects it is assumed that the interest rate is expected to remain unchanged into the future, but follows the stochastic process:

$$dr = \sigma\sqrt{r}\cdot d\omega \tag{4.16}$$

where $\sigma\sqrt{r}$ is the standard deviation of real interest rates, and $d\omega$ is the increment of a standard Weimar process.[64] Ingersoll and Ross (1992) find that, as in Pindyck's (1991) model, the greater the uncertainty relating to the investment project the greater the value of the option to wait. This means that the trigger value of real interest rates, r^*, will be reduced from the break even interest rate of, r^0. When considering projects lasting 10 years of less, the difference between the break even and trigger rates of interest rate (r^0-r^*) is found to be proportional to the standard deviation of the real interest rate. With the above conditions:

$$(4.17) \qquad \left(r^0 - r^*\right) \approx \vartheta\left(\sigma\sqrt{r}\right)$$

varying σ has little impact upon relationship, when the real interest rate is assumed to be 4%, the difference between the break even and trigger interest rates is found to be roughly three and a half times the annual standard deviation, ($\vartheta \approx 3.5$). This means that delay is roughly invariant for different levels of interest rate volatility, as ($r^0 - r^*$) increases with σ, so although the triggered interest rate falls it is reached roughly with the same frequency. Investment projects with longer maturities are also considered but it is found that there is little affect on the difference between r^0 and r^* other than when the volatility of interest rates is high. Ingersoll and Ross therefore show that the assumption of irreversible investment has the same impact upon the uncertainty-investment relationship if the uncertainty is attributable to fluctuating interest rates, as well as demand or price variables.

Caballero (1991), however, suggests that the connection between irreversibility and the negativity of the relationship between investment and uncertainty may not be that strong, and suggests that imperfect competition and

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[64] The Weimar process follows $d\omega = \varepsilon_t\sqrt{dt}$ where ε_t is a normally distributed random variable that is serially uncorrelated has a zero mean and unit variance.

decreasing returns to scale may be the main factors producing the negative relationship. Using a two period model it is found that as competition is made less perfect, the elasticity of demand becomes more inelastic. The more inelastic is demand, the less convex the marginal profitability of capital with respect to price uncertainty becomes. Caballero finds that due to this effect, under perfect competition, investment is almost exclusively related to the price and marginal profitability of capital discounted into the future. Therefore a positive relationship holds between investment and uncertainty, as predicted by traditional theories of investment. Moreover, imperfect competition results in the profitability of capital being greatly affected by the capital stock, and as the convexity of the relationship between prices and marginal profitability of capital disappears, the positive effects of greater uncertainty disappear. Therefore the relative costs of having too large a capital stock are increased, and the 'option to wait' becomes more influential. Irreversibility still impacts upon the investment decision, as it makes it far worse to hold a capital stock that is too large rather than too small. Thus:

> "An increase in investment today makes it more likely that the firm will find its second-period capital "too large" relative to the desired capital stock. When adjustment costs are asymmetric having "too much" capital is worse than having "too little" of it, since increasing the stock of capital is cheaper than decreasing it. If this effect is sufficiently strong (i.e., the asymmetry of adjustment costs is large and the negative dependence of the marginal profitability of capital on the level of capital is strong), the investment-uncertainty relationship becomes negative. The irreversible-investment arguments analysed in the literature typically correspond to this case."
>
> Caballero (1991) page 286

In short, decreasing returns to scale were found to make a negative relationship more likely.

Pindyck (1993b) examines a similar model to Caballero (1991), where a two period model is examined under two differing sets of conditions. First, certainty about market demand in both periods and, second, uncertainty in market demand in the second period. Pindyck examines the model from the point of view of firms operating in a market that is assumed to be competitive, and finds that, as with traditional theories of investment with a mean-preserving spread, there will be a greater incentive for firms to invest whilst there is convexity in the value of the marginal unit of capital. Pindyck notes that although there is an incentive for firms to increase the capital stock there would be no actual increase in the level of investment as firms would note that others would be equally induced into investing, which would increase their capital stock and therefore the capacity and output of the industry exactly enough to drive the price of output down to the level that would exist under certainty.

4.3.2 – Investment Timing verses Intensity

Most of the work involving lumpy investment and the relationship between the capital stock/investment and uncertainty has found that the greater the level of uncertainty the higher the trigger value that will be required to induce firms to invest. This means that investment will generally be delayed, and therefore it is expected that there will be a negative relationship between the uncertainty and investment. However, as Hubbard (1994) notes, much of the work regarding lumpy investment and the option value of waiting in the early 1990s simply looked at the timing of investment rather than the capital stock associated with it.

Dixit and Pindyck (1994, Chapter 11) examine a model of incremental investment (or capacity choice) with irreversible investment. As noted above, an increase in uncertainty results in the trigger value required for investment to take place being increased. However, as uncertainty increases, although the trigger values of investment are increased, the greater variability of the demand shift variable will result in the trigger being reached more often so that there is a balance between the two effects, making it difficult to determine whether the investment rate will increase of decrease.

Bar-Ilan and Strange (1999) produce a model that not only examines the timing of investment, but also the intensity of investment. Their paper compares the capital stocks associated with different investment patterns, including incremental investment as observed in the traditional theories of investment and lumpy investment patterns from the 'new wave' theories of investment. Firms are assumed to acquire capital at a cost of P^K per unit, which produce forever at a production rate of K^a. Bar-Ilan and Strange find that when investment is taken in an incremental fashion, uncertainty will reduce the capital stock purchased by the firm relative to that under lumpy investment. Although most work on the impact of uncertainty when investment is lumpy has found that this results in the trigger values being raised and thus investment delayed, Bar-Ilan and Strange find that although the investment is delayed it is ambiguous whether the capital stock chosen under lumpy investment will be reduced or increased when there is uncertainty present, and is dependent on the price of capital.

Under incremental investment, for all price ranges, the capital stock is either unaffected by uncertainty or negatively related to uncertainty. Under lumpy investment, there is no impact upon the capital stock in very low price ranges. For a mid range of prices, there is a negative relationship between investment and uncertainty, because once uncertainty is introduced into the system the option value of waiting is greater. In higher price ranges, therefore, there is a positive relationship between investment and uncertainty. This is because although investment is delayed by uncertainty once it occurs it is at a higher intensity, and therefore the capital stock is higher in uncertain conditions.

Hartman and Hendrickson (2002) derive a model of optimal investment with partially reversible investment similar to that produced by Abel and Eberly (1996), (see sub-section 3.2.1). Abel and Eberly use an additive term (I^S) to represent the difference between the purchase price of capital and the price that firms are able to sell capital for. The Hartman and Hendrickson (2002) model differs in one main respect in that it is assumed that I^S enters the model multiplicatively so that the firms purchase capital for a price of P_t^K at time *t* and are able to sell capital for P_t^K / I^S. They analyse the effect of complete irreversibility ($I^S \rightarrow \infty$), partial reversibility ($I^S >$ 1) and complete reversibility ($I^S = 1$) of investment upon the patterns of investment. As in the Abel and Eberly (1996) model, partial reversibility results in a three regime pattern, with the area of inaction between the two trigger values dependant upon the level of uncertainty of capital returns and output prices. However, when looking at the long run growth rate of capital, although investment will take very different paths depending upon the level of reversibility that exists, the long run growth rate is the same under irreversible, partially reversible and reversible investment.

4.3.3 – Output Growth and Uncertainty

Although the 'new wave' theories of investment have lead to a resurgence of interest in investment-uncertainty relationship, another branch of work has also indirectly examined this relationship, but through the output growth-uncertainty relationship. As noted above Keynes (1936) suggested that uncertainty will make investments riskier which, unless accompanied by higher returns, would discourage investment. The opposite view of the output growth-uncertainty relationship can be expressed through

Solow's (1957) neo-classical growth model. Sandmo (1970) suggests that greater uncertainty will lead to higher levels of saving.[65] This should move the economy to a higher level of growth as the greater savings generate higher levels of investment in Solow's model.

Mirman (1971) shows that the relationship can be either positive or negative depending upon the shape of the firms utility function, with a convex (concave) utility function generating a positive (negative) relationship between investment and output uncertainty. This indicates individuals either lowering present consumption to raise future consumption prospects, or raising present consumption to hedge against an uncertain future. Black (1987) suggests that an economy is faced with a trade-off between higher output growth rates and lower volatility. This is because only with greater volatility will higher levels of returns be available, which will encourage greater investment.

Blackburn and Galindev (2003) show that the sign of the relationship may be driven by the source of productivity gains. Where productivity gains are external to the production process, recessions will be periods when the opportunity cost of making productivity gains will be low, whilst if productivity gains are fortuitous accidental discoveries linked to the production process then recessions will be characterised by a slowdown in productivity gains. The mixture of sources of productivity gains will make it more likely that the output growth-volatility relationship will be positive if the sources of productivity gains are more heavily

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[65] It should be noted that Sandmo divides uncertainty into two types, income risk and capital risk. Income risk refers to risk relating to future income levels for which savings act as a method of guaranteeing future consumption. Higher income risk therefore always reduces current consumption so savings rise. Capital risk relates to the level of uncertainty relating to expected returns from capital investment, and has two opposing affects upon the consumption decision, an income and a substitution effect. The income effect sees consumption fall to hedge against very low levels of future consumption, whilst the substitution effect sees capital investment decline, as investors become less willing to expose resources to possible losses. The overall effect of increasing capital risk depends upon which effect dominates.

weighted outside the production process, and more likely to be negative if gains more readily come from within the production process. Blackburn and Pelloni (2004) further indicate that the source of shocks will also be important in determining the relationship. Both greater dispersion of nominal (money transfer) and real (preference) shocks will raise the variance of growth rates, however real shocks will generate a positive effect upon the average growth rate through greater savings, whilst nominal shocks will have a negative effect.[66]

4.4 – Empirical Tests of the Investment – Uncertainty Relationship

As the proceeding three sections described, the theoretical investment-uncertainty relationship is a matter of considerable controversy, the traditional theories pointing towards a positive relationship, whilst the 'new wave' theories indicate that there is likely to be a negative relationship. This section reviews the empirical work that has been produced in order to try and clear up the confusion associated with uncertainty's role in the investment decision.[67]

4.4.1 – Output Growth and Uncertainty

As discussed in sub-section 4.3.3 the relationship between investment and uncertainty has been examined directly, but the consequences of this relationship have also been a

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[66] Blackburn and Pelloni (2005) expand their model to include three types of shock, monetary, technological and preference, and show that only the stabilisation of monetary shocks will increase the output growth rate, and that under other shocks the central bank faces a trade-off between stabilisation and the growth rate. Therefore the degree to which stabilisation is undertaken depends upon the relative welfare effects.

[67] Some studies rather than determining the sign of the relationship add to the confusion by estimating relationships of both sign, such as Sing and Patel (2001), who study the UK property market. Although a majority of results are negative, certain sources of uncertainty are found to generate significant positive relationships at certain lag lengths when the relationship between investment and 'instantaneous uncertainty' is significantly negative.

topic of discussion, with the effect of uncertainty upon output growth producing two main rival theories championed by Black (1987) and Bernanke (1983) respectively. Empirical studies of this relationship, as with the direct investment-uncertainty relationship, face the same difficulties discussed above, of which the most prominent is the correct (relevant) source of uncertainty and how is this best modelled. Earlier studies used cross sectional approaches, such as Kormendi and Meguire (1985) who use a sample of 47 countries to assess the determinants of international growth rates for the period 1950-1977. Output growth uncertainty is measured as the standard deviation of real output growth (*SDY*) for the sample period. A positive relationship is found between the mean growth rate and output growth uncertainty.[68] Grier and Tullock (1989) use a similar approach using a sample of 113 countries, but rather than using a cross sectional approach, five-year averages of the data are used to remove cyclical fluctuations but still allow temporal variation. The standard deviation of growth is again used as the uncertainty measure, and a positive relationship is found with growth initially. However, extensions to separate countries into sub-samples of OECD and rest of world find these results are not robust, particularly when dummies are included for civil liberties, where only Asian countries display a significant effect of output growth volatility upon output growth, but this is found to be a negative relationship.

Ramey and Ramey (1995), however, find a negative relationship when using a similar uncertainty variable, the standard deviation of output growth per capita.[69] Ramey and Ramey (1995) suggest the differing sign on the uncertainty variable in

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[68] Kormendi and Meguire (1985) further isolate the Black hypothesis and the Sandmo higher savings effect by allowing the mean investment to income ratio (*MIX*) to enter their estimations. Again a positive relationship is found between *MIX* and growth whilst the effect of *SDY* is still found to be significantly positive implying that both Sandmo and Black effects do exist and are identified by the positive coefficients on *MIX* and *SDY* respectively.

[69] Ramey and Ramey (1995) use two samples of countries, 92 countries with annual data for the period 1960-1985, and a second sample of 24 OECD countries running from 1950-1988.

their study may be due to the inclusion of the standard deviation of monetary shocks in earlier studies, which had a negative relationship with growth, and possibly a positive correlation with output growth volatility. This may mean that the positive relationship is found in earlier studies only accounts for the predictable movements of growth, which are largely due to the persistence of growth. Ramey and Ramey (1995) estimate output growth without an uncertainty measure and then re-estimate output growth using two further 'uncertainty' measures, the standard deviation of innovations and standard deviation of fitted values. A positive relationship is found for the standard deviation of fitted values (the predictable persistent component) but, as before, a negative relationship for the standard deviation of innovations (the unpredictable uncertainty component). Ramey and Ramey also suggest that a positive relationship between government spending volatility and output growth volatility exists. Estimating government spending growth using a simple model based upon lagged GDP per capita, lags of government spending per capita and a quadratic time trend, Ramey and Ramey estimate output growth innovations using squared innovations from the government spending equation. A significant positive relationship is found for the squared government spending innovations and output growth innovation volatility. Therefore their findings suggest that higher government spending volatility is likely to be associated with low output growth.

Two failures of earlier approaches using the variance of output growth as an uncertainty term within a cross sectional setting become apparent, first that uncertainty for individual countries cannot vary through time, and second that variance of output growth may not be a good measure of uncertainty, as it contains the measure is equally influenced by predictable movements in output as unpredictable ones.[70] Caporale and McKiernan (1996) offer a solution to these failings by utilising a Generalised Autoregressive Conditional Heteroskedastic in Mean (GARCH-M) approach.[71] The conditional variance calculated by the GARCH process has the benefits of evolving through time, based upon past innovations of the mean equation and lagged values of the conditional variance to model persistence of the measure. The conditional variance makes a better measure of uncertainty as it is not influenced by predictable movements in output growth. Caporale and McKiernan (1996) find a positive relationship between output growth and output growth uncertainty for the UK.[72] Speight (1999), however, notes that the in-mean term used by Caporale and McKiernan (1996), the log of the conditional variance, will be negative if the conditional variance is less than 1. This will generate a coefficient on the in-mean term of the opposite sign to the true relationship between output growth and uncertainty. Speight (1999) reassesses the same data using the conditional standard deviation as the in-mean term, and allows for non-normally distributed errors in the conditional mean equation. No significant relationship is found for the output growth-uncertainty relationship. Caporale and McKiernan (1998) apply the GARCH-M approach to annual US data running from 1870-1993. Using the conditional standard deviation a positive relationship is found. Impulse response functions show that the positive relationship only takes effect after 3 years, which is consistent with the Black hypothesis, given the delays present in the investment process. Marci and Sinha (2000) look at Australian industrial production using the same technique and find a significantly negative relationship. Whilst the GARCH-M approach appears to solve

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[70] Ramey and Ramey (1995) attempt to solve these problems by using innovations from their government spending equation as a determinant of output growth uncertainty, which allows output growth to vary through time, and the use of innovations means that only the unpredictable movements can influence uncertainty.

[71] Please see Section 9.2 for a detailed explanation of GARCH and related models.

[72] Monthly growth of industrial production data from Citibase running from 1948:1-1991:09.

the two problems identified by Ramey and Ramey (1995) in modelling the output growth-uncertainty relationship, applications of the technique have found widely differing results from different data sets.

Later studies using GARCH-M techniques to model the output growth-uncertainty relationship have included this relationship in more complicated models where the main aim has not been to study this relationship. For example Henry and Olekalns (2002) model the relationship, but included it within a current depth of recession (CDR) model where the in-mean component was insignificant. Other studies including, Grier and Perry (2000), Grier et al. (2004), and Shields et al. (2005) model the output growth-uncertainty relationship in conjunction with relationships relating to inflation uncertainty. Whilst Grier and Perry (2000) use a bivariate GARCH-M system and find no evidence of a relationship between output growth and output growth uncertainty, Grier at al. (2004) using a Vector Autoregressive Moving Average (VARMA) with variance governed by a GARCH-M process find evidence of a positive relationship.[73] Grier et al. (2004) also find evidence of asymmetric effects of shocks, with a negative growth innovation causing more volatility than a positive one. Shields et al. (2005) show that output growth uncertainty has a much more persistent response from output growth and inflation than from inflation uncertainty. As with Grier et al. (2004), there appears to be a 'bad news' effect with uncertainty being more strongly increased by negative output growth innovations, and again a positive impact of output growth uncertainty upon output growth.

Using a similar approach to the later studies of the output growth-uncertainty relationship described above, Price (1995) examines the impact of the conditional

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[73] One major advantage of Grier et al.'s (2004) over Grier and Perry (2000) is that conditional correlation across equations is not assumed to be constant as in Grier and Perry's (2000) bivariate GARCH-M system.

variance of GDP upon investment in the UK.[74] A significantly negative investment-uncertainty relationship is estimated. The long-run negative effect of uncertainty upon investment is calculated to be approximately 5% per year. The negative long-run affect upon investment rises to peaks of 48% (1974) and 38% (1979-80) associated with oil crisis shocks.

Whilst it appears that a majority of studies find a positive relationship between output growth and output growth uncertainty, it is by no means a complete consensus of opinion. Although few studies find a negative relationship there are a considerable number that find the absence of a relationship.

4.4.2 – Price Uncertainty and Investment

The sign of the relationship between investment and uncertainty as discussed above is likely depend upon the importance of the irreversibility constraint. However, choosing the correct measure of uncertainty may also have importance. The studies described below use a number of different uncertainty measures and obtain different results.

As discussed in the proceeding three sections the way that uncertainty is measured can be very important in determining the impact that uncertainty will have upon the investment rate. Caruso (2001) uses a number of different measures of output price uncertainty to examine the impact that these different forms have upon investment. Caruso's study uses data from 17 Italian industry sectors in 20 Italian regions, with annual data collected for the period 1980-1994. Caruso regresses gross investment per effective worker upon output per worker, non-performing loans as a ratio of value added per regional economic sector, the average local output inflation rate, and measure(s) of output inflation uncertainty. The uncertainty variables

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[74] Price (1995) uses a GARCH(1,1) process to estimate the conditional variance of GDP.

included in different forms of the equation were intended to represent the different types of uncertainty firms face with regard to inflation in output prices. The simplest uncertainty variable calculated is the unconditional volatility (standard deviation) of the inflation rate. The other measures of uncertainty are calculated from one of two auxiliary equations, modelling price inflation by region, and industry sector, and decomposed to provide measures of anticipated inflation volatility, and unanticipated inflation volatility. Two further uncertainty variables are calculated, which measure the persistence of price uncertainty following Cochrane (1988) and Campbell and Mankiw (1987a, b). The results of the regressions undertaken by Caruso (2001) indicate that the coefficients of the inflation, unconditional variance, and unanticipated uncertainty variables are negative, but insignificant. The anticipated volatility variables were found to have significant negative effects upon investment, as was the persistence of price uncertainty. A similar analysis was also conducted to assess the impact of uncertainty relating to output, but only the anticipated component of output uncertainty was found to be significant, the sign of the effect once again being negative. Quantitatively the negative impact of a one standard deviation rise in volatility above the sample mean upon investment was found to be a reduction of roughly 7.5%. Of this reduction 2.6% is accounted for by anticipated inflation volatility, 2.9% is due to the persistence of price volatility and the remaining 2% is due to anticipated output volatility.

Darby et al. (1999) examine the relationship between exchange rate uncertainty and investment under irreversible investment, where a firm faces a private discount rate of:

(4.18) $$\mu = r + \phi\rho_{PM}\sigma$$

where r is the risk free discount rate, ϕ is the market price of risk, and ρ_{PM} is the coefficient of correlation between the (exchange rate) price P and the portfolio of possible investments used to calculate the opportunity cost of waiting. When volatility increases some literature suggests that investment will fall as the area of inaction between the price that induces investment (P_H) and the price at which an investment is scrapped (P_L) will increase. Darby et al. (1999) show that although this is true in their model the probability that the price is greater than P_H and less than P_L both rise with an increase in volatility, but $\Pr(P > P_H)$ rises at a faster rate than $\Pr(P < P_L)$. The reason for this is that as prices are restricted to $P > 0$, volatility rises will not be mean preserving. In addition to this, the opportunity cost of waiting also rises as the firm's discount rate rises with volatility. This means that although the trigger value increases there may not necessarily be a reduction in the investment rate. How a firm's overall decision is affected then depends upon the firm's opportunity cost of waiting and scrapping value of the project (P_L), where the higher each of these values are, the stronger is the impact of $\Pr(P > P_H)$ as volatility rises. Investment equations are estimated for five OECD countries, and there is found to be a negative investment-uncertainty relationship, but where this negative impact is much smaller than suggested by the 'new wave theories'.[75]

4.4.3 – Aggregate or Idiosyncratic Uncertainty

Henley et al. (2003) consider whether uncertainty affecting the industry as a whole or uncertainty only affecting the firm in question have different impacts on the decision to invest. It is quite logical that this might be the case, since uncertainty affecting only

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[75] The investment equations modelled are selected on a country by country basis for France, Germany, Italy the UK and US. The estimations use quarterly data with a sample period spanning the late 70s, 80s and early 90s.

the firm might be seen as offering the firm the opportunity to invest in projects with more risk but higher returns, whilst industry wide uncertainty would suggest that there might be difficulty in reselling industry specific capital. This could be viewed as making industry specific capital more irreversible. Henley et al. (2003) measure the level of industry uncertainty $\left(\sigma_{it}^{S}\right)$, as a moving average of the standard deviation of the sector's producer price index. The firm specific uncertainty is calculated by forecasting the returns of the firm using the capital assets pricing model (CAPM), and then using an average of the forecast residual as the firm specific uncertainty $\left(\sigma_{it}^{F}\right)$, as follows:

$$(4.19) \qquad R_{it} - R_t^f = \alpha_i + \beta_i\left(R_t^m - R_t^f\right) + \varepsilon_{it}$$

Equation (5.26) above is the CAPM equation used to form the forecasts of the firms returns, where R_{it} is the return from firm i in period t, R^f is the risk free rate of return, and R^m is the market rate of return. Empirically, investment is found to be inversely related to industry uncertainty, in that a one standard deviation increase in industry uncertainty lowers investment by 3.6%, but positively related to firm specific uncertainty, in that a one standard deviation increase in firm specific uncertainty lagged by one year raises the investment rate by 7.5%.[76]

Caruso (2001) also examined the impact of uncertainty upon those firms most greatly affected by aggregate shocks. His study, developed a measure of price uncertainty persistence (see sub-section 4.4.2). In order to determine whether firms that had greater co-movements with the aggregate were more strongly affected by

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[76] Bulan (2005) uses a similar technique to Henley et al. (2003) to calculate a measure of firm specific uncertainty from equity returns for a panel of US firms. A measure of industry uncertainty is also calculated from the volatility of the retruns of the industry index orthogonal to the market return. Unlike Henley et al., Bulan finds both sources of uncertainty have a negative effect upon investment, but with firm specific uncertainty having the greater impact in lower investment. The negative relationships are found to be stronger when investment is to a greater extent irreversible, as measured by the mix of investment goods purchased by the industry in question.

price uncertainty persistence, Caruso split his sample into two sub-samples. This was done by running an auxiliary regression of each economic sector's change in output upon the overall output change per worker for Italy, and dividing the sample in two by the median R^2 value. The firms with the larger co-movements were found to be more greatly affected in terms of the reduction of their investment by the persistence of price uncertainty variable.

4.4.4 – Uncertainty and Strategic Considerations

The studies covered in the proceeding sections found that, in general, the theoretical conclusions of work on the uncertainty-investment relationship were that although a positive relationship was suggested by earlier studies, this implication is reversed when the assumption of irreversibility is introduced. The empirical studies reviewed above have found that the relationship has typically been found to be negative so providing support for the 'new wave' theories. In sub-section 3.3.3 however, it was suggested that the negative relationship between uncertainty and investment may break down when strategic considerations are taken into account. This sub-section examines the empirical studies that have examined the role played by market structure and market power in that relationship.

Ghosal and Loungani (1996) examine panel data for 254 4-digit manufacturing industries obtained form the US Annual Survey of Manufacturers and Census of Manufacturers. The uncertainty measure used is calculated using the standard deviation of the residuals from an auxiliary autoregressive regression model for output prices. The standard deviation of the residuals was calculated for fourteen year periods, 1958-71, 1959-1972 …1975-88. These were then used as the measures of uncertainty in investment equations calculated for each industry for the years 1972-

89. In order to examine the strategic impacts upon the relationship the industries were split into a number of different groups using the four firm seller concentration ratio (CR4). The groupings are CR4 ratios of less than 20%, less than 40%, greater than 40%, and greater than 60%. A number of alternative specifications of the investment equation were used with investment determined by one of the following; sales and cash flow as shares of capital stock, and growth of real sales ΔS. Two final specifications used measures of uncertainty where more recent years in the 14 year samples of the residual terms were weighted more heavily, with one weighting giving weights to last 4 years of the sample as 52% of the total, and the second, weighting the most recent four years as 60% of the total. The results reported reveal that as the CR4 rises, so that firms have to operate in a more oligopolistic environment and therefore think more strategically, the irreversibility constraint loses its impact, and the uncertainty-investment relationship becomes positive (as indicated by Hartman, 1972). The groups containing firms where the CR4 is low display a significant negative relationship between investment and uncertainty in all of the specifications tested by Ghosal and Loungani. The positive coefficients are not significant for the CR4 $\geq$ 60%, but the absence of a significant negative coefficient suggests that it is important to take strategic considerations into account. However, it is unclear whether reducing the high concentration group to firms with even more market power would produce a significant positive relationship, as strategic considerations take over, or whether monopoly power would begin to develop and a negative relationship take over again. The coefficients produced using all industries in the sample find a mixture of results, with no significant coefficients. This might explain some of the difficulty in finding a single investment-uncertainty relationship in other studies.

Henley et al.'s (2003) study of industry and idiosyncratic uncertainty splits the sample into firms belonging to industries with highly concentrated markets and those belonging to industries with low concentration markets. The highly concentrated industries were found to be affected more strongly by both types of uncertainty, whilst the low concentration markets were found to be unaffected by industry uncertainty at a statistically significant level. This could be a sign that, whereas those firms in highly concentrated industries were able to fully maximise the option value of investment, firms in more competitive markets were unable to wait for further information in the face of industry specific uncertainty, and therefore only the positive relationship from firm specific uncertainty remained.

The relationship between investment and uncertainty as shown in the above studies is dependent on the measure of uncertainty used (firm, industry or aggregate), and the market structure that applies to the firm in question. The strategic considerations that have been examined in this sub-section become important as the concentration ratio rises but, theoretically at least, where a single firm is the only one that is able to make the investment the uncertainty-investment relationship once again becomes negative.

4.4.5 – Further Considerations

Given the numerous sources of uncertainty affecting firms' investment decisions, further complication seems far from warranted. Rather than additional sources of uncertainty it is the form that this uncertainty takes and the way that firms react to it that needs to be considered. One notable refinement is the separating of permanent and transitory components of uncertainty. Chadha and Sarno (2002), for example, split monetary policy uncertainty into temporary and permanent components (following Kim, 1993). More specifically uncertainty arises from a permanent component, and a slowly decaying temporary component. In application to data for seven OECD countries,[77] both permanent and temporary uncertainty components were found to be significant for some countries. All the significant uncertainty coefficients generated were negative, but the temporary components were quantitatively more important, and Chadha and Sarno therefore conclude that inflation targeting regimes rather than price level targeting regimes would boost investment more.[78]

Baum et al. (2001) suggest that if movements within the exchange rate can be decomposed into permanent and transitory components, then these will have very differing effects upon firms' actions. Firms should only take account of those movements in the permanent component, and ignore the transitory movements. Greater volatility in the permanent component will result in firms updating their investment decisions frequently to account for these changes, this should raise the volatility of firms' profits. Which as described in Section 4.1 should raise the desired capital stock and therefore investment rate through the Jenson inequality. However, firms will not be able to observe the permanent and transitory components separately, and therefore if the transitory component is very volatile the firms may not be able to observe any changes in the permanent component. Baum et al. suggest that this will encourage firms to take a more conservative approach making fewer changes to their investment decisions, which is likely to lead to less volatile profits for the firms, and

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[77] The countries examined are the US, UK, Germany, France, Italy, Sweden and Spain, with quarterly data covering the period 1948-1997, and an earlier sample period running up to 1913. Starting with a very general model non-significant components were dropped and the models re-estimated with the final model being selected using the AIC. A Kalman filter procedure was utilised to allow all components to vary through time.

[78] Similar results are found by Byrne and Davis (2004) using a Markov switching approach to generate permanent and temporary measures of inflation uncertainty, the temporary component again having the strongest negative impact.

therefore, lower investment. Byrne and Davis (2005) uses a component GARCH (CGARCH) model to estimate the uncertainty relating to the permanent and transitory components of exchange rate movements, for a panel of countries, and find a negative relationship between transitory uncertainty and investment, whilst a positive relationship is found for uncertainty relating to the permanent component.

4.5 – Summary of Chapter

The theoretical studies that have been undertaken to determine the relationship between investment and uncertainty have been many and varied, as have their results. Even determining the sign of the relationship has been difficult, as the way in which, uncertainty enters the decision making process of a firm can be through a number of possible channels. A majority of the literature produced in the absence of the assumption that there is some degree of irreversibility in investment has suggested that there was a positive relationship between uncertainty and investment, This is a result of the convexity between the marginal revenue product of capital and the capital stock, whereby the increase in returns associated with a mean-preserving spread means that an increase in uncertainty leads to an increase in the optimum capital stock.[79]

The 'new wave' theories with irreversibility incorporated are based upon the existence of an 'option value of waiting for further information', in which case an increase in uncertainty would increase this value of waiting, resulting in investment being delayed. This initially appears to suggest that irreversible investment generates a negative relationship between uncertainty and the investment rate. However, this need not be the case as, although investment may be delayed, in the case of lumpy

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[79] Later studies found that this result held only with an inelastic elasticity of substitution (Rothschild and Stiglitz, 1971; Smith, 1969), and convex capital adjustment costs (Pindyck, 1982).

investment when investment occurs it may be at a higher intensity. Further, where firms pursue a course of barrier control, such that investment is undertaken incrementally, the higher trigger values for investment will be to some degree counteracted by the fact that the trigger values are reached more quickly under greater uncertainty.

Section 4.4 showed where additional complications may also arise. As well as attempting to model the various option values that firms have to take into account when making investments, there are also different forms of uncertainty that will impact upon the investment decision. Section 4.4 showed that whereas traditional theory has suggested that there will be a positive relationship between investment and uncertainty, and the ‘new wave’ theories suggest the opposite, there have been mixed empirical results so neither point of view can yet be confirmed. Sub-section 4.4.3 offered one possible explanation for these mixed results, which involves taking strategic considerations into account. That is, if both effects are in operation, so that the convexity of the profit function increases investment whilst the option value of waiting for further information delays investment, it will depend on the relative values of these effects as to whether there is a positive or negative investment-uncertainty relationship. As concentration ratios rise the strategic considerations become more important and the positive impact of the convex profit function will take control, but at either end of the competition spectrum it appears that the time value of waiting is more important and therefore uncertainty delays investment.

Although there is strong evidence for irreversibilities being present in investment at the plant or firm level its effect upon both the overall aggregate investment patterns observed, and the investment-uncertainty relationship (if any), is still unclear in magnitude and to some degree direction. The following chapter introduces the data and methods that are utilised in this study in order to attempt to further clarify these relationships, particularly at the semi-aggregated industry and industry group levels.

Chapter 5 – Asymmetry Tests

Whilst the effects of investment being irreversible can be identified relatively easily at the firm or plant level where lumpy investment patterns will be evident, when examining aggregated investment series this becomes more difficult with the lumpy investment patterns disappearing due to stochastic and structural heterogeneity relating to the firms. The higher the level of aggregation the smoother patterns that are likely to be observed within the investment series. However, as firms are likely to have skewed investment rate distributions with a relatively small number of years presenting a high investment rate when an investment spike is undertaken, and a relatively large number of years with relatively low investment rates, when no investment (or only replacement investment) takes place, the aggregate is likely to display some asymmetry where shocks common to all or a group of firms occur, and a number of firms undertake an investment spike in the same period. As discussed within sub-section 3.4.2 this asymmetry can take two main forms transversal asymmetry and longitudinal asymmetry. If irreversible investment is present and firms have enough in common that shocks occur which cause a large enough percentage of firms within the aggregated investment series to under take investment spikes together, both of these forms of asymmetry are likely to be found in the investment series. Transversal asymmetry will be created by fewer, but absolutely larger observations being above the trend than below it, caused by the investment spikes. Longitudinal asymmetry is also likely to occur as firms are likely to increase investment rates rapidly once an investment spike is induced, but given 'time to build' considerations and delivery lags the rate is likely to decrease to the original level more slowly, giving a 'fast up, slow down' pattern.

Sections 1.2 and 3.4 noted that one of the simplest ways of identifying the presence of asymmetry in an economic series is to determine whether the series' distribution is skewed. A large number of different tests have been developed in order to test for skewness using different assumptions. These include using the skewness variable itself as the test statistic. This approach however comes with a number of drawbacks, the main one being that the assumption of a normally distributed population is imposed upon the tested series, which may be incorrect. Alternatives to this approach have used a number of non-parametric tests to test for asymmetry without the need to impose the assumption of normality upon the distribution.

This chapter therefore utilises the skewness based 'deepness' and 'steepness' tests as developed by Sichel (1993) to test for both longitudinal and transversal asymmetry but in addition to this an a non-parametric test is proposed to provide comparative results to those of the initial deepness and steepness tests, the proposed test being the Triples test developed by Randles et al. (1980).

Section 5.1 outlines the 'deepness' and 'steepness' tests and Section 5.2 will discuss the Triples tests. The previous studies applying the Sichel and Triples tests are reviewed in 5.3 Section 5.4 looks at the different issues that must be considered in selecting the appropriate sources of investment data, in order to detect the presence of irreversible investment. The investment data used within this chapter and later chapters are introduced in Section 5.5. Alternative detrending techniques that can be applied to impose stationarity upon the data are discussed in Section 5.6. The results of the tests will be analysed in Section 5.7, and the chapter summarised in Section 5.8.

5.1 – Sichel's Deepness and Steepness Tests

As noted above and in Section 1.2 one of the simplest ways of identifying the presence of asymmetry in an economic series is to determine whether the series' distribution is skewed. Sichel (1993) developed two tests to examine the skewness of a detrended series, which makes it possible to identify a number of characterisations of any asymmetry present in the series. One advantage of Sichel's tests is that they allow the separate identification of two differing types of asymmetry, (as noted in Section 1.2). When analysing economic time series it is necessary to look at this skewness relative to the trend followed by the series (Delong and Summers, 1986).

This section describes Sichel's (1993) tests that can be applied to the detrended component, x_t, of variable y_t, thus:

$$x_t = y_t - \tau_t \tag{5.1}$$

where τ_t is a non-stationary trend component, and the stationary component, x_t, possibly consists of cycle and noise components. As discussed above a series exhibiting positive (negative) transversal asymmetry has fewer observations above (below) the trend than below (above), but the average deviation of observations above (below) trend should exceed the average deviation of observations below (above). Sichel (1993) describes series displaying positive (negative) transversal asymmetry as displaying 'highness' ('deepness'). Transversal asymmetry is therefore associated with significant skewness, Sichel's 'deepness' is therefore tested for using the following test statistic:

$$D(x) = \left[(1/T) \sum_t (x_t - \bar{x})^3 \right] / \sigma(x)^3 \tag{5.2}$$

where $\bar{x}$ is the mean of series x_t, which has a standard deviation of $\sigma(x)$, and T is the sample size. As this process is applied mainly to time series, in order to calculate consistent asymptotic standard deviation of a series with serial correlation and heteroskedastic properties the following variable is constructed:

$$(5.3) \qquad z_t = (x_t - \bar{x})^3 / \sigma(x)^3$$

This variable is then regressed on a constant which gives an estimate that is identical to the value obtained by *D*(*x*). The Newey and West (1987) standard error can be calculated, of which the ratio of *D*(*x*) to, is asymptotically normal. This allows the use of conventional critical values.[80] The test statistic for Steepness is the same as that for deepness but conducted in first differences:

$$(5.4) \qquad ST(\Delta x) = \left[(1/T) \sum_t (\Delta x_t - \overline{\Delta x})^3 \right] / \sigma(\Delta x)^3$$

where $\overline{\Delta x}$ is the sample mean of Δx, and $\sigma(\Delta x)$ is its standard deviation. The standard error is calculated in the same manner as used for *D*(*x*).

5.2 – Randles et al. (1980) Triples Test

One major problem with Sichel's 'deepness' and 'steepness' tests is that they assume that the underlying distribution of the series is normal. If this is not the case then the value of the test statistic may be affected to such an extent that the results become unreliable. Therefore a number of alternatives have been suggested that dispense with the assumption of normality. One of these is the Triples test developed by Randles et al. (1980). The Triples test is an asymptotically distribution-free test for symmetry against the alternative of asymmetry. Therefore the assumption of normality can be dropped and unlike Sichel's skewness test, the results are not unduly affected by outliers (Verbrugge, 1997).

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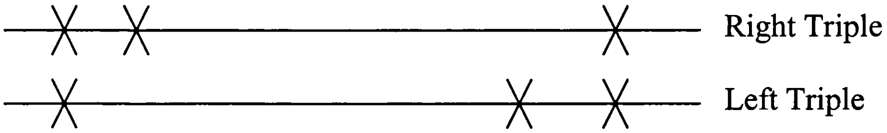
[80] The Newey-West truncation lag (*q*) is, set according to $q = \text{floor}\left(4(T/100)^{2/9}\right)$.

The Triples test determines whether there is asymmetry around an unknown median of θ. Randles et al. (1980) assume that a random sample $(X_1,\ldots,X_N)$ is taken from a continuous population with a distribution of $F(x - \theta)$. A triple of a observations is taken (X_i, X_j, X_k) where *i, j* and *k*, are integers $(1 \leq i, j, k \leq N)$. A right triple is defined as a triple where the middle observation is closest to the smallest observation, so the triple is skewed towards the larger value, and a left triple therefore sees the middle observation closest to the largest observation, making it skewed towards the lower value. Figure 5.1 below shows examples of right and left triples, where the crosses represent the three observations in the triple.

Figure 5.1 – Left and Right Triples



In a symmetrical stationary series the number of right and left triples should be roughly equal. The following equation assigns values to each of the triples depending on whether they are right, left or neutral triples, allowing the calculation of the number of right verses left triples:[81]

$$f^*(X_i, X_j, X_k) = \begin{bmatrix} sign(X_i + X_j - 2X_k) + sign(X_i + X_k - 2X_j) \\ + sign(X_j + X_k - 2X_i) \end{bmatrix} / 3 \tag{5.5}$$

where X_i, X_j and X_k represent the three observations making up a triple and $sign(u)$ = -1, 0, 1 for $u < 0$, $u = 0$, and $u > 0$ respectively, with u representing the three combinations $(X_i + X_j - 2X_k)$, $(X_i + X_k - 2X_j)$, and $(X_j + X_k - 2X_i)$, two of which will be negative and one positive if the triple is a left triple, if the triple is a right triple two of

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[81] It is the relative number of right and left triples that is important rather than the 'size' of individual triples. Equation (5.5) assigns the same value to each right triple (1/3) and each left triple (-1/3) regardless of the 'size' of each individual triple.

the combinations will be positive and one negative. This means that $f^*(X_i, X_j, X_k)$ can only take the values $-^1/_3$, 0 and $^1/_3$, representing a left, neutral and right triple respectively.[82] Randles et al. (1980) therefore propose the following test statistic:

$$\hat{\eta} = \binom{N}{3}^{-1} \sum_{i<j<k} f^*(X_i, X_j, X_k) \tag{5.6}$$

where $\hat{\eta}$ is effectively the number of right triples less the number of left triples, divided by three times the total number of triples in the sample. The null of symmetry (H_0: $\eta = 0$) is tested the alternative of asymmetry (H_1: $\eta \neq 0$) using:

$$T = \frac{\hat{\eta}}{\sigma_\eta / \sqrt{N}} \tag{5.7}$$

where the numerator is provided in Equation (5.6) and the square of the denominator is derived as:

$$\frac{\sigma_\eta^2}{N} = \binom{N}{3}^{-1} \sum_{c=1}^{3} \binom{3}{c} \binom{N-3}{3-c} \varsigma_c \tag{5.8}$$

where:

$$\begin{aligned} \varsigma_1 &= \frac{1}{N} \sum_{i=1}^{N} \left(f_1^*(X_i) - \hat{\eta}\right)^2; \\ \varsigma_2 &= \binom{N}{2}^{-1} \sum\sum_{j<k} \left(f_2^*(X_i, X_k) - \hat{\eta}\right)^2; \\ \varsigma_3 &= \frac{1}{9} - (\hat{\eta})^2 \end{aligned} \tag{5.9}$$

and:

$$\begin{aligned} f_1^*(X_i) &= \binom{N-1}{2}^{-1} \sum\sum_{\substack{j<k \\ i \neq j, i \neq k}} f^*(X_i, X_j, X_k); \\ f_2^*(X_i, X_k) &= \frac{1}{N-2} \sum\sum_{\substack{i=1 \\ i \neq j \neq k}} f^*(X_i, X_j, X_k) \end{aligned} \tag{5.10}$$

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[82] Please note that when drawing from a continuous distribution the probability of a neutral triple is zero, and therefore there can only be right and left triples produced.

Randles et al. (1980) show that the test statistic *T* is asymptotically standard normally distributed, allowing the use of conventional critical values to test the null hypothesis, they also demonstrate with Monte Carlo simulation that the test maintains appropriate power even with small samples.

The Triples test can be used to identify both longitudinal and transversal asymmetry using similar techniques as the Sichel skewness test. In order to detect transversal asymmetry ('deepness' or 'highness') the Triples test is applied to the detrended levels of the series. A significantly positive Triples test statistic will indicate that the stationary component of the investment series is positive skewed, and therefore displays 'highness' with fewer observations above the mean than below, but with on average larger absolute values. As described at the beginning of this chapter this would be the result expected *a priori* if irreversible investment considerations are encouraging firms to make investment in a 'lumpy' fashion with large infrequent investment spikes. Whether these peaks caused by investment spikes are approached more quickly than troughs, or visa versa, can be determined by applying the Triples test to the first differences of the stationary component of the investment series. A statistically positive Triples statistic when using first differences will indicate the presence of positive 'steepness', and therefore the investment series will display the 'fast up, slow down' that would be expected from irreversible investment.[83]

5.3 – Previous Asymmetry Studies

The renewed in interest in identifying the asymmetry of the business cycle driven by Neftci's (1984) paper has encouraged the application of the Sichel and Triples tests

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[83] As noted above the steepness form of the Sichel skewness test could be applied to the first differences of the detrended series although Sichel (1993) argues that this is unnecessary and the first differences of the series can be used to avoid any complications of additional detrending being applied.

outline in the proceeding sections.[84] Whilst these studies have not concentrated upon different measures of investment with the objective of identifying the patterns associated with irreversible investment, the existing studies can provide valuable information relating to the difficulties in applying the two tests. Some studies do include more aggregated measures of investment than utilised within this study and therefore provide an indication of the results that will be produced by the series utilised in this study. Studies applying the Sichel test are presented in sub-section 5.3.1, and those using the Triples test covered in sub-section 5.3.2.

5.3.1 – Applications of Sichel Tests

Much of the work relating to the asymmetry thought to be present in business cycles has concentrated upon the US business cycle. The US business cycle has been found by a number of authors such as Neftçi (1984), Delong and Summers (1986) and Hamilton (1989) to display asymmetry.[85] Sichel (1993) applies 'deepness' and 'steepness' test statistic to US employment, industrial production and GNP data. Sichel finds evidence of 'deepness' in the employment and industrial production data, and steepness in the employment data, but no evidence of either 'deepness' or 'steepness' is found in the GNP data. Sichel therefore suggests that certain components of US national income are asymmetric but not others. However, this leads to the question as to whether the US business cycle is typical of other countries' business cycles?

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[84] See sub-section 3.4.2 for review of empirical work relating to the asymmetry of the business cycle in general.

[85] Although it should be noted that a number of other studies including those by Falk (1986) and Sichel (1989) have show that the US business cycle only displays asymmetry in certain components. Both found the Neftçi's findings did not apply to all aspects of the US business cycle and Sichel (1989) shows an empirical error casts doubts on the significance of Neftçi's results, although a slightly different method used by Sichel (1989) does find strong evidence of asymmetry.

Speight (1997) examines ‘steepness’ and ‘deepness’ in the volumes of industrial production for 16 OECD countries and the aggregate OECD pattern, and finds that the asymmetry results vary greatly from country to country. Although both the deepness and steepness statistics were insignificant for most countries, Germany and Japan were found to have significantly deep production cycles, whilst Sweden was found to have a significantly high production pattern.[86] Japan and Sweden were also found to display significant negative steepness asymmetry. Andreano and Savio (2002) conduct a large number of different asymmetry tests upon monthly coincident economic indicators of the business cycle for the G7 countries. The series tested for asymmetry are composite indexes of economic activity produced using countries’ national income, sales, industrial production and employment data. Among the tests undertaken are Sichel’s ‘deepness’ and ‘steepness’ tests. Of the G7 countries tested only the US and Canada display ‘deepness’, and only the US displays ‘steepness’, in their economic activity.

Holly and Stannett (1995) look at aggregate consumer expenditure and find there to be significant positive ‘deepness’ (‘highness’), but no evidence of ‘steepness’ asymmetry. This is looked at in more detail by Speight and McMillan (1997), who examine consumer expenditure at a number of different levels of aggregation. Speight and McMillan (1997, 1998) use a structural time series model (STM) approach to smooth the data as well as the Hodrick-Prescott filter. For the most part, whilst some significant results are given by the Hodrick-Prescott technique, and a number of significant ‘steepness’, ‘deepness’ and ‘highness’ results are found for various consumption categories. the STM does not find significant results for these measures of consumer expenditure for either type of asymmetry. This is probably due to the

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[86] The Deepness tests were significant for Germany, Japan and Sweden at the 5% level when using a Parzen window of T/3.

reason cited by Speight and McMillan (1998) in their later paper, that the STM follows the actual data too tightly.

Speight and McMillan (1998) look for asymmetries using the Sichel tests in a large number of UK macroeconomic time series. Included within these time series are a number of aggregate investment time series: Total Investment; Fixed Investment; Inventory Investment; and Investment in Plant and Machinery. The deepness coefficients are negative for all measures of investment apart from investment in plant and machinery. Although this is not the anticipated result under irreversible investment the results are statistically insignificant. Interestingly, only investment in plant and machinery gives a significant result (at the 1 percent level) for the 'steepness' test, and is found to be negatively steep. Sensier (2003) applies the 'deepness' and 'steepness' tests to UK inventory investment but obtains no significant results.

5.3.2 – Applications of the Triples Test

Razzak (2001) utilised the Triples test to examine the business cycles of six OECD economies using GDP as the measure of economic performance.[87] Most earlier studies using other tests for asymmetry had found no evidence of either 'deepness' or 'steepness' when using such a broad a measure as GDP. Razzak (2001) on the other hand found strong evidence for 'deepness' in the Australian business cycle and 'highness' in the Japanese business cycle, whilst New Zealand's business cycle was also found to be negatively 'steep'. However, Verbrugge (1998) applies the triples test to a large number of international macroeconomic time series, finding a large degree

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[87] The economies examined were those of the US, UK, Japan, Germany, Australia, and New Zealand. The data runs from 1960:4 to 1999:2 and was seasonally adjusted.

of variation in the asymmetry patterns identified for individual countries and macroeconomic series.

Verbrugge (1997) studies a large number of US macroeconomic series including real investment, using the Triples test, applying a number of different detrending techniques to isolate the stationary 'cycle' component of the series. Testing for transversal asymmetry Verbrugge finds the real investment series detrended with the use of Hodrick-Prescott filter displays significant 'deepness', but when testing the same real investment series, but detrended by the Beveridge-Nelson decomposition statistically significant 'highness' is found. This is a problem faced by both the Sichel and Triples tests, although both transversal and longitudinal asymmetry can be identified where present by both tests, the tests rely on the correct isolation of the stationary cyclical component of the time series being examined.[88]

Cook and Speight (2005) applying the Triples test to disaggregated UK consumption series from the National Statistics' *Consumer Trends* publication, identify 'highness' for a number of durable and semi-durable goods categories. The authors suggest that these results could be driven by 'lumpiness' in the purchase patterns of these goods, it is suggested that this could reflect threshold effects in inventory control, in a similar manner to capital adjustments under irreversible investment.[89]

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[88] Section 5.6 examines further the choice of detrending technique appropriate for isolating the cyclical component of the investment series.

[89] Cook and Speight (2005) suggest that it is more likely that the 'lumpiness' found in the consumption patterns is due to credit rationing, and expenditures are more likely to be made where these credit restrictions are lifted.

5.4 - The Definition of Investment

The definition of investment that is used in empirical studies of fixed capital investment varies greatly from study to study. These empirical studies fall into two main categories when grouped by the measure of investment that is utilised: those that examine gross capital accumulation; and those, which consider the firms decision from the point of view of net capital accumulation. Each of these specifications of investment comes with weaknesses and complications in analysing the firm's investment decision, and these are covered in sub-section 5.4.1. Chapter 3 showed that whilst irreversible investment is most obvious at the firm or plant level, policy makers are most concerned with higher levels of aggregation and therefore sub-section 5.4.2 discusses the appropriate level of cross-sectional aggregation required. Subsection 5.4.3 notes another difficulty in identifying the effects of irreversible investment, namely temporal aggregation smoothing investment spikes. Sub-section 5.4.4 completes the section by examining the issue of adjusting the data for inflation.

5.4.1 – Net and Gross Investment

The grouping of studies using the net capital accumulation definition of investment has the advantage that the investment equation does not have to incorporate both expansionary and replacement reasons for investment being undertaken. However, in order to calculate net capital accumulation, gross capital accumulation must be adjusted so that replacement investment is no longer included.[90]

Studies of investment that make use of gross capital accumulation, as the measure of investment, examine both expansionary and replacement investment

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[90] An example of one such study is that of Caballero et al. (1995) which compares the mandated rate of investment with the actual rate. The mandated investment rate is given by the difference between the desired and actual capital rates, and therefore represents the net investment rate required to reach the desired capital stock.

jointly. This means that when attempting to model the determinants of investment there are two very different reasons for making investments in fixed capital that must be taken into account. Replacement and expansionary investment are normally modelled separately, as the determinants of each are usually assumed to be different. Replacement of worn out equipment is usually assumed to be proportional to the capital stock that is held by the firm (Frisch, 1931).[91] As the existing capital stock held by a firm at any point in time is a result of past capital acquisitions and depreciation of these acquisitions, current replacement investment will be a function of both past replacement and past expansionary investment. Current expansionary investment on the other hand is more commonly thought to be driven by the returns to capital at any time, or by accelerator theory changes in consumer demand. Measuring the marginal profitability of investment *ex ante* is of course impossible and therefore a number of proxies are used, not only by those attempting to model the investment decision of the firm but also by firms themselves, (see Chapter 2).

Gross investment is also used in a number of studies, particularly where the influence of various factors affecting the amount spent on capital goods is being tested, such as the influence of uncertainty (for example, Henley et al., 2003; Ghosal and Loungani, 1996).

The introduction of the 'new wave' investment theories, however, makes it less attractive to examine only net capital accumulation, and to disregard replacement investment that is taking place.[92] This is because the assumption that investment is

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[91] Calculating replacement investment as being proportional to capital stock may not be accurate given heterogeneous capital goods with different rates of depreciation. In company accounts capital is depreciated according to accounting conventions, which may have little resemblance to reality.

[92] A number of studies look at gross investment data, but ignore replacement investment by assuming that capital lasts forever and therefore a depreciation rate of zero is assumed, so net and gross investment are identical. Inclusion of a positive depreciation rate has a considerable impact on investment patterns by lowering the hurdle rate required to induce investment where options to invest are renewable (Dixit and Pindyck, 1994).

irreversible to some degree, will result in firms choosing to make investments in lumps rather than smoothing investment through time, in order to avoid incurring the large fixed costs associated with irreversible investments. This process of investing in spikes, it has been theorised, affects both expansionary and replacement investment.[93] This suggests that in order to examine the time path of the capital stock both replacement and expansionary investment need to be examined. This implies that the correct definition of investment should be gross capital formation when utilising 'new wave' theories of investment.

5.4.2 – Cross-sectional Aggregation

Doms and Dunne (1998) show that as the level of aggregation rises from plant to firm level, the lumpiness of investment decreases. This, it is suggested, is due to fixed costs of adjusting at the plant level (e.g. plant shutdowns), but convex adjustment costs at the firm level (e.g. capital good supply constraints). The literature on (S,s) models reviewed in Section 3.2 also shows how aggregation with idiosyncratic shocks and idiosyncratic uncertainty could reduce the lumpiness of investment (Caballero et al., 1995; Bertola and Caballero, 1994).

Shocks that impact upon all firms within an economy or industry will have the impact of pushing more firms to their investment thresholds. Although there are few shocks that are likely to have a recognisable impact upon all firms within the economy (oil crises apart) there may still be shocks that hit specific sectors or industries within the economy as a whole.[94] This means that at the aggregate

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[93] Nilsen and Schiantarelli (1997) dispute this by suggesting that the large number of Norwegian manufacturing firms they find adjusting capital stocks by very small positive percentages is due to replacement investment, which is not affected fixed costs of adjustment.

[94] It should be noted that even a shock that affects all firms within an economy will have a reduced effect if it affects different firms/industries at different speeds.

investment level there is likely to be little evidence of lumpy investment patterns, but at sector or industry level there may still be evidence.

A final consideration to be made when choosing the correct investment variable is whether the work should be limited to just one type of capital good such as either structures or equipment. Those investment models, which have split investment by type of capital good, have often found that the investment patterns vary greatly between the investment goods due to differing characteristics and lifetimes.

Although investment spikes are more likely to be visible at the firm level, policy makers are more likely to be interested in aggregate investment. Previous studies have shown that investment spikes associated with irreversible investment are likely to have all but disappeared at the aggregate level, however it might be possible that irreversibilities induced by industry specific capital could generate investment spikes within industries hit by industry specific shocks that then have a significant affect upon the industry investment patterns. Therefore, this is the level of aggregation that this study concentrates upon, the industry group, and industry level data, with aggregate data sources also used for comparative purposes.

5.4.3 – Temporal Aggregation

It is also important to take into account the frequency of the data available. With lower frequency data investment spikes may be masked, by appearing to be spread over a longer time period. What therefore is the required data frequency? How often do firms make decisions about adjusting their capital stocks? This may vary greatly from firm to firm, due to the size of the firm, the nature of the investment being undertaken, and at what level of the firm investment decisions are taken at.

The considerations above suggest that quarterly or even monthly data are likely to reveal much more about any lumpiness in investment patterns than will data over the longer term. This does not necessarily mean that annual data will not show lumpy investment patterns, as was shown by Doms and Dunne (1998), but any investment spikes apparent in a particular year, may be accounted for by an investment spike in only one quarter. An opposing view is that given the decision and delivery delays present in capital adjustments it is more appropriate to use lower frequency data, and that lower frequency data is also likely to contain less noise (Neftçi, 1984). An additional consideration relating to the issue of cross-sectional aggregation discussed above, is that it is often the case when choosing the frequency of data and the aggregation level, that there will be a trade off between more disaggregated cross-sectional data and data frequency. Further where GARCH processes are utilised to model uncertainty, as in Chapters 7 and 8 below, higher frequency data are again more desirable as Baillie and Bollerslev (1989) have shown that GARCH effects dissipate as data are summed over time to create lower frequency data. The use of higher frequency data also gives a greater number of observations per cycle aiding estimation, but as such higher frequency data often covers a shorter period than lower frequency data, fewer full cycles are covered by the data set. With the above in mind both quarterly and annual data are utilised to maximise the benefits available from both frequencies of data.

5.4.4 – Price Deflation

Deflating nominal data can be more complicated than it may initially appear, as the choice of price index deflator can affect the characterisation and interpretation of the data.[95] Alternative price indices that can be used are the retail price index (RPI) or producer price index (PPI). Deflating the investment by RPI gives the investment in terms of foregone output. This measure of 'real investment' will therefore give investment in terms most relevant to consumers, and the population as a whole. However this might not be the most relevant concept for the producer. Although it gives investment in terms of goods it is not solely in terms of the producers own output, which may be all that is really important to the producer. In contrast deflating by the PPI will give the investment in terms of materials and inputs that could have been purchased instead of the capital goods. This might be the most relevant measure as this is the decision that is most likely to face the producer. If the producer chooses not to invest, the money will be spent on materials for additional output. Investment is the foregoing of current output for greater future output.

5.5 – Data Sources

Section 5.4 looked at the investment variables that have been used by other studies, and it becomes apparent from the variety of variables used that there is no single investment variable that is most appropriate to use above all others. The choice of variable is often dictated by the aims of the study and the data that are available. The investment data used within the empirical chapters of this study is taken from the Office for National Statistics (ONS). Three main data sets are used, the Annual Business Inquiry (ABI), First Release quarterly industry group data, and National

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[95] Whilst a capital goods price index might initially be considered appropriate, this may obscure asymmetric time irreversibilities and lumpy investment patterns under endogenous capital prices. The reason is that due to the nature of lumpy investment, the rapid increase in demand for capital goods will drive up the price of capital in the short term, so that deflating the investment figures by a capital goods price index, results in a smoothed real investment series, and will not give any clear indication of how tightly concentrated actual investment spending is suggesting that more general price indices should be used instead.

Accounts aggregate investment data. The following three sub-sections examine these data and the reasoning behind the choice of each.

5.5.1 – Annual Business Inquiry (ABI) Data

The ABI is an annual sample survey of production and construction (formally known as the Annual Census of Production and Annual Census of Construction). Collected according to the Standard Industrial Classification 1992 (SIC92), with data available at the two, three and four digit levels. This allows data to be examined at the sector and industry levels.

The form in which investment is recorded in the ABI is net capital expenditure. This is defined as the amount that is charged to the capital account together with any other amounts, which are considered capital expenditure items for taxation purposes (after 1988 this figure also includes assets acquired by the respondent of the survey under leasing arrangements). Contributions made by public bodies towards the cost of capital are also included within the cost of capital expenditure, and capital goods produced by the firm in question for use within its own production are also included. Assets acquired by mergers and acquisitions of existing businesses, are not however included within capital expenditure. VAT is included where non-deductible, but is excluded where it is deductible. No allowance is made for depreciation, amortisation or obsolescence. The values of buildings, structures, plant, equipment and vehicle acquisitions less disposals are recorded as net capital expenditure.[96]

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[96] An alternative investment measure available in the ABI data is net capital expenditure upon acquisitions. The separation of acquisitions and disposals may allow investment patterns as dictated by financing considerations, and those dictated more by irreversibility considerations, to be parted from one another. Whereas total net capital expenditure may observe smoother investment patterns, as firms balance acquisitions against disposals to avoid having to seek more expensive sources of finance, it may become apparent that firms intentionally cluster acquisitions in order to make lumpy investments.

As disposals within the ABI do not include depreciation or scrapping the net capital expenditure is a gross investment figure. As noted in the preceding section the choice of gross or net investment is very subjective. Net investment may allow expansionary spikes to be isolated (Doms and Dunne, 1998), however it may not only be expansionary investment that is made in spikes. One of the most compelling reasons for using gross investment is the difficulty in splitting expansionary and replacement investment, especially with different vintages of capital where replacement of an old machine may also allow greater production (Cooper et al., 1999).

Whilst ABI data are available down to the 4-digit industry level for later periods this is not the case for all periods. Also the availability of data declines at lower aggregation levels, as figures are not reported for confidentiality reasons. However, data are available without gaps or omissions for UK manufacturing at the 2-digit level, and therefore this is the investment series used, the ABI data running from 1970 to 2001. As discussed in sub-section 5.1.4, a more general price index is perhaps the most appropriate to deflate investment data, in order to avoid endogenous investment spikes being produced by supply shortages raising capital prices, therefore the RPI is used with ABI investment data reported in constant 1985 prices. The 2-digit SIC(92) UK manufacturing industries are allocated the codes 15-36,[97] and are

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This would not be apparent with the total net capital expenditure, but the net capital expenditure upon acquisitions should show a lumpier pattern. However, the separation of capital acquisitions and disposals may not be appropriate as the two decisions are often two parts of the one decision. Although net capital expenditure may smooth away some lumpiness, part of the reason that an investment spike is occurring is the availability of funds released by a large disposal of capital. The main reason for turning away from acquisitions as a data form is their availability within the ABI, since where large acquisitions or disposals are made in a single year the figures are often not released for reasons of confidentiality. Therefore the net capital expenditure variable is used as the investment figure from the ABI data.

[97] More recent years also include data on sector 37 Recycling, this is only a recent addition and is therefore ignored to allow consistency of data.

listed below in Table 5.1 (please see Table A1 in the appendix for a full listing of all industries down the to 4-digit level of aggregation).

Table 5.1 - 2-Digit SIC(92) Codes for UK Manufacturing Industries

SIC (92) Code	Definition of Industry
15	Manufacture of food products and beverages
16	Manufacture of tobacco products
17	Manufacture of textiles
18	Manufacture of wearing apparel; dressing and dyeing of fur
19	Manufacture of leather and leather products
20	Manufacture of wood and wood products
21	Manufacture of pulp, paper and paper products
22	Publishing, printing and reproduction of recorded media
23	Manufacture of coke, refined petroleum products and nuclear fuel
24	Manufacture of chemicals, chemical products and man-made fibres
25	Manufacture of rubber and plastic products
26	Manufacture of other non-metallic mineral products
27	Manufacture of basic metals
28	Manufacture of fabricated metal products, except machinery and equipment
29	Manufacture of machinery and equipment not elsewhere classified
30	Manufacture of office machinery and computers
31	Manufacture of electrical machinery and apparatus not elsewhere classified
32	Manufacture of radio, television and communication equipment and apparatus
33	Manufacture of medical, precision and optical instruments, watches and clocks
34	Manufacture of motor vehicles, trailers and semi-trailers
35	Manufacture of other transport equipment
36	Manufacture of furniture; manufacturing not elsewhere classified

5.5.2 – First Release Data

Whilst the ABI investment data are available at low levels of aggregation it is only produced annually, this means relatively small numbers of observations in the series. This is likely to make estimation in Chapters 7 and 8 impractical, and the power of asymmetry tests applied in this chapter and Chapter 6 are likely to be greatly affected by the shortness of sample. This means that it is preferable to have an alternative investment dataset.

First Release investment data are published, using investment data taken from the Quarterly Capital Expenditure Inquiry, and therefore generates series with a greater number of observations.[98] Included within the definition of investment in the First Release data are capital expenditure upon new buildings capital equipment and vehicles, but not upon existing land or buildings. The First Release data are, however, only available at the industry group level of aggregation, with the 21 2-digit industries from the ABI combined into 7 industry groups, as listed in Table 5.2 below (see Tables A1 and A2 in the appendix for a full listing and summary of industries contained within the individual industry groups). The first release data are available from 1966:1 to 2004:2 for the aggregate, and 1979:1 to 2004:2 for the industry group data. The investment figures in the First Release data are likely to differ from their counterparts in the ABI data due to differing treatments of expenditure figures, with larger disparities are likely to be found in those industries with high capital expenditure upon existing buildings and structures.

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[98] Neftci (1984) also argues that quarterly data makes the best compromise in smoothing data (reducing noise errors) without reducing the number of observations to too low a level.

Table 5.2 – Industry Groups and Component 2-Digit Industries

Sector Code	Sector Name	2-digit SIC(92) Industries contained within sector
INJX	Solid and Nuclear Fuels, Oil Refining	23,
INKA	Metals and Metal Goods	27 & 28
INJY	Chemicals and Man Made Fibres	24
INJO	Engineering and Vehicles	29, 30, 31, 32, 33, 34 & 35
INJT	Food, Drink and Tobacco	15 & 16
INJU	Textiles, Clothing, Leather and Footwear	17, 18, & 19
JZKL	Other Manufacturing	20, 21, 22, 25, 26, 36 & 37

Unlike the data from the ABI the data from the Business Investment First Release is already deflated, and seasonally adjusted. The price index used is that of capital goods prices for each sector. A chained volume approach is used which means that each pair of years is rebased for makeup of the basket of goods purchased in those years rather than assuming a constant fixed basket of goods for a number of years which is rebased every five or ten years. This ensures that the actual capital purchased is deflated correctly and avoids the basket of goods making up the price index becoming unrepresentative (Tuke, 2002). The figures are deflated on an annual basis rather than on a quarterly basis, which ameliorates one of the possible difficulties noted in sub-section 5.4.4, that the price of capital goods would be endogenous and therefore add to the complications of determining when investment spikes occur. This may have been an even greater problem with quarterly price index data, as a large investment spike in a short time period such as a quarter, would put a strain on the capacity of the capital producing industries and therefore in the short term the price is likely to rise significantly.

5.5.3 – National Accounts Data

Evidence to date for asymmetry in aggregate investment has been poor at best, (see Section 3.4 for a review of the empirical literature on investment spikes and asymmetry). As discussed in Section 3.2 this is due to idiosyncratic shocks smoothing the aggregate investment pattern. Although evidence of investment spikes have been found at the firm and plant level it is this general absence at the aggregate level that inspires the use of industry and industry group level data in this study, to determine whether the effects of irreversible investment are evident at this level of aggregation. It would however be imprudent to analyse data at this level of aggregation without having an aggregate data set with which to draw comparisons.

For both the ABI and First Release data an aggregate investment measure is available for the manufacturing industries, which permits some comparison with the disaggregated industry data. National Accounts Data (from the ONS national accounts 'Blue Book'), however, allows an alternative method of gaining insight into the patterns hidden within the aggregate, by breaking capital expenditure down by investment good category. Three additional investment series are therefore considered: expenditure on new building work; purchases of vehicles; and other investment. Gross fixed capital expenditure is also included as a measure of acquisitions (see sub-section 5.4.1). This National Accounts data are quarterly, and seasonally adjusted in the same manner as the First Release investment data, covering the period from 1966:1 - 2004:2.

5.6 – Detrending Techniques

One condition that is required in order to obtain valid results from tests such as those undertaken in this and the following chapter is that these series under consideration are stationary. This is not the case for a vast majority of macroeconomic time series with some form of trend being present in the data. Sub-section 5.6.1 discusses a number of alternative detrending techniques that can be applied, and sub-section 5.6.2 looks at comparisons that have been made of the filters available.

5.6.1 – A Selection of Detrending Techniques

Choosing the correct method of detrending is important as it is possible to create a series that appears to be asymmetric when actually there is no asymmetry. A widely used approach is to use first differences, but it has been found that first differencing induces a phase shift and re-weights a series towards higher frequencies (Baxter and King, 1999). A large selection of alternative possible filters exists, but care must be taken to avoid the introduction of spurious asymmetry by observing the condition that the detrending filter used must have a linear representation, so that it is incapable of inducing asymmetry if none is originally present (Speight, 1997).

One of the most widely used filters in the study of the business cycle is the Hodrick-Prescott trend filter (Hodrick and Prescott, 1980, 1997). The Hodrick-Prescott filter operates by finding the solution to the convex minimisation problem below:

$$\text{(5.11)} \qquad \min \sum \left\{ (y_t - \tau_t)^2 + \lambda \left[(1-L)^2 \tau_t \right]^2 \right\}$$

where L is the lag operator, and τ is the trend component of series y. Whereas the first quadratic term is a measure of goodness of fit the second quadratic component gives a measure of trend smoothness. This means that the parameter λ determines the balance between goodness of fit and smoothness of the trend series produced. The greater the value of λ used, the greater the weight attributed to changes in the trend in the minimisation problem. This means that choice of $\lambda = \infty$ will result in a linear trend, while if $\lambda = 0$ the trend will be exactly the same as the original series and therefore no smoothing will have taken place. The usual convention is to choose $\lambda = 1600$ for quarterly data. This will produce a trend without fluctuations of durations of 32 quarters or less.[99]

The Hodrick-Prescott filter has been criticised by a number of different sources. Cogley and Nason (1995) suggest that frequencies around those of the business cycle are amplified whilst others are suppressed, and therefore business cycle dynamics are induced into series that contain none, an effect also found by Harvey and Jaeger (1993). However, Pederson (2001) shows through analysis of the Hodrick-Prescott filters' power transfer function that no spurious cycles are induced, and that the effects observed by Cogley and Nason are due to leakages of low frequency data into the smoothed series.

An alternative family of filters, which can be used to detrend the data are band pass filters. These filters take a moving average of a period with a lead and lag of fixed length K, and pass through fluctuations, which have a frequency between an upper and lower limit (P_U, P_L), extracting them from the data and removing fluctuations with a lower frequency. A number of alternative band pass filters have been developed with differing weightings of the moving average lags and leads. Two prominent filters of this type are the Baxter-King (Baxter and King, 1999) and Christiano-Fitzgerald (Christiano and Fitzgerald, 2003) fixed length symmetric filters.

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[99] Pederson (2001) suggests that the optimal value for λ in order to minimise distortions when trying to remove frequencies of less than 32 quarters should be 1000-1050.

An additional filter that can be applied is the full length asymmetric Christiano-Fitzgerald filter which calculates the lags and leads according to the data, and where the number of lags and leads can change as can the weighting of those lags/leads. A major disadvantage of the fixed length symmetric band pass filters is that observations are lost from the beginning and end of the sample equal to the length of the lead/lag, K.[100,101] The full length asymmetric Christiano-Fitzgerald filter does not suffer from this problem as the length of lag and lead adjust as the ends of the sample period are approached to allow calculation of values towards the ends of the sample. Baxter and King (1999) suggest that an advantage of band pass filters is that, unlike the Hodrick-Prescott filter which is effectively only a high pass filter eliminating low frequency data (data with a frequency of roughly 32 quarters or longer), band-pass filters prevent high frequency 'noise' being allowed into the smoothed series.

5.6.2 – Comparison of Detrending Techniques

Movshuk (2003) looks at a number of possible detrending methods, and the degree of distortion that the filters produce, in order to determine which is the best detrending method to apply. The ranking of filters is achieved by comparing the results of the filters with that of an ideal high pass filter, using the following metric developed by Pederson (2001):

$$\Delta S_y(w) = \left|S_y^*(w) - S_y(w)\right| = \left|\left|H_{HP}^*(w)\right|^2 - \left|H_{HP}(w)\right|^2\right| S_x(w) \tag{5.12}$$

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[100] Increasing K moves the band-pass filter towards the optimum band-pass filter where no leakage or compression occurs. Leakage is when the filter allows components through that it should not whilst compression is the removal of components, which should be kept by the filter. This means there is a tradeoff from between accuracy and lost information.

[101] Baxter and King (1999) suggest that the loss of observations is no real disadvantage compared to the Hodrick-Prescott filter, as the rapidly changing weightings at the beginning and end of the series when using the Hodrick-Prescott filter can produce unreliable smoothed observations, and therefore it is best to discard these observations anyway, putting the two filters on a par with one another.

where $S_y^*(w)$ and $S_y(w)$ are the spectrum of the smoothed series using the ideal band pass and test filter at frequency w (measured in radians) respectively, whilst $H_{HP}^*(w)$ and $H_{HP}(w)$ are the power transfer functions of the ideal band pass and test filter respectively. The difference between the two gives $\Delta S_y(w)$, which is the distortion in the spectrum at frequency w caused by the filter under test relative to the ideal band pass filter. The final part of Equation (5.12) shows that part of this is due to the spectrum of the original series, $S_x(w)$, and the other is due to the power transfer function of the filter, $|H_{HP}(w)|^2$. The test statistic is given as the integral of these measures over the whole spread of frequencies under consideration:

$$Q = 2\int_0^{\pi} \left| \left| H_{HP}^*(w) \right|^2 - \left| H_{HP}(w) \right|^2 \right| S_x(w) dw \tag{5.13}$$

Movshuk finds that the Hodrick-Prescott and Baxter-King filters used here rank relatively highly, whilst the first difference method is fairly lowly ranked.

Psaradkis and Sola (2003) used Monte Carlo tests to determine not only the power of a number of tests to detect asymmetry but also applied a number of different detrending techniques to determine the effect that each had upon the asymmetry present within a series. The filters used were: Hodrick-Prescott; Band Pass (Baxter and King, 1999); and the Beverage-Nelson decomposition (Beveridge and Nelson, 1981). Using an unobserved-components model to represent the data generating process, as given by:

$$x_t = \xi_t + y_t \tag{5.14}$$

$$\xi_t = 0.01 + \xi_{t-1} + 0.01\eta_t \tag{5.15}$$

$$y_t = 1.5y_{t-1} - .58y_{t-2} + 0.01u_t \tag{5.16}$$

where η_t are i.i.d. $N(0,1)$. Psaradkis and Sola use the stationary component, y_t, as the test series. As the stationary series y_t does not require detrending or differencing, this allows Psaradkis and Sola to identify any distortions, which the detrending techniques introduce to the series. Asymmetry is imposed upon the series by assuming u_t to be i.i.d. with a mean of zero and unit variance, but with a non-normal distribution. Four different distributions are utilised, lognormal, standard Weibull, gamma, and a member of the S_U system. These were compared with Gaussian innovations, and in each case the level of asymmetry was varied from high to low to observe the affect of the filters upon the asymmetry. The rejection rates of the tests for symmetry were then compared to the original stationary series. All of the filters were found to substantially reduce the asymmetry present in the series. Whilst the Hodrick-Prescott and Baxter-King filters had least affect upon the asymmetry present even these removed roughly half the asymmetry or greater. The Beverage-Nelson decomposition removed almost all asymmetry, which makes it hardly suitable for tests attempting to identify asymmetry.[102] This means that when testing for asymmetry after imposing stationarity through detrending it should be remembered that much of the asymmetry will be removed by the detrending technique. Nevertheless, as alternatives to first differencing, the Hodrick-Prescott and Baxter-King filters appear to be most suitable given their ease of use, minimal distortion, and ability to retain the asymmetric properties of the original series.[103]

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[102] Rather than non-Gaussian innovations Psaradakis and Sola (2003) also allowed a non-linear logistic smooth-transition autoregressive (LSTAR) process to generate y_t and found similar results.

[103] Whilst suitable for asymmetry testing, it should be noted however that these methods are inappropriate for empirical work in later chapters for two different reasons. The Baxter-King filter suffers from loss of observations at both ends of the sample period, whilst start and end values from the Hodrick-Prescott filter may not be reliable. A second problem relating to the Hodrick-Prescott filter is the possibility that spurious cycles are introduced into the smoothed series, which may produce spurious relationships between smoothed series (Harvey and Jaeger, 1993).

5.7 – Results

This section covers the results of the three groups of tests undertaken to test for asymmetry within the series. Given the differing requirements of the tests and characteristics of the datasets different detrending techniques were applied where appropriate. These were discussed in sub-section 5.6.2 and a summary of detrending techniques used can be found in Table 5.3 below. Whilst a variety of detrending techniques were often applied, for preservation of space the results generated using Hodrick-Prescott filtered data are those reported with attention drawn to other results where appropriate.

Table 5.3

Summary of Detrending Techniques in Asymmetry Tests

Data Set	Test Applied[a]	Deepness Detrending[b]	Steepness Detrending[b]
First Release and National Accounts Data	Sichel Skewness Test	HP BK (fixed) CF (fixed) CF (full)	FD of HP FD of BK FD of CF (fixed) FD of CF (full)
	Triples Test	HP BK (fixed) CF (fixed) CF (full)	FD of HP FD of BK FD of CF (fixed) FD of CF (full)
ABI	Sichel Skewness	HP	FD of HP
	Triples	HP	FD of HP

(a) The tests applied were the Sichel skewness test (Sichel 1993), the Triples Test (Randles et al 1980), and the Wilcoxon Rank Sum, Siegel-Tukey and Kolmogorov-Smirnov two sample Non-parametric tests (Peiró 2004).

(b) The detrending techniques are defined as follows; HP = Hodrick-Prescott filter; BK (fixed) = Baxter King fixed length symmetric filter; CF(fixed) = Christiano-Fitzgerald fixed length symmetric filter; CF (full) = Christano-Fitzgerald full length asymmetric filter; FD = First Differences.

Sub-section 5.7.1 looks at the results generated using the Sichel skewness tests, and 5.7.2 uses the Triples non-parametric form to test for asymmetry without having to impose the assumption of normality upon the data.

5.7.1 – Skewness Test Results

Given the lack of significant Sichel test results from previous studies using measures of aggregate investment (either aggregate investment or investment broken down by investment good category), it would not be expected that the aggregate investment measure will generate many, if any significant results. This result is found also to be the case here using the National Accounts aggregate data. Even when broken down by investment good category no 'deepness' or 'steepness' is identified. Tables 5.4 and 5.5 below present the 'deepness' and 'steepness' test results for the National Accounts data. The results presented in the below are those calculated using the Hodrick-Prescott filter in order to calculate 'deepness' statistics, and the first differences of the Hodrick-Prescott filtered series in order to calculate 'steepness' statistics.[104]

Table 5.4

Deepness Test Results - National Accounts Data

Investment Good Category	D(x)[a]	S.E.[b]	t-value	p-value
New Building Work	0.123708	0.327472	0.377766	(0.7061)
Vehicles Expenditure	0.043569	0.789815	0.055164	(0.9561)
Other Investment	0.333871	0.406692	0.820944	(0.413)
Fixed Capital Expenditure	0.657639	0.601908	1.092592	(0.2763)

(a) D(x) is the deepness statistic calculated by the Sichel (1993) skewness test, emboldened values are significant at the 5% level.
(b) Standard Errors are calculated using the Newey-West robust standard errors with a truncation lag set by $q = \text{floor}\left(4(T/100)^{2/9}\right)$.

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[104] Results of all Sichel tests in this chapter were unaffected by use of alternative detrending techniques, see Section 5.6 for description of alternative detrending techniques.

Table 5.5

Steepness Test Results – National Accounts Data

Investment Good Category	ST(x)[a]	S.E.[b]	t-value	p-value
New Building Work	-0.55048	0.744389	-0.73951	(0.4607)
Vehicles Expenditure	0.121746	0.626423	0.194351	(0.8462)
Other Investment	-0.00421	0.288242	-0.01461	(0.9884)
Fixed Capital Expenditure	-0.66277	0.552959	-1.19858	(0.2326)

(a) ST(x) is the steepness statistic calculated by the Sichel (1993) skewness test, emboldened values are significant at the 5% level.

(b) Standard Errors are calculated using the Newey-West robust standard errors with a truncation lag set by $q = \text{floor}\left(4(T/100)^{2/9}\right)$.

As there are no previous studies of asymmetry I am aware of using the Sichel test at lower levels of aggregation for investment it was unclear whether there would be more asymmetry at the industry group level of aggregation. As irreversible investment can be due to the purchase of industry specific capital, industry specific shocks are likely to have significant effects on delaying investment or inducing an investment spike at the industry level of aggregation. This might be expected to produce more asymmetric investment patterns at industry or industry group levels of aggregation.

Tables 5.6 and 5.7 below present the ‘deepness’ and ‘steepness’ test results for the First Release industry group data.

Table 5.6

Deepness Test Results – First Release Data

Investment Good Category	D(x)[a]	S.E.[b]	t-value	p-value
Aggregate Business Investment	0.392464	0.428673	0.915533	(0.3614)
Chemicals	0.396476	0.373478	1.061579	(0.291)
Engineering	0.601692	0.565854	1.063333	(0.2902)
Food Processing	-0.00153	0.447096	-0.00341	(0.9973)
Fuels	0.528972	0.600254	0.881247	(0.3803)
Metals Production	0.967587	0.717785	1.348018	(0.1807)
Textiles	0.651875	0.528774	1.232805	(0.2205)
Other Manufacturing	0.347189	0.415575	0.835441	(0.4054)

(a) D(x) is the deepness statistic calculated by the Sichel (1993) skewness test, emboldened values are significant at the 5% level.

(b) Standard Errors are calculated using the Newey-West robust standard errors with a truncation lag set by $q = \text{floor}\left(4(T/100)^{2/9}\right)$.

Table 5.7

Steepness Test Results – First Release Data

Investment Good Category	ST(x)[a]	S.E.[b]	t-value	p-value
Aggregate Business Investment	0.169942	0.280521	0.605808	0.5455
Chemicals	0.809201	0.861184	0.939638	0.3496
Engineering	0.334385	0.504597	0.662678	0.509
Food Processing	0.186459	0.266379	0.699977	0.4856
Fuels	-1.20363	1.098427	-1.09577	0.2758
Metals Production	-0.04399	0.433374	-0.1015	0.9194
Textiles	0.021082	0.384323	0.054854	0.9564
Other Manufacturing	-0.2026	0.308545	-0.65662	0.5129

(a) ST(x) is the steepness statistic calculated by the Sichel (1993) skewness test, emboldened values are significant at the 5% level.

(b) Standard Errors are calculated using the Newey-West robust standard errors with a truncation lag set by $q = \text{floor}\left(4(T/100)^{2/9}\right)$.

As with the National Accounts data, no significant results are generated. Looking at the 'deepness' coefficients for both datasets they are all positive with the exception of the near-zero Food Processing coefficient. Positive coefficients are the result that might have been expected from irreversible investment rather than the traditional view of the business cycle, however, even the quantitatively largest test statistics are not significant at the 10% level. The 'steepness' coefficients are much more mixed and therefore it is harder to discern whether investment cycles follow the 'steep' increases in investment most likely associated with lumpy investment.

Similarly no significant results are generated by the ABI data (see Tables 5.8 and 5.9 below). The results strongly suggest that there is no asymmetry within the investment data. Although this would not eliminate the possibility of firms making 'lumpy' investments due to irreversible investment it would mean that the majority of shocks inducing investment spikes were idiosyncratic to the degree that firms' investment spikes do not coincide to the extent required to make this evident at the aggregate level.[105] An alternative interpretation, as suggested in the earlier sections of this chapter, is that the nature of the skewness test imposes an assumption of normality upon the data that may not be accurate.

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[105] Stanca (1999) has questioned the power of tests to identify asymmetry in time series given that a number of different tests for non-linearity found evidence of non-linearity in Italian investment, but the skewness tests found neither 'deepness' nor 'steepness'. Cook (2000) finds time deformation tests to identify asymmetry in UK and US exports, for which 'deepness' and 'steepness' tests only produce statistics significant at the 10% level at best.

Table 5.8

Sichel Deepness Test Results – ABI Data

Industry	D(x)[a]	S.E[b]	t-value	p-value
Aggregate	0.133507	0.495299	0.269548	(0.7893)
Industry 15	0.118097	0.475765	0.248225	(0.8056)
Industry 16	0.150264	0.445247	0.337485	(0.738)
Industry 17	0.708854	0.871902	0.812997	(0.4224)
Industry 18	0.136729	0.435046	0.314287	(0.7554)
Industry 19	0.227197	0.417737	0.543877	(0.5904)
Industry 20	0.460028	0.634441	0.725092	(0.4738)
Industry 21	0.835601	0.602453	1.386997	(0.1753)
Industry 22	0.271113	0.988018	0.274401	(0.7856)
Industry 23	0.27556	0.541858	0.508546	(0.6147)
Industry 24	0.007714	0.574025	0.013439	(0.9894)
Industry 25	-0.245122	0.473025	-0.5182	(0.608)
Industry 26	0.69103	0.929497	0.743445	(0.4628)
Industry 27	0.491659	0.875378	0.561654	(0.5784)
Industry 28	0.304368	0.526773	0.577798	(0.5676)
Industry 29	0.402745	0.636981	0.632272	(0.5318)
Industry 30	-0.082413	0.647098	-0.127358	(0.8995)
Industry 31	0.671817	0.743068	0.904112	(0.3729)
Industry 32	0.243533	0.620387	0.39255	(0.6973)
Industry 33	-0.041424	0.687004	-0.060296	(0.9523)
Industry 34	0.497324	0.561269	0.886072	(0.3824)
Industry 35	-0.083792	0.45009	-0.186167	(0.8535)
Industry 36	0.176726	0.497838	0.354987	(0.725)

(a) D(x) is the deepness statistic calculated by the Sichel (1993) skewness test, emboldened values are significant at the 5% level.

(b) Standard Errors are calculated using the Newey-West robust standard errors with a truncation lag set by $q = \text{floor}\left(4(T/100)^{2/9}\right)$.

Table 5.9

Sichel Steepness Test Results – ABI Data

Industry	ST(x)[a]	S.E[b]	t-value	p-value
Aggregate	0.074554	0.450032	0.165663	(0.8695)
Industry 15	-0.381741	0.4165	-0.916547	(0.3667)
Industry 16	0.034708	0.323466	0.107301	(0.9153)
Industry 17	0.487854	0.87122	0.559966	(0.5797)
Industry 18	-0.821627	0.736043	-1.116275	(0.2732)
Industry 19	-0.455755	0.440724	-1.034103	(0.3094)
Industry 20	-1.148831	0.705134	-1.629239	(0.1137)
Industry 21	-0.18277	0.54853	-0.333199	(0.7413)
Industry 22	-0.257783	0.584349	-0.441146	(0.6623)
Industry 23	-0.036277	0.687927	-0.052734	(0.9583)
Industry 24	0.089812	0.565979	0.158685	(0.875)
Industry 25	-0.46887	0.444728	-1.054285	(0.3002)
Industry 26	-0.841902	0.730179	-1.153008	(0.258)
Industry 27	0.48312	0.849963	0.568401	(0.574)
Industry 28	-0.094769	0.371908	-0.254817	(0.8006)
Industry 29	-0.095952	0.380657	-0.25207	(0.8027)
Industry 30	0.124061	0.334188	0.371232	(0.7131)
Industry 31	-0.441946	0.56819	-0.777814	(0.4428)
Industry 32	0.680008	0.695456	0.977788	(0.336)
Industry 33	0.660345	0.935685	0.705735	(0.4858)
Industry 34	0.063504	0.363486	0.174708	(0.8625)
Industry 35	-0.783366	0.558397	-1.402885	(0.1709)
Industry 36	-0.434055	0.367972	-1.179585	(0.2474)

(b) ST(x) is the steepness statistic calculated by the Sichel (1993) skewness test, emboldened values are significant at the 5% level.

(c) (b) Standard Errors are calculated using the Newey-West robust standard errors with a truncation lag set by $q = \text{floor}\left(4(T/100)^{2/9}\right)$.

5.7.2 – Triples Test

If the assumption of normality is not misplaced the lack of significant results for the Sichel tests discussed in the previous sub-section should be replicated by the non-parametric Triples test results discussed within this sub-section. Tables 5.10 to 5.13 contain the results from the 'deepness' and 'steepness' forms of the Triples test for the National Accounts and First Release data. Following the discussion in sub-sections 5.6.1 and 5.6.2 it seems that the Hodrick-Prescott filter is the most appropriate detrending technique to apply to the investment data in order to extract the cycle component.

Table 5.10

Triples Test (Deepness) Results – National Accounts Data

Detrending Technique		Baxter-King	Symmetric Christiano-Fitzgerald	Asymmetric Christiano-Fitzgerald	Hodrick-Prescott
Gross Fixed Capital Expenditure	D(x)[a] p-value	**0.039998** (0.0026)	0.004643 (0.7414)	**0.041474** (0.0014)	**0.032216** (0.0204)
New Building Work	D(x) p-value	0.016016 (0.2938)	0.000863 (0.5418)	0.018853 (0.215)	0.002445 (0.8494)
Vehicles Expenditure	D(x) p-value	0.006412 (0.7188)	0.004852 (0.7642)	0.003852 (0.818)	-0.00448 (0.8026)
Other Investment	D(x) p-value	0.004459 (0.7872)	0.021941 (0.0892)	0.016461 (0.303)	**0.028093** (0.0308)

(a) D(x) is the Triples test statistic (Randles et al 1980), emboldened values are significant at the 5% level.

Table 5.11

Triples Test (Steepness) Results – National Accounts Data

Detrending Technique		Baxter-King	Symmetric Christiano-Fitzgerald	Asymmetric Christiano-Fitzgerald	Hodrick-Prescott
Gross Fixed Capital Expenditure	ST(x)	0.003733	-0.01566	0.013621	-0.01403
	p-value	(0.8026)	(0.238)	(0.3472)	(0.3682)
New Building Work	ST(x)	-0.01109	-0.01053	-0.01715	-0.00593
	p-value	(0.5092)	(0.4902)	(0.3682)	(0.704)
Vehicles Expenditure	ST(x)	-0.00702	-0.0072	-0.0031	-0.00819
	p-value	(0.704)	(0.6818)	(0.865)	(0.5962)
Other Investment	ST(x)	-0.02578	-0.02126	-0.0278	-0.00785
	p-value	(0.091)	(0.1388)	(0.0414)	(0.5824)

(a) ST(x) is the Triples test statistic (Randles et al 1980), emboldened values are significant at the 5% level.

Table 5.12

Triples Test (Deepness) Results - First Release Data

Detrending Technique		Baxter-King	Symmetric Christiano-Fitzgerald	Asymmetric Christano-Fitzgerald	Hodrick-Prescott
Aggregate	D(x)[a]	0.008819	**0.028619**	0.020102	**0.030587**
	p-value	(0.603)	(0.0188)	(0.2302)	(0.025)
Chemicals	D(x)	**0.039993**	0.012736	**0.052329**	**0.041078**
	p-value	(0.0466)	(0.4296)	(0.0016)	(0.0046)
Engineering	D(x)	0.036296	0.009	**0.055133**	**0.042158**
	p-value	(0.0524)	(0.66)	(0.0052)	(0.0132)
Food Processing	D(x)	0.020016	0.003394	0.021286	0.002178
	p-value	(0.2892)	(0.8258)	(0.2262)	(0.8966)
Fuels	D(x)	**0.046196**	0.002279	0.030996	0.023578
	p-value	(0.012)	(0.8886)	(0.1212)	(0.1676)
Metals	D(x)	**0.082689**	**0.055711**	**0.081988**	**0.071793**
	p-value	(0)	(0)	(0)	(0)
Textiles	D(x)	**0.042902**	-0.00329	**0.041412**	**0.036086**
	p-value	(0.03)	(0.8336)	(0.0394)	(0.0124)
Other Manufacturing	D(x)	0.02303	0.019393	0.030049	**0.033134**
	p-value	(0.242)	(0.327)	(0.1118)	(0.0332)

(a) D(x) is the Triples test statistic (Randles et al 1980), emboldened values are significant at the 5% level.

Table 5.13

Triples Test (Steepness) Results - First Release Data

Detrending Technique		Baxter-King	Symmetric Christiano-Fitzgerald	Asymmetric Christano-Fitzgerald	Hodrick-Prescott
Aggregate	ST(x)[a]	**-0.03513**	**-0.04143**	**-0.04185**	0.009952
	p-value	(0.0188)	(0.0032)	(0.0028)	(0.4412)
Chemicals	ST(x)	0.008858	0.001996	0.004979	0.030924
	p-value	(0.603)	(0.8886)	(0.7642)	(0.1164)
Engineering	ST(x)	0.005341	0.016069	0.008275	-0.01657
	p-value	(0.7718)	(0.2758)	(0.6818)	(0.4354)
Food Processing	ST(x)	0.004174	-0.00954	-0.001	0.025489
	p-value	(0.8572)	(0.6024)	(0.9602)	(0.1188)
Fuels	ST(x)	-0.00871	-0.01323	0.004274	-0.0081
	p-value	(0.6744)	(0.4902)	(0.8336)	(0.6818)
Metals	ST(x)	-0.0147	-0.02228	-0.01657	0.00428
	p-value	(0.5222)	(0.2224)	(0.4532)	(0.8026)
Textiles	ST(x)	0.01686	0.006953	0.01079	-0.01118
	p-value	(0.3682)	(0.6744)	(0.5754)	(0.562)
Other Manufacturing	ST(x)	-0.02007	**-0.03726**	-0.02258	0.003188
	p-value	(0.3174)	(0.0272)	(0.2224)	(0.8572)

(a) ST(x) is the Triples test statistic (Randles et al. 1980), emboldened values are significant at the 5% level.

The Triples test produces a significant ‘deepness’ results for the Other Investment and Fixed Capital Expenditure series from the National Accounts data. The coefficients are positive suggesting that the series produces fewer but larger observations above the trend than below it, as might be expected with irreversible investment (‘highness’). Looking at the ‘deepness’ test results for the First Release data displayed in Table 5.12 there are significant positive coefficients for all series with the exceptions of the Food Processing and Fuels industry groups. Even the aggregate measure generates a significant positive ‘deepness’ statistic. This suggests that contrary to the findings of the Sichel test results there is strong evidence for 'highness' in a number of the investment series, both aggregated and disaggregated. The 'steepness' forms of the test however produce no significant results.

Results generated using alternative detrending techniques back up those generated with the Hodrick-Prescott filter to varying degrees. Whilst there is complete consensus that there is 'highness' in the Metals investment series, and only the symmetrical Christiano-Fitzgerald filter, is not in agreement with the Hodrick-Prescott filter for the Fixed Capital Expenditure investment goods category, Chemicals and Textiles industry groups, finding no evidence of 'highness'. It does, however, display 'highness' in the aggregate as does the Hodrick-Prescott filtered data, unlike the Asymmetric Christiano-Fitzgerald filtered and Baxter-King filtered data. The Hodrick-Prescott filtered data are alone in displaying 'highness' for the Other Manufacturing industry group's investment. Whilst the Food Processing industry group shows least evidence of irreversible investment with no 'highness' found with any detrending technique applied. Data detrended using the Hodrick-Prescott filter does appear to have a greater tendency to display asymmetry,[106] the exception being for the Fuels industry group where only data detrended using the Baxter-King band pass filter displays 'highness'. The other series find backing from only one other detrending technique's results. No matter what the detrending technique applied, there does appear to be more evidence of irreversibility in the First Release data, disaggregated by industry group, compared to the National Accounts data, disaggregated by investment good category, with 'highness' found for many industry groups.

Whereas no evidence of 'steepness' was found using the Hodrick-Prescott detrended data, all three alternative detrending techniques find negative 'steepness'

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[106] Sichel (1993) suggests that the tendency to amplify fluctuations at the business cycle frequency also noted by Cogley and Nason (1995), would aid identification of business cycle asymmetry within macroeconomic series.

for the aggregate. This, however, is not the case for the data when disaggregated by industry group, with a single significant negative ‘steepness’ statistic produced for the Other Manufacturing industry group when using data detrended using the symmetrical Christiano-Fitzgerald filter, which has shown by the ‘deepness’ Triples test results above a tendency to produce results that differ from those generated using any of the three alternative detrending techniques.

The Sichel test results found no evidence of additional asymmetry when looking at the more disaggregated ABI data, but whether this is due to the shortness of series, temporal aggregation or simply because there is no asymmetry to detect is unclear. The Triples test, however, finds evidence of asymmetry in both the National Accounts and First Release data. This may mean that if any asymmetry is present in the ABI data that the Sichel tests failed to pick up, it may be possible to identify it with the use of the Triples test. Triples test results for the ABI data are presented below in Tables 5.14 and 5.15 below.

The Triples test results for the ABI data generate unsurprising results for the ‘deepness’ form of the test with a single positive result for Industry 21, (Manufacture of pulp, paper and paper products), but very surprising results for the ‘steepness’ form of the test with Industries 25 and 35 (manufacture of rubber and plastic products; and manufacture of other transport equipment respectively) both producing significant negative results. Given the National Accounts and First Release data results it was only to be expected that one of the industries in the ABI data would display ‘highness’, the ‘steepness’ results however are very surprising given the complete lack of significance generated by the Triples results from the National Accounts and First Release data.

Table 5.14

Triples Test (Deepness) Results – ABI Data

Industry	η^a	σ_η^2	t-value	p-value
Aggregate	0.0125	0.001003	0.39	(0.6966)
Industry 15	0.000806	0.000925	0.03	(0.976)
Industry 16	0.010215	0.001574	0.26	(0.7948)
Industry 17	0.032124	0.001201	0.93	(0.3524)
Industry 18	0.003629	0.001179	0.11	(0.9124)
Industry 19	0.032124	0.000769	1.16	(0.246)
Industry 20	0.05	0.000728	1.85	(0.0644)
Industry 21	**0.091668**	0.000499	4.10	(0)
Industry 22	0.016667	0.002096	0.36	(0.7188)
Industry 23	0.025403	0.000797	0.90	(0.3682)
Industry 24	-0.02527	0.001225	-0.72	(0.4716)
Industry 25	-0.03844	0.001002	-1.21	(0.2262)
Industry 26	0.030108	0.001105	0.91	(0.3628)
Industry 27	0.015054	0.001419	0.40	(0.6892)
Industry 28	0.027151	0.000841	0.94	(0.3472)
Industry 29	0.041801	0.000868	1.42	(0.1556)
Industry 30	0.025269	0.001042	0.78	(0.4354)
Industry 31	0.03965	0.000969	1.27	(0.204)
Industry 32	0.009812	0.001097	0.30	(0.7642)
Industry 33	-0.00793	0.001506	-0.20	(0.8414)
Industry 34	0.050134	0.000819	1.75	(0.0802)
Industry 35	-0.00968	0.001145	-0.29	(0.7718)
Industry 36	0.006317	0.001098	0.19	(0.8494)

(a) η is the Triples test statistic (Randles et al. 1980), emboldened values are significant at the 5% level.

Table 5.15

Triples Test (Steepness) Results – ABI Data

Industry	η^a	σ_η^2	t-value	p-value
Aggregate	0.004227	0.00104799	0.13	(0.8966)
Industry 15	-0.02455	0.00149291	-0.64	(0.5222)
Industry 16	0.009863	0.00107866	0.30	(0.7642)
Industry 17	-0.00971	0.00216815	-0.21	(0.8336)
Industry 18	-0.05465	0.00136636	-1.48	(0.1388)
Industry 19	-0.05421	0.00105884	-1.67	(0.095)
Industry 20	-0.05436	0.00149969	-1.40	(0.1616)
Industry 21	-0.01995	0.00164738	-0.49	(0.6242)
Industry 22	-0.00794	0.00135958	-0.22	(0.8258)
Industry 23	-0.00126	0.00196979	-0.03	(0.976)
Industry 24	0.012681	0.00120232	0.37	(0.7114)
Industry 25	**-0.05836**	0.00082768	-2.03	(0.0424)
Industry 26	-0.05717	0.00102473	-1.79	(0.0734)
Industry 27	-0.00719	0.00224566	-0.15	(0.8808)
Industry 28	-0.0066	0.00102101	-0.21	(0.8336)
Industry 29	-0.00349	0.00129789	-0.10	(0.9204)
Industry 30	0.00838	0.00089871	0.28	(0.7794)
Industry 31	-0.04383	0.00149182	-1.13	(0.2584)
Industry 32	0.036559	0.00193727	0.83	(0.4066)
Industry 33	0.029144	0.00177209	0.69	(0.4902)
Industry 34	-0.002	0.0009742	-0.06	(0.9522)
Industry 35	**-0.06874**	0.00070495	-2.59	(0.0096)
Industry 36	-0.04724	0.00071866	-1.76	(0.0784)

(a) η is the Triples test statistic (Randles et al. 1980), emboldened values are significant at the 5% level.

5.8 – Summary of Chapter

The business cycle has often thought to be asymmetric with shorter sharper recessions than expansions. A number of tests have been developed to test for the presence of this asymmetry. This chapter has tested for the presence of asymmetry in one particular component of the business cycle, investment. In contrast to the usual pattern of a negatively skewed business cycle, it is possible that the presence of irreverisbilities in the investment decision will result in a positively skewed investment pattern. Using two tests developed for the testing of asymmetry, the possibility of a positively skewed investment pattern was therefore tested.

Initially the Sichel (1993) skewness test utilised was unable to identify the presence of any asymmetry in the detrended series. It has however been suggested that the assumption of normality imposed by the Sichel test is inappropriate, so the Randles et al. (1980) nonparametric Triples test was also applied to the series, finding evidence of positive skewness in a large number of the detrended series which would indicate the 'highness' that might be associated with irreversible investment. This was found to be particularly the case with the industry group First Release data, which suggests that irreversible investment combined with industry group specific shocks resulted in firms making investments in spikes, which were detectable at the industry group level of aggregation. No evidence of 'steepness' was found in either the National Accounts or First Release data. The ABI data disaggregated to a lower level found 'highness' for one industry and interestingly negative 'steepness for two industries. The relatively small number of significant results generated by the ABI data may be due to the shortness of the time series.

Although the asymmetry test applied in this chapter have by no means found evidence of asymmetry rife throughout all industry groups investment series, such tests are noted by Psaradakis and Sola (2003) to have low power to reject the null of symmetry. It does however appear that any irreversible investment effects that are present, are not very strong at this level of aggregation, and the ABI data are unable to identify any stronger evidence (possibly in part due to shortness of series). The following chapters therefore attempt to identify further evidence of the irreversible nature of investment by taking a different approach. Firstly, by applying a direct statistical test for the time irreversibility of investment and second, by examining one particular relationship involving investment that is thought to be particularly strongly affected by irreversibilities, the investment-uncertainty relationship.

Chapter 6 – Time Reversibility Tests

The asymmetry tests conducted in Chapter 5 suggest there is little evidence of asymmetry within UK manufacturing investment that could be attributed to irreversible investment, with the Sichel (1993) tests in particular identifying no significant asymmetry indicative of irreversible investment. Whilst the Triples tests does find some evidence of highness within some industry groups and investment good categories. The asymmetry tests therefore suggest that either investment is reversible or alternatively the patterns linked to irreversible investment are hidden by aggregation even at the industry group level. The relatively low power of asymmetry tests to reject the null of symmetry could alternatively mean that the patterns are present, but not large enough to be detected.

This chapter therefore uses a test for directly identifying time irreversibility introduced by Ramsey and Rothman (1996), rather than attempting to identify the asymmetry that would be present within a time irreversible series, as was the case in the proceeding chapter. As discussed in more depth in Section 6.1 the *TR* test has additional benefits, not present in the asymmetry tests, including the abilities to identify the source of any time irreversibility detected, and the family of non-linear models most appropriate for modelling series displaying time irreversibility. The particular test utilised is the Time Reversibility (*TR*) test. This test looks at whether there would be a change in the probability distribution faced if the series was reversed in time. Section 6.1 will introduce the concepts of time reversibility and irreversibility, and look at how it can be tested for in each of the data sets used. Section 6.2 will examine the results from the *TR* tests using each of the three datasets described in Chapter 5 in turn. Section 6.3 summarises the results found in the proceeding section, and the chapter, as a whole.

6.1 – Time Irreversibility

Ramsey and Rothman (1996) define time reversibility as follows:

> "If the probabilistic structure of a time series going forward in time is identical to that in reverse time, the series is said to be time reversible"
>
> Ramsey and Rothman (1996) page 5

This definition is therefore highly appropriate for attempting to identify irreversible investment, as the costs that make investment irreversible have the exact affect of making the investment series time irreversible.[107] A firm that faces irreversible investment has the problem that it cannot reverse time and simply return to the point before the investment is made without some cost. How then can we identify the presence of irreversible investment? Sub-section 6.1.1 describes the theory behind the test for time irreversibility developed by Ramsey and Rothman, while sub-section 6.1.2 covers the methodology used and choice of data for the tests. The ability of the *TR* test to identify the source of time irreversibility is discussed in sub-section 6.1.3. One requirement of the *TR* test is that the series being tested is stationary, sub-section 6.1.4 presents Augmented Dickey-Fuller (ADF) tests for the presence of unit roots to ensure this is the case with the data utilised in this chapter. Sub-section 6.1.5 describes the considerations that need to be made in applying of the *TR* test to each of the three investment datasets.

6.1.1 – The Theory of Time Irreversibility

Ramsey and Rothman (1996) formally define a zero mean stationary time series, X_t, as being time reversible if, the vectors $\left(X_{t_1}, X_{t_2}, \ldots, X_{t_n}\right)$ and

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[107] A time irreversible series will also display longitudinal asymmetry, which is in itself indicative of the presence of irreversible investment considerations when found in investment time series. Chapter 5 covers the asymmetric nature of an irreversible investment series in more detail.

$\left(X_{-t_1+m}, X_{-t_2+m}, \ldots, X_{-t_n+m}\right)$ have the same joint probability distributions for every positive integer *n*, every t_1, t_2, . . . $t_n \in R$, and all $m \in N$. In the presence of stationarity, the vectors $\left(X_{t_1}, X_{t_2}, \ldots, X_{t_n}\right)$ and $\left(X_{t_n}, X_{t_{n-1}}, \ldots, X_{t_1}\right)$ will also have the same joint probability distributions, which are assumed to be uniquely characterised by the respective sequence of moments and cross moments, such that time reversibility holds only if:

$$(6.1) \qquad E\left[X_t^i \cdot X_{t-k}^j\right] = E\left[X_t^j \cdot X_{t-k}^i\right] \qquad \text{for all } i, j, k \in \mathrm{N}.$$

The existence of a lag *k* for which these two moments are not equal provides a sufficient though not necessary condition for time irreversibility, prompting Ramsey and Rothman to propose a test procedure based on consideration of the difference between the symmetric bicovariances for a zero-mean stationary process:

$$(6.2) \qquad \gamma_{i,j}(k) = E\left[X_t^i \cdot X_{t-k}^j\right] - E\left[X_t^j \cdot X_{t-k}^i\right]$$

In order for a series to be time reversible $\gamma_{i,j}(k) = 0$ for all *i*, *j*, and *k*. The comparison of all bicovariances for a time series is impractical and therefore a series is said to be time reversible to order *m* and degree *K* where the following limits have been enforced.

$$(i + j) \leq m \qquad \text{and} \qquad k \leq K$$

Ramsey and Rothman suggest that the appropriate values for *m* and *K* that should be applied to the tests for time reversibility should be 3 and 5. The choice of identifying time reversibility of order 3 is found to be the best compromise value for identifying time reversibility with the degrees of freedom available, similarly the choice of time reversibility to degree 5.

6.1.2 – The *TR* Test

The *TR* test statistics are based on a sample estimate of the symmetric-bicovariance function $(\hat{\gamma}_{2,1}(k))$, where the sample bicovariances for a zero mean stationary time series (X_t) with T observations are:[108]

(6.3) $$\hat{B}_{2,1}(k) = (T-k)^{-1} \cdot \sum_{t=K+1}^{T} X_t^2 \cdot X_{t-k}$$

and:

(6.4) $$\hat{B}_{1,2}(k) = (T-k)^{-1} \cdot \sum_{t=K+1}^{T} X_t \cdot X_{t-k}^2$$

which then are used to create the estimates of the symmetric-bicovariance function:

(6.5) $$\hat{\gamma}_{2,1}(k) = \hat{B}_{2,1}(k) - \hat{B}_{1,2}(k)$$

If X_t is a stationary sequence of zero mean independently and identically distributed (*i.i.d*) random variables then the exact small sample variance of $\hat{\gamma}_{2,1}(k)$ is given by the function:

(6.6) $$\mathrm{Var}[\hat{\gamma}_{2,1}(k)] = 2(\mu_4\mu_2 - \mu_3^2)/(T-k) - 2\mu_2^3(T-2k)/(T-k)^2$$

where:

(6.7) $$\begin{aligned} \mu_2 &= E[X_t^2] \\ \mu_3 &= E[X_t^3] \\ \mu_4 &= E[X_t^4] \end{aligned}$$

The result does not hold where X_t is serially correlated, as is the case for the data under consideration here, and therefore following Ramsey and Rothman (1996) and

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[108] In order to impose the assumptions of zero mean and unit variance, the mean of the original series is subtracted from the original series, Y_t, and divided through by its standard deviation, to create the tested series X_t.

Rothman (1997) computation of the test statistics variance is performed by means of Monte Carlo simulation of the hypothetical linear model which generated the data.[109]

Dividing the estimates of the symmetric-bicovariance function, by its standard deviation produces the *TR* test statistic, *TR*(*k*), where *TR* test statistics for lags (*k*) 1 to 5 are calculated:

$$TR(k) = \hat{\gamma}_{1,2}(k) / \sqrt{\operatorname{var}(\hat{\gamma}_{1,2}(k))} \tag{6.8}$$

Under the null hypothesis of time reversibility the expected value of $\hat{\gamma}_{2,1}(k)$ is zero and under certain mixing conditions (see Ramsey and Rothman, 1996), *TR*(*k*) is asymptotically distributed as *N*(0,1), permitting straightforward calculation of probability values associated with rejection of the null. However, in order to account for possible interdependence among the test statistics for different values of *k*, following Ramsey and Rothman (1996) and Rothman (1997) a portmanteau version of the *TR* test statistic based upon the largest absolute value among individual *TR* test statistics calculated for $k = 1,..,5$, is reported in this study.

6.1.3 – Type I and Type II Time Irreversibility and the *TR* Test

A series may be time irreversible due to one of two causes, the series may be produced by a non-linear data generating process with symmetric innovations, or alternatively the series is drawn from a linear data generating process with non-

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[109] With this approach an estimate of the variance of the variance of $\hat{\gamma}_{2,1}(k)$ is calculated by fitting a linear autoregressive (AR) model to the data, obtaining an estimate of the innovations variance, and then simulating a series using the estimated AR coefficients and generating a Gaussian error process with zero mean and variance equal to that estimated in the preceding stage. Values of $\hat{\gamma}_{2,1}(k)$ are calculated for each such replication for *N* replications, where *N*=100, permitting straightforward computation of the estimated variance using the replicated values of $\hat{\gamma}_{2,1}(k)$. If the process is truly Gaussian, and time reversible, this is an exact simulation procedure. If the series is truly non-linear (Type I time irreversible), the linear model constitutes a local approximation to the unknown non-linear model, but the procedure should nonetheless provide asymptotically unbiased estimates of the variance of $\hat{\gamma}_{2,1}(k)$ in the presence of uncorrelated innovations.

Gaussian innovations. The existence of time irreversibility due to a non-linear data generating process is referred to as Type I irreversibility, whilst time irreversibility due to the presence of non-Gaussian innovations produced from a linear data generating process is described as Type II irreversibility.

Both Type I and Type II time irreversibility should reject the null of reversibility for the *TR* test on the raw data. In order to identify which type of time irreversibility is present, the residuals of estimating the series using an AR model can be tested using the *TR* test. If the time irreversibility is due to Type II time irreversibility (non-Gaussian innovations generated by a linear model) the approximation using an AR model will produce residuals that should be approximately time reversible due to the low level of correlation between the residuals. This means that the null of time reversibility should be not rejected by the *TR* test upon the residuals. If on the other hand the asymmetry is due to Type I asymmetry from the existence of a non-linear model, the approximation using an AR model should generate residuals that will reject the null of reversibility when using the *TR* test upon the residuals. The test of the residuals is referred to as the *TR2* test in the results whilst the initial test using the raw data are referred to as the *TR1* test.

6.1.4 – Unit Root Tests

In order to apply the *TR* test, the series must be stationary, and therefore growth rates are used created as the first differences of natural logarithms. In order to test for the presence of stationarity Augmented Dickey Fuller (ADF) Tests are used to test for the presence of unit roots. The Dickey-Fuller test looks for a unit root within a series (y_t) such that $|\rho| = 1$ in the equation below:

(6.9) $$y_t = \rho y_{t-1} + x_t'\delta + \varepsilon_t$$

where x_t are exogenous regressors. The actual Dickey-Fuller test subtracts y_{t-1} from both sides to give:

$$\Delta y_t = \alpha y_{t-1} + x_t'\delta + \varepsilon_t \tag{6.10}$$

where $\alpha = \rho - 1$, so can test the Null of H_0: $\alpha = 0$ (presence of a unit root), against the alternative H_1: $\alpha < 0$ (absence of a unit root), with significance calculated using the t-value:

$$t_\alpha = \hat{\alpha}/(s.e(\hat{\alpha})) \tag{6.11}$$

this is only valid if the series is an AR(1) process, the Augmented Dickey-Fuller (ADF) test allows for the series to follow an AR(p) process by allowing lagged values of the change in the series to enter the test equation:

$$\Delta y_t = \alpha y_{t-1} + x_t'\delta + \beta_1 \Delta y_{t-1} + \beta_2 \Delta y_{t-2} + \ldots + \beta_p \Delta y_{t-p} + \varepsilon_t \tag{6.12}$$

The order of the AR process is selected using the Schwarz Information Criterion (SIC). A time trend component can be allowed for in the test, and in the tests described below this was the case for those tests undertaken on all series.

The Augmented Dickey-Fuller tests were applied to the levels, first differences and growth rates of the investment series within the data sets. Tables 6.1, 6.2 and 6.3 below display the unit root tests for the First Release, ABI and National Accounts investment data respectively.

Table 6.1

Unit Root Tests of First Release Investment Data

		Levels	First Differences	Growth Rates[a]
Aggregate	Lag Length[b]	3	2	2
	t-value[c]	**-3.85475**	**-4.64877**	**-4.59367**
	p-value	(0.0163)	(0.0012)	(0.0015)
Chemicals	Lag Length	0	0	0
	t-value	-2.46143	**-10.9864**	**-11.0433**
	p-value	(0.3464)	(0)	(0)
Engineering	Lag Length	0	0	0
	t-value	-2.62091	**-10.9931**	**-9.77869**
	p-value	(0.2722)	(0)	(0)
Food Processing	Lag Length	0	0	0
	t-value	-2.72807	**-14.1352**	**-13.8446**
	p-value	(0.2279)	(0)	(0)
Fuels	Lag Length	1	0	0
	t-value	-2.17316	**-14.3482**	**-14.0949**
	p-value	(0.4989)	(0)	(0)
Metals	Lag Length	0	0	0
	t-value	-2.11828	**-9.92634**	**-10.6977**
	p-value	(0.5292)	(0)	(0)
Textiles	Lag Length	0	0	0
	t-value	-3.10029	**-12.7504**	**-12.8814**
	p-value	(0.1119)	(0)	(0)
Other Manufacturing	Lag Length	0	0	0
	t-value	-2.78886	**-12.1664**	**-12.4411**
	p-value	(0.2049)	(0)	(0)

(a) Growth rates are calculated as first difference of natural logarithms.
(b) Lag length selected by the SIC.
(c) Emboldened values are those significant at the 5% level with p-values in parentheses.

Table 6.2

Augmented Dickey-Fuller Unit Root Tests of ABI data

2 digit SIC[a]		Levels	First Difference	Growth Rate[b]
Agg	Lag Length[c]	1	1	1
	t-value[d]	**-4.45649**	**-4.80057**	**-4.94126**
	p-value	(0.0069)	(0.0032)	(0.0022)
15	Lag Length	0	0	0
	t-value	-3.14427	**-5.36082**	**-5.27642**
	p-value	(0.1142)	(0.0008)	(0.0009)
16	Lag Length	0	0	0
	t-value	-2.58461	**-6.27921**	**-5.30138**
	p-value	(0.2892)	(0.0001)	(0.0009)
17	Lag Length	0	0	0
	t-value	-2.54736	**-4.9145**	**-4.46329**
	p-value	(0.305)	(0.0023)	(0.0068)
18	Lag Length	0	0	0
	t-value	-2.33109	**-6.00188**	**-6.68972**
	p-value	(0.406)	(0.0002)	(0)
19	Lag Length	0	0	0
	t-value	-2.38174	**-4.53081**	**-6.43578**
	p-value	(0.3811)	(0.0058)	(0)
20	Lag Length	1	1	1
	t-value	**-4.20365**	**-5.28877**	**-5.53246**
	p-value	(0.0124)	(0.001)	(0.0005)
21	Lag Length	0	1	0
	t-value	-2.12983	**-5.04117**	**-4.24806**
	p-value	(0.5099)	(0.0018)	(0.0112)
22	Lag Length	0	2	2
	t-value	-2.51741	**-4.36201**	**-4.76288**
	p-value	(0.3181)	(0.0092)	(0.0036)
23	Lag Length	0	0	0
	t-value	-1.72246	**-4.44134**	**-4.22749**
	p-value	(0.7169)	(0.0071)	(0.0117)
24	Lag Length	1	3	2
	t-value	**-4.13472**	-3.03266	**-3.64408**
	p-value	(0.0145)	(0.1422)	(0.0439)
25	Lag Length	1	0	0
	t-value	-3.20343	**-3.64298**	**-3.91314**
	p-value	(0.1028)	(0.0428)	(0.0239)
26	Lag Length	1	1	7
	t-value	**-4.23496**	**-5.45012**	**-3.98308**
	p-value	(0.0115)	(0.0007)	(0.0245)
27	Lag Length	1	0	0
	t-value	-2.69474	**-4.2405**	-3.37416
	p-value	(0.2455)	(0.0114)	(0.074)
28	Lag Length	1	6	6
	t-value	-2.91776	**-4.15511**	**-4.97252**
	p-value	(0.1714)	(0.0166)	(0.0028)

Table 6.2 continued

Augmented Dickey-Fuller Unit Root Tests of ABI data

2 digit SIC		Levels	First Differences	Growth Rate
29	Lag Length	5	1	1
	t-value	**-5.29715**	**-5.0878**	**-5.25928**
	p-value	(0.0012)	(0.0016)	(0.001)
30	Lag Length	0	0	0
	t-value	-2.43583	**-5.50211**	**-5.33241**
	p-value	(0.3553)	(0.0005)	(0.0008)
31	Lag Length	1	1	1
	t-value	**-3.83243**	**-5.94683**	**-5.44479**
	p-value	(0.0285)	(0.0002)	(0.0007)
32	Lag Length	0	0	0
	t-value	-3.31082	**-6.69935**	**-6.40134**
	p-value	(0.0832)	(0)	(0.0001)
33	Lag Length	0	0	0
	t-value	-1.66204	**-4.43909**	**-4.30786**
	p-value	(0.7438)	(0.0072)	(0.0097)
34	Lag Length	1	3	3
	t-value	**-4.18834**	**-4.33693**	**-4.16403**
	p-value	(0.0129)	(0.0101)	(0.0148)
35	Lag Length	6	0	0
	t-value	**-4.1099**	**-5.30616**	**-5.30946**
	p-value	(0.0177)	(0.0009)	(0.0009)
36	Lag Length	1	7	7
	t-value	-2.00102	**-5.33617**	**-4.84404**
	p-value	(0.5772)	(0.0014)	(0.004)

(a) Industries in the ABI dataset comprise the 2-digit SIC(92) industries 15 to 36 forming the manufacturing sector, Agg refers to the aggregate of these industries.
(b) Growth rates are calculated as first difference of natural logarithms
(c) Lag length selected by the SIC.
(d) Emboldened values are those significant at the 5% level with p-values in parentheses.

Table 6.3

Augmented Dickey-Fuller Unit Root Tests for National Accounts Data

Panel (a) 1966 – 2004		Levels	First Differences	Growth Rates[a]
Gross Fixed Capital Expenditure	Lag Length[b]	0	0	0
	t-value[c]	-1.83488	**-14.9505**	**-9.618919**
	p-value	(0.6804)	(0)	(0)
New Building Work	Lag Length	1	0	0
	t-value	-1.441296	**-12.6832**	**-13.03684**
	p-value	(0.8427)	(0)	(0)
Vehicle Investment	Lag Length	0	0	0
	t-value	**-3.900735**	**-12.8386**	**-13.60164**
	p-value	(0.0155)	(0)	(0)
Other Investment	Lag Length	0	0	0
	t-value	-1.924243	**-12.4911**	**-9.336233**
	p-value	(0.6346)	(0)	(0)
Panel (b) 1979 – 2004		Levels	First Differences	Growth Rates
Gross Fixed Capital Expenditure	Lag Length	0		0
	t-value	-1.00945	n/a	**-13.9834**
	p-value	(0.9387)		(0)
New Building Work	Lag Length	3		2
	t-value	-2.45892	n/a	**-5.96944**
	p-value	(0.3481)		(0)
Vehicle Investment	Lag Length	0		0
	t-value	-2.95307	n/a	**-15.1918**
	p-value	(0.1491)		(0)
Other Investment	Lag Length	0		1
	t-value	-2.35912	n/a	**-7.50932**
	p-value	(0.3995)		(0)

(a) Growth rates are calculated as first difference of natural logarithms.
(b) Lag length selected by the SIC.
(c) Emboldened values are those significant at the 5% level with p-values in parentheses.

For a vast majority of the series the presence of a unit root cannot be rejected from the levels forms of the data in all three datasets. However, the presence of a unit root can be rejected at the 5% level for all series in the First Release and National Accounts investment data when using both the first differences and growth rate forms of the data. The ABI data consisting of relatively short series, is more likely to lack the degrees of freedom to confirm the absence of a unit root by rejecting the null of a unit root. Even with the relatively short series only two of the industries cannot reject the presence of a unit root at the 5% level. Those industries being Industries 24 and 27, where the it is the first difference form of industry 24 which fails to reject the presence of a unit root, and growth rates for industry 27. Whilst the unit root for growth rates of industry 27 can be rejected at the 10% level, this is not the case for the first differences of industry 24. This means that the results using these particular forms of the data for industries 24 and 27 are not reliable, and more attention should be paid to the results generated by other forms of the data, (growth rates of industry 24 and first differences of industry 27). It is of particular importance that the First Release investment growth rates are stationary as these are not only used in the time reversibility tests in this chapter, but also in the investment estimations in Chapter 8.

6.1.5 – Testing Investment Data

The methodology described in the previous three subsections will be used to test for the presence of time irreversibility in the three investment data sets described in Chapter 5. Ramsey and Rothman (1996) looked at the growth rates of most of the macroeconomic series they analysed, with the raw first differences also used for some series to ensure that stationarity was imposed upon the tested series, sub-section 6.1.4 above presented the unit root tests conducted upon the growth rates of the three investment datasets to ensure stationarity was present.[110] All three datasets are tested, and although the First Release and ABI data are disaggregated by industry group and industry respectively, it is likely that comparisons will be more easily made between

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[110] The macro economic series analysed by Ramsey and Rothman are US data series for: Real GNP, Nominal GNP, Real Per Capita GNP, Industrial Production, Employment, Unemployment Rate, GNP Price Deflator, CPI, Nominal Wage, Real Wage, Money, Velocity, Bond Yields, S&P500. Growth rates were used for all series in calculations with the exceptions of the Unemployment Rate and Bond Yields. The use of raw first differences rather than growth rates was found to have little effect upon the results obtained from the investment series tested in this study, and therefore for the purposes of preservation of space only the results generated from the growth rates of the investment series are reported.

the First Release and National Accounts data as both these data sets are quarterly whilst the ABI data are annual.

As noted above the variance of the *TR* statistic is calculated by estimating the series with an AR model. The order of which is selected using either the AIC or SIC. The AR models selected by these information criteria often differ as the AIC favours models with more terms whilst the SIC favours models with fewer terms. For comparison, and robustness, both information criteria are therefore used.[111]

As discussed earlier in this section the choice of how many lags should be examined in the *TR* test is a compromise between testing as many lags as possible to determine whether there is asymmetry present in the series and maintaining the power of the test to reject the null of symmetry. Ramsey and Rothman (1996) found that testing with k taking values of 1 to 5 was sufficient to identify any asymmetry that might be present in the series. However Ramsey and Rothman test for time reversibility in a number of annual time series whilst the First Release and National Accounts series used in this study are quarterly (see sub-section 5.4.3 for discussion on frequency choice). This means that whilst a K value of 5 is adequate to cover all relationships in a business cycle whilst using annual data such as the ABI data, when using quarterly data the K value must be increased in order to cover more of the business cycle. As K is increased, however, the efficiency of the estimates falls and the power of the *TR* test to reject the null of time reversibility is reduced. In order to get round this problem, the test is repeated here with two different values of K. The original value of 5 will be used and also to test for longer time reversibility relationships K will also be increased to 10 in a lengthened form of the test.

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[111] Whereas the maximum order of the AR model selected is allowed to vary from 1 to 15 for the quarterly National Accounts and First Release data, this might cause difficulties when using the shorter span ABI annual data, and therefore a maximum AR order for this data is therefore set at 5.

6.2 – Results of the *TR* Tests

The previous section described the theory behind the *TR* test for time irreversibility and how it relates to the presence of irreversibilities in the investment decision. This section presents the results of the *TR* test for the three investment datasets in turn. Sub-section 6.2.1 presents the evidence of time irreversibility for the First Release investment data disaggregated by industry group. Sub-section 6.2.2 presents the results of the *TR* tests when applied to the ABI investment data, which disaggregates data to the 2-digit SIC industry level. Sub-section 6.2.3 presents the results using the National Accounts data.

6.2.1 – *TR* Test Results for First Release Data

This section presents the results for the *TR* tests run upon quarterly data for investment disaggregated by the seven manufacturing industry groups that make up the manufacturing sector in the UK, and the aggregate for manufacturing. It is important to remember that the tests were conducted twice on each set of investment variables with K taking the value of 5 in one run of tests and 10 in the other. The *TR* statistics should be the same for $k = 1 \ldots 5$, but the significance of the *TR* values will be reduced in the tests using $K = 10$.

The results for the various forms of the *TR* test conducted are contained in the tables listed below:

Table 6.4	-	Growth Rate of Investment Data ($K = 5$)
Table 6.5	-	Residuals from Growth Rates of Investment ($K = 5$)
Table 6.6	-	Growth Rate of Investment Data ($K = 10$)
Table 6.7	-	Residuals from Growth Rates of Investment ($K = 10$)

Initially the series were tested with *K* taking a value of 5. Table 6.4 below presents the results of the *TR* tests for the raw growth rates. Significant *TR* statistics are generated for the Engineering, Fuels and Textiles industry groups.[112] In each case the AR processes selected by both the AIC and SIC generate significant results. With the exception of Engineering the significant statistics are well above the 5% level.[113]

The results of the Time Reversibility test upon the original investment growth rates (referred to from this point as the *TR1* test) suggests that there is time irreversibility displayed by three of the seven industry groups. The cause of this time irreversibility is however not available from the *TR1* test. Conducting a *TR* test upon the residuals produced by the AR process representing the investment series, however, allows the cause of this time irreversibility to be determined as either a non-linear underlying data generating process (Type I time irreversibility), or alternatively a linear process with non-Gaussian innovations (Type II time irreversibility). This second application of the *TR* test upon the residuals is referred to as the *TR2* test.

Table 6.5 presents the results of the *TR2* test. Whilst the Textiles industry group generates a significant *TR* statistic neither the Engineering nor Fuels industry groups do. This means that only the Textiles industry group appears to display time irreversibility generated by a non-linear data generating process.[114]

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[112] In terms of asymmetry, a significantly positive *TR1* statistic suggests a 'fast up, slow down' longitudinally asymmetric pattern, as displayed by the Engineering and Textiles industry groups, whilst a negative *TR1* statistic is associated with a 'slow up, fast down' pattern, which is the found to be the case for the Fuels industry group.

[113] The results of Increasing the number of lags within the test to 10 ($K = 10$) presented in Tables 6.6 and 6.7 generate no additional significant *TR* statistics, and due to the associated reduction in power from increasing the number of lags, the significant results for the Engineering industry group are lost.

[114] As an alternative to using growth rates to detrend the investment series, the Hodrick-Prescott filter was used to impose stationarity, although it should be noted that Harvey and Jaeger (1993) suggest that spurious cycles can be introduced into a series using the Hodrick-Prescott filter, and therefore these results are only included for comparative purposes with the results generated using the investment growth rates. Only the Fuels industry group displayed time irreversibility with this form of the First Release investment series, but a significant *TR2* statistic indicated that this was due to an underlying non-linear data generating process, as opposed to the Type II time irreversibility found for the Fuels industry group growth rate.

Table 6.4

TR Test Results for First Release Investment Growth Rates Raw Data (*TR*1)

Industry Group	Information Criterion[a]	AR(p)	$TR(k)$[b] k=1	k=2	k=3	k=4	k=5	Abs[c]	p-value
Aggregate	AIC	3	-1.04873	-0.06904	-0.21705	0.8467	0.78446	1.04873	(0.756)
	SIC	3	-1.04873	-0.06904	-0.21705	0.8467	0.78446	1.04873	(0.756)
Chemicals	AIC	6	0.06337	0.69364	0.30153	-0.20565	1.39839	1.39839	(0.551)
	SIC	1	0.05985	0.69648	0.24515	-0.2308	1.4927	1.4927	(0.529)
Engineering	AIC	1	0.00371	1.06714	0.09838	**2.799**	-0.28494	**2.799**	(0.042)
	SIC	1	0.00371	1.06714	0.09838	**2.799**	-0.28494	**2.799**	(0.042)
Food Processing	AIC	3	-0.11907	-1.16142	-1.09648	-1.17597	0.24827	1.17597	(0.671)
	SIC	1	-0.133	-1.5129	-0.71965	-1.37461	0.25626	1.5129	(0.479)
Fuels	AIC	7	0.54802	-0.70926	0.32565	1.1078	**-3.0013**	**3.0013**	(0.018)
	SIC	1	0.58455	-0.84331	0.28099	1.30867	**-3.67225**	**3.67225**	(0.007)
Metals	AIC	13	-0.18992	-0.14577	0.72281	0.14923	-0.01305	0.72281	(0.935)
	SIC	1	-0.18217	-0.11992	0.69891	0.16536	-0.01386	0.69891	(0.961)
Textiles	AIC	4	**3.0733**	1.06432	-0.86461	-2.73142	0.42883	**3.0733**	(0.024)
	SIC	1	**3.19635**	1.17274	-0.94311	-2.92992	0.38745	**3.19635**	(0.017)
Other Manufacturing	AIC	3	-0.53057	-0.09653	-1.24249	2.20787	-0.44743	2.20787	(0.129)
	SIC	2	-0.53135	-0.09938	-0.94775	2.27072	-0.42045	2.27072	(0.109)

(a) Industry Groups codes (IG), Chem, Eng, Food, Fuels, Met, Text, and Other represent the, Chemicals, Engineering, Food Processing, Fuels, Metals, Textiles and Other Manufacturing industry groups with Agg representing the aggregate manufacturing investment.

(b) Time Reversibility statistics for $k = 1$ to 5, emboldened figures are significant at the 5% level.

(c) Absolutely largest TR-statistic for each industry group estimation, emboldened figures are significant at the 5% level and p-values are shown in parenthesis.

Table 6.5

TR Test Results for First Release Investment Growth Rates (Residuals *TR*2)

Industry Group	Information Criterion	AR(*p*)	*TR(k)*[a] *k*=1	*k*=2	*k*=3	*k*=4	*k*=5	Abs[b]	p-value
Aggregate	AIC	3	-1.73722	-0.49052	-0.70259	1.04566	1.04951	1.73722	(0.388)
	SIC	3	-1.73722	-0.49052	-0.70259	1.04566	1.04951	1.73722	(0.388)
Chemicals	AIC	6	0.25305	0.50065	0.28038	-0.38961	1.69825	1.69825	(0.403)
	SIC	1	-0.37065	0.67322	0.35546	-0.11932	1.31043	1.31043	(0.653)
Engineering	AIC	1	0.01561	0.93688	0.12456	2.27999	-0.23036	2.27999	(0.12)
	SIC	1	0.01561	0.93688	0.12456	2.27999	-0.23036	2.27999	(0.12)
Food Processing	AIC	3	-0.73994	-1.48791	-0.79077	-1.71666	0.25692	1.71666	(0.388)
	SIC	1	-0.791	-1.36864	-0.71381	-1.66733	-0.0142	1.66733	(0.415)
Fuels	AIC	7	1.3253	-2.04227	0.52467	0.66174	0.15751	2.04227	(0.204)
	SIC	1	0.6912	-0.9201	0.28825	0.50688	-1.83947	1.83947	(0.315)
Metals	AIC	13	0.60556	0.03915	-0.27655	-0.73744	-0.68681	0.73744	(0.948)
	SIC	1	-0.14932	-0.22587	0.48674	0.17175	0.10712	0.48674	(0.991)
Textiles	AIC	4	**3.22697**	0.43595	-0.14818	-1.51368	-0.22288	**3.22697**	(0.012)
	SIC	1	**3.30583**	0.11132	-0.14942	-2.02429	-0.08278	**3.30583**	(0.01)
Other Manufacturing	AIC	3	-0.52026	-0.05711	-1.26988	2.5412	-0.39354	2.5412	(0.06)
	SIC	2	-0.08525	-0.7836	-0.61933	2.50588	-0.80268	2.50588	(0.067)

(a) Industry Groups codes (IG), Chem, Eng, Food, Fuels, Met, Text, and Other represent the, Chemicals, Engineering, Food Processing, Fuels, Metals, Textiles and Other Manufacturing industry groups with Agg representing the aggregate manufacturing investment.

(b) Time Reversibility statistics for $k = 1$ to 5, emboldened figures are significant at the 5% level.

(c) Absolutely largest TR-statistic for each industry group estimation, emboldened figures are significant at the 5% level and p-values are shown in parenthesis.

Table 6.6

TR Test Results for First Release Investment Growth Rates (Raw Data *TR*1)

IG[a]	IC[b]	AR(*p*)	*TR(k)*[c]											
			k=1	*k*=2	*k*=3	*k*=4	*k*=5	*k*=6	*k*=7	*k*=8	*k*=9	*k*=10	Abs[d]	p-value
Agg	AIC	3	-1.04873	-0.06904	-0.21705	0.8467	0.78446	0.57413	0.9169	1.05045	1.63501	1.07852	1.63501	(0.602)
	SIC	3	-1.04873	-0.06904	-0.21705	0.8467	0.78446	0.57413	0.9169	1.05045	1.63501	1.07852	1.63501	(0.602)
Chem	AIC	6	0.06337	0.69364	0.30153	-0.20565	1.39839	0.8828	0.10822	0.54146	0.903	0.81469	1.39839	(0.768)
	SIC	1	0.05985	0.69648	0.24515	-0.2308	1.4927	0.63788	0.11304	0.48274	0.89767	0.87325	1.4927	(0.725)
Eng	AIC	1	0.00371	1.06714	0.09838	2.799	-0.28494	-0.59124	1.8219	-0.60097	-0.45483	1.21308	2.799	(0.081)
	SIC	1	0.00371	1.06714	0.09838	2.799	-0.28494	-0.59124	1.8219	-0.60097	-0.45483	1.21308	2.799	(0.081)
Food	AIC	3	-0.11907	-1.16142	-1.09648	-1.17597	0.24827	1.88357	-1.22643	0.36647	0.78236	0.39788	1.88357	(0.42)
	SIC	1	-0.133	-1.5129	-0.71965	-1.37461	0.25626	1.7109	-1.35434	0.36551	0.8066	0.42375	1.7109	(0.562)
Fuels	AIC	7	0.54802	-0.70926	0.32565	1.1078	**-3.0013**	0.5924	1.96019	-1.40085	0.21832	1.00262	**3.0013**	(0.039)
	SIC	1	0.58455	-0.84331	0.28099	1.30867	**-3.67225**	0.48936	1.51995	-1.60625	0.20576	0.97209	**3.67225**	(0.012)
Met	AIC	13	-0.18992	-0.14577	0.72281	0.14923	-0.01305	0.46781	-1.01717	0.25998	0.39303	0.35499	1.01717	(0.949)
	SIC	1	-0.18217	-0.11992	0.69891	0.16536	-0.01386	0.39282	-1.18484	0.28107	0.35494	0.30801	1.18484	(0.899)
Text	AIC	4	**3.0733**	1.06432	-0.86461	-2.73142	0.42883	0.98548	-0.73465	-0.58474	-1.05339	-0.07255	**3.0733**	(0.042)
	SIC	1	**3.19635**	1.17274	-0.94311	-2.92992	0.38745	0.96981	-0.7104	-0.58636	-1.04575	-0.07185	**3.19635**	(0.039)
Other	AIC	3	-0.53057	-0.09653	-1.24249	2.20787	-0.44743	0.95795	0.02698	0.97713	1.75805	1.11427	2.20787	(0.24)
	SIC	2	-0.53135	-0.09938	-0.94775	2.27072	-0.42045	0.91865	0.02704	0.97592	1.78205	1.13201	2.27072	(0.21)

(a) Industry Groups codes (IG), Chem, Eng, Food, Fuels, Met, Text, and Other represent the, Chemicals, Engineering, Food Processing, Fuels, Metals, Textiles and Other Manufacturing industry groups with Agg representing the aggregate manufacturing investment.

(b) AIC and SIC refer to the information criterion used to select the order of the autoregressive process used to estimate the investment series.

(d) Time Reversibility statistics for *k* = 1 to 10, emboldened figures are significant at the 5% level.

(e) Absolutely largest TR-statistic for each industry group estimation, emboldened figures are significant at the 5% level and p-values are shown in parenthesis.

Table 6.7

TR Test Results for First Release Investment Growth Rates (Residuals *TR*2)

IG[a]	IC[b]	AR(*p*)	*TR(k)*[c]										Abs[d]	p-value
			k=1	*k*=2	*k*=3	*k*=4	*k*=5	*k*=6	*k*=7	*k*=8	*k*=9	*k*=10		
Agg	AIC	3	-1.73722	-0.49052	-0.70259	1.04566	1.04951	0.79816	0.94566	0.26859	2.24412	1.80984	2.24412	(0.244)
	SIC	3	-1.73722	-0.49052	-0.70259	1.04566	1.04951	0.79816	0.94566	0.26859	2.24412	1.80984	2.24412	(0.244)
Chem	AIC	6	0.25305	0.50065	0.28038	-0.38961	1.69825	0.99495	-0.17069	-0.47046	0.68755	0.51151	1.69825	(0.637)
	SIC	1	-0.37065	0.67322	0.35546	-0.11932	1.31043	0.50751	-0.08504	0.1741	0.7455	0.70863	1.31043	(0.875)
Eng	AIC	1	0.01561	0.93688	0.12456	2.27999	-0.23036	-0.52057	1.63733	-0.5017	-0.33237	0.98542	2.27999	(0.224)
	SIC	1	0.01561	0.93688	0.12456	2.27999	-0.23036	-0.52057	1.63733	-0.5017	-0.33237	0.98542	2.27999	(0.224)
Food	AIC	3	-0.73994	-1.48791	-0.79077	-1.71666	0.25692	1.5745	-0.49219	0.46663	0.51744	0.51507	1.71666	(0.607)
	SIC	1	-0.791	-1.36864	-0.71381	-1.66733	-0.0142	2.07428	-1.19608	0.23153	0.73537	0.3448	2.07428	(0.337)
Fuels	AIC	7	1.3253	-2.04227	0.52467	0.66174	0.15751	-0.1414	0.60142	-1.95757	-0.01438	-0.85983	2.04227	(0.376)
	SIC	1	0.6912	-0.9201	0.28825	0.50688	-1.83947	-0.04447	0.77804	-1.35854	0.2304	-0.14558	1.83947	(0.518)
Mets	AIC	13	0.60556	0.03915	-0.27655	-0.73744	-0.68681	0.14577	-0.20941	1.20164	0.87654	1.52719	1.52719	(0.779)
	SIC	1	-0.14932	-0.22587	0.48674	0.17175	0.10712	0.50105	-0.73211	0.44334	0.26205	0.33494	0.73211	(0.998)
Text	AIC	4	**3.22697**	0.43595	-0.14818	-1.51368	-0.22288	-0.05143	-0.70715	-0.97134	-1.03179	-0.52208	**3.22697**	(0.026)
	SIC	1	**3.30583**	0.11132	-0.14942	-2.02429	-0.08278	0.42246	-0.52903	-0.89174	-0.55969	-0.13953	**3.30583**	(0.016)
Other	AIC	3	-0.52026	-0.05711	-1.26988	2.5412	-0.39354	1.35225	-0.04733	0.28092	2.08581	1.5035	2.5412	(0.113)
	SIC	2	-0.08525	-0.7836	-0.61933	2.50588	-0.80268	1.09998	0.36221	0.47809	1.80646	1.12256	2.50588	(0.124)

(a) Industry Groups codes (IG), Chem, Eng, Food, Fuels, Met, Text, and Other represent the, Chemicals, Engineering, Food Processing, Fuels, Metals, Textiles and Other Manufacturing industry groups with Agg representing the aggregate manufacturing investment.

(b) AIC and SIC refer to the information criterion used to select the order of the autoregressive process used to estimate the investment series.

(c) Time Reversibility statistics for $k = 1$ to 10, emboldened figures are significant at the 5% level.

(d) Absolutely largest TR-statistic for each industry group estimation, emboldened figures are significant at the 5% level and p-values are shown in parenthesis.

Rothman (1990, 1999) applies Monte Carlo simulations to the *TR* test and shows that the family of non-linear model indicated by Type I time irreversibility can be identified from the *TR2* statistics. Whereas non-linear models falling in the bilinear class (BL) will display *TR2* statistics which exponentially decline, those belonging to the threshold family of non-linear models will generate a single significant *TR2* statistic where $k = 1$, with other *TR2* statistics being insignificant. For the Textiles growth rate the later was found to be the case. This suggests that, as would be expected with irreversible investment considerations, some form of threshold model may best describe the investment decisions taken by the firms in these industry groups.

6.2.2 – *TR* Test Results for ABI Data

In the previous sub-section it was found that there was evidence for time irreversibility in the Engineering, Fuels and Textiles industry groups. The ABI data may find more irreversibility due to being at a lower aggregation level, and also by virtue of being annual data that are less noisy. If the time irreversibility found in the First Release data are also to be found at the lower aggregation levels, the industries most likely (a priori) to display time irreversibility are, Industries 17 to 19 for Textiles, Industry 23 for Fuels, and Industries 30 to 35 for Engineering. As described in Chapter 5 the investment figures from the two sources are calculated differently and this may affect the results, particularly for industries such as Fuels where there is likely to be high capital expenditure on existing buildings which is included in the ABI data but not the First Release Data.

The results reported are not as detailed as those for the First Release data due to the number of series utilised and the space required to show these results. Only the results produced using the AR process selected by the AIC are presented, as the two information criterion mostly agreed in the choice of model,[115] and only the largest absolute *TR* statistic is presented to preserve space. The *TR* test results are presented in the tables listed below:

Table 6.8	-	*TR* results for Investment Growth Rates (max $p = 5$)
Table 6.9	-	*TR* results for Residuals of Growth Rates (max $p = 5$)

Only three significant *TR1* statistics are generated, these being for Industries 19, 23 and 33, which are manufacture of leather goods, fuels production, electrical and optical equipment manufacture respectively. These significant statistics generated, are all for industries that are components of the three industry groups found to display time irreversibility in sub-section 6.2.1. The similarity of results generated by the First Release and restricted ABI investment growth rate data provides confidence in the earlier results obtained.[116] Only one significant *TR2* statistic is generated, but this does not coincided with a significant *TR1* statistic. Whilst the reliability of the results generated from the ABI data are questionable to an extent the results do backup those found for the First Release data.[117]

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[115] Note that as discussed sub-section 6.1.5 the maximum order of the AR processes used to approximate the investment series is limited to 5 given the relatively small number of observations available for the annual ABI data, in contrast to the quarterly First Release and National Accounts data, where a maximum AR order of 15 is permitted.

[116] However, it should be noted that whilst the industries displaying time irreversibility are those which agree with the findings of sub-section 6.2.1, the ABI *TR1* statistics are all negative where significant, which is the opposite to the results found for the First Release *TR1* statistics for Textiles and Engineering.

[117] Using the alternative detrending technique (Hodrick-Prescott filtered levels rather than growth rates) produces only three significant *TR1* statistics for industries 20, 27, and 33. Only Industry 33 (Medical and Precision Instruments) falls within the three industry groups identified as being time irreversible in the First Release data. No corresponding *TR2* statistics are produced suggesting Type II time irreversibility is present in these three industries.

Table 6.8

*TR*1 Statistics for ABI Investment Growth Rates (*p* = 5)

Industry[a]	AR(*p*)[b]	Abs[c]	p-value
Aggregate	2	0.62335	(0.93)
Industry 15	3	1.86919	(0.291)
Industry 16	1	-1.99518	(0.237)
Industry 17	3	1.22824	(0.641)
Industry 18	1	1.33886	(0.591)
Industry 19	1	**-5.77741**	(0)
Industry 20	2	1.19076	(0.66)
Industry 21	2	1.27204	(0.634)
Industry 22	3	-1.166	(0.699)
Industry 23	1	**-2.80269**	(0.05)
Industry 24	1	-1.64094	(0.358)
Industry 25	4	-1.20812	(0.622)
Industry 26	2	0.9756	(0.769)
Industry 27	3	0.36996	(0.99)
Industry 28	3	0.60831	(0.957)
Industry 29	2	-0.37965	(0.991)
Industry 30	1	-1.2627	(0.652)
Industry 31	2	0.84098	(0.854)
Industry 32	5	1.00948	(0.806)
Industry 33	1	**-2.80657**	(0.048)
Industry 34	4	-1.11558	(0.705)
Industry 35	1	-1.91416	(0.266)
Industry 36	4	-1.26097	(0.597)

(a) Industries in the ABI dataset comprise the 2-digit SIC(92) industries 15 to 36 forming the manufacturing sector, Agg refers to the aggregate of these industries (b) Order of autoregressive process used to estimate investment series. (c) Absolutely largest TR-statistic for each industry group estimation, emboldened figures are significant at the 5% level and p-values are shown in parenthesis.

Table 6.9

*TR*2 Statistics for Residuals of ABI Investment (p = 5)

Industry[a]	AR(*p*)[b]	Abs[c]	p-value
Aggregate	2	1.80294	(0.386)
Industry 15	3	-0.90479	(0.926)
Industry 16	1	-2.20325	(0.186)
Industry 17	3	1.40927	(0.66)
Industry 18	1	1.42619	(0.632)
Industry 19	1	-2.4291	(0.12)
Industry 20	2	1.46954	(0.625)
Industry 21	2	1.37933	(0.687)
Industry 22	3	2.10768	(0.252)
Industry 23	1	-2.04285	(0.268)
Industry 24	1	-1.43957	(0.618)
Industry 25	4	0.94585	(0.895)
Industry 26	2	1.46531	(0.621)
Industry 27	3	1.06548	(0.858)
Industry 28	3	2.6602	(0.07)
Industry 29	2	-2.16907	(0.2)
Industry 30	1	-1.64497	(0.492)
Industry 31	2	-1.37806	(0.683)
Industry 32	5	-1.53403	(0.602)
Industry 33	1	-2.58635	(0.069)
Industry 34	4	0.84364	(0.94)
Industry 35	1	-1.89973	(0.336)
Industry 36	4	1.54988	(0.564)

(a) Industries in the ABI dataset comprise the 2-digit SIC(92) industries 15 to 36 forming the manufacturing sector, Agg refers to the aggregate of these industries. (b) Order of autoregressive process used to estimate investment series. (c) Absolutely largest TR-statistic for each industry group estimation, emboldened figures are significant at the 5% level and p-values are shown in parenthesis.

6.2.3 – *TR* Test Results for National Accounts Data

As was noted above in Section 6.1, when looking at the aggregate investment series the *TR* tests are best conducted in a similar manner to those carried out upon the First Release data as both are quarterly, and therefore it is necessary to conduct normal tests and lengthened tests ($K = 5$ and $K = 10$ respectively).[118] The tables of *TR* test results are listed below:

Table 6.10 – *TR* results for Investment Growth Rates ($K = 5$)

Table 6.11 – *TR* results for Residuals of Growth Rates ($K = 5$)

Table 6.12 – *TR* results for Investment Growth Rates ($K = 10$)

Table 6.13 – *TR* results for Residuals of Growth Rates ($K = 10$)

Describing the National Accounts data used to generate the results covered in this section as aggregate measures is misleading to some extent. Whilst Gross Fixed Capital Expenditure is a true aggregate measure, this measure deals with acquisitions of capital, which may be lumpier than a net investment measure (see sub-section 5.5.1). The other measures examined in this section, whilst covering the whole economy rather than just a single industry group, are disaggregated by investment good category.

Disaggregating by investment good category may be expected to produce more evidence of time irreversibility. For example, if there are larger irreversibilities present in the purchase of one particular type of capital than another. However, it is difficult to say a priori where these greater irreversibilities may lie. New Building

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[118] The National Accounts data also spans a longer period of time (1966 – 2004) compared to that for the First Release data (1979 – 2004), which has benefits that more degrees of freedom are available, and more full cycles are contained within the National Accounts investment data. However, this does mean that the time periods covered by the two data sets are not comparable. Therefore, if the additional years available for the display atypical investment patterns to those found in the remainder of the sample period, different conclusions may be incorrectly inferred from the similarities and disparities between the two datasets' results. With this in mind the results for the National Accounts data are presented such that the results generated by the full sample period are displayed in panel (a) of each table, and results generated using the shortened sample period (1979 – 2004) to match those of the First Release data are presented in panel (b) of each results table.

Work may require a larger capital expenditure, for example, than purchases of vehicles, but the irreversible portion of the investment expenditure may be larger for vehicles than buildings, as there may be a particularly strong lemons problem with vehicles. The category Other Investment may also display irreversibility as this contains the purchases of equipment that is likely to be more bespoke, or at least industry specific, than is likely to be the case for the purchases of vehicles or buildings.

Tables 6.10 and 6.11 present the *TR1* and *TR2* results respectively for the National Accounts data. Significant *TR1* statistics are generated for Fixed Capital Expenditure and Vehicles Expenditure. A corresponding significant *TR2* statistic is found for Fixed Capital expenditure but not Vehicles Expenditure, suggesting Type I time irreversibility is present in the Fixed Capital Expenditure, but Type II time irreversibility characterises Vehicles Expenditure.[119] As with the *TR2* results for the Textiles industry group the pattern observed for these statistics for the Gross Fixed Capital Expenditure series suggests the non-linear data generating process belongs to the threshold family of models.

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[119] In terms of asymmetry the *TR1* statistic for Fixed Capital Expenditure is positive, as seen for the Engineering and Textiles industry group results in sub-section 6.2.1, where a 'fast up, slow down' pattern is suggested. Vehicle Expenditure on the other hand has a negative *TR1* statistic suggesting the 'slow up, fast down' pattern as found for the Fuels industry group.

Table 6.10

*TR*1 Test Results for National Accounts Investment Growth Rates

Panel (a) National Accounts Data Full Sample Period (1966 – 2004)

Investment Good Category	Information Criterion[a]	AR(*p*)	*TR(k)*[b] *k*=1	*k*=2	*k*=3	*k*=4	*k*=5	Abs[c]	p-value
Fixed Capital Expenditure	AIC	7	**3.08924**	-0.54627	0.68491	1.65354	-1.64659	**3.08924**	(0.017)
	SIC	1	**2.91216**	-0.48701	0.55388	1.62908	-1.64408	**2.91216**	(0.017)
New Building Work	AIC	10	-1.44273	-1.24236	1.76914	0.99406	-1.77911	1.77911	(0.238)
	SIC	3	-1.44316	-1.28378	1.41903	1.09738	-2.05375	2.05375	(0.167)
Vehicle Expenditure	AIC	1	-3.13205	0.23674	0.07546	**-3.59055**	-0.45542	**3.59055**	(0.006)
	SIC	1	-3.13205	0.23674	0.07546	**-3.59055**	-0.45542	**3.59055**	(0.006)
Other Investment	AIC	3	-0.53057	-0.09653	-1.24249	2.20787	-0.44743	2.20787	(0.129)
	SIC	2	-0.53135	-0.09938	-0.94775	2.27072	-0.42045	2.27072	(0.109)

Panel (b) National Accounts Data Shortened Sample Period (1979 – 2004)

Investment Good Category	Information Criterion[a]	AR(*p*)	*TR(k)*[b] *k*=1	*k*=2	*k*=3	*k*=4	*k*=5	Abs[c]	p-value
Fixed Capital Expenditure	AIC	7	**3.33143**	0.33229	0.72219	2.01157	-1.53331	**3.33143**	(0.012)
	SIC	1	**3.27698**	0.27257	0.56847	1.76034	-1.5878	**3.27698**	(0.014)
New Building Work	AIC	15	-1.57242	-1.59909	2.16323	1.38351	-2.27557	2.27557	(0.128)
	SIC	3	-1.03445	-0.94249	1.11734	0.83211	-1.55534	1.55534	(0.418)
Vehicle Expenditure	AIC	10	**-3.23755**	0.40192	-0.70021	-2.88906	-0.38766	**3.23755**	(0.013)
	SIC	1	-3.19372	0.43438	-0.59766	**-3.65614**	-0.44162	**3.65614**	(0.007)
Other Investment	AIC	1	-0.52634	0.51229	-0.85832	**3.20241**	0.79775	**3.20241**	(0.016)
	SIC	1	-0.52634	0.51229	-0.85832	**3.20241**	0.79775	**3.20241**	(0.016)

(a) AIC and SIC refer to the information criterion used to select the order of the autoregressive process used to estimate the investment series.
(b) Time Reversibility statistics for $k = 1$ to 5, emboldened figures are significant at the 5% level.
(c) Absolutely largest TR-statistic for each industry group estimation, emboldened figures are significant at the 5% level and p-values are shown in parenthesis.

Table 6.11

*TR*2 Test Results for Residuals of National Accounts Investment Growth Rates

Panel (a) National Accounts Data Full Sample Period (1966 – 2004)

Investment Good Category	Information Criterion[a]	AR(p)			$TR(k)$[b]				
			k=1	k=2	k=3	k=4	k=5	Abs[c]	p-value
Fixed Capital Expenditure	AIC	7	**3.58743**	0.53655	0.04829	0.97522	-0.76179	**3.58743**	(0.004)
	SIC	1	**2.97466**	-0.28134	0.4958	1.05944	-0.82752	**2.97466**	(0.026)
New Building Work	AIC	10	-0.31457	0.07653	-0.98071	1.12386	1.16321	1.16321	(0.775)
	SIC	3	-1.07037	-0.31755	-1.04382	0.3373	0.03562	1.07037	(0.826)
Vehicle Expenditure	AIC	1	-1.64056	-0.48349	-0.07555	-2.42183	-0.86499	2.42183	(0.09)
	SIC	1	-1.64056	-0.48349	-0.07555	-2.42183	-0.86499	2.42183	(0.09)
Other Investment	AIC	3	-0.52026	-0.05711	-1.26988	2.5412	-0.39354	2.5412	(0.06)
	SIC	2	-0.08525	-0.7836	-0.61933	2.50588	-0.80268	2.50588	(0.067)

Panel (b) National Accounts Data Shortened Sample Period (1979 – 2004)

Investment Good Category	Information Criterion[a]	AR(p)			$TR(k)$[b]				
			k=1	k=2	k=3	k=4	k=5	Abs[c]	p-value
Fixed Capital Expenditure	AIC	7	**3.25456**	0.18241	-0.26535	1.11855	-1.12651	**3.25456**	(0.008)
	SIC	1	2.17	0.21233	0.39804	1.26433	-1.2491	2.17	(0.153)
New Building Work	AIC	15	0.29415	-0.6479	-1.02177	1.29955	0.14348	1.29955	(0.689)
	SIC	3	-0.77093	-0.21447	-1.06017	0.40383	0.21562	1.06017	(0.829)
Vehicle Expenditure	AIC	10	-0.14324	-1.59889	-0.7595	-0.46435	-0.47522	1.59889	(0.46)
	SIC	1	-1.22751	-0.69556	-0.70205	-2.37754	-1.18648	2.37754	(0.103)
Other Investment	AIC	1	-0.47653	0.43483	-1.1235	**3.70043**	0.86341	**3.70043**	(0.001)
	SIC	1	-0.47653	0.43483	-1.1235	**3.70043**	0.86341	**3.70043**	(0.001)

(a) AIC and SIC refer to the information criterion used to select the order of the autoregressive process used to estimate the investment series.
(b) Time Reversibility statistics for k = 1 to 10, emboldened figures are significant at the 5% level.
(c) Absolutely largest TR-statistic for each industry group estimation, emboldened figures are significant at the 5% level and p-values are shown in parenthesis.

It is interesting that neither New Building Work with its associated high levels of fixed costs, nor Other Investment with its tendency to involve firm or industry specific purchases, show no evidence of time irreversibility,[120] whilst Gross Fixed Capital Expenditure does.[121] This might be suggestive of it being more appropriate to look at acquisitions and disposals separately rather than together, as investment spikes may be being hidden by sales of older vintages of capital that are being partially used to fund new capital purchases. Unfortunately, data are not available for purchases of individual investment good categories split into acquisitions and disposals.

As with the First Release data the National Accounts data are quarterly, which means that in order to cover the same period of the business cycle with the *TR* test the value of K must be increased. As before, a compromise of $K = 10$ is used as an alternative to the results already obtained above. The results of these tests are presented in Tables 6.12 and 6.13 below.

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[120] It is surprising, however, that no significant TR-statistic is generated for the Other Investment series for the full sample, although a significant *TR1* statistic was found for the series when only looking at the shorter sample period (1979 – 2004). The change from the full sample period to the shorter period precludes a significant *TR1* statistic for New Building Work. It therefore seems that the patterns found in the 1970s are atypical of those found in the period that followed.

[121] *TR* tests conducted using the National Accounts data detrended using the Hodrick-Prescott filter also finds evidence of time irreversibility for Gross Fixed Capital Expenditure, confirming that this acquisition based measure of investment is time irreversible. Time irreversibility is also present in the Vehicles Expenditure investment series when detrended using the Hodrick-Prescott filter.

Table 6.12

*TR*1 Test Results for National Accounts Investment Growth Rates

Panel (a) National Accounts Data Full Sample Period (1966 – 2004)

Investment Good Category			*TR*(*k*)[b]											
	IC[a]	AR(*p*)	*k*=1	*k*=2	*k*=3	*k*=4	*k*=5	*k*=6	*k*=7	*k*=8	*k*=9	*k*=10	Abs[c]	p-value
Fixed Capital Expenditure	AIC	7	**3.08924**	-0.54627	0.68491	1.65354	-1.64659	0.60848	0.14909	-0.41917	-2.31732	-0.66428	**3.08924**	(0.032)
	SIC	1	**2.91216**	-0.48701	0.55388	1.62908	-1.64408	0.65618	0.11837	-0.46234	-2.36621	-0.63985	**2.91216**	(0.046)
New Building Work	AIC	10	-1.44273	-1.24236	1.76914	0.99406	-1.77911	**3.29872**	-1.18233	-2.88468	1.54272	2.37945	**3.29872**	(0.014)
	SIC	3	-1.44316	-1.28378	1.41903	1.09738	-2.05375	1.991	-1.19289	**-3.16073**	1.28357	2.02436	**3.16073**	(0.03)
Vehicle Expenditure	AIC	1	-3.13205	0.23674	0.07546	**-3.59055**	-0.45542	-0.5039	-1.96444	1.76143	1.13095	0.47757	**3.59055**	(0.011)
	SIC	1	-3.13205	0.23674	0.07546	**-3.59055**	-0.45542	-0.5039	-1.96444	1.76143	1.13095	0.47757	**3.59055**	(0.011)
Other Investment	AIC	3	-0.53057	-0.09653	-1.24249	2.20787	-0.44743	0.95795	0.02698	0.97713	1.75805	1.11427	2.20787	(0.24)
	SIC	2	-0.53135	-0.09938	-0.94775	2.27072	-0.42045	0.91865	0.02704	0.97592	1.78205	1.13201	2.27072	(0.21)

Panel (b) National Accounts Data Shortened Sample Period (1979 – 2004)

Investment Good Category			*TR*(*k*)[b]											
	IC[a]	AR(*p*)	*k*=1	*k*=2	*k*=3	*k*=4	*k*=5	*k*=6	*k*=7	*k*=8	*k*=9	*k*=10	Abs[c]	p-value
Fixed Capital Expenditure	AIC	7	**3.33143**	0.33229	0.72219	2.01157	-1.53331	0.44577	-0.52926	-0.88614	-2.91065	-0.91756	**3.33143**	(0.027)
	SIC	1	**3.27698**	0.27257	0.56847	1.76034	-1.5878	0.49762	-0.39283	-0.97027	-3.08122	-0.89509	**3.27698**	(0.026)
New Building Work	AIC	15	-1.57242	-1.59909	2.16323	1.38351	-2.27557	4.96001	-1.60983	**-5.1622**	1.48941	3.8687	**5.1622**	(0.003)
	SIC	3	-1.03445	-0.94249	1.11734	0.83211	-1.55534	1.57635	-0.93751	-2.4402	0.91012	1.35749	2.4402	(0.152)
Vehicle Expenditure	AIC	10	**-3.23755**	0.40192	-0.70021	-2.88906	-0.38766	-1.58619	-2.57824	1.33736	-0.22758	-0.65142	**3.23755**	(0.026)
	SIC	1	-3.19372	0.43438	-0.59766	**-3.65614**	-0.44162	-1.3353	-2.38374	1.51416	-0.19323	-0.71746	**3.65614**	(0.012)
Other Investment	AIC	1	-0.52634	0.51229	-0.85832	**3.20241**	0.79775	1.40982	-0.41756	0.62138	0.85534	0.66239	**3.20241**	(0.032)
	SIC	1	-0.52634	0.51229	-0.85832	**3.20241**	0.79775	1.40982	-0.41756	0.62138	0.85534	0.66239	**3.20241**	(0.032)

(a) AIC and SIC refer to the information criterion used to select the order of the autoregressive process used to estimate the investment series.

(b) Time Reversibility statistics for $k = 1$ to 10, emboldened figures are significant at the 5% level.

(c) Absolutely largest TR-statistic for each industry group estimation, emboldened figures are significant at the 5% level and p-values are shown in parenthesis.

Table 6.13

*TR*2 Test Results for Residuals of National Accounts Investment Growth Rates

Panel (a) National Accounts Data Full Sample Period (1966 – 2004)

Investment Good Category	IC[a]	AR(*p*)	*TR*(*k*)[b] *k*=1	*k*=2	*k*=3	*k*=4	*k*=5	*k*=6	*k*=7	*k*=8	*k*=9	*k*=10	Abs[c]	p-value
Fixed Capital Expenditure	AIC	7	**3.58743**	0.53655	0.04829	0.97522	-0.76179	1.52555	-0.48994	-1.17012	-1.20451	-0.81163	**3.58743**	(0.006)
	SIC	1	**2.97466**	-0.28134	0.4958	1.05944	-0.82752	0.23045	0.13568	-0.34761	-1.31643	-0.49428	**2.97466**	(0.035)
New Building Work	AIC	10	-0.31457	0.07653	-0.98071	1.12386	1.16321	0.28409	-0.32219	0.04022	-0.02536	1.28132	1.28132	(0.92)
	SIC	3	-1.07037	-0.31755	-1.04382	0.3373	0.03562	1.09551	-1.16431	-0.76802	-0.21131	1.0385	1.16431	(0.954)
Vehicle Expenditure	AIC	1	-1.64056	-0.48349	-0.07555	-2.42183	-0.86499	-0.59061	-1.49225	1.82494	0.97896	0.49721	2.42183	(0.159)
	SIC	1	-1.64056	-0.48349	-0.07555	-2.42183	-0.86499	-0.59061	-1.49225	1.82494	0.97896	0.49721	2.42183	(0.159)
Other Investment	AIC	3	-0.52026	-0.05711	-1.26988	2.5412	-0.39354	1.35225	-0.04733	0.28092	2.08581	1.5035	2.5412	(0.113)
	SIC	2	-0.08525	-0.7836	-0.61933	2.50588	-0.80268	1.09998	0.36221	0.47809	1.80646	1.12256	2.50588	(0.124)

Panel (b) National Accounts Data Shortened Sample Period (1979 – 2004)

Investment Good Category	IC[a]	AR(*p*)	*TR*(*k*)[b] *k*=1	*k*=2	*k*=3	*k*=4	*k*=5	*k*=6	*k*=7	*k*=8	*k*=9	*k*=10	Abs[c]	p-value
Fixed Capital Expenditure	AIC	7	**3.25456**	0.18241	-0.26535	1.11855	-1.12651	1.66495	-0.4113	-1.39396	-1.57319	-0.68965	**3.25456**	(0.022)
	SIC	1	2.17	0.21233	0.39804	1.26433	-1.2491	0.48072	-0.28535	-0.74727	-2.15581	-0.66228	2.17	(0.268)
New Building Work	AIC	15	0.29415	-0.6479	-1.02177	1.29955	0.14348	0.47582	-0.77927	0.06301	-0.54879	1.54934	1.54934	(0.77)
	SIC	3	-0.77093	-0.21447	-1.06017	0.40383	0.21562	0.97888	-1.05955	-0.55039	-0.44718	0.70063	1.06017	(0.962)
Vehicle Expenditure	AIC	10	-0.14324	-1.59889	-0.7595	-0.46435	-0.47522	-1.12801	-1.08783	**3.00545**	-0.2693	-0.90966	**3.00545**	(0.036)
	SIC	1	-1.22751	-0.69556	-0.70205	-2.37754	-1.18648	-1.43302	-1.75391	2.0726	-0.13179	-0.7877	2.37754	(0.196)
Other Investment	AIC	1	-0.47653	0.43483	-1.1235	**3.70043**	0.86341	1.60986	-0.54	0.79328	0.77839	0.72929	**3.70043**	(0.005)
	SIC	1	-0.47653	0.43483	-1.1235	**3.70043**	0.86341	1.60986	-0.54	0.79328	0.77839	0.72929	**3.70043**	(0.005)

(a) AIC and SIC refer to the information criterion used to select the order of the autoregressive process used to estimate the investment series.

(b) Time Reversibility statistics for $k = 1$ to 10, emboldened figures are significant at the 5% level.

(c) Absolutely largest TR-statistic for each industry group estimation, emboldened figures are significant at the 5% level and p-values are shown in parenthesis.

Whilst the extension of the order of the *TR* test to 10 for the First Release data were found to have little effect other than reducing the power to detect time irreversibility already identified with $K = 5$, this is not the case for the National Accounts data. The significant *TR1* statistics for Fixed Capital Expenditure and Vehicles Expenditure remain but additional significant statistics are also generated for the New Building Work series. No corresponding *TR2* statistic is generated and therefore the time irreversibility found is Type II. The additional significant *TR* statistics generated for the National Accounts data when using the lengthened test were always more likely to be found for New Building Work rather than any of the other series given the 'time to build' considerations involved in buildings.[122]

6.3 – Summary of *TR* Tests

The *TR* test of Ramsey and Rothman (1996) allows the potential presence of irreversible investment in investment time series to be identified explicitly. An additional advantage that the *TR* test has over related tests for asymmetry is that as well as being able to identify longitudinal asymmetry within a series, it is also able to differentiate between the sources of this asymmetry. That is, whether it is due to a non-linear data generating process or, alternatively, a linear data generating process with non-Gaussian innovations (Type I and Type II time irreversibility respectively). Rothman (1999) suggests further that when Type I time irreversibility is identified it is possible to also determine the family of non-linear models the data generating process belongs to. Whilst aggregation is likely to cloud the picture, irreversible investment would be expected a priori to generate Type I time irreversibility due to a data generating process belonging to the SETAR family.

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[122] There is however one difficulty, the differing AR processes selected to represent New Building Work produce significant *TR1* statistics but with opposite signs to one another.

Whilst the time reversibility has not been applied to aggregate UK investment before it would be expected that those series more likely to display time irreversibility would be those at a lower level of aggregation, where investment spikes undertaken by firms within the series are more synchronised. As one explanation for irreversible investment is the purchase of industry specific capital equipment preventing resale when faced with a downturn in market conditions, it was expected that the First Release industry sector data and ABI industry data might show evidence of irreversible investment. Three industry groups were found to display time irreversibility in the First Release data, (Engineering, Fuels and Textiles). Only one of these suggested it to be due to Type I time irreversibility (Textiles). Whilst the ABI data had the advantage of being at a lower aggregation level the number of observations was greatly reduced by the necessary switching from a quarterly to annual frequency of data, although this lower frequency data are theoretically more pleasing. A relatively small number of significant *TR* statistics were produced, but nevertheless, the results did suggest that those 2-digit industries that were components of the Engineering, Fuels and Textiles industry groups have a greater tendency to display time irreversibility relative to those from other industry sectors.

Whilst disaggregating data by industry group or industry was expected to help identify the presence of irreversible investment, an alternative investigated in sub-section 6.2.3 was to disaggregate investment, by investment good category. All three investment good categories have a claim to be more likely to display irreversible investment than the aggregate, as does Gross Fixed Capital Expenditure, which only measures acquisitions rather than the net of acquisitions and disposals (though these may be timed to offset one another, see sub-section 5.5.1). Whilst there was strong evidence for time irreversibility in Fixed Capital Expenditure and Vehicles

Expenditure (Type I and Type II respectively) both New Building Work and Other Investment also display some evidence under certain specifications. New Building Work in particular appeared to show more evidence when using a lengthened version of the test, whilst Other Investment only generated significant *TR* statistics when considering a shortened sample period.

Chapter 7 – Uncertainty and Output Growth

Whilst some evidence of asymmetry was identified, in Chapter 5 the more direct *TR* tests of time irreversibility reported in Chapter 6 identified Gross Fixed Capital Expenditure, New Building Work, and Vehicles Expenditure investment good categories, and the Engineering, Fuels and Textiles industry groups as displaying time irreversibility. Having identified certain expenditure categories and industry groups that may be more strongly affected by irreversible investment considerations, this chapter and the next move on from attempting to identify the presence of irreversible investment directly, to studying one particular relationship that is thought to be strongly affected by the presence of irreversible investment, the investment-uncertainty relationship.

More specifically, this chapter utilises an Asymmetric Power Autoregressive Conditional Heteroskedastic in Mean (APARCH-M) model to look at the relationship between output growth and output growth uncertainty, in order to provide some insight into the investment-uncertainty relationship that exists for firms operating within UK manufacturing. The chapter is structured as follows. Section 7.1 provides a brief recap of the investment-uncertainty theories covered in Chapter 4. Section 7.2 introduces the Autoregressive Conditional Heteroskedastic (ARCH) model and its derivatives as a method of modelling uncertainty. Section 7.3 reviews earlier studies using this technique of modelling uncertainty, and introduces the exact specification that will be utilised in this work. Section 7.4 present the results produced for output growth when looking at the industry sector level of aggregation, whilst Section 7.5 focuses upon a small selection of industry sectors in order to test the output growth-output growth uncertainty relationship for the 4-digit SIC industries contained within them. A summary of the chapter is provided in Section 7.6.

7.1 –Recap

Chapter 4 provided a detailed review of the literature relating to the investment-uncertainty relationship, but as a quick refresher, the main theoretical arguments and empirical results are briefly revisited below.

7.1.1 – Recap of Theoretical Investment-Uncertainty Relationships

The impact that uncertainty has, not only upon investment decisions by firms, but also upon a number of other macroeconomic variables such as output and inflation, has been studied in depth. Keynes (1936) suggested that the impact of uncertainty upon investment would be to reduce the level of investment as firms found that in order to compensate for the higher risk a much higher return was required, and everything else being equal a rise in uncertainty would make investments less attractive. In contrast Oi (1961) showed that price volatility and therefore uncertainty could be desirable to firms, and Hartman (1972) showed that this could lead to a positive investment-uncertainty relationship. This is because, based on the assumption of a convex relationship between prices (or output) and profits, a firm would wish to sell more when uncertainty is greater.

The introduction of the 'new wave' theories of investment has again switched the theoretically expected sign of the relationship between investment and uncertainty. The importance of uncertainty being shown by the title of Pindyck's and Dixit's book surveying the work on the 'new wave' theories, *Investment Under Uncertainty*. In particular, the 'new wave' theories suggest that a firm will only undertake investment when the value of the investment is at least equal to the option value of waiting to invest. The effect of uncertainty must therefore be considered in terms not only of the expected value of the investment project, but also of the option value of waiting. It is this option value that is most strongly affected by uncertainty. The greater the uncertainty, the greater the value in waiting for more information to become available. Therefore, in short, a negative relationship between investment and uncertainty is the theoretical outcome of the new wave theories.[123]

7.1.2 – Empirical Evidence

As discussed in Section 4.4, although the evidence has not always been strong, most empirical studies have found that there is a negative relationship between uncertainty and investment. This suggests that the irreversibility of investment plays an important part in the decisions taken by firms. For example, authors including Caruso (2001) and Henley et al. (2003) have found a mainly negative relationship between uncertainty and investment, particularly when looking at the effect that industry level uncertainty has upon individual firms' investments. However, as was noted in Chapter 4, one of the most important issues when looking at uncertainty is how it is measured. Some studies such as Goldberg (1993) utilise the volatility of a series or the residuals of an ARMA model to estimate it as a proxy for uncertainty, but there is not always evidence of a strong correlation between the two. The reason for this is that greater volatility does not necessarily mean greater uncertainty if firms are able to predict these larger movements.

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[123] It should be noted that much of the work examining the relationship between investment in the new wave theories and uncertainty has concentrated upon the timing rather than the level of investments made, an exception to this being Bar-Ilan and Strange (1999) who show that although uncertainty delays investment when irreversiblities are present, when it does occur it results in a higher capital stock than would be present where investment is completely reversible.

An alternative is to model the conditional variance using an Autoregressive Conditional Heteroskedasticity (ARCH) or Generalised Autoregressive Conditional Heteroskedasticity (GARCH) model as the measure of uncertainty (Engle, 1982, 1983; Bollerslev, 1986). This approach has been used by a number of studies to model not only the reaction of investment to uncertainty (Huizinga, 1993; Episcopos, 1995; Price, 1995, 1996), but also other macroeconomic series such as output (Caporale and McKiernan 1996 and 1998; Speight, 1999; Apergis, 2004; Kontonikas, 2004).

7.2 – GARCH Modelling of Uncertainty

As discussed in the previous section the conditional variance as represented by a GARCH model can be used as a measure of uncertainty. This section will look at the GARCH model and how it can be used in different forms to model the uncertainty relating to a series through time.

7.2.1 – Different Models of the GARCH Family

ARCH and GARCH models were originally developed in order to model inflation series. Classical linear regression models assume that the variance of errors is constant, homoskedasticity. This is unlikely to be true of financial series, ARCH and GARCH models allow the conditional variance of a series to vary through time so as to account for periods of greater and lesser volatility. The original ARCH model was developed by Engle (1982), who proposed that the conditional variance of a series could be modelled as a function of lagged innovations (ε) where ε_t represents a collective measure of news at time *t*, to estimate models where the variance of the equation is determined by the past squared errors of the model as below:

(7.1) $$h_t = \alpha_0 + \alpha_1 \varepsilon_{t-1}^2$$

where h_t is the conditional variance of the mean-equation:

$$(7.2) \qquad Y_t = \beta_0 + \beta_1 X_{1t} + \varepsilon_t \qquad \varepsilon_t \sim N\left(0, \sqrt{h}\right)$$

and:

$$(7.3) \qquad z_t = \frac{\varepsilon_t}{\sqrt{h_t}}$$

where z_t, is the standardised error, which is identically and independently distributed (i.i.d.) with zero mean and unit variance, and where $\alpha_0 > 0$, and $\alpha_1 \geq 0$ are sufficient but not necessary conditions for non-negativity of the conditional variance. The conditional variance must be strictly positive, as a negative variance at any point in time would be meaningless. More lagged squared error terms can be included to allow for greater persistence of volatility, to form an ARCH(q) model. Older news will have less impact upon current volatility, with an ARCH(q) model news which arrived more than q periods ago has no effect upon volatility. An alternative to using a high order ARCH model is to include past values of the conditional variance to produce a GARCH model, as a high order ARCH model is simply a distributed lag model for the conditional variance (Bollerslev, 1986). This means the conditional variance equation for a GARCH(q,p) becomes:

$$(7.4) \qquad h_t = \alpha_0 + \sum_{i=1}^{q} \alpha_i \varepsilon_{t-i}^2 + \sum_{j=1}^{p} \gamma_j h_{t-j}$$

The GARCH(q,p) model comprises of autoregressive GARCH terms, moving average ARCH terms and a constant term, again the standardised error $z_t = \varepsilon_t / \sqrt{h_t}$ is identically and independently distributed with zero mean and unit variance. The non-negativity condition is satisfied when $\alpha_0 > 0$, $\alpha_i \geq 0$, and $\gamma_i \geq 0$. It is also a necessary and sufficient condition that the sum $\varpi = \sum_{i=1}^{q} \alpha_i + \sum_{i=1}^{p} \gamma_i < 1$ in order for a finite unconditional variance to exist. GARCH models are more widely used than equivalent ARCH models, as GARCH models are more parsimonious and avoid overfitting. As such the GARCH model is less likely to violate non-negativity constraints. GARCH models have been widely used in empirical applications for finance in particular, but also in other fields as well, due to their ability to account for observed features of data such as thick tails of the distributions, clustering of large and small observations and nonlinearity. There are, however, limitations to the GARCH model, which include: constraint of non-negativity on the parameters, which may cause difficulties in running the estimation procedures; and volatility is only a function of the magnitudes of past volatility and shocks.

An extension is to look for asymmetric affects. Does 'bad news' have a greater impact upon uncertainty than 'good news'? It has been observed of financial data that volatility tends to rise when excess returns are lower than expected ('bad news'), and fall when excess returns are higher than expected ('good news'). This observation is also likely to be applicable to some extent to data other than financial data.[124] Zakoïan (1994) modelling the conditional standard deviation and Glosten et al. (1993) modelling the conditional variance separately introduced the concept of the Threshold GARCH (TGARCH) model.[125] In the Glosten et al. (1993) TGARCH model conditional variance is given by equation (7.5):

$$(7.5) \qquad h_t = \alpha_0 + \sum_{i=1}^{p} \alpha_i \varepsilon_{t-i}^2 + \sum_{l=1}^{L} \xi_l \varepsilon_{t-l}^2 d_{t-l} + \sum_{j=1}^{q} \gamma_j h_{t-j}$$

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[124] An explanation of this noted by Black (1976) is the 'leverage effect'. That is, where a firm with debt and equity outstanding is exposed to large negative returns that decrease the market value of the firm, raising the debt-to-equity ratio and increasing the risk associated with the claim of equity, so increasing returns volatility. An alternative explanation is offered by 'volatility feedback' (Campbell and Hentschel, 1992). This occurs where large items of 'news' increase expected future volatility, so increasing the required rate of return and depressing the current asset price, thereby magnifying the negative price effects of negative news and mitigating the positive price impact of positive news.

[125] Nelson's (1991) earlier Exponential-GARCH (EGARCH) model also captures asymmetric effects of past innovations upon volatility.

where $d_t = 1$ if $\varepsilon_{t-1} < 0$, and 0 otherwise. In the above model 'good news', $\varepsilon_{t-i} > 0$, has an impact of α_i, while 'bad news' ($\varepsilon_{t-i} < 0$), has an impact of $\alpha_i + \xi$. If $\xi > 0$ then negative innovations have a greater impact upon volatility than positive innovations, the symmetric GARCH model is nested within the TGARCH model, and is a special case where $\xi = 0$. The non-negativity conditions are $\alpha_0 > 0$, $\alpha_i > 0$, $\gamma_i > 0$ and $\alpha_i + \xi > 0$.

Engle's (1982) ARCH and Bollerslev's (1986) GARCH models calculate the conditional variance of a series with moving average ARCH and autoregressive GARCH components as described above, in order to account for the clustering of volatility into periods of greater and lesser volatility, but this clustering is by no means confined to the squared error terms. Rather than modelling the conditional variance in the variance equation, the power of the dependant variable $\left(\sqrt{h_t}\right)^{\delta}$ can be varied, so for example by setting $\delta = 1$, the conditional standard deviation can be calculated, Taylor (1986) and Schwert (1989) for example both suggest modelling the conditional standard deviation in the variance equation in preference the conditional variance.[126] The power term, δ, emphasises the periods of greater and lesser volatility by magnifying the outliers in a series. The common choice of $\delta = 2$ is suggestive of the normality assumption usually applied to data, as normally distributed data can be completely characterised by its first two moments. Relaxing this assumption of a power term of 2, to allow contemplation of power terms of 3, or 4 allows for the presence of skewness and kurtosis within the distribution respectively (Brooks et al., 2000; McKenzie and Mitchell 2002).

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[126] Ding et al. (1993) find this could be highly beneficial given the long memory properties present in absolute stock market returns, $|r|$ with significant positive correlations found at over 2700 lags for daily observations of Standard and Poors 500 Index. Further investigation found that the autocorrelation of $|r|^{\delta}$ was maximised when δ took a value close to 1.

The Asymmetric Power ARCH (APARCH) model developed by Ding et al. (1993) allows the use of an infinite number of alternative power terms. It is possible to allow δ to be estimated rather than fixed. The estimated variance equation therefore becomes:

$$(7.6)\qquad \left(\sqrt{h_t}\right)^{\delta} = \alpha_0 + \sum_{j=1}^{p}\gamma_j\left(\sqrt{h_{t-j}}\right)^{\delta} + \sum_{i=1}^{q}\alpha_i\left(\left|\varepsilon_{t-i}\right| - \xi_i\varepsilon_{t-i}\right)^{\delta}$$

where as before if $\xi \neq 0$ then the response to 'bad' and 'good' news is asymmetric.

One of the great strengths of the APARCH is that a large number of other ARCH and GARCH specifications are nested within the APARCH model as special cases. Imposing restrictions upon the values taken by α, γ, ξ, and δ can reduce the APARCH model to one of the simpler ARCH or GARCH specifications. For example when the following restrictions are imposed $\delta = 2$, γ and $\xi = 0$ Engle's (1982) ARCH model is specified. McKenzie and Mitchell (2002) estimate 17 bilateral exchange rates using APARCH models and a large selection of nested special cases including, ARCH, GARCH, TGARCH, and Taylor's (1986) GARCH. The power terms estimated for the APARCH representations were significantly different from 2 for 7 bilateral exchange rates, and significantly different from 1 for 5 bilateral exchange rates, showing that the restrictions of either $\delta = 2$ or $\delta = 1$, would have resulted in a misspecification of the variance equation for a large minority of bilateral exchange rates in both cases. McKenzie and Mitchell do, however, show that when using the log likelihood ratio test the APARCH failed in many cases to outperform the simple GARCH. The APARCH model does, however, allow the selection of specific restricted ARCH and GARCH specifications nested within it by examining those components that are significant and those which are not.

In a number of relationships (particularly finance applications) the volatility coefficient has a direct impact upon the dependant variable. The most common example of this given is stock returns. Stock returns are often based upon the volatility related to them, and therefore it is appropriate that the conditional variance appears within the mean equation as a determinant, to represent a trade off between the risk and expected mean return. Engle et al. (1987) formulate the ARCH-in-mean (ARCH-M) class of models, and the mean equation becomes:

$$y_t = \mu + \beta_t X_{it} + \lambda\sqrt{h_t} + \varepsilon_t \tag{7.7}$$

where y_t is the dependent variable, X_{it} is a matrix of regressors, and as before h_t represents the conditional variance calculated by a ARCH process as shown in equation (7.1). In the above example volatility enters the mean equation as the condition standard deviation. Engle (1990) suggests that logarithmic functions of h_t work best as time varying risk premia. However, in this form problems can occur when $h_t < 1$, because as $h_t \rightarrow 0$, the effect on y_t, will become infinite, (Pagan and Hong, 1991). In-mean forms of all ARCH and GARCH specifications can be used, such as the APARCH-in mean (APARCH-M) specification used within this chapter, and as discussed in Section 7.1, the in-mean term can be used to represent an uncertainty term instead of its risk premia application in the financial literature.

7.2.2 - Non-Normally Distributed Error Terms

Work upon the first differences of cotton and common stock prices by Mandelbrot (1963) and Fama (1965) respectively found that the distributions of the variables had fatter tails than compatible with the normal distribution. Therefore it was more appropriate to model these distributions using a *t* distribution. Although GARCH models are able to model the persistence of volatility through the conditional variance they do not account fully for these different fluctuations.

It is also possible to allow the distribution of error terms to be of the form: Normal; Student's-*t*; or Generalised Error (GED) distributions. If, for example, a GARCH(1,1) process is assumed for a model with dependent variable Y_t, independent variables X_t, and exogenous variables Z_t entering the variance equation with coefficients λ, and the coefficients are calculated using maximum likelihood, then the log-likelihood for observation t with a normal distribution is:

$$(7.8) \qquad l_t = -\frac{1}{2}\log(2\lambda) - \frac{1}{2}\log h_t - \frac{1}{2}(y_t - X_t'\alpha)/h_t$$

whilst for observation t with a Student's-t distribution the log-likelihood is given by:

$$(7.9) \qquad l_t = -\frac{1}{2}\log\left(\frac{\lambda(v-2)\Gamma(v/2)^2}{\Gamma((v+1)/2)^2}\right) - \frac{1}{2}\log h_t - \frac{(v+1)}{2}\log\left(1 + \frac{(y_t - X_t'\alpha)^2}{h_t(v-2)}\right)$$

where the degree of freedom, v, controls the tail behaviour, such that as v approaches infinity the t-distribution approaches the normal distribution. (where v can be predetermined or estimated from the data). Alternatively, using a GED for observation t gives a log-likelihood of:

$$(7.10) \qquad l_t = -\frac{1}{2}\log\left(\frac{\Gamma(1/r)^3}{\Gamma(3/r)(r/2)^2}\right) - \frac{1}{2}\log h_t - \left(\frac{\Gamma(3/r)(y_t - X_t'\alpha)^2}{h_t\Gamma(1/r)}\right)^{r/2}$$

where the tail parameter, r, determines the fatness of the tails. When $r = 2$ the distribution is normal. When $r < 2$ the tails are fatter, and as $r > 2$ the tails become thinner and the distribution approaches the uniform distribution. As with the *t*-distribution the tail parameter can be predetermined or estimated.[127]

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[127] This is of particular importance for financial models such as option pricing which rely on full conditional distribution for accuracy.

7.3 – Examples of GARCH Modelling of Uncertainty

As noted in sub-section 7.1.1, uncertainty has been introduced into a number of models explaining not only investment, but also output and inflation. This section looks at a range of models utilised in the existing empirical and theoretical work. Sub-section 7.3.1 takes a look at some of the models discussed in Section 7.2 and how they have been utilised to model the relationship of uncertainty and output growth. Whilst, sub-section 7.3.2 looks at how these models can be used to study the relationships present in the First Release data.

7.3.1 – Modelling Uncertainty and Output Growth

This subsection will look more closely at one particular macroeconomic relationship. The relationship in question is that between output and various forms of uncertainty. A number of authors such as Bernanke (1983a), Pindyck (1991) and Black (1987) have suggested explanations for the expected sign of the relationship between output and uncertainty based on the investment decisions made by firms. That is, whereas the option value of waiting to invest leads Bernanke (1983a) and Pindyck (1991) to suggest a negative relationship between output growth and uncertainty, Black (1987) suggests that there will be a positive relationship as riskier technologies will be pursued only if the average rate of growth is large enough to compensate for the extra risk, such that the economy is faced by a trade off between volatility and output growth.

Empirical studies of this topic have failed to bring much greater understanding of the topic, with studies for various countries and periods producing conflicting results as to the sign of the relationship. Earlier studies used output variability as a measure of uncertainty, with cross sectional (Kormendi and Meguire, 1985) and pooled data studies (Grier and Tullock, 1989) finding a positive link. Ramey and Ramey (1995) use a panel of countries and found a negative relationship between growth and output variability. Later studies have typically turned towards using the conditional variance as estimated by one or more variant of the generalised autoregressive conditional heteroskedastic in mean (GARCH-M) model as a measure of uncertainty. Caporale and McKiernan (1996 and 1998) find a positive relationship lending support to the Black hypothesis using UK and US data respectively. Speight (1999) reassesses the UK data used by Caporale and McKiernan (1996) and, using a different form for the in-mean term and allowing for the possibility of non-normally distributed data, finds no such relationship.[128]

Fountas and Karanasos (2002) use a GARCH-M specification to model the annual output growth rates of five European countries, where output growth is measured using year to year changes in the log of industrial production.[129] The in-mean term was found to be significant for Germany and Italy at the 5% level and UK at the 10% level, and such that output growth uncertainty has a positive affect upon output growth. This would suggest that the Black hypothesis rather than the Bernanke hypothesis is correct and that there is no evidence that irreversible investment has a significant impact. It should be noted that this is only one type of uncertainty being examined. Fountas and Karanasos (2002) note the suggestion made by Taylor (1979) that inflation uncertainty and output uncertainty appear to trade off against one another, such that the relationship between inflation uncertainty and output growth is negative. The model is therefore adapted so lagged output growth enters the variance

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[128] Whilst Caporale and McKiernan (1996) use log of the conditional variance as the in-mean term Speight (1999) uses the conditional standard deviation arguing that if the conditional variance falls below 1 then the log of the conditional variance will be negative and the in-mean term will have the opposite implication for the output growth-output growth uncertainty relationship.

[129] The five countries examined are France, Germany, Italy, Sweden and UK. The data runs from 1815, 1850, 1861, 1861, and 1860 respectively ending in 1999.

equation to control for this effect and this is found to be negatively related to the conditional variance, and is significant for all of the countries except Sweden. This suggests that the output-uncertainty relationship depends upon the source of uncertainty (this is discussed in more detail in sub-section 7.3.2),[130] an alternative explanation is that the source of productivity gains within a firm determine the sign of the output-uncertainty relationship independent of the type of uncertainty.[131]

Apergis (2004) uses a panel of G7 countries to test for the relationship between inflation uncertainty, inflation and output growth. The GARCH(1,1) format was used to test the impact of inflation upon the other variables, but was included as part of an error correction system where inflation was modelled as being dependant on past inflation and past output growth, whilst output growth was measured as being determined by past output growth and past inflation. The causality tests undertaken find that inflation causes inflation uncertainty and visa versa. More interestingly for this study there is found to be a negative relationship between inflation uncertainty and output growth, which suggests that as uncertainty increases the irreversibilities will result in firms delaying investments.[132]

Shields et al. (2005) use monthly data covering the period April 1947 to October 2000 to look at the relationships between US real activity, inflation, real

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[130] Blackburn and Pelloni (2004) show that when looking at the expected impact of shocks and variance of shocks upon output in the presence of ridgities caused by nominal wage contracts. These ridgities create a linear relationship between employment and nominal shocks, which with diminishing returns to labour, result in the variance of nominal shocks having a negative impact on growth. Real shocks have a positive impact on growth through convexities in savings behaviour in relation to the preference (real) shock variable. This leads to investment being an increasing function of the variance of real shocks.

[131] Blackburn and Galindev (2003) model the impact of volatility upon productivity, where productivity gains are either internal or external to the production process. Internal productivity gains are realised through activities outside the production process and so involve foregoing production. External productivity gains are attributed to non-deliberate actions, which are complements to production. Thus whilst a recession will have a positive affect on growth through internal gains, it will have a negative impact on growth through external means as factor employment will be reduced. This means there is an ambiguous relationship between short-term volatility and long-term growth, and that the importance of internal and external productivity gains will determine the sign of this relationship.

[132] Output growth was also found to be a positive cause of inflation uncertainty, presumably through a Phillips curve affect.

activity uncertainty and inflation uncertainty.[133] The basic model is a Vector Autoregressive Moving Average (VARMA) where the variance is determined by a GARCH process. Using information criterion the model is found to be VARMA(2,2) with a conditional variance determined by a GARCH(1,1) process. This is an in-mean model where the conditional variance of both inflation and real activity are allowed to enter the mean equations of both real activity and inflation. Shields et al. find that innovations to inflation (real activity) affect the conditional variance of real activity (inflation), and that real activity (inflation) uncertainty affects inflation (real activity). The overall impact on real activity of additional inflation uncertainty is negative, while the overall impact of real activity uncertainty upon inflation is positive. Output is found to be positively related to output uncertainty, and suggests that output growth uncertainty does have a positive impact upon output growth as indicated by the Black hypothesis, but equally, uncertainty relating to inflation has a negative impact on the output growth rate as driven by irreversible investment decisions. Therefore a negative relationship between output growth and uncertainty will suggest the presence of irreversibilities, and whilst a positive relationship does not necessarily rule out the existence of irreversibilities, it does suggest their contribution to the investment decision is of secondary importance.

7.3.2 – Directions to be Followed

The previous work making use of GARCH modelling techniques to represent uncertainty have tested for irreversible investment in two main ways. Whereas Price (1995 and 1996) and others have directly modelled investment and included a proxy for uncertainty produced from the conditional variance, Fountas and Karansos (2002)

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[133] The source of the data is the FRED database at the Federal Reserve Bank of Saint Louis. Real activity is found as the change in the log of the index of industrial production at annualised rate, inflation rate is formed in the same manner from the producer price index.

and others look at the relationship between output as a whole and various uncertainty proxies. Whilst the next chapter follows the former approach, this chapter follows the later approach applied to the First Release data in order to test for a negative relationship between uncertainty and investment (Bernanke irreversibility hypothesis) or a positive relationship between output uncertainty and output/investment (the Black hypothesis). Initially, using the basic Fountas and Karanasos approach a GARCH-M model can be used to check the influence of output's own uncertainty upon its growth:

$$(7.11) \qquad \Delta Q_t = a_{Q0} + \sum_{n=1}^{N} a_{Qf} \Delta Q_{t-n} + b_{Q1}\sqrt{h_{Qt-1}} + \varepsilon_{Qt}$$

where the GARCH process modelling the conditional variance of the model would be chosen using AIC and SIC. By generalisation it would also appear sensible to allow lagged output growth to appear in the conditional variance as this allows for the Phillips/Friedman/Taylor or Brunner/Taylor interactions to take place, as noted by Fountas and Karansos (2002). This is, where a change in output growth will result in higher or lower output uncertainty through the interactions with inflation and inflation uncertainty. These interactions are described below.

If the short term Phillips curve holds than a rise in output growth will lead to an increase in inflation. Friedman (1977) explains that higher levels of inflation will result in higher inflation uncertainty as monetary policy becomes less predicable. Taylor (1979) finds that there is a trade off between inflation uncertainty and output growth uncertainty. A rise in inflation uncertainty therefore reduces output uncertainty, and these three effects taken together suggest that as output growth rises there will be a fall in output uncertainty.

An alternative argument runs as follows. As output growth falls the reaction of monetary policy is more uncertain and therefore inflation uncertainty rises (Brunner, 1993). But now, the Taylor relationship between inflation uncertainty and output growth uncertainty will result in a fall in output growth uncertainty.

If either of the above interactions hold then it becomes necessary to include lagged output growth or the absolute value of lagged output growth, and the conditional variance equation therefore takes the form:

$$(7.12) \qquad h_{Qt} = \alpha_{Q0} + \sum_{i=1}^{q} \alpha_{Qi}\varepsilon_{Q,t-i}^{2} + \sum_{j=1}^{p} \gamma_{Qj} h_{Q,t-j} + \sum_{v=1}^{V} \lambda_{Qv} z_{t-v}$$

where z_t represents some form of lagged output growth value, either $z_t = \Delta Q_t$ or $z_t = |\Delta Q_t|$.

7.4 – GARCH Models of Production

As discussed in Section 7.2 there are a number of different forms that can be used in order to model the conditional variance of a series with each additional consideration allowing the form and distribution of the conditional variance to be modelled more accurately. However, the addition of each of these refinements makes the model a little more complicated and can cloud the most important results. This means it is most sensible to start with a simple model and make additions once all that can be learnt from the simple model has been revealed.

Before applying different ARCH/GARCH model specifications to the data it should first be confirmed that the conditional variance follows an ARCH process. Sub-section 7.4.1 will introduces the output data utilised, and describes the selection of the mean equation and the testing procedure for determining the existence and nature of any ARCH processes present. Sub-section 7.4.2 describes the results of the simplest GARCH process utilised, while sub-section 7.4.3 looks at the impact of accommodating a 'bad news' effect when using a TGARCH model. Sub-sections

7.4.4 and 7.4.5 look at the results of using PARCH and APARCH models and in order to account for differing distributions more effectively. After selecting the appropriate form of GARCH process in the preceding sub-sections, 7.4.6 will allow lagged values of output to enter the variance equation to examine the influence that past output growth has upon the level of uncertainty, and sub-section 7.4.7 provides a summary of the section.

7.4.1 – Testing for the Presence of ARCH Processes

The data utilised in this chapter is from the ONS First Release publication, consisting of Production Indices for the UK manufacturing sector. These output measures are deflated using the chained value method for constant 2000 prices (see Tuke, 2002). In order to ensure stationarity, growth rates are taken produced using the first differences of natural logarithms. Table 7.1 below presents the unit root tests for the output growth rates, which indicate that stationarity is induced. The output data are available in annual, quarterly and monthly frequencies. In order to determine the robustness of results both the monthly and quarterly forms of the data are used (the annual form is not utilised due to the relatively low number of observations).[134]

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[134] Although Kontonikas (2004) suggests that lower frequency data is more appropriate due to the length of decision/response lags involved in making monetary decisions, ARCH processes are known to be stronger in higher frequency data (Baillie and Bollerslev, 1989).

Table 7.1

Augmented Dickey-Fuller Tests for Unit Roots in First Release Production Series

Sector Code	Sector Description		Quarterly		Monthly	
			Levels[a]	Growth Rate	Levels	Growth Rate
A	Food products, beverages and tobacco	lagged terms[b]	2	1	1	1
		t-value	-0.64063	**-13.6424**	**-4.8686**	**-20.276**
		p-value	(0.9753)	(0)	(0.0004)	(0)
B	Manufacture of textiles and textile products	lagged terms	0	0	2	1
		t-value	-0.80594	**-13.1331**	-1.89575	**-19.7291**
		p-value	(0.9626)	(0)	(0.655)	(0)
C	Manufacture of leather and leather products	lagged terms	0	0	1	0
		t-value	-1.41901	**-15.874**	-2.33875	**-24.9931**
		p-value	(0.853)	(0)	(0.4115)	(0)
D	Manufacture of wood and wood products	lagged terms	0	0	1	0
		t-value	-1.39727	**-13.6406**	-2.43621	**-27.3476**
		p-value	(0.8595)	(0)	(0.3602)	(0)
E	Manufacture of pulp, paper, and paper products; publishing and printing	lagged terms	2	0	1	0
		t-value	-2.99674	**-11.5309**	-1.71669	**-26.1288**
		p-value	(0.1355)	(0)	(0.7425)	(0)
F	Manufacture of coke, refined petroleum products and nuclear fuel	lagged terms	2	1	0	3
		t-value	-1.33381	**-14.026**	-4.96197	**-14.3984**
		p-value	(0.8768)	(0)	(0.0003)	(0)
G	Manufacture of chemicals, chemical products and man-made fibres	lagged terms	1	0	1	0
		t-value	-1.68426	**-11.1834**	-1.44908	**-29.4974**
		p-value	(0.7552)	(0)	(0.8452)	(0)

Table 7.1 continued

Augmented Dickey-Fuller Tests for Unit Roots in First Release Production Series

Sector Code	Sector Description		Quarterly		Monthly	
			Levels	Growth Rate	Levels	Growth Rate
H	Manufacture of rubber and plastic products	lagged terms	3	3	1	1
		t-value	-3.08023	**-7.09576**	-1.63858	**-19.1439**
		p-value	(0.1136)	(0)	(0.7762)	(0)
I	Manufacture of other non-metallic mineral products	lagged terms	0	0	1	0
		t-value	-1.77404	**-17.6637**	-2.89865	**-25.3546**
		p-value	(0.7142)	(0)	(0.1639)	(0)
J	Manufacture of basic metals and fabricated metal products	lagged terms	0	0	2	1
		t-value	-2.40146	**-13.727**	-2.35382	**-21.5228**
		p-value	(0.3773)	(0)	(0.4035)	(0)
K	Manufacture of machinery and equipment Not elsewhere classified	lagged terms	0	0	2	1
		t-value	-1.73849	**-14.643**	-2.50155	**-19.7976**
		p-value	(0.7309)	(0)	(0.3273)	(0)
L	Manufacture of electrical and optical equipment	lagged terms	1	0	4	0
		t-value	-2.48538	**-13.2173**	-2.27854	**-24.9514**
		p-value	(0.3352)	(0)	(0.4443)	(0)
M	Manufacture of transport equipment	lagged terms	1	0	5	4
		t-value	-2.3009	**-20.1412**	-1.40427	**-14.4627**
		p-value	(0.4313)	(0)	(0.8587)	(0)

Table 7.1 continued

Augmented Dickey-Fuller Tests for Unit Roots in First Release Production Series

Sector Code	Sector Description		Quarterly		Monthly	
			Levels	Growth Rate	Levels	Growth Rate
N	Manufacture not elsewhere classified	lagged terms	0	0	1	0
		t-value	-1.48282	**-13.8684**	-1.67451	**-25.3348**
		p-value	(0.8328)	(0)	(0.7611)	(0)
Eng	Engineering Industry Group	lagged terms	0	0	2	1
		t-value	-2.05188	**-14.5692**	-1.60541	**-18.3016**
		p-value	(0.5693)	(0)	(0.7896)	(0)
Text	Textiles Industry Group	lagged terms	0	0	2	1
		t-value	-1.3507	**-14.8923**	-1.22986	**-24.7446**
		p-value	(0.8724)	(0)	(0.9028)	(0)
Other	Other Manufacturing Industry Group	lagged terms	2	1	1	0
		t-value	-2.50446	**-7.96806**	-1.79809	**-25.8384**
		p-value	(0.3258)	(0)	(0.7043)	(0)
Agg	UK Manufacturing Production	lagged terms	2	0	1	1
		t-value	-2.22112	**-12.8216**	-1.90837	**-18.555**
		p-value	(0.4751)	(0)	(0.6484)	(0)

a) Emboldened values are those significant at the 5% level with p-values in parentheses.
b) Selected using SIC.

Unlike the investment data used in chapters 5 and 6 the First Release output data are available at a variety of aggregation levels. For comparative purposes with the results obtained in using the investment data in chapters 5 and 6 a relatively high level of aggregation is used, with data being examined at the industry sector and industry group level. Even at the industry sector level, the data are available for 14 individual sectors rather than just the seven industry groups. Whilst the Food, Fuels, Chemicals and Metals industry groups each form four of these sectors, the Engineering, Other Manufacturing and Textiles industry groups can each be split into two or more sectors.[135] In the case of the Engineering and Textiles industry groups the combined industry sectors seem to be reasonable fits together, but this is definitely not the case with the Other Manufacturing industry group where industry sectors as disparate as Wood and Plastic products lumped together.

The first question that needs answering is do production indices follow a GARCH process of some kind. An appropriate test for this is the ARCH-LM test. This test is undertaken by first estimating the standard OLS relationship between the independent and dependent variables, which generates an error series (*e*). The following auxiliary regression is then estimated to test for the presence of an ARCH(*q*) process:

$$e_t^2 = \hat{\alpha}_0 + \hat{\alpha}_1 e_{t-1}^2 + \ldots + \hat{\alpha}_q e_{t-q}^2 + \varepsilon_t \tag{7.13}$$

The joint significance of $\hat{\alpha}_1,\ldots,\hat{\alpha}_q$ is then tested for. If the coefficients are significantly different from zero the assumption of conditionally homoskedastic disturbances can be rejected in favour of ARCH disturbances. It should be noted however that any specification errors in the original relationships between the

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[135] Contained within the Engineering industry group are industry sectors K, L and M (Equipment, Electrical and Transport Products). Other Manufacturing contains industry sectors D, E, H, I, and N (Wood, Paper, Plastic, Mineral and Other Products). The Textiles industry group combines industry sectors B and C, (Textiles and Leather Products respectively).

dependent and independent variables can produce evidence of ARCH disturbances where there are none in the true relationship.

The mean equation used to model the output growth rate is assumed to be a simple AR model with firms basing production upon the past levels of output growth. As the data are seasonally adjusted much of the correlation of lagged terms that are multiples of four should have disappeared, which means that simple, low order, AR(N) models should be suitable. The order of the AR process is selected using the AIC and SIC. The models are selected separately for the quarterly and monthly forms of the data.

Table 7.2 below presents the results of ARCH-LM tests for the quarterly and monthly versions of the output growth rate data when testing for the presence ARCH(q) processes of orders $q = 1$ and $q = 16$.[136] The correlogram of squared residuals was also examined for industry group and industry sector to give a rough idea of the order of any ARCH processes present. The most appropriate specification was the confirmed using the AIC and SIC to compare estimations of the output growth series using the models suggested by the ARCH-LM tests and correlogram of squared residuals. The standardised residuals were re-examined through the correlogram of squared residuals, and ARCH-LM tests in order to confirm that all ARCH processes had been fully accounted for.

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[136] The two ARCH orders are tested for in order to give an indication of whether ARCH processes were present, and in the case of the higher order $q = 16$, to suggest whether the conditional variance displayed persistence of volatility.

Table 7.2

ARCH-LM Tests (Production Growth Rates)

	Monthly				Quarterly			
Lagged Terms	16		1		16		1	
Industry[a]	AIC[bc]	SIC	AIC	SIC	AIC	SIC	AIC	SIC
A	**2.843152**	**3.034991**	**7.970517**	**14.36287**	1.570238	1.527824	0.135953	0.039362
	(0.00021)	(0.000078)	(0.004977)	(0.000172)	(0.080196)	(0.093331)	(0.712694)	(0.842917)
B	**2.257626**	1.647758	3.078343	3.33175	0.047924	0.048122	0.392658	0.395796
	(0.00378)	(0.054375)	(0.080071)	(0.068646)	(1)	(1)	(0.531558)	(0.529921)
C	1.533352	**2.006583**	**4.47753**	**8.839553**	**1.736301**	**1.891453**	0.904669	1.442821
	(0.08484)	(0.011887)	(0.034927)	(0.003113)	(0.043648)	(0.023298)	(0.342637)	(0.230975)
D	1.071417	1.061153	**3.972953**	**4.954732**	1.013892	0.779861	**10.80541**	**8.262472**
	(0.380612)	(0.390974)	(0.046867)	(0.026535)	(0.443881)	(0.707145)	(0.00118)	(0.004444)
E	**5.284116**	**8.946668**	**52.31959**	**74.90898**	**1.852092**	**7.991618**	0.499175	**23.86163**
	(0)	(0)	(0)	(0)	(0.02813)	(0)	(0.480681)	(0.000002)
F	1.160596	1.541394	**4.60177**	**8.059315**	1.324116	1.324116	**7.956487**	**7.956487**
	(0.297414)	(0.082209)	(0.03251)	(0.004742)	(0.18586)	(0.18586)	(0.005232)	(0.005232)
G	**3.201772**	**3.488234**	**48.90553**	**54.18311**	**4.859577**	**4.707051**	**16.22459**	**16.68556**
	(0.000033)	(0.000007)	(0)	(0)	(0)	(0)	(0.000078)	(0.000062)
H	**1.994253**	**3.076879**	**8.559494**	**20.91426**	1.176006	0.982645	**13.83847**	**11.54188**
	(0.012663)	(0.000063)	(0.003626)	(0.000006)	(0.290546)	(0.477344)	(0.000254)	(0.000808)
I	1.043856	1.477972	3.161153	**5.539512**	**5.266823**	**4.218255**	**59.72915**	**51.6532**
	(0.408805)	(0.104074)	(0.076116)	(0.019039)	(0)	(0.000001)	(0)	(0)
J	**6.174622**	**6.174622**	**68.48522**	**68.48522**	0.763598	0.763598	1.812951	1.812951
	(0)	(0)	(0)	(0)	(0.722605)	(0.722605)	(0.18033)	(0.18033)
K	**3.288593**	**3.288593**	**7.368545**	**7.368545**	**2.562782**	**2.471472**	**6.620495**	**16.90919**
	(0.000021)	(0.000021)	(0.006904)	(0.006904)	(0.001347)	(0.001955)	(0.010767)	(0.000055)
L	**4.310376**	**4.147117**	**25.38211**	**17.29967**	**1.837881**	**1.905218**	**16.80434**	**15.91881**
	(0)	(0)	(0.000001)	(0.000039)	(0.029357)	(0.022037)	(0.000059)	(0.00009)
M	**2.425816**	**2.425816**	**5.540346**	**5.540346**	0.982551	0.982551	3.429773	3.429773
	(0.001681)	(0.001681)	(0.019034)	(0.019034)	(0.477446)	(0.477446)	(0.065371)	(0.065371)
N	**2.081625**	**2.720997**	2.662975	3.172466	1.620776	1.585321	**17.45537**	**16.9923**
	(0.008541)	(0.000388)	(0.103462)	(0.075592)	(0.066825)	(0.075851)	(0.000043)	(0.000053)
Agg	**3.650554**	**3.968402**	**39.89884**	**47.43291**	**2.472559**	**2.472559**	**10.54131**	**10.54131**
	(0.000003)	(0.000001)	(0)	(0)	(0.001953)	(0.001953)	(0.001351)	(0.001351)
Eng	**3.592664**	**3.830001**	**25.88147**	**30.07625**	0.989874	1.241406	**8.441343**	**10.14814**
	(0.000004)	(0.000001)	(0.000001)	(0)	(0.469623)	(0.239911)	(0.004051)	(0.001654)
Text	**3.399775**	**2.453998**	**6.472983**	**6.868505**	1.107507	1.240729	**15.82831**	**18.95285**
	(0.000008)	(0.001274)	(0.011179)	(0.008971)	(0.350644)	(0.240398)	(0.000095)	(0.000021)
Man	**2.443863**	**3.686502**	**17.60064**	**27.79209**	**2.418723**	**2.418723**	**24.48037**	**24.48037**
	(0.001554)	(0.000002)	(0.000033)	(0)	(0.00248)	(0.00248)	(0.000001)	(0.000001)

(a) The industries A to N refer to are the SIC(92) sector classifications DA to DN. Whilst Agg, Eng, Text, and Man refer to the Aggregate of manufacturing industries, and the Engineering, Textiles and Other Manufacturing industry groups respectively.

(b) AIC and SIC refers to the information criterion used to select the order of AR process best representing each series.

(c) Emboldened figures are those significant at the 5% significant level with p-values shown in parenthesis

The LM-tests for the presence of ARCH processes within the variance indicate that there appears to be an ARCH process present for 16 of the 18 industry groups and industry sectors. 7 of the industry groups and industry sector showed evidence of higher order ARCH processes. Using the AIC and SIC it was confirmed that the correct specification for the ARCH process was a GARCH(1,1). Where the ARCH-LM test for ARCH(16) processes was insignificant, the correlogram of the squared residuals for Industries D, H, N and the Textiles industry group suggested no persistence in the conditional variance. The AIC and SIC were used to confirm that an ARCH(1) process was most appropriate.

Longer ARCH processes with some persistence were suggested by the ARCH-LM and correlogram results for Industries A, F, J, M and Engineering industry group. The AIC and SIC were compared for the models produced using most likely alternative specifications, only Industry J was found to be modelled more accurately with an ARCH(3) process, with the others most appropriately modelled with a GARCH(1,1) process. Two series were found to display no evidence of any ARCH process, industries B and C, using the AIC and SIC of the models produced it was found an ARCH(1) process best fitted Industry B whilst a GARCH(1,1) process was more appropriate for Industry C.

The ARCH-LM tests for the monthly data found the presence of ARCH processes in all 18 industry groups and industry sectors. Only four of the industry sectors did not clearly show persistence in the conditional variance through the ARCH-LM tests for $q = 16$, and the correlogram of squared residuals. It was confirmed by the AIC and SIC that a GARCH(1,1) specification most appropriately represented the conditional variance of the other 14 industry groups and sectors. Of those industries not displaying strong persistence Industries D and F followed

ARCH(1) processes and Industries I and N follow ARCH(2) and ARCH(3) processes respectively, according to the AIC and SIC. Please see Table 7.4 for a summary of the selected GARCH processes.[137]

7.4.2 – Modelling with Simple GARCH Models

The simplest form for the variance equation that the GARCH model that can encompass is that presented in equation (7.4) where no leverage terms are included and only lagged terms of the squared error values and conditional variance are included (with no exogenous terms). The results of the ARCH-LM tests described in sub-section 7.4.1 show that in a majority of cases the null of conditionally homoskedastic disturbances can be rejected in favour of the alternative of the presence of ARCH processes. Therefore, it is appropriate to model the production indices with the inclusion of a conditional variance following an ARCH process. As was found in the previous sub-section the ARCH processes were generally of high orders and therefore it is appropriate to include lagged terms of the conditional variance within the variance equation for a majority of series with the exceptions noted in sub-section 7.4.1. For all sectors, production was modelled using both GARCH and GARCH-M models. Obviously as the aim of this chapter is to uncover the effect of uncertainty upon output, and therefore ultimately investment, the second of these is of more interest. Initially no in-mean term was included to observe the GARCH processes presented when no volatility feedback was included in the mean equation. The distribution of the error terms is initially assumed to be normal, but

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[137] It was shown by Baillie and Bollerslev (1989) that the averaging of series to form lower frequency data, has the effect of hiding ARCH effects within the data. This is shown by the greater tendency for the presence of ARCH processes to be found in the monthly data. Whilst as discussed above the quarterly data may be more theoretically pleasing (even though containing fewer observations), the lack of an ARCH process make it less likely that significant in-mean terms will be calculated representing the output growth-output growth uncertainty relationship.

with the large literature associated with GARCH models suggesting that the distribution often has fatter tails, it is appropriate to allow an alternative specification utilising either the Students *t* or GED.

The mean equations were simple AR processes with the order determined using either the AIC or SIC. Both selected AR processes were utilised in order for comparisons to be drawn. Table 7.3 summarises the AR processes selected for each series. Table 7.4 contains the in-mean terms for the models incorporating ARCH processes used to represent both the quarterly and monthly production indices. The in-mean terms used in the models are the conditional standard deviation calculated by the variance equation, unless marked with an asterisk. This indicates the use of the log of the conditional variance to resolve computational difficulties faced when the conditional standard deviation was used, such as failure for the likelihood function to converge fully.

Table 7.3

AR Processes Used to Estimate First Release Production Series

	Monthly		Quarterly	
Industry[a]	AIC	SIC	AIC	SIC
A	6	2	2	1
B	13	2	2	1
C	10	1	13	1
D	2	1	4	1
E	16	1	20	2
F	12	4	2	2
G	13	4	4	1
H	18	2	4	1
I	3	1	2	1
J	2	2	1	1
K	2	2	9	1
L	9	1	12	1
M	5	5	1	1
N	15	1	5	1
Aggregate	8	2	2	2
Engineering	8	2	6	1
Textiles	13	2	4	1
Other Manufacturing	15	1	2	2

(a) The industries A to N refer to are the SIC(92) sector classifications DA to DN. Whilst Agg, Eng, Man and Text refer to the Aggregate of manufacturing industries, and the Engineering, Textiles and Other Manufacturing industry groups respectively.

Table 7.4

In-Mean Terms for Normally Distributed Errors

	Quarterly				Monthly			
Industry[a]	GARCH Process	AIC[bcd]	GARCH Process	SIC	GARCH Process	AIC	GARCH Process	SIC
A	(1,1)	0.149274 (0.7449)	(1,1)	-0.036 (0.9383)	(1,1)	0.011368 (0.9519)	(1,1)	0.083426 (0.6503)
B	(1,0)	-0.0367 (0.716)	(1,0)	-0.11092 (0.2992)	(1,1)	1.410715 (0.2555)	(1,1)	0.36045 (0.1429)
C	(1,1)	-0.48032 (0.3598)	(1,1)	-0.6441 (0.228)	(1,1)	-0.22197 (0.5853)	(1,1)	-0.25804 (0.5063)
D	(1,0)	0.038591 (0.9531)	(1,0)	-0.28916 (0.5917)	(1,0)	**0.264056*** (0.0032)	(1,0)	**0.499039*** (0)
E	(1,1)	0.266545 (0.1719)	(1,1)	0.430282 (0.2133)	(1,1)	1.23526 (0.1025)	(1,1)	0.692399 (0.1254)
F	(1,1)	-0.12067 (0.4363)	(1,1)	-0.12067 (0.4363)	(1,0)	-0.22431 (0.4811)	(1,0)	-0.00389 (0.9919)
G	(1,1)	0.196224 (0.4842)	(1,1)	0.220627 (0.4143)	(1,1)	**0.19916*** (0)	(1,1)	-0.006572 (0.9684)
H	(1,0)	-0.02335 (0.9625)	(1,0)	-0.16529 (0.7012)	(1,1)	0.306534 (0.1667)	(1,1)	0.245491 (0.2126)
I	(1,1)	**1.750872** (0.0017)	(1,1)	**2.086612** (0.0002)	(2,0)	4.668599 (0.2005)	(2,0)	**1.9627** (0)
J	(3,0)	0.207401 (0.2656)	(3,0)	0.207401 (0.2656)	(1,1)	-0.00892 (0.9358)	(1,1)	-0.00892 (0.9358)
K	(1,1)	-0.26337 (0.3857)	(1,1)	-0.36552 (0.1455)	(1,1)	-0.03396 (0.8549)	(1,1)	-0.03396 (0.8549)
L	(1,1)	-0.50114 (0.1066)	(1,1)	-0.66045 (0.0817)	(1,1)	-0.2879 (0.2482)	(1,1)	-0.27496 (0.2283)
M	(1,1)	0.372528* (0.0052)	(1,1)	0.372528* (0.0052)	(1,1)	-0.27602 (0.1452)	(1,1)	-0.27602 (0.1452)
N	(1,0)	-0.09108 (0.8386)	(1,0)	-0.11493 (0.7803)	(3,0)	0.010323 (0.954)	(3,0)	-0.08897 (0.6235)
Agg	(1,1)	0.044515 (0.8641)	(1,1)	0.044515 (0.8641)	(1,1)	0.012272 (0.9369)	(1,1)	0.123703 (0.5734)
Eng	(1,1)	-0.56044 (0.3923)	(1,1)	-0.85055 (0.1375)	(1,1)	-0.2599 (0.1718)	(1,1)	-0.31931 (0.0719)
Text	(1,0)	0.022329 (0.9802)	(1,0)	0.083066 (0.9213)	(1,1)	1.888635 (0.0732)	(1,1)	1.350301 (0.0983)
Man	(1,1)	0.229419 (0.3137)	(1,1)	0.229419 (0.3137)	(1,1)	0.026182* (0.092)	(1,1)	1.616474 (0.0748)

(b) The industries A to N refer to are the SIC(92) sector classifications DA to DN. Whilst Agg, Eng, Text, and Man refer to the Aggregate of manufacturing industries, and the Engineering, Textile and, Other Manufacturing industry groups respectively.

(c) Refers to the information criterion used to select the order of AR process best representing each series.

(d) Emboldened figures are those significant at the 5% significant level with p-values shown in parenthesis

(e) Those values marked with an asterisk are where the log of the variance has been used as the in-mean term rather than the standard deviation.

There is little evidence that the uncertainty terms have a major impact upon the production of industries when using simple GARCH models. The only sector to produce significant uncertainty coefficients is Industry I, (the minerals industry) when examining quarterly data and industries D, G and I, (the wood products, chemicals and minerals industries) when data are monthly. The significant coefficients are positive indicating a positive output growth-uncertainty relationship with the exception of the in-mean terms for the monthly versions of Wood Products and Chemicals.[138]

As noted by others the distribution of innovations does not always appear to follow a normal distribution, but has fatter tails so the errors terms might be better modelled as following a Students-*t* distribution or GED where the distribution of error terms can also be estimated and the fatness of tails discovered. The Student's-*t* distribution tail variables estimated for the production series are clustered around 4.5. This suggests that when using a *t*-distribution much fatter tails than the normal distribution, produce the best fit for the calculated error terms. In the case of a GED distribution the tail variable values were clustered in a range between 1 and 1.55. The GED similar to the *t*-distribution finds the smaller the tail variable the fatter the tails of the distribution, with a tail variable of 2 having the same fatness of tail as the normal distribution. This means that both alternatives to the normal distribution have selected a distribution with fatter tails, but what is the affect that this has upon the in-mean term? As these two alternative error distributions produced similar results on the whole, for preservation of space the discussion here will concentrate on the results obtained when using the GED.[139]

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[138] The sign of the relationship is reversed when using log of the conditional variance.

[139] This is also because the estimates of the tail variables for the GED have smaller standard error on average than for the Student's-*t* distribution and therefore the tail variable can be calculated with more precision for this distribution.

Table 7.5 presents the GARCH in-mean variables calculated for the quarterly and monthly data when assuming a GED.[140] Although significant coefficients are found for Industry I (Minerals) as when using normally distributed errors, further coefficients are also significant for Industries C and L (Leather and Electrical Goods). A further significant result is generated for the Textiles industry group, (perhaps due to the influence of the Leather industry within this industry group). These significant coefficients are negative apart from Industry I, suggesting that for most industries and industry groups, uncertainty has no impact upon output growth levels but where it does it is a negative effect.

The in-mean terms for monthly data are significant for industries H, J, L, (Plastics, Metals, and Electrical Products respectively), and industry group Other Manufacturing. Electrical Products produces a negative coefficient whilst the other significant variables are positive, (or implying a positive relationship where the log of the conditional variance is used). The evidence from the simple ARCH and GARCH models used in this subsection therefore appear to suggest that uncertainty does not affect production for most industries, but where it does have an effect there is evidence for both a negative and positive influence varying across industry sectors.

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[140] Please refer to Table 7.4 for details of the selected GARCH processes for each series.

Table 7.5

In-Mean Terms for GARCH models with GED

Industry[a]	Quarterly		Monthly	
	AIC[bcd]	SIC	AIC	SIC
A	0.147696	-0.01035	-0.03131	0.080009
	(0.704)	(0.979)	(0.843)	(0.6263)
B	-0.05256	-0.06705	0.181456	0.375725
	(0.7191)	(0.6696)	(0.4571)	(0.0958)
C	**-0.63051**	-0.65838	-0.52343	-0.2448
	(0.0008)	0.1879	(0.0703)	(0.2322)
D	-0.04167	-0.42415	0.201547*	0.700208*
	(0.9502)	(0.4515)	(0.8328)	(0.9938)
E	5.024156	0.48564	0.012714	0.715916
	(0.0983)	(0.1241)	(0.9465)	(0.0556)
F	-0.1414	-0.1414	-0.20072	-0.03515
	(0.3726)	(0.3726)	(0.5111)	(0.8953)
G	0.147996	0.159597	0.033995*	-0.03915
	(0.5431)	(0.5142)	(0.4278)	(0.7632)
H	-0.08983	-0.18938	**0.405687**	**0.300232**
	(0.8106)	(0.6278)	(0.0057)	(0.0419)
I	**1.461546**	0.4702	3.406568	1.13707
	(0.0066)	(0.2791)	0.1706	0.0719
J	0.215871	0.215871	**0.188025**	**0.188025**
	(0.3109)	(0.3109)	(0.0443)	(0.0443)
K	-0.29315	-0.43019	-0.03767	-0.03767
	(0.3323)	(0.0978)	(0.7904)	(0.7904)
L	-0.22648	**-0.7693**	**-0.39343**	-0.24052
	(0.0562)	(0.033)	(0.0252)	(0.161)
M	0.019463*[e]	0.019463*[e]	-0.18727	-0.18727
	(0.1041)	(0.1041)	(0.251)	(0.251)
N	-0.01451	-0.06134	2.39E-05	-0.07491
	(0.9688)	(0.8605)	(0.9999)	(0.6085)
Agg	0.018451	0.018451	0.025813	-0.04219
	(0.9301)	(0.9301)	(0.7756)	(0.6425)
Eng	-0.44064	-0.75873	-0.22566	-0.26719
	(0.3637)	(0.0981)	(0.1882)	(0.1007)
Text	**-0.700258**	-0.507494	0.161028	0.189509
	(0.0406)	(0.2059)	(0.461)	(0.464)
Man	0.159718	0.159718	**-0.009687***	5.833173
	(0.3444)	(0.3444)	(0.0339)	(0.3534)

(a) The industries A to N refer to are the SIC(92) sector classifications DA to DN. Whilst Agg, Eng, Text, and Man refer to the Aggregate of manufacturing industries, and the Engineering, Textiles and Other Manufacturing industry groups respectively.

(b) Refers to the information criterion used to select the order of AR process best representing each series.

(c) Emboldened figures are those significant at the 5% significant level with p-values shown in parenthesis

(d) Those values marked with an asterisk are where the log of the variance has been used as the in-mean term rather than the standard deviation.

7.4.3 – Leverage Effects

In the above sub-section it was found that output uncertainty has an impact upon output growth for certain industries and industry groups. One of the interesting aspects is that the sign of this relationship differs between industries, which implies that very different effects are being taken into account by the firms within these industries.

As described in Section 7.2 another way in which a series may be governed by uncertainty is the 'bad news' effect, whereby positive shocks may have a very different affect than negative shocks. Can this effect positively account for some of the differences between those industries that have a positive growth/uncertainty relationship and those for which there is a negative relationship?[141]

Table 7.6 shows the in-mean terms calculated using TGARCH models under GED. When using quarterly data, significant in-mean coefficients are obtained for industries, A, C, L (Food, Leather, and Electrical Products) and the Engineering industry group. All of these influences are negative with the exception of Industry A.

The monthly data reveal significant in-mean terms for industries, B, D, E, G, H, I, L and the Other Manufacturing industry group. Only one of these industries generates coefficients that are negative, Industry L (Electrical Products), but the in-mean terms for industries D, G, I and the Other Manufacturing industry group are logs of the conditional variance and so represent a negative relationship. The tendency towards predominately negative in-mean terms for quarterly data and positive ones for monthly data may suggest that there are two processes generating the positive and negative relationships working over different time frames.

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[141] French and Sichel (1993) using an asymmetric EGARCH only find weak evidence of asymmetry for investment in structures, with negative innovations increasing volatility more than positive innovations.

Table 7.6

In-Mean Terms for TGARCH Models with GED

Industry[a]	Quarterly		Monthly	
	AIC[bcd]	SIC	AIC	SIC
A	**0.468658**	0.267645	-0.06465	0.027484
	(0.0326)	(0.1553)	(0.6711)	(0.8657)
B	-0.02699	-0.04128	**2.577765**	0.851688
	(0.8566)	(0.8058)	(0.0466)	(0.3222)
C	**-2.70487**	-0.4459	-0.89065	-0.28181
	(0)	0.2209	(0.2154)	(0.0856)
D	0.071185	-0.33107	**0.055096***	0.499214*
	(0.9203)	(0.6071)	(0)	(0.6607)
E	1.410752	0.64787	**0.724767**	0.653396
	(0.1239)	(0.0655)	(0.027)	(0.0684)
F	-0.23084	-0.23084	-0.18025	-0.01832
	(0.1761)	(0.1761)	(0.5728)	(0.9479)
G	0.122873	0.026473	**0.022321***	0.422616
	(0.6827)	(0.9223)	(0)	(0.177)
H	-0.20696	-0.10799	**0.385589**	**0.314935**
	(0.6081)	(0.7981)	(0.0093)	(0.008)
I	0.417234	-0.06903	**0.048659***	1.13707
	(0.2566)	(0.8452)	(0.001)	(0.0719)
J	0.270534	0.270534	0.183916	0.183916
	(0.199)	(0.199)	(0.0503)	(0.0503)
K	-0.34629	-0.5524	-0.00138	-0.00138
	(0.2804)	(0.0578)	(0.9921)	(0.9921)
L	-10.3027	**-0.98201**	**-0.41998**	**-0.4635**
	(0.2843)	(0.0162)	(0.0273)	(0.0205)
M	0.288089*	0.288089*	-0.1767	-0.1767
	(0.2321)	(0.2321)	(0.2694)	(0.2694)
N	0.055797	-0.04971	0.012825	-0.05751
	(0.8937)	(0.8953)	(0.9348)	(0.6997)
Agg	-0.03268	-0.03268	0.077778	-0.029
	(0.8875)	(0.8875)	(0.3899)	(0.7515)
Eng	-0.24751	**-1.00513**	-0.23137	-0.26981
	(0.6613)	(0.0381)	(0.1917)	(0.1022)
Text	-0.68223	-0.4637	1.820211	0.077618
	(0.1368)	(0.3408)	(0.0843)	(0.7597)
Man	0.121843	0.121843	**0.014812***	**2.246172**
	(0.5178)	(0.5178)	(0.0002)	(0)

(a) The industries A to N refer to are the SIC(92) sector classifications DA to DN. Whilst Agg, Eng, Text, and Man refer to the Aggregate of manufacturing industries, and the Engineering, Textiles, and Other Manufacturing industry groups respectively.

(b) refers to the information criterion used to select the order of AR process best representing each series.

(c) Emboldened figures are those significant at the 5% significant level with p-values shown in parenthesis.

(d) Those values marked with an asterisk are where the log of the variance has been used as the in-mean term rather than the standard deviation.

7.4.4 – Power ARCH models

If the GARCH and TGARCH models utilised in the proceeding two sub-sections, are correctly specified then the PARCH δ coefficient would be expected to be estimated with a value close to 2. Figures 7.1 and 7.2 below show the histograms of the δ value distributions for normally distributed errors and when using GED.

Figure 7.1

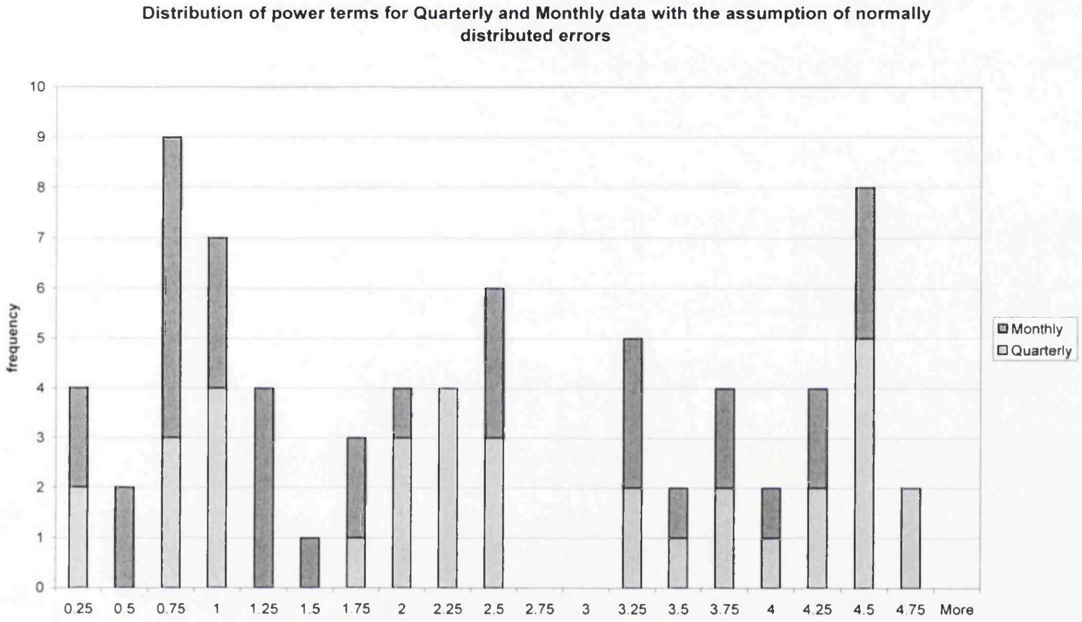
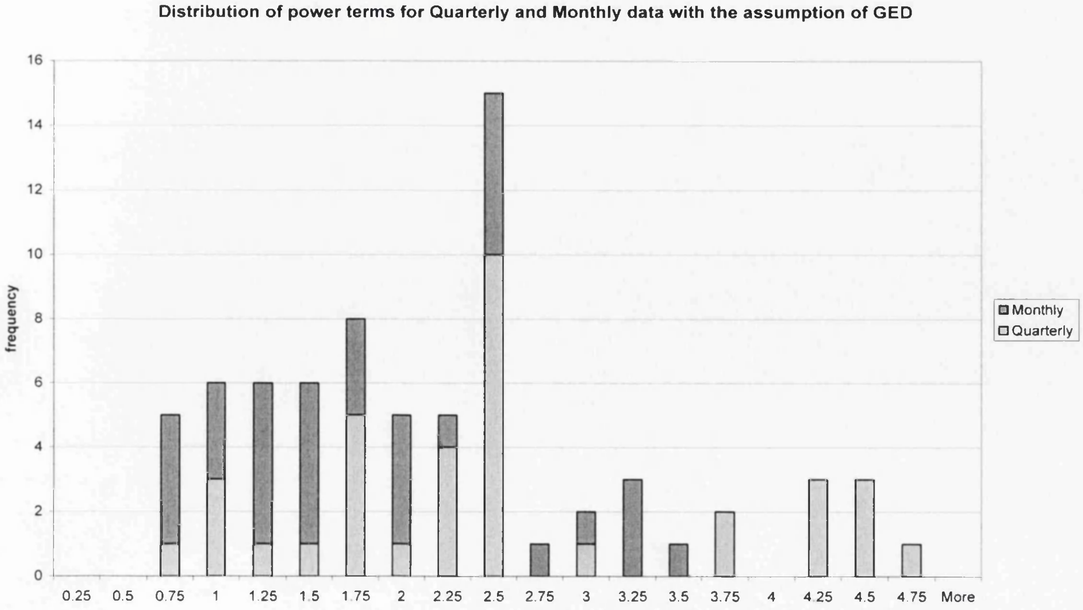


Figure 7.2



The distributions of δ appear to be made up of three separate groups. Whilst some of the values estimated are clustered around $\delta = 1$, another group of values is clustered around 2.5, the third group around 4.5. This is particularly evident for the models estimated with the assumption of normally distributed errors, and although visible when using the GED, it is less pronounced. This may be due to the fact that larger power terms would contain information relating to kurtosis that is also contained within the estimated GED. This might explain why the number of larger power terms is considerably reduced when using the GED rather than a normal distribution.

Table 7.7 presents the in-mean terms calculated for the PARCH models without the inclusion of a leverage term when using GED. As can be seen for the quarterly data there are only two significant in-mean terms, for the Minerals and Electrical Products industries (I and L). The monthly data generates a greater number of significant terms with significant coefficients found for industries H, J and L, (Plastics, Metals and Electricals). With the exception of the Electrical Products industry, the significant coefficients are all positive. The coefficients for the estimated GARCH-M and PARCH-M models are very similar with the same industries producing significant terms on the whole.[142]

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[142] In order to estimate the PARCH models it was often necessary to calculate the in-mean term as the log of conditional variance rather than the conditional standard deviation for more of the models than when estimating the simple GARCH models. This accounts for a majority of larger changes in the coefficients calculated for the two groups of models.

Table 7.7

In-Mean Terms for PARCH models with GED

Industry[a]	Quarterly		Monthly	
	AIC[bcd]	SIC	AIC	SIC
A	-2.64956	0.267645	-0.00622	0.049813
	(0.2014)	(0.3555)	(0.9687)	(0.7572)
B	-0.05042	-0.07036	0.838079	0.369252
	(0.6611)	(0.609)	(0.2886)	(0.0962)
C	-0.67825	-0.77913	-0.45537	-0.34733
	(0.1451)	(0.1562)	(0.0795)	(0.0962)
D	0.04697	-0.37554	0.007844*	-0.019202*
	(0.9485)	(0.4939)	(0.4002)	(0.9913)
E	4.318888	0.483252	0.038896	0.71543
	(0.0517)	(0.1405)	(0.8381)	(0.0558)
F	-0.12937	-0.12937	-0.29957	0.015944
	(0.4149)	(0.4149)	(0.2674)	(0.9514)
G	0.101775	0.104088	0.016983*	-0.04267
	(0.6909)	(0.6756)	(0.194)	(0.7422)
H	-0.07846	-0.50761	**0.377111**	**0.309262**
	(0.8331)	(0.1862)	(0.0082)	(0.0379)
I	**1.39576**	0.522151	1.154958	1.124951
	(0.0086)	(0.2674)	(0.1214)	(0.1239)
J	0.178969	0.178969	**0.135647**	**0.135647**
	(0.4237)	(0.4237)	(0.0281)	(0.0281)
K	-0.2118	-0.42535	-0.04562	-0.04562
	(0.4224)	(0.1049)	(0.7481)	(0.7481)
L	-0.21566	**-1.02314**	**-0.39061**	-0.23752
	(0.1299)	(0.0156)	(0.029)	(0.1706)
M	0.136183*	0.136183*	-0.00965	-0.00965
	(0.2792)	(0.2792)	(0.9466)	(0.9466)
N	-0.00164	-0.21033	0.06755	-0.0315
	(0.9965)	(0.5473)	(0.6271)	(0.8206)
Agg	0.004057	0.004057	0.044873	-0.03514
	(0.9846)	(0.9846)	(0.6019)	(0.696)
Eng	-0.46054	-0.79124	-0.22627	-0.28232
	(0.344)	(0.0906)	(0.1884)	(0.0812)
Text	-0.388514	-0.40365	0.080377	0.456842
	(0.2052)	(0.3967)	(0.7759)	(0.2565)
Man	0.152129	0.152129	0.021744*	0.873726
	(0.3609)	(0.3609)	(0.123)	(0.14)

(a) The industries A to N refer to are the SIC(92) sector classifications DA to DN. Whilst Agg, Eng, Text and Man refer to the Aggregate of manufacturing industries, and the Engineering, Textiles and Other Manufacturing industry groups respectively.

(b) AIC and SIC refer to the information criterion used to select the order of AR process best representing each series.

(c) Emboldened figures are those significant at the 5% significant level with p-values shown in parenthesis

(d) Those values marked with an asterisk are where the log of the variance has been used as the in-mean term rather than the standard deviation.

7.4.5 – Asymmetric Power-ARCH Models (APARCH)

As was found in sub-section 7.4.3 the inclusion of a leverage term has a considerable affect on the significance of the in-mean term. Table 7.8 presents the in-mean terms for the APARCH models. The number of significant results is increased, as before, with the simple GARCH-M and TGARCH-M models. However, there are still only two significant in-mean terms from the quarterly data. The two industries that generate these significant terms are Electricals and the aggregate of all industries/industry groups. As before it is a negative term found for the Electrical Products industry. The monthly data generates significant in-mean terms for Leather, Plastics, Metals, Electricals, and the Other Manufacturing industry group, where Leather, Electricals and the Other Manufacturing industry group produce negative terms or represent a negative relationship, whilst the others are all positive.[143]

Unlike when using the TGARCH models the APARCH models do not generate significant leverage terms within the variance equations of those industries producing significant in-mean terms. For the APARCH models with significant in-mean terms only one of the leverage terms is negative. This occurs for the Leather industry (Industry Sector C) where the existence of a negative in-mean term makes this 'good news' effect confusing.

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[143] Unlike when using the TGARCH models the APARCH models do not generate significant leverage terms within the variance equations for those industries producing significant in-mean terms. Plus for the APARCH models with significant in-mean terms only one of the leverage terms is negative. This occurs for the Leather industry (Industry Sector C) where the existence of a negative in-mean term makes this 'good news' effect confusing.

Table 7.8

In-Mean Terms for APARCH models with GED

Industry^{a}	Quarterly		Monthly	
	AIC^{bcd}	SIC	AIC	SIC
A	-2.81028	**0.289049**	-0.05952	0.032488
	(0.1876)	(0.0349)	(0.6957)	(0.8387)
B	-0.0357	-0.02742	1.12286	0.505005
	(0.7565)	(0.8453)	(0.2641)	(0.4233)
C	-0.76738	-0.6814	**-0.64468**	-0.21894
	(0.1159)	(0.0916)	(0.0133)	(0.145)
D	0.115761	-0.36309	-0.10749*	0.348714*
	(0.8811)	(0.5716)	(0.9876)	(0.9122)
E	1.467077	0.715783	0.361447	0.647414
	(0.2231)	(0.0673)	(0.1828)	(0.0774)
F	-0.20359	-0.20359	-0.29459	0.079386
	(0.2277)	(0.2277)	(0.315)	(0.7551)
G	0.218482	0.044316	0.001566*	-0.04945
	(0.4865)	(0.8747)	(0.2699)	(0.7088)
H	-0.19573	-0.50911	**0.404579**	**0.32739**
	(0.6322)	(0.2513)	(0.0076)	(0.0337)
I	0.74898	0.626059	3.280411	2.480436
	(0.1364)	(0.2894)	(0.33)	(0.1863)
J	0.255007	0.255007	**0.14044**	**0.14044**
	(0.2285)	(0.2285)	(0.0211)	(0.0211)
K	-0.29311	-0.51855	-0.0058	-0.0058
	(0.3049)	(0.0702)	(0.9665)	(0.9665)
L	**-0.42886**	**-0.98129**	**-0.43901**	**-0.49074**
	(0.0301)	(0.0177)	(0.0257)	(0.0183)
M	0.192327*	0.192327*	-0.11747	-0.11747
	(0.3879)	(0.3879)	(0.4462)	(0.4462)
N	0.064509	-0.0567	0.063035	-0.0188
	(0.8785)	(0.8806)	(0.6552)	(0.8885)
Agg	**1.171968**	**1.171968**	0.032832	-0.03595
	(0)	(0)	(0.6368)	(0.6898)
Eng	-0.33469	-0.96673	-0.23089	-0.29829
	(0.5707)	(0.0739)	(0.1969)	(0.069)
Text	-0.799641	-0.478894	0.385486	0.7026
	(0.1078)	(0.3367)	(0.3067)	(0.1398)
Man	0.152329	0.152329	**0.887539***	0.818415
	(0.4008)	(0.4008)	(0)	(0.1138)

(a) The industries A to N refer to are the SIC(92) sector classifications DA to DN. Whilst Agg, Eng, Text, and Man refer to the Aggregate of manufacturing industries, and the Engineering, Textiles and Other Manufacturing industry groups respectively.

(b) Refers to the information criterion used to select the order of AR process best representing each series.

(c) Emboldened figures are those significant at the 5% significant level with p-values shown in parenthesis

(d) Those values marked with an asterisk are where the log of the variance has been used as the in-mean term rather than the standard deviation.

(e) Figures calculated using Bernt, Hall, Hall and Hausman optimisation algorithm rather than Marquardt algorithm used elsewhere.

7.4.6 – How does Output Affect Uncertainty?

As discussed in sub-section 7.3.2 as well as testing for the output-uncertainty relationship in order to determine whether the Black or Bernanke hypotheses hold it is also possible to determine whether the level of output growth has an influence upon its own volatility. The Phillips/Friedman/Taylor interaction suggests a negative relationship whilst there would be a positive relationship with the Brunner/Taylor interaction.[144] Lagged values of the growth rates of the production series are therefore allowed to enter the variance equation in order to capture either of the two interactions outlined in sub-section 7.3.2. The length of lag between a change in output and the uncertainty it creates/reduces is likely to be relatively short, as producers are normally well placed to recognise changes in output within their own or related industries. With this in mind the series are estimated with two specifications for the quarterly and monthly data, with one lagged value and four lagged value respectively ($V = 1$ or 4 in equation 7.12). The models estimated were of the form APARCH-M, as these were generally found to represent the data better according to the information criterion, (and also as discussed in Section 7.2 nest the simpler GARCH models as special cases).[145]

Although the initial intention of the inclusion of the output growth terms within the variance equation was to identify and control for the presence of either the Phillips/Friedman/Taylor or Brunner/Taylor interactions the main finding was the huge difference that this change in specification makes upon the in-mean terms of the models. Generally there is found to be more significance in the in-mean terms

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[144] Although these theories were generally concerned with the aggregate it is possible to see that there might also be a weaker connection at the sector level.

[145] The results of output growth entering the variance equation are not included here due to constraints on space, but it was found that only one model used to represent the data found these coefficients to be significant. The model in question being the AR(2) selected by the SIC to represent the monthly form of the Other Manufacturing industry group when $V = 4$. The coefficients were found to have different signs and therefore no conclusion as to which interaction was at work can be drawn.

estimated in this sub-section and the APARCH-M processes estimated in sub-section 7.4.5. The largest impact is found where four lagged terms are included, and these results are reported in Table 7.9. There are quite clearly many more significant terms produced with a mixture of signs found upon the quarterly in-mean terms, and mostly negative terms found for the monthly series, with the exceptions of industry H and the Textiles industry group. One interesting impact is while the quarterly aggregate series produced a significantly negative in-mean term when estimated without lagged output terms, the inclusion of lagged terms has switched the sign of this relationship.[146] Although the lagged output terms within the variance equation are far from significant the total value of the four lagged terms is positive which may mean that a Taylor/Brunner interaction and Black hypothesis combination is present whereby the additional uncertainty created by higher levels of output is seen as a being accompanied by higher rewards, which will back up the Black hypothesis' existence. Without this output growth induced uncertainty being included the remaining uncertainty does not suggest to firms that profits will be correspondingly higher and therefore investment is suppressed as Bernanke suggested.

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[146] Although the lagged output terms within the variance equation are far from significant the total value of the four lagged terms is positive which may mean that a Taylor/Brunner interaction and Black hypothesis combination is present whereby the additional uncertainty created by higher levels of output is seen as a being accompanied by higher rewards, which will back up the Black hypothesis. Without this output growth induced uncertainty being included the remaining uncertainty does not suggest to firms that profits will be correspondingly higher and therefore investment is suppressed as Bernanke suggested.

Table 7.9

In-Mean Terms for APARCH models with GED

(with four lagged output growth terms in the variance equation)

Industry[a]	Quarterly		Monthly	
	AIC[bcd]	SIC	AIC	SIC
A	**0.414209**	0.308863	-0.06746	-0.02873
	(0.0153)	(0.0839)	(0.6249)	(0.8343)
B	-0.72098	-0.15611	0.729519	1.979454
	(0.1698)	(0.3003)	(0.2951)	(0.0616)
C	-3.29092	-0.37821	**-0.65198**	-0.4518
	(0.6067)	(0.1517)	(0.018)	(0.091)
D	-0.19923	0.584919	**0.071935***	0.246774*
	(0.8098)	(0.2529)	(0.0284)	(0.68)
E	**0.751317**	**0.597721**	1.152715	1.329802
	(0.0322)	(0.0044)	(0.0906)	(0.0734)
F	**-0.78978**[e]	**-0.78978**[e]	-0.33721	0.207737
	(0.0001)	(0.0001)	(0.2832)	(0.3157)
G	0.268795[e]	0.048479	**0.007679***	**0.020303***
	(0.1427)	(0.8078)	(0.0086)	(0.0237)
H	0.165686[e]	-0.24336	**0.397635**	**0.32502**
	(0.7223)	(0.3659)	(0.0114)	(0.019)
I	**1.009579**	**1.839661**	3.715494	1.555524
	(0.0297)	(0.0396)	(0.1493)	(0.1623)
J	0.192358	0.192358	0.125033	0.125033
	(0.3759)	(0.3759)	(0.1523)	(0.1523)
K	**-1.19327**	**-0.79751**[e]	-0.00926	-0.00926
	(0.0001)	(0)	(0.9418)	(0.9418)
L	-0.49059	-0.22403	**-0.38671**[e]	-0.04893[e]
	(0.0797)	(0.2901)	(0.0018)	(0.331)
M	0.220431	0.220431	-0.04063	-0.04063
	(0.3748)	(0.3748)	(0.7689)	(0.7689)
N	0.225146	0.611765	0.207851	-0.03532
	(0.5106)	(0.1797)	(0.2046)	(0.5304)
Agg	**-0.49808**[e]	**-0.49808**[e]	0.037425	-0.05545
	(0.0023)	(0.0023)	(0.6584)	(0.4947)
Eng	-0.4825[e]	-0.50163[e]	-0.20044	-0.21879
	(0.3628)	(0.2015)	(0.1695)	(0.1441)
Text	0.150067	0.021039	**2.038612**	**2.253194**
	(0.8946)	(0.968)	(0)	(0)
Man	0.046595[e]	0.046595[e]	**0.032365***	**3.078036**[e]
	(0.897)	(0.897)	(0)	(0)

(a) The industries A to N refer to are the SIC(92) sector classifications DA to DN. Whilst Agg, Eng, Text and Man refer to the Aggregate of manufacturing industries, and the Engineering, Textiles and Other Manufacturing industry groups respectively.

(b) Refers to the information criterion used to select the order of AR process best representing each series.

(c) Emboldened figures are those significant at the 5% significant level with p-values shown in parenthesis

(d) Those values marked with an asterisk are where the log of the variance has been used as the in-mean term rather than the standard deviation.

(e) Figures calculated using Bernt, Hall, Hall and Hausman optimisation algorithm rather than Marquardt algorithm used elsewhere

7.4.7 – Summary of Section

The variety of GARCH-M processes used to model the relationship between output growth and uncertainty has found that for most industries there appears to be no affect upon of output growth uncertainty on output growth, but for a small number of industries there does seem to be a significant relationship. However, as has been found by previous research on aggregate output and uncertainty, the sign of this relationship is not clear-cut. Whilst a greater number of the significant in-mean terms have been found to be positive (particularly the Plastics, Mineral and Metals industries), suggesting the Black hypothesis holds, there are some industries, which are exceptions (Leather and Electricals), and suggest the presence of irreversible investment that creates a negative relationship.

As to which conditional variance specification is most appropriate for modelling the industry production series, there does seem to be a strong leverage effect present. As with the uncertainty relationship the sign of this leverage effect is mainly positive suggesting a 'bad news' effect but there are exceptions. There also seems to be strong evidence that the errors are not drawn from a normal distribution. This makes it appropriate to either utilise a Student's-*t* distribution or GED, or alternatively to employ a PARCH model in order to account for kurtosis.[147]

A final extension to the model was implemented to attempt to identify the relationship between the output growth variable and uncertainty, by allowing output growth to enter the variance equation. Although very few of the lagged output growth terms were found to be significant the impact that the inclusion of these terms had upon the in-mean terms was considerable, with a large number of newly significant terms generated. A similar pattern was found as with the other models, described

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[147] Whether it is necessary to employ both is unclear as the PARCH models, where used with the assumption of GED, generally estimate power terms for the variance equation much closer to 2 than the PARCH models using normally distributed error terms.

above. In that whilst the sign of the quarterly in-mean terms was mixed, generally a positive term was for a majority of the monthly in-mean terms, with the exceptions of the leather and electricals industries (C and L). The sign found for the in-mean term of the quarterly aggregate series was altered with the inclusion of the lagged output growth terms. This may suggest that both the Bernanke and Black hypotheses hold, but the measure of uncertainty to which each is applicable may not be the same.

7.5 – Analysis of the Output Growth – Uncertainty Relationship for 4-digit SIC Industries

The previous section presented the results of the output growth – uncertainty relationship results when utilising data at the industry group and industry sector levels of aggregation. This level of data were chosen as it allows the results to be compared with the First Release investment data used in Chapters 5 and 6 to test for asymmetry and time irreversibility. However, this level of aggregation, even at the more disaggregated industry sector level, still groups quite disparate firms together. The ONS First Release output indices are, however, available at much lower levels of aggregation (2-digit, 3-digit and 4-digit SIC industry level). Whilst comparison would no longer be possible with the results of chapters 5 and 6 it does allow the possibility of a more detailed examination of the reasons for the results found in the results presented above. Whilst it would be impractical to examine the relationships for all of the 4-digit industries for which data are available it is interesting to use the results found above to select those industries which comprise industry sectors which have shown evidence of a significant output growth-uncertainty relationship.

The remainder of this section is divided thus. Sub-section 7.5.1 looks at the choice of industry sectors to examine in more detail, 7.5.2 presents the AR(N)

processes selected to represent output growth, and the ARCH processes selected. Subsection 7.5.3 presents the results of the estimation and 7.5.4 concludes and summarises the section.

7.5.1 – Industry Sectors to be Examined

Whilst a large number of industry sectors produced significant results either for the monthly or quarterly frequency data in one or other specification of the ARCH process estimated, the number of 4-digit industries in the manufacturing sector is too large to estimate models for each. It is therefore more efficient to select a small number of industry sectors that consistently produced significant results through different specifications of ARCH model, and preferably for both frequencies of data. For comparative purposes it is also logical to select some industry groups displaying evidence of the Black hypothesis and some suggesting the presence of the Bernanke hypothesis.

The industry sectors selected are J, H and L (Metals, Plastics and Electricals respectively). Table 7.8 shows that both J and H have a positive output growth-uncertainty relationship. In the case of industry sector J this is also the case when output growth is allowed to enter the output growth variance equation. The in-mean term is still positive for industry sector H but no longer significant at the 5% level when output growth enters the variance equation. Industry sector L on the other hand is found to generate significantly negative in-mean terms both when output growth is excluded and when allowed to enter the variance equation.[148] The output growth-

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[148] The reason for selecting two examples of a positive relationship and only one negative relationship, is partially because very few industry sectors consistently generate negative relationships, but also because whilst industry sector L is composed of four 2-digit industries (30-33), industry sectors H and J are only composed of one and two 2-digit industry sectors respectively (industry 25 is the same as industry sector H and industries 27 and 28 comprise industry sector J). This means that roughly the

uncertainty relationships displayed by individual 4-digit industries, may not follow directly that of the industry sector they are components of, but it is possible that different patterns may be found for industries within different industry sectors.[149]

7.5.2 – Output Growth Equations and ARCH Processes

As before the output growth equations take the form of a simple AR(*N*) process selected using the AIC and SIC and, as before, where the information criterion disagreed upon the order of AR process the two models were estimated in order to test the robustness of the results with regard to model selection. Table 7.10 below summarises the AR processes selected for the 4 digit industries.

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same number of 2-digit industries, are being examined from those industry sectors providing evidence of positive and negative relationships.

[149] Whilst there is no reason to expect all industries within sectors H and J displaying significant in-mean terms to suggest a positive relationship, and those within the Electricals sector to be negative, it might be expected that certain similar industries within each sector might display the expected sign for significant terms. Industries might display the opposite relationship to expected for those within a particular sector, but they would be expected to be in the minority. One possibility however is that a small number of industries within a sector due to their relative size dominate the sector, and therefore only a small number of one relationship or another found in a sector could generate the relationship observed for the whole sector.

Table 7.10

4-Digit AR(*N*) orders

Industry Sector	2-Digit SIC(92)	4-Digit SIC(92)	Quarterly		Monthly	
			AIC^a	SIC	AIC	SIC
Industry Sector H (Plastics)	Industry 25 (Plastics)	2511	1	1	12	2
		2513	1	1	20	2
		2512	1	1	4	2
		2521	2	2	1	1
		2522	1	1	2	1
		2523	1	1	15	1
		2524	7	1	1	1
Sector J (Metals)	Industry 27 (Basic Metals)	2710	1	1	2	2
		2721	1	1	2	2
		2722	7	1	7	2
		2731	2	1	2	2
		2732	3	1	2	2
		2733	1	1	2	2
		2739	1	1	13	1
		2741	13	1	16	2
		2742	1	1	5	1
		2744	9	1	2	2
		2745	1	1	5	4
		2751	4	1	16	2
		2752	2	2	19	2
		2754	1	1	2	2
	Industry 28 (Metal Products)	2811	1	1	2	2
		2812	1	1	2	1
		2821	1	1	5	2
		2822	10	1	1	1
		2830	1	1	12	2
		2840	1	1	4	4
		2851	4	1	2	2
		2852	4	4	14	2
		2861	4	1	17	1
		2862	1	1	2	2
		2863	1	1	12	1
		2871	1	1	12	3
		2872	1	1	5	3
		2873	7	4	15	1
		2874	8	1	12	2
		2875	1	1	13	1

Table 7.10 continued

Industry Sector	2-Digit SIC(92)	4-Digit SIC(92)	Quarterly		Monthly	
			AIC	SIC	AIC	SIC
Sector L (Electrical Products)	Ind 30	3001	3	1	12	2
		3002	1	1	6	1
	Industry 31 (Electrical Machinery not elsewhere classified)	3110	1	1	13	3
		3120	1	1	2	2
		3130	1	1	6	1
		3140	6	1	4	1
		3150	15	1	1	1
		3161	1	1	12	2
		3162	8	1	8	2
	Ind 33 (Radio, TV equip.)	3210	12	4	13	3
		3220	3	1	3	1
		3230	2	1	2	1
	Industry 34 (Medical equip)	3310	2	1	5	1
		3320	1	1	1	1
		3330	9	1	17	2
		3340	4	1	15	1
		3350	1	1	12	1

(a) AIC and SIC refer to the information criterion used to select the autoregressive process used to estimate the production series.

The ARCH/GARCH processes governing the conditional 'variance' of the series were selected by conducting ARCH-LM tests with lag lengths of 1 and 16 as with the industry sector data to test roughly for the presence of ARCH(1) and GARCH processes. This was supplemented with examination of the squared residual correlogram, with the final selection being determined by comparison of the AIC and SIC for competing specifications. For a majority of the 4-digit industries a GARCH(1,1) was found to be an accurate representation of the true variance equation. Whilst it is inappropriate to show all the results of the ARCH-LM tests conducted, the industries for which alternatives to a GARCH(1,1) are appropriate are shown in Table 7.11. The models that are estimated are APARCH-M under GED. This is because the APARCH specification nests within it a large number of other ARCH style processes as special cases such as simple GARCH and TARCH models.

Table 7.11

ARCH/GARCH Processes Utilised in Variance Equations of Selected 4-Digit Industries

4-Digit Industry Code	Quarterly		Monthly	
	GARCH(q,p)		GARCH(q,p)	
Ind2521 (plastic plates, sheets, tubes and profiles)	1	1	1	0
Ind2732 (cold rolling of narrow strip)	1	1	1	0
Ind2733 (cold forming or folding)	1	0	1	1
Ind2754 (casting of other non-ferrous metals)	1	0	1	1
Ind2812 (builders' carpentry and joinery of metal)	1	1	1	0
Ind2821 (tanks, reservoirs and containers of metal)	1	0	1	1
Ind2852 (general mechanical engineering)	1	0	1	1
Ind2861 (cutlery)	4	0	1	1
Ind2863 (locks and hinges)	1	0	1	0
Ind2871 (steel drums and similar containers)	1	1	1	0
Ind2872 (light metal packaging)	3	0	1	1
Ind2873 (wire products)	4	0	1	1
Ind3001[a] (office machinery)	1	1	1	0
Ind3150 (lighting equipment and electric lamps)	1	1	1	0
Ind3161 (electrical equipment for engines and vehicles)	1	0	1	1
Ind3230 (televisions and radio transmitters)	1	1	3	0
Ind3310 (medical and surgical equipment)	1	1	1	0
Ind3330 (industrial process control equipment)	2	0	1	1
Ind3350[a] (watches and clocks)	1	1	1	0

a) Only for SIC selected output equation

7.5.3 – Results of APARCH-M Models

As noted above the models estimated take the same specifications as those utilised earlier for the industry sector data. The in-mean term utilised is the conditional standard deviation where possible, unless for purposes of convergence in estimation it was necessary to use the log of the conditional variance. Where this has been necessary it is indicated in the table of results, remembering that when the conditional variance is less than unity the log of the conditional variance becomes negative, and therefore the sign of the in-mean term is the reverse of the actual relationship between output growth and output growth uncertainty. Due to the number of results produced, each group of industries from the three industry sectors will be looked at in turn.

Table 7.12 shows the in-mean terms calculated for the industries making up industry sector H (Plastics).

Table 7.12

APARCH-M in-mean terms for 4-Digit Component Industries of Industry Sector H

	Output Growth Excluded from Variance Equation				Output Growth Allowed to Enter Variance Equation			
4-Digit SIC	Quarterly		Monthly		Quarterly		Monthly	
	AIC[cd]	SIC	AIC	SIC	AIC	SIC	AIC	SIC
2511	1.65131	1.65131	**-0.21739**	**-0.28252**	**2.933342**	**2.933342**	-0.17346	**-0.48356**
	(0.0516)	(0.0516)	(0.0131)	(0.0011)	(0.0166)	(0.0166)	(0.0956)	(0)
2512	n/a	n/a	0.221486	0.194351	n/a	n/a	**0.652974**	**0.685371**
			(0.1829)	(0.2347)			(0.0002)	(0)
2513	-3.40371	-3.40371	0.323129	0.050254	**-1.13291**	**-1.13291**	0.363638	**0.449007**
	(0.4914)	(0.4914)	(0.2316)	(0.8414)	(0.048)	(0.048)	(0.2137)	(0.0184)
2521	-0.69577	-0.69577	0.114855[b]	0.114855[b]	-0.28289	-0.28289	0.183068[b]	0.183068[b]
	(0.2424)	(0.2424)	(0.4631)	(0.4631)	(0.326)	(0.326)	(0.3834)	(0.3834)
2522	9.554691	9.554691	0.621902	0.433317	0.360297	0.360297	0.105555	0.100099
	(0.696)	(0.696)	(0.053)	(0.1179)	(0.6207)	(0.6207)	(0.6471)	(0.6806)
2523	-0.32559	-0.32559	-0.9627	-0.51538	n/a	n/a	-0.68013	-0.2143
	(0.5644)	(0.5644)	(0.2764)	(0.2166)			(0.3078)	(0.4512)
2524[a]	0.961138	2.506551	0.378608	0.378608	-0.2593	**0.381668**	1.293128	1.293128
	(0.2831)	(0.0541)	(0.2567)	(0.2567)	(0.9279)	(0.042)	(0.0679)	(0.0679)

a) Shorter time period covered by series, 1983 to 2004.
b) Log of conditional variance used as in-mean term rather than conditional standard deviation
c) AIC and SIC refer to the information criterion used to select the order of autoregressive process used to estimate the production series.
d) Emboldened figures are significant at the 5% level, with p-values shown in parenthesis.

The in-mean terms for the industries comprising Industry Sector H, shows that just because the in-mean term for the industry sector was significant with one sign does not prevent component 4-digit industries displaying significant results with the opposing sign. Table 7.12 contains the in-mean terms calculated with both output growth excluded from the variance equation, and output growth allowed to enter the variance equation. Whilst most of the results retain the same sign between the two sets of results, a much larger number of significant terms are found when output growth is allowed to enter the variance equation as was found with the industry sector analysis. The results are split roughly equally with about the same number of positive in-mean terms generated as negative ones. One interesting aspect that has appeared in the industry sector analysis is that the sign of the results often changes between monthly and quarterly frequencies of data, with both results being significant, suggesting that different processes are captured by data of different frequencies. The positive monthly in-mean terms found for the industry sector appears not to be generated by one dominant industry with a highly significant output growth-uncertainty relationship nor a majority of industries having a small positive relationship. The industries suggesting the presence of a positive relationship just have the edge, but it is not an industry sector dominated by positive relationships at the 4-digit industry level.

Table 7.13 shows the in-mean terms estimated for the industries making up industry sector J (Metals).[150]

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[150] Data was not available for Industry 2743, (Lead, zinc and tin production), and is therefore excluded from the results. Industries 2734 and 2735 (Wire drawing, and Other first Processing of iron and steel not elsewhere classified) have been redefined as Industry 2739, (Wire drawing and other processing of iron and steel).

Table 7.13

APARCH-M in-mean terms for 4-Digit Component Industries of Industry Sector J

	Output Growth Excluded from Variance Equation				Output Growth Allowed to Enter Variance Equation			
4-Digit	Quarterly		Monthly		Quarterly		Monthly	
SIC	AIC[cd]	SIC	AIC	SIC	AIC	SIC	AIC	SIC
2710[a]	0.189121	0.189121	0.14913	0.14913	**0.795938**	**0.795938**	0.303848	0.303848
	(0.9947)	(0.9947)	(0.639)	(0.639)	(0.001)	(0.001)	(0.0661)	(0.0661)
2721	n/a	n/a	**0.095767**	**0.095767**	n/a	n/a	**0.298721**	**0.298721**
			(0.0091)	(0.0091)			(0.0127)	(0.0127)
2722[a]	1.448723	**7.505695**	0.191839	0.939886	0.996714	13.0144	-0.39728	**-1.05206**
	(0.1623)	(0.0004)	(0.6142)	(0.1125)	(0.1097)	(0.7374)	(0.174)	(0.0132)
2731[a]	-2.91297	-2.32052	**0.941627**	**0.941627**	-2.11353	**-2.96407**	-0.09246	-0.09246
	(0.5407)	(0.431)	(0.0417)	(0.0417)	(0.1456)	(0.0036)	(0.8945)	(0.8945)
2732[a]	-0.29735	-0.04385	-0.17857	-0.17857	0.168542	-0.22423	-0.49673	-0.49673
	(0.4977)	(0.9588)	(0.675)	(0.675)	(0.866)	(0.6338)	(0.1758)	(0.1758)
2733[a]	0.297817	0.297817	**3.092517**	**3.092517**	**9.580429**	**9.580429**	**0.535881**	**0.535881**
	0.5329	0.5329	(0.0258)	(0.0258)	(0.0057)	(0.0057)	(0.0037)	(0.0037)
2739	-0.47734[b]	-0.47734[b]	-0.05916	0.320934	**-1.9253**	**-1.9253**	-0.08914	0.310985
	(0.3743)	(0.3743)	(0.8267)	(0.0881)	(0)	(0)	(0.747)	(0.1293)
2741	1.21611	0.052709	0.305512	0.272737	1.893039	-0.12737	0.182282	-0.01455
	(0.0669)	(0.8433)	(0.1213)	(0.1703)	(0.3063)	(0.7135)	(0.2875)	(0.9233)
2742	-1.52513	-1.52513	-0.29071	-0.14505	**-0.72596**	**-0.72596**	-0.35433	-0.30415
	(0.2607)	(0.2607)	(0.14)	(0.3716)	(0.0368)	(0.0368)	(0.07)	(0.0708)
2744	-0.41317	-5.45135	-0.2117	-0.2117	**-4.20229**	0.626288	-0.22403	-0.22403
	(0.7627)	(0.369)	(0.1721)	(0.1721)	(0.0445)	(0.8475)	(0.1799)	(0.1799)
2745	-1.36361	-1.36361	0.27112	-0.89166	**-2.90552**	**-2.90552**	-2.79547	**-1.94018**
	(0.0571)	(0.0571)	(0.4859)	(0.1588)	(0)	(0)	(0.2164)	(0.0101)
2751	-0.32866	0.285309	-0.32185	**-0.18966**	-4.36352	1.825508	**-0.62882**	**-0.21418**
	(0.1748)	(0.5587)	(0.0795)	(0.001)	(0.9989)	(0.1036)	(0.0023)	(0.0034)
2752	-0.15792	-0.15792	-0.11461	-0.07924	4.197054	4.197054	-0.11485	-0.13405
	(0.6242)	(0.6242)	(0.4079)	(0.3086)	(0.2694)	(0.2694)	(0.3091)	(0.0906)
2753	-0.01923	-0.01923	**0.132252**	0.077119	-0.12881	-0.12881	**0.175945**	0.091773
	(0.9275)	(0.9275)	(0.0236)	(0.2122)	(0.5289)	(0.5289)	(0.0095)	(0.1783)
2754	-0.76675	-0.76675	-0.02222	-0.02222	-3.14542	-3.14542	0.092979	0.092979
	(0.3464)	(0.3464)	(0.8591)	(0.8591)	(0.2083)	(0.2083)	(0.4918)	(0.4918)
2871	6.324394	6.324394	0.044352	-0.04332	**4.653721**	**4.653721**	0.015121	0.056166
	(0.9783)	(0.9783)	(0.7982)	(0.7958)	(0)	(0)	(0.9334)	(0.7338)
2872	-2.20067	-2.20067	-0.22094	-0.1528	-0.15058[b]	-0.15058[b]	-0.23156	-0.14433
	(0.4727)	(0.4727)	(0.3636)	(0.4982)	(0.9654)	(0.9654)	(0.3627)	(0.5322)
2873	**-3.19857**	**-3.19857**	-0.02531	-0.06554	**-6.21961**	**-6.21961**	-0.00125	-0.01538
	(0.0035)	(0.0035)	(0.8891)	(0.65)	(0)	(0)	(0.9936)	(0.9042)
2874	-0.84637	-0.46869	0.598302	2.04547	-1.14626	**-4.18078**	0.258624	**6.533002**
	(0.1049)	(0.1077)	(0.2512)	(0.0576)	(0.1092)	(0.0074)	(0.3383)	(0.0392)
2875	-0.27193	-0.27193	0.045823	0.092053	-0.16953	-0.16953	0.126777	0.238421
	(0.2713)	(0.2713)	(0.8303)	(0.6506)	(0.7159)	(0.7159)	(0.4619)	(0.2663)

(a) Shorter time period covered by series, 1983 to 2004. (b) Log of Conditional Variance Used Rather than Conditional Standard Deviation. (c) AIC and SIC refer to the information criterion used to select the order of autoregressive process used to estimate the production series. (d) Emboldened figures are significant at the 5% level, with p-values shown in parenthesis.

Like industry sector H (Plastics), industry sector J generated a positive output growth-uncertainty relationship at the industry sector level, but unlike H, J is comprised of more than one 2-digit industry, and therefore the positive relationship found might be due to the dominance of this type of relationship in one or other 2-digit industry.

The patterns observed for the in-mean terms calculated for industry sector J are closer to what might have been expected, and particularly for 2-digit industry 27. When broken down to the 4-digit industry level these industries tend to produce significant in-mean terms with the same sign as other industries in the same 3-digit industry class. For example, a small majority of significant in-mean terms for 3-digit industries 271, 272, 273 are positive, whilst all significant terms generated for 274 are negative, this pattern is not as clear for 2-digit industry 28. Again the positive relationship found at the industry sector level has not resulted in an absence of negative in-mean terms being found in the 4-digit data.

The final industry sector examined is industry sector L (Electrical products), which was found to produce negative in-mean terms at the industry sector level. The results from examining the industries forming industry sectors with a positive output growth-uncertainty relationship, found that neither a positive relationship or negative relationship was present for all of the component industries. It is unclear whether this mixed picture will be found for the component industries of industry sector L that displayed a negative relationship, or whether the component industries will predominately display a negative relationship. Table 7.14 displays the in-mean terms calculated for industry sector L.

Table 7.14

APARCH-M in-mean terms for 4-Digit Component Industries of Industry Sector L

	Output Growth Excluded from Variance Equation				Output Growth Allowed to Enter Variance Equation			
4-Digit	Quarterly		Monthly		Quarterly		Monthly	
SEC	AIC[cd]	SIC	AIC	SIC	AIC	SIC	AIC	SIC
3001	0.140748	0.140748	-0.02364[b]	0.220178	-0.014	-0.014	0.089003[b]	2.080209
	(0.7872)	(0.7872)	(0.9258)	(0.607)	(0.992)	(0.992)	(0.9912)	(0.1465)
3002	0.848605	0.848605	0.016266	3.077392	0.976552	0.976552	-0.28807	-0.62814
	(0.0861)	(0.0861)	(0.9772)	(0.5757)	(0.2889)	(0.2889)	(0.5735)	(0.0749)
3110[a]	7.299673	7.299673	-0.78073	0.063528	0.720305[b]	0.720305[b]	**-1.11718**	-0.30664
	(0.0796)	(0.0796)	(0.1982)	(0.8935)	(0.9789)	(0.9789)	(0.0156)	(0.5309)
3120	**-3.33471**	**-3.33471**	-0.31184	-0.31184	**-1.97148**	**-1.97148**	-0.43991	-0.43991
	(0.0194)	(0.0194)	(0.1811)	(0.1811)	(0)	(0)	(0.0747)	(0.0747)
3130	0.198295	0.198295	0.281593	0.043711	0.173676	0.173676	0.291535	0.014848
	(0.5543)	(0.5543)	(0.769)	(0.8636)	(0.7869)	(0.7869)	(0.704)	(0.9033)
3140	-0.67553	-0.77228	-0.58137	-0.13715	-0.9181	-1.9274	0.203306	**-0.67453**
	(0.5303)	(0.4744)	(0.1296)	(0.6204)	(0.5722)	(0.2433)	(0.3221)	(0)
3150[a]	4.501173	**-0.83242**	0.151341	0.151341	**2.340529**	**-1.60871**	0.081727	0.081727
	(0.2712)	(0.0214)	(0.5225)	(0.5225)	(0.0001)	(0.0342)	(0.6679)	(0.6679)
3161	-0.80525	-0.80525	0.044277	0.17342	-0.62366	-0.62366	0.253713	0.365368
	(0.3719)	(0.3719)	(0.8549)	(0.4579)	(0.3215)	(0.3215)	(0.289)	(0.0679)
3162[a]	n/a	-2.64457	-0.27856[b]	-0.00581[b]	n/a	-2.07349	-3.09961[b]	-0.05724[b]
		(0.3507)	(0.4949)	(0.1509)		(0.3904)	(0.9006)	(0.7347)
3210	**-0.46936**	**-0.93873**	-0.37185	-0.03288	-0.77267	**-0.85169**	-0.19345	0.211101
	(0.0404)	(0.0068)	(0.2108)	(0.916)	(0.0503)	(0.0117)	(0.4765)	(0.4473)
3220	-1.47034	-1.92867	**-0.69289**	-0.52164	**-0.82762**	**-0.4604**	**-0.73957**	**-0.8523**
	(0.3601)	(0.3366)	(0.0424)	(0.0713)	(0.03)	(0.0281)	(0.0352)	(0.0159)
3230[a]	-2.43289	-0.6237	0.632856	1.000521	**-1.9998**	**-1.44214**	0.633196	0.82441
	(0.2866)	(0.3154)	(0.2079)	(0.1393)	(0.0001)	(0)	(0.1382)	(0.0567)
3310	-0.1348	-0.59182	0.324063	0.218914	0.354755	-0.47071	**0.727384**	**1.959878**
	(0.7187)	(0.315)	(0.6103)	(0.7264)	(0.318)	(0.1768)	(0.0043)	(0.0105)
3320[a]	5.294149	5.294149	-2.28663	-2.28663	0.389602	0.389602	-2.81627	-2.81627
	(0.3642)	(0.3642)	(0.0852)	(0.0852)	(0.1948)	(0.1948)	(0.1065)	(0.1065)
3330[a]	**1.051437**	0.1747	0.217962	0.056411	1.421016	**0.199352**	0.210796	0.080216
	(0.0367)	(0.0954)	(0.0675)	(0.6613)	(0.1353)	(0.0348)	(0.1041)	(0.3694)
3340[a]	0.789162	-0.45498	**-2.31292**	-0.93632	-0.54457	**1.446212**	**-1.12338**	**-1.87152**
	(0.2755)	(0.3025)	(0.0208)	(0.1286)	(0.9152)	(0.003)	(0.0293)	(0.0001)
3350[a]	0.285216	0.285216	**-0.088[b]**	-0.16347[b]	1.721325	1.721325	**-0.26914[b]**	-0.07896[b]
	(0.5083)	(0.5083)	(0)	(0.1004)	(0.3132)	(0.3132)	(0)	(0.1955)

a) Shorter time period covered by series, 1983 to 2004.
b) Log of Conditional Variance used as in-mean term rather than Conditional Standard Deviation
c) AIC and SIC refer to the information criterion used to select the order of autoregressive process used to estimate the production series.
d) Emboldened figures are significant at the 5% level, with p-values shown in parenthesis.

The in-mean terms for the industries within industry sector L show a similar pattern to those in industry sector J, with significant results with the same signs being clustered into certain 2 or 3 digit industries. Whilst a majority of significant results are negative, as was expected, 2-digit industry 32 (Manufacture of radio, television, and communication equipment and apparatus) shows a particularly large number of significant negative terms. 2-digit industry 33 (Manufacture of medical, precision and optical instruments, watches and clocks) shows the most evidence of a positive relationship in some of its component 4-digit industries.

7.5.4 – Summary and Conclusion of Section

The analysis of the 4-digit industries that make up industry sectors H, J and L found that a positive (negative) relationship found at the industry sector level does not mean that a majority of industries within the industry sector will also have a significantly positive (negative) relationship. It was found that many industries within an industry sector displayed the opposite sign to the industry sector as a whole. Whilst in industry sectors J and L there appears to be some grouping of the industries that display the same relationship by their 2-digit or 3-digit industry classifications, industry sector H showed no obvious patterns.

What the results do show is that whilst it would have been nice to hope that the results of studying the industry sectors would give a pointer as to the potential for either the Bernanke or Black hypothesis to exist, and which firms the correct hypothesis or hypotheses apply to, this is not the case. Therefore, there is potential for any of the industry sectors whether producing significant in-mean terms of either sign or insignificant in-mean terms, to contain industries within them that show a highly significant output growth-uncertainty relationship.

7.6 – Summary of Chapter

The relationship between output growth and output growth uncertainty has been examined at the aggregate level in a number of different studies, few of which have been able to conclude whether a positive or negative relationship exists. This chapter attempted to determine whether the difficulty in proving a relationship of either sign existed is due to individual industries adjusting output growth differently to changes in output growth uncertainty. Starting with a simple GARCH form to model the output growth uncertainty through the conditional variance, an APARCH-M model was finally applied.

The data examined were initially at the industry sector level, at two frequencies, monthly and quarterly. Whilst little evidence was found for output growth uncertainty having an impact upon output growth for a majority of the series a small number of series did appear to display either a positive or negative relationship, and robust to the specification of the GARCH process used to model the uncertainty. A further extension applied was allowing lagged output growth to enter the variance equation, in order to control for the impact that the output growth level has upon output growth volatility, through either the Phillips/Friedman/Taylor interaction or Brunner/Taylor interaction. Whilst these additional terms were almost always found to be insignificant, the impact that these terms had upon the significance of the in-mean terms was considerable, in that a much greater number of series were found to generate significant in-mean terms.

The obvious next question was why should some industry sectors have a relationship of one sign and some another? One possibility is that the industries that fall into one group have a similar mix of capital goods to each other. A difficulty with testing this is that at the industry sector level firms within the industry sectors are still very diverse, and the relationship may be being formed by a small subgroup within the industry sector. In order to test this more disaggregate data were used at the SIC 4-digit level. The number of industries at this level of aggregation is so large that it makes it impractical to estimate all industries' output growth-output growth uncertainty relationships. Therefore three industry sectors were examined, which appeared to display stronger relationships at the industry sector level. The results suggest that even studying the relationship at the industry sector level may be inappropriate, as all three industry sectors contained industries displaying significant in-mean terms of both signs. However, there does appear to be some clustering of results carrying the same sign for the 4-digit industries falling within the same 2-digit or 3-digit industry classification.

The results of this chapter suggest that there is much further work required using disaggregated data to find the reasons why some industries display a relationship of one sign and some another.[151] An alternative direction of enquiry is to move away from looking at the investment-uncertainty relationship indirectly through the output growth-output growth uncertainty relationship, and to model the investment-uncertainty relationship directly. This is the topic of the following chapter.

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[151] It is also noticeable that there seems to be little or no relationship between those industry groups, which displayed asymmetry in the proceeding chapters, and those identified in this chapter as showing a strong output growth-output growth uncertainty relationship.

Chapter 8 – Investment and Production Uncertainty

8.1 – Introduction

The preceding chapter examined the relationship between output growth and its own uncertainty as measured by the conditional variance of some variant of a GARCH process. The sign of this relationship, it has been suggested, will be determine, which of two hypotheses hold. The Black hypothesis based on the existence of a trade-off between volatility and average growth will result in a positive relationship. The Bernanke hypothesis, driven by irreversible investment, will result in a negative relationship if output uncertainty induces firms to postpone investment until more information becomes available. As can be clearly seen, the explanations for any link between output growth and its own uncertainty are strongly related to the investment decision. Therefore, the fundamental relationship of interest is not necessarily that between output growth and output growth uncertainty, but between investment and output growth uncertainty.

This chapter attempts to model the relationship between investment and output growth uncertainty directly in order to see more clearly which of the above hypotheses obtains greater support from the data, if either. The previous chapter found that individual industry sectors and industry groups revealed different signs for the relationship of output growth to output growth uncertainty. This mix of evidence may mean that both hypotheses hold with differing sectors being most strongly affected by one or the other of the considerations above, or alternatively it may be that the true relationship between the investment decision and output growth uncertainty is being obscured by short-term output decisions. Hence the need to more closely model the relationship.

The uncertainty measures calculated in the previous chapter are used as proxies for production uncertainty and used to model the investment data from the First Release industry group data. Section 8.2 looks at previous studies using similar techniques, whilst 8.3 introduces the methodology utilised in this study. Section 8.4 examines the results, and 8.6 summarises the chapter.

8.2 – Previous Studies

As discussed in the preceding chapter, plus Chapters 3 and 4, there exists, a considerable literature on the relationship between investment and uncertainty. Consensus is found neither in the theoretical nor empirical work, which perhaps explains the scale of the existing literature. At this point, therefore, it is reasonable to consider only the literature that uses similar techniques to those employed within this chapter, where a GARCH process is used to model the conditional variance of output growth and this is used as a measure of uncertainty in the investment equation. The uncertainty process is assumed to be governed by an APARCH-M process, with the change in the natural log of industry group production as the measure of output growth utilised.

Price (1995 and 1996) uses a similar approach to study the relationship between aggregate output growth uncertainty and investment. Price (1995) finds that the uncertainty measure has a significant negative affect reducing investment in the long run by an average of 5%, but, also that uncertainty reduced investment by as much as 48% in 1974 where uncertainty peaked during the oil crisis. Price (1996) extends this approach to form a non-linear model of investment which is dependent not only upon uncertainty as a determinant, but also for the speed of adjustment towards a desired investment rate governed by the deviation from the trend rate of output (as measured by the Hodrick-Prescott filter). An alternative specification in Price (1996) also allowed the effect upon the speed of adjustment to only vary when uncertainty rose above a threshold level. There was found to be a direct negative affect of uncertainty upon investment and a negative impact upon the speed of adjustment as uncertainty increased, both significant at the 5% level, and where the addition of the threshold effect in the alternative model specification also increased the significant of both the direct and adjustment speed effects.

Price (1995 and 1996) finds the conditional variance of output growth to be significant in modelling investment in a number of different specifications, and always negative. This suggests that the Bernanke hypothesis is more likely to hold than the alternative Black hypothesis. However using the output growth data in the previous section there were a number of results that appeared to find evidence of the presence of the Black hypothesis in some industry sectors. It therefore seems appropriate to apply a similar method to Price to model the affect of output growth uncertainty upon the investment rates of individual industry sectors.

8.3 – Methodology

The use of the conditional variance as a measure of uncertainty is widely accepted as a good proxy, as it is a measure of unpredictable volatility, whereas other measures of volatility or dispersion fail to distinguish between predictable and unpredictable volatility, (where predictable volatility, by definition, cannot add to uncertainty). However, when looking at investment, the exact process that should be used to model the conditional variance of a series generating uncertainty, the source of uncertainty itself, and the underlying model of the series being examined all need to be determined. This section looks at the choice of each of the above and then introduces the data available for analysis. Specifically, sub-section 8.3.1 looks at the process chosen to estimate the conditional variance, 8.3.2 examines alternative sources of uncertainty within the investment decision, 8.3.3 outlines the prospective models to represent the underlying investment series. Sub-section 8.3.4 discusses the data utilised for modelling the uncertainty and investment series, and 8.3.5 looks at techniques for selecting the appropriate processes to represent each series.

8.3.1 – Choice of GARCH Uncertainty Measure

The previous chapter used a number of different processes to model the conditional variance of output growth including a simple normally distributed GARCH-M processes, and an APARCH-M process following a GED, with lagged output growth control terms being allowed to enter the variance equation to accommodate the effect of inflation uncertainty. In this chapter the more general APARCH-M model alone is utilised, but which nests the simple GARCH form (and numerous other forms) in any case (McKenzie and Mitchell, 2002; Laurent, 2004), and under GED.[152] It was found in sub-section 7.4.6 that whilst output growth terms in the variance equation were insignificant, their introduction had a major impact on the significance of in-mean terms in the output growth equation. That approach is also followed here, and two alternative APARCH-M specifications, both excluding output growth and allowing its entry into the variance equation, are used to produce the uncertainty measures used in this chapter.

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[152] Section 7.2.1 in the preceding chapter discusses the ability of the APARCH model to nest other GARCH specification by restricting parameters to predetermined values rather allowing them to be freely estimated, in more detail.

8.3.2 – Sources of Uncertainty for the Investment Decision

It may seem obvious that industry groupings will be most strongly affected by output growth uncertainty within their own industry group, taking this as a sign of uncertainty of future sales levels. If irreversible investment is a major consideration then a Bernanke style hypothesis may hold and firms delay making investments because of uncertainty rising. An alternative possibility is that, a firm may look to the economy in general or manufacturing as a whole, as giving a better clue as to future economic conditions. Therefore, the conditional variance calculated for an aggregate output growth series may be most appropriate. Therefore, there are two sources of uncertainty that could impact upon the investment level: industry specific output growth uncertainty; and aggregate output growth uncertainty for manufacturing. How these sources of uncertainty relate to investment, and to each other, is discussed in the next subsection.

8.3.3 – Modelling the Impact of Uncertainty upon Investment

As in previous chapters the investment rate is initially assumed to follow an AR(*M*) process, the order of which will be selected by AIC and SIC; as before where no agreement is reached upon the order of the process, both processes will be utilised. The output growth uncertainty will be produced from the conditional variance of the output growth APARCH-M models reported in Chapter 7 where, as discussed above, lagged output growth terms are permitted to enter the variance equation in the more general form. Therefore, the initial investment and uncertainty equations are of the form shown in equations (8.1), (8.2) and (8.3) below:

$$(8.1) \qquad \Delta \ln I_t = \phi_0 + \sum_{m=1}^{M} \phi_m \Delta \ln I_{t-m} + \varphi \sqrt{h_{igQ,t}} + \varepsilon_{I,t}$$

,

$$\Delta \ln Q_{ig,t} = \beta_{ig0} + \sum_{n=1}^{N} \beta_{ig,n} \Delta \ln Q_{ig,t-n} + \lambda_{ig} \sqrt{h_{igQ,t}} + \varepsilon_{igQ,t} \tag{8.2}$$

$$\begin{aligned} \left(\sqrt{h_{igQ,t}}\right)^{\delta} &= \alpha_{ig0} + \sum_{j=1}^{q} \gamma_{ig,j} \left(\sqrt{h_{igQ,t-j}}\right)^{\delta} + \\ & \sum_{i}^{p} \alpha_{ig,i} \left(\left|\varepsilon_{igQ,t-i}\right| - \xi_i \varepsilon_{igQ,t-i}\right)^{\delta} + \sum_{v=1}^{V} z_{ig,k} \Delta \ln Q_{ig,t-v} \end{aligned} \tag{8.3}$$

where equation (8.1) is an AR process of order *M,* governing investment growth, $\Delta \ln I_t$, which is partially determined by output growth uncertainty, represented by the conditional standard deviation of the individual industry group's (*ig*), output growth, $\sqrt{h_{igQ,t}}$, with the *N*th order AR process representing output growth, ΔQ_{ig} for the industry group given by equation (8.2), which also allows output growth volatility to influence output growth as an in-mean term. Equation (8.3) is a APARCH(q,p) process governing the conditional variance of output growth, with δ the power term selected to model the volatility of output growth most accurately. In order to account for the influence of inflation volatility, *K* lags of output growth is allowed to enter the output growth uncertainty equation,[153] (From this point on equations (8.1), (8.2) and (8.3) will be referred to as the investment, output growth, and output growth uncertainty equations respectively).

As noted in the previous section, rather than uncertainty relating only to the firm's particular industry group affecting the investment growth rate of a firm, it may be possible that firms will also be affected by uncertainty in the aggregate economy as well. This would give an investment equation of the firm:

$$\Delta \ln I_t = \phi_0 + \sum_{m=1}^{M} \phi_m \Delta \ln I_{t-m} + \varphi_1 \sqrt{h_{igQ,t}} + \varphi_2 \sqrt{h_{aggQ,t}} + \varepsilon_{I,t} \tag{8.4}$$

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[153] Output growth is either excluded from the output growth uncertainty equation ($V = 0$) or allowed to enter the equation with four lags ($V = 4$)

where $\left(\sqrt{h_{igQ,t}}\right)$ is the conditional standard deviation of the output growth of the industry group being examined (as estimated by the output growth equation (8.2) and the output growth uncertainty equation (8.3)), and $\left(\sqrt{h_{aggQ,t}}\right)$, is the conditional standard deviation of the aggregate output growth rate produced by:

$$\Delta \ln Q_{agg,t} = \beta_{agg0} + \sum_{n=1}^{N} \beta_{agg,n} \Delta \ln Q_{agg,t-n} + \lambda_{agg} \sqrt{h_{aggQ,t}} + \varepsilon_{aggQ,t} \tag{8.5}$$

$$\begin{aligned} \left(\sqrt{h_{aggQ,t}}\right)^{\delta} &= \alpha_{agg0} + \sum_{j=1}^{q} \gamma_{agg,j} \left(\sqrt{h_{aggQ,t-j}}\right)^{\delta} + \\ &\sum_{i}^{p} \alpha_{agg,i} \left(\left|\varepsilon_{aggQ,t-i}\right| - \xi_i \varepsilon_{aggQ,t-i}\right)^{\delta} + \sum_{k=1}^{K} z_{agg,k} \Delta \ln Q_{agg,t-k} \end{aligned} \tag{8.6}$$

again the output growth equation (8.5) for the aggregate is an AR(*N*) process, and the output growth uncertainty equation (8.6) for the aggregate is an APARCH(*q*, *p*) process, where *K* lags of aggregate output growth are allowed to enter conditional variance equation.

A final extension to the investment equation is that not only is investment assumed to be an autoregressive process but there is also an accelerator effect whereby past output growth will also affect investment, and therefore is allowed to enter the investment equation directly:

$$\begin{aligned} \Delta \ln I_t &= \phi_0 + \sum_{m=1}^{M} \phi_m \Delta \ln I_{t-m} + \sum_{s=1}^{S} \vartheta_s \Delta \ln Q_{ig,t-s} + \varphi_1 \sqrt{h_{igQ,t}} + \\ &\varphi_2 \sqrt{h_{aggQ,t}} + \varepsilon_{I,t} \end{aligned} \tag{8.7}$$

the accelerator version of the investment equation above includes *M* lags of investment growth, $\Delta \ln I_t$, and *S* lags of the industry group's output growth, $\Delta \ln Q_{ig,t}$. The industry group output growth uncertainty, $\left(\sqrt{h_{igQ,t}}\right)$ again being estimated by equations (8.2) and (8.3), and aggregate output growth uncertainty, $\left(\sqrt{h_{aggQ,t}}\right)$, estimated by equations (8.5) and (8.6).

8.3.4 – Data

The data used in this study are from the ONS First Release data. The investment data from this source were used in Chapters 5 and 6 to examine the asymmetry and time reversibility of the investment series respectively, whilst the output growth data were used to test for the Black and Bernanke hypotheses in the preceding chapter. The output growth data are available for a much longer period and at a lower level of aggregation than is the investment data. This means that the investment data provides most of the limitations that must be applied. In particular whilst monthly and quarterly frequencies of the output growth data are available, the investment data are only available at the quarterly frequency (see Chapter 5 for more details on investment data and Chapter 7 for the production data). Further, whilst for a majority of the output growth series, the data covers the period 1948-2004, the investment series are only available for 1979-2004. This means that the investment equation can only be calculated for this shorter period. However, given the availability of earlier data for output growth, the full series available is used in modelling output growth uncertainty.[154] Moving onto the issue of the level of aggregation in the data, whilst the output growth data are divided into 14 industry sectors, the investment data are only split into 7 industry groups.[155] Obviously this will mean that much of the industry specific effects will be lost in this more aggregated data and therefore there may be a bias towards those relationships operating through the aggregate.

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[154] If the relationships for output growth as consistent throughout the entire period then it is sensible to estimate using the whole stretch of data. If structural breaks exist then it may be that to ensure the correct relationship is used to calculate output growth uncertainty only data from the same period as the investment data should be used. Estimation of the uncertainty series over the longer and short time period produced very similar results, therefore for the benefit of more accurate modelling of the uncertainty relationship, the uncertainty series were estimated using all the production observations available.

[155] This is the reason that the work in the previous chapter looked at the output growth – output growth uncertainty relationship at the higher level of aggregation (industry group) as well as at the lower industry sector aggregation level. This allows comparison to be made between the results of this chapter and those of the proceeding chapter.

8.3.5 – Choice of Models

In a number of the conditional mean equations above AR(*M*) processes are used to estimate the dependant variable. The order of the process in each of these cases will be selected using Ljung-Box analysis. However, there are a number of estimations where a number of lagged terms enter an equation where these terms are not lagged terms of the dependant variable but of another series, such as output growth terms entering the investment equation to represent an accelerator effect. Where this is the case, as with the results to be presented in Section 8.5, the lagged investment variables will be selected to remove any autocorrelation present, and then having chosen the underlying AR(*M*) process the number of accelerator terms selected will be chosen by use of the AIC.

So far this chapter has discussed the methodology and theory being applied to testing the uncertainty relationship between investment and output growth uncertainty. The following sections will introduce the estimation results. Section 8.4 will look at the results obtained when estimating the investment equation when using AR processes, and accelerator models. Section 8.5 summarises the chapter.

8.4 – Investment and Uncertainty

This section covers the results produced when using an autoregressive process to model the investment growth rate. It is assumed that both the investment and output growth rates are stationary series, as this has been tested for in previous chapters and no problems found with this form of the data (See sub-section 6.1.4 and sub-section 7.4.1, and Tables 6.1 and 7.1).[156]

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[156] Estimation of the investment equation is conducted by Generalised Methods of Moments (GMM), to account for the fact that the output growth uncertainty variables will be measured with error. The instruments used are the lagged values of the investment and output uncertainty variables.

Sub-section 8.4.1 starts with the effect of utilising a simple AR(*M*) process to represent the data and initially assuming that the output growth uncertainty enters as industry group specific uncertainty. The results in sub-section 8.4.2, allow aggregate output growth uncertainty to also influence the investment rate. Sub-section 8.4.3 provides a summary of the results reported.

8.4.1 – Industry Group Specific Uncertainty

It is initially assumed that the firms' investment decisions are only affected by past investment growth values and uncertainty relating to output growth of the firm's own industry group. These assumptions are represented by the investment equation (8.1) above, with output growth uncertainty being determined by the output growth equation (8.2), and output growth uncertainty equation (8.3).

As two separate AR processes may be selected for both the output growth and investment series it is possible for four combinations of specifications to be used to model the investment – output growth uncertainty relationship for each series. When output growth is allowed to enter the output growth variance equation this allows the number of specifications for each series to be doubled to eight.

Table 8.1 below shows the output growth uncertainty terms to enter the investment equation as in equation (8.1).

Table 8.1

Industry Specific Output Growth Uncertainty Terms

Panel (a) **No lagged output growth in variance equation**

Investment AR(*M*)[a]	AIC		SIC	
Production AR(*N*)[b]	AIC[c]	SIC	AIC	SIC
Aggregate	-0.5591	-0.5591	-0.5591	-0.5591
	(0.4146)	(0.4146)	(0.4146)	(0.4146)
Chemicals	**-2.12203**	**-2.16331**	**-2.05972**	**-1.96069**
	(0.0072)	(0.0026)	(0.0009)	(0.0012)
Engineering	**-5.94457**	**-6.06346**	**-5.94457**	**-6.06346**
	(0.0134)	(0.0004)	(0.0134)	(0.0004)
Food Production	-87.6237	-1.31438	-43.9956	-0.05036
	(0.3072)	(0.6113)	(0.567)	(0.9816)
Fuels	-0.05398	-0.05398	-0.39906	-0.39906
	(0.9148)	(0.9148)	(0.5119)	(0.5119)
Metals	-3.39246	-3.39246	**-1.43476**	**-1.43476**
	(0.1791)	(0.1791)	(0.0002)	(0.0002)
Textiles	**-25.3266**	**-24.639**	-22.9837	-22.0169
	(0.0016)	(0.0025)	(0.0746)	(0.0692)
Other Manufacturing	0.095406	0.095406	-1.46586	-1.46586
	(0.9827)	(0.9827)	(0.2524)	(0.2524)

Panel (b) **Lagged output growth in variance equation**

Investment AR(*M*)	AIC		SIC	
Production AR(*N*)	AIC	SIC	AIC	SIC
Aggregate	-1.41012	-1.41012	-1.41012	-1.41012
	(0.1491)	(0.1491)	(0.1491)	(0.1491)
Chemicals	**-1.84426**	**-2.042**	**-1.86147**	**-2.07862**
	(0.0103)	(0.013)	(0.0009)	(0.0022)
Engineering	**-6.20686**	**-7.19249**	**-6.20686**	**-7.19249**
	(0.0393)	(0.0044)	(0.0393)	(0.0044)
Food Production	-1.31984	-1.63896	-0.90076	-1.10206
	(0.6669)	(0.4557)	(0.7513)	(0.592)
Fuels	-0.09653	-0.09653	-0.70659	-0.70659
	(0.9243)	(0.9243)	(0.5173)	(0.5173)
Metals	-5.91329	-5.91329	**-1.56072**	**-1.56072**
	(0.1569)	(0.1569)	(0.0008)	(0.0008)
Textiles	**-25.4424**	**-37.6756**	**-31.9831**	-55.7496
	(0.001)	(0.05)	(0.0415)	(0.2684)
Other Manufacturing	4.09044	4.09044	-1.41732	-1.41732
	(0.4386)	(0.4386)	(0.6392)	(0.6392)

(a) Information criterion used to select order of AR processes for investment series.
(b) Information criterion used to select AR process for production series.
(c) Emboldened figures are significant at the 5% level, p-values are in parenthesis.

For the Chemicals, Engineering and Textiles industries groups there is a significant negative effect of uncertainty upon investment. This is true of both the uncertainty variable calculated as dependent upon lagged output growth (panel (b)) and where it is not (panel (a)). The Metals industry group on the other hand only generates significant results when using one order of AR process to represent the investment equation that selected by the SIC, when the longer AR process selected by the AIC finds no significance for the uncertainty term. This is true of both the uncertainty term calculated with output growth entering and being excluded from the variance equation (panels (a) and (b) respectively). The aggregate only finds a significant uncertainty term when using the uncertainty series created when output growth enters the variance equation. No significant terms were found for Food, Fuels and Other Manufacturing.

There appears to be evidence that output growth uncertainty has a negative effect upon the investment growth rate within certain industry groups, but not others. Those unaffected are interesting. The food industry might be expected to have less influence from uncertainty given the stability of demand for its products, while the Other Manufacturing industry group is possibly less influenced by its own output growth uncertainty due to the disparity of the component industries, as compared to the other industry groups. The fuels industry group on the other hand is an interesting result as it is the oil industry, which is normally selected as one of the best examples of an industry displaying irreversible investment (Paddock et al., 1988), and also since the *TR* tests in Chapter 6 identified the Fuels industry group as displaying irreversible investment.

8.4.2 – Investment and Aggregate Output Growth Uncertainty

Rather than just looking at the effect of a industry groups' own output growth uncertainty upon the investment growth rate as noted above some industry groups may use the general level of uncertainty within the economy as a better barometer of current and future economic conditions. This means that aggregate output growth uncertainty may have a more significant impact upon the investment series. In order to accommodate this the conditional volatility of the aggregate of the manufacturing industry groups is calculated by the aggregate output growth equation (8.5), and aggregate output growth uncertainty equation (8.6), with the conditional volatility of aggregate output growth entering the investment equation (8.4) as the conditional standard deviation of aggregate output growth, $\left(\sqrt{h_{aggQ,t}}\right)$. Both industry group specific and aggregate uncertainty terms are allowed to enter the investment equation with the results presented in Table 8.2. Panel (a) shows the affects of the uncertainty terms using the uncertainty series calculated when lagged output growth is excluded from the uncertainty equations. There generally seems to be a smaller affect for uncertainty upon the investment series, but Engineering and Textiles still appear to observe a Bernanke style effect upon the investment rate under some specifications. The food industry group, however, is strongly affected by the aggregate uncertainty term, with significant negative coefficients being found for all specifications of the Food investment rate.

The results produced when output growth is allowed to enter the uncertainty equations are shown in panel (b). The results produced are similar to those where output growth was excluded with the exceptions of the Textiles, Other Manufacturing and Metals industry groups. The number of significant uncertainty terms is reduced for both forms of the Textiles investment equations. On the other hand, certain specifications of Other Manufacturing produce significant aggregate uncertainty terms. The introduction of output growth therefore appears to increase the significance of aggregate uncertainty and lessen that of industry specific uncertainty.

Table 8.2

Industry Specific and Aggregate Uncertainty with AR Processes

Panel (a) **No lagged output growth in variance equation**

Inv AR(*M*)	AIC				SIC			
Prod AR(*N*)[a]	AIC		SIC		AIC		SIC	
Uncertainty[b]	Ind Unc[c]	Agg Unc	Ind Unc	Agg Unc	Ind Unc	Agg Unc	Ind Unc	Agg Unc
Chem	-1.68799	-1.59139	-1.69949	-1.4404	-2.62137	1.454523	-2.13879	0.875087
	(0.314)	(0.7013)	(0.3426)	(0.7456)	(0.0798)	(0.6504)	(0.1644)	(0.8003)
Eng	-4.56223	-0.22195	**-7.79927**	3.472713	-4.56223	-0.22195	**-7.79927**	3.472713
	(0.0974)	(0.9426)	(0.0058)	(0.2919)	(0.0974)	(0.9426)	(0.0058)	(0.2919)
Food	112.7051	**-3.7923**	4.450098	**-3.96605**	135.9464	**-3.43691**	4.824178	**-3.47071**
	(0.2933)	(0.0358)	(0.1038)	(0.0143)	(0.1847)	(0.0469)	(0.058)	(0.0217)
Fuels	-0.15387	-0.81931	-0.15387	-0.81931	-0.21617	2.475941	-0.21617	2.475941
	(0.7559)	(0.8923)	(0.7559)	(0.8923)	(0.6614)	(0.5059)	(0.6614)	(0.5059)
Met	-1.05106	-1.92657	-1.05106	-1.92657	-1.22975	-1.07322	-1.22975	-1.07322
	(0.6251)	(0.781)	(0.6251)	(0.781)	(0.1443)	(0.7604)	(0.1443)	(0.7604)
Text	**-8.80522**	-3.46799	**-9.37957**	-2.47895	**-8.23131**	-1.13292	**-9.05827**	-0.23384
	(0.0029)	(0.4032)	(0.0011)	(0.5519)	(0.0045)	(0.7491)	(0.0014)	(0.9475)
Other	0.000289	-1.84332	0.000289	-1.84332	-0.85045	-1.37457	-0.85045	-1.37457
	(0.9999)	(0.6151)	(0.9999)	(0.6151)	(0.6587)	(0.6479)	(0.6587)	(0.6479)

Panel (b) **Lagged output growth in variance equation**

Inv AR(*M*)	AIC				SIC			
Prod AR(*N*)	AIC		SIC		AIC		SIC	
	Ind Unc	Agg Unc	Ind Unc	Agg Unc	Ind Unc	Agg Unc	Ind Unc	Agg Unc
Chem	-0.92275	-3.59996	-0.95182	-3.74262	-1.39587	-1.39308	-1.70222	-1.48238
	(0.4367)	(0.2874)	(0.4549)	(0.2598)	(0.2085)	(0.6659)	(0.1628)	(0.622)
Eng	-3.43681	-0.43035	**-4.19499**	0.908724	-3.43681	-0.43035	**-4.19499**	0.908724
	(0.1443)	(0.9001)	(0.0103)	(0.7524)	(0.1443)	(0.9001)	(0.0103)	(0.7524)
Food	1.344558	**-5.68029**	0.698984	**-5.49191**	2.267015	**-4.84695**	1.300654	**-4.54797**
	(0.4466)	(0.0007)	(0.6519)	(0.001)	(0.2095)	(0.0029)	(0.4124)	(0.0048)
Fuels	-0.37582	-0.34625	-0.37582	-0.34625	-0.66094	3.316337	-0.66094	3.316337
	(0.694)	(0.9606)	(0.694)	(0.9606)	(0.4695)	(0.4655)	(0.4695)	(0.4655)
Met	-0.17977	-9.04301	-0.17977	-9.04301	-0.48219	-6.4326	-0.48219	-6.4326
	(0.916)	(0.1179)	(0.916)	(0.1179)	(0.5012)	(0.0927)	(0.5012)	(0.0927)
Text	-4.05743	-9.79245	-3.65487	**-10.1348**	**-5.13143**	-6.41043	-4.64029	-6.71779
	(0.1333)	(0.0531)	(0.1733)	(0.0454)	(0.0406)	(0.1421)	(0.0615)	(0.1249)
Other	6.359121	-5.5253	6.359121	-5.5253	4.573294	**-6.74504**	4.573294	**-6.74504**
	(0.1557)	(0.1405)	(0.1557)	(0.1405)	(0.1959)	(0.0246)	(0.1959)	(0.0246)

(a) Information criterion used to select the order of AR processes used to estimate the investment and production growth series.

(b) Ind Unc is output growth uncertainty specific to the industry group in question, Agg Unc is the aggregate output growth uncertainty measure.

(c) Emboldened figures are significant at the 5% level, with p-values in parenthesis.

It appears that aggregate uncertainty has a significant impact for investment within certain industry groups. All of the significant terms are negative which suggests the existence of the Bernanke hypothesis, but it would normally be expected that if this is what is generating the negative uncertainty-investment relationship, industry specific investment would have a much greater affect than the aggregate, due to irreversibilities introduced by industry specific investment. The presence of negative uncertainty terms for aggregate uncertainty requires another explanation, the simplest being that some industries just follow the economy as a whole more strongly than their own industry as fluctuations in industry output may be transitory whilst economy wide movements are more permanent.

8.4.3 - Accelerator Specifications

Up to this point it has been assumed that the investment growth rate was an autoregressive process. Theoretical work has generally attempted to model investment as being driven by the return relative to cost of capital (Q theory) or as a function of past, sales or profits (accelerator theory). Even the relatively simple accelerator is perhaps a more realistic method of modelling the investment decision, (see Chapter 2 for discussion of traditional investment theory). It is unlikely that a firm will make all decisions relating to the investment rate based upon past investment purchases, and it is more likely that firms will be influenced by changes in the demand for output, as been shown by past empirical work. This section therefore investigates the investment-uncertainty relationship allowing for investment to be influenced by the output growth rate new investment equations, in order to determine whether the relationships found above are robust when a more realistic investment equation is adopted.

As earlier Ljung-Box analysis is initially used to determine the order of the AR(M) process governing the investment series. The number of lagged output growth terms to include within the investment equation was then found using the AIC. Once the appropriate number of accelerator terms was selected the AIC was again used to confirm that the AR(*M*) was of the correct order with the addition of the accelerator terms. The AIC was then used to confirm the correct number of accelerator terms if the number investment growth terms were altered. This process was continued until the correct combination of accelerator and autoregressive terms was selected to minimise the AIC, (see Table 8.3 below for summary of models used in this sub-section).

Table 8.3

Lagged Output and Investment Growth Terms Selected for Each Industry Group When Using AR and Accelerator Specifications

Specification[a]		No Output		Output		AR	
Information Criterion[b]		AIC	SIC	AIC	SIC	AIC	SIC
Agg	ΔQ[c]	13	13	11	11	-	-
	ΔI[d]	3	3	3	3	3	3
Chem	ΔQ	3	5	3	3	-	-
	ΔI	6	5	6	6	6	1
Eng	ΔQ	2	2	4	3	-	-
	ΔI	3	2	3	2	1	1
Food	ΔQ	12	7	7	9	-	-
	ΔI	3	3	3	3	3	1
Fuels	ΔQ	1	1	1	1	-	-
	ΔI	7	7	5	5	7	1
Met	ΔQ	3	3	4	4	-	-
	ΔI	13	13	13	13	13	1
Text	ΔQ	3	4	4	3	-	-
	ΔI	2	2	5	2	4	1
Other	ΔQ	3	3	1	1	-	-
	ΔI	4	4	3	3	8	1
Met ARCH(1)	ΔQ	5	5	5	5	-	-
	ΔI	13	13	13	13	13	1
Text ARCH(3)	ΔQ	3	3	3	4	-	-
	ΔI	2	2	4	4	4	1

(a) No Output and Output refer to the accelerator models where output growth is excluded from and allowed into the output variance equation respectively. AR refers to the simple AR(*M*) investment equations used in the previous section.
(b) Information criterion used to select the order of AR process in the output equation.
(c) Number of lagged output growth terms entering the investment equation.
(d) Number of lagged investment growth terms entering the investment equation.

As before output growth was estimated using an APARCH-M form. Both the industry group specific (from equations (8.2) and (8.3)) and aggregate sources of uncertainty (from equations (8.5) and (8.6), considered in sub-section 8.4.2, were allowed to enter the investment equation (8.7). Table 8.4 presents the uncertainty terms estimated for the investment equations when output growth was excluded from the output uncertainty equation.

Table 8.4

Accelerator Models of Investment-Uncertainty Relationship

(Lagged Output Growth Excluded From Output Uncertainty Equation)

Output AR(*N*)[a]	AIC		SIC	
Uncertainty[b]	Ind Unc[c]	Agg Unc	Ind Unc	Agg Unc
Aggregate	-	0.295359	-	0.295359
		(0.6199)		(0.6199)
Chemicals	-0.56735	-1.53434	-1.79572	-1.65825
	(0.8929)	(0.8214)	(0.7232)	(0.8539)
Engineering	-9.12114	3.161329	**-17.4086**	9.971847
	(0.2387)	(0.5143)	(0.007)	(0.0504)
Food Processing	42.79563	-2.07965	0.23568	-1.61727
	(0.6018)	(0.2113)	(0.897)	(0.2628)
Fuels	-0.03389	-1.82702	-0.03389	-1.82702
	(0.9442)	(0.6899)	(0.9442)	(0.6899)
Metals	-2.0314	0.409408	-2.0314	0.409408
	(0.4039)	(0.9604)	(0.4039)	(0.9604)
Textiles	-12.693	4.490387	-1.42427	1.620092
	(0.3451)	(0.3277)	(0.9571)	(0.7845)
Other Manufacturing	1.798523	-0.17638	1.798523	-0.17638
	(0.5751)	(0.9657)	(0.5751)	(0.9657)

(a) Information criterion used to select the order of AR process in the output equation.
(b) Ind Unc is output growth uncertainty specific to the industry group in question, Agg Unc is the aggregate output growth rate uncertainty measure.
(c) Emboldened figures significant at the 5% level, p-values in parenthesis.

A single significant industry group specific uncertainty is produced for Engineering, and is negative, as was the case before when using the AR processes to model investment. The aggregate uncertainty coefficient estimated for the same Engineering model is significantly positive at the 10% level, which supports the earlier suggestion that where the Bernanke and Black hypotheses both hold, the Bernanke hypothesis would be likely to operate through industry group uncertainty, while the Black hypothesis is more likely to operate through the aggregate uncertainty term. The lifting of the restriction upon output growth entering the output uncertainty equation produces the results shown in Table 8.5.

Table 8.5

Accelerator Models of Investment-Uncertainty Relationship

(Lagged Output Growth Allow to Enter the Output Uncertainty Equation)

Output AR(N)[a]	AIC		SIC	
Uncertainty[b]	Ind Unc[c]	Agg Unc	Ind Unc	Agg Unc
Aggregate	-	0.243223 (0.8639)	-	0.243223 (0.8639)
Chemicals	-0.18503 (0.9509)	-2.9713 (0.7034)	-0.50316 (0.8525)	-2.74229 (0.7091)
Engineering	-1.69888 (0.7844)	0.60772 (0.946)	-14.3265 (0.0568)	11.50357 (0.1452)
Food Processing	0.88885 (0.6465)	**-4.21338** (0.0222)	0.274904 (0.864)	**-4.35365** (0.0198)
Fuels	-0.54147 (0.6921)	6.679267 (0.1621)	-0.54147 (0.6921)	6.679267 (0.1621)
Metals	-2.34074 (0.5551)	-2.54136 (0.9499)	-2.34074 (0.5551)	-2.54136 (0.9499)
Textiles	-41229.1 (0.995)	1351.025 (0.995)	-62.3659 (0.0571)	-10.54 (0.2756)
Other Manufacturing	5.380477 (0.3346)	-5.36914 (0.2612)	5.380477 (0.3346)	-5.36914 (0.2612)

(a) Information criterion used to select the order of AR process in the output equation.
(b) Ind Unc is output growth uncertainty specific to the industry group in question, Agg Unc is the aggregate output growth rate uncertainty measure.
(c) Emboldened figures are significant at the 5% level, with p-values in parenthesis.

Very few significant results are found with no significant industry specific uncertainty terms at the 5% level, (although both Engineering and Textiles produced significantly negative industry group uncertainty terms at the 10% level), and only the Food Processing industry group generating significant negative aggregate uncertainty terms.

8.4.4 – Summary of Section

Initially the use of only the industry specific output growth uncertainty appeared to indicate that certain industry groups were greatly influenced by uncertainty, and reduced the investment rate accordingly. However, the introduction of aggregate output growth uncertainty reduced the influence of industry specific uncertainty. Different industry groups were found to be influenced by different sources of uncertainty more strongly than others. For example, whilst the Textiles industry group is still significantly affected by uncertainty relating to the output growth rate of the industry group itself, the Foods industry group appeared to be more strongly influenced by aggregate output growth uncertainty.[157]

A vast majority of significant terms found were negative, which suggests that the Bernanke irreversible investment hypothesis is more likely to hold than the Black hypothesis. However, when both forms of uncertainty were included in the investment equation it was found that some positive terms were generated for the Fuels industry group. The positive term for the Fuels industry group seems strange. Whilst the Black hypothesis could produce this result the selection of the Fuels industry group is odd because the oil industry is generally regarded as the best example of an industry affected by irreversible investment, and therefore it would be expected that this

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[157] A further extension is to consider whether the investment-uncertainty relationships remain constant over the business cycle. This can be accomplished with the use of dummy variables to represent the presence of an expansionary period, attached to the uncertainty variables. Whether the industry group or aggregate is in an expansionary period can be modelled as to whether output growth is above trend or not, with the trend being modelled by the Hodrick-Prescott filter. How an expansionary period for a single industry group, and the presence of an expansionary period in the aggregate interact, (whether the presence of an expansion in the industry group or aggregate influences the investment-uncertainty relationship on its own, or do both expansions have to be present to have an effect) can also be modelled by using two independent sets of expansion dummies, or where both expansions need to be present, one set of dummies to represent all possible combinations of expansions. It was, however, found that when applying these dummies to the First Release data the dummy variables were mostly insignificant, and the uncertainty variables unaffected (One exception being the Textiles industry group where the presence of an aggregate expansion was found to lessen the negative effect of industry group uncertainty, and increase the negative influence of aggregate uncertainty), and therefore to preserve space the results are not reported in this study. The topic of business cycle influences on the investment-uncertainty relationship is revisited in more detail in Chapter 9.

negative influence would override the Black hypothesis if present. It is suggested that this could be due to a positive correlation between fuels prices and aggregate uncertainty.

8.5 – Summary of Chapter

Although data were not available to examine the relationship between output growth uncertainty and investment directly at the same aggregation level as the output growth and output growth uncertainty relationship examined in Chapter 7 (where industry sector and 4-digit industry level data were used), the results found in this chapter are quite illuminating. As well as looking at output growth uncertainty from one industry group affecting investment growth within the same industry group, the relationship between each industry groups' investment to aggregate output growth uncertainty and uncertainty as to the investment growth rate were also examined.

The model was developed using the conditional standard deviation of the output growth models estimated in the previous chapter as the output growth uncertainty terms. The APARCH-M forms of the conditional variance equations were used as these processes nest various other models of the GARCH genre within them. The investment equations utilised were built upon simple AR(M) processes where industry specific and/or aggregate output growth uncertainty, were allowed to enter the conditional mean equation. A final extension allowed the underlying investment process to be in part determined by an accelerator process.

Overall the results produced using the various specifications were in general agreement as to the uncertainty-investment relationship present for each separate industry group, although the nature of the relationship was found to vary from one industry group to the next. Certain industry groups were found to be more greatly effected by industry specific output growth uncertainty, such as Textiles and Engineering, whilst others were more strongly affected by the aggregate, Food and Metals. One explanation for this is that whilst the manufacturing within the Food industry group is relatively close to the finish product that is consumed by the end consumer other industry groups do not, such as Engineering, where production includes large quantities of capital and intermediate goods. However, for Textiles, much of production is of intermediate goods, and the metals industry is harder to produce an explanation for.

One thing that the results have in common was that investment-uncertainty relationships were generally negative, suggesting the presence of irreversible investment and the holding of the Bernanke hypothesis. A significant positive aggregate uncertainty term was returned only for the Fuels industry, which seems contrary to popular opinion as the Fuels industry group and oil industry in particular is generally held up as a good example of an industry with highly irreversible investment. One postulated explanation is that aggregate uncertainty is positively correlated with fuel prices, as periods of high fuel (or energy) prices often result in periods of higher volatility in many sectors of the economy. Therefore the positive effect upon the fuels industry group's investment from aggregate uncertainty could be a result of firms increasing investment as returns rise, as suggested by Black, a trade-off between returns and stability.

Chapter 9 – Estimation of Investment using SETAR Models

The preceding chapters attempted to identify the presence of irreversible investment using either, asymmetry tests, tests of time reversibility, or through modelling the investment-uncertainty relationship. This chapter attempts to pull the two sections of work together, by simultaneously modelling the time series consequences of investment irreversibility and the effects of uncertainty. More specifically, this chapter tests for the presence of irreversible investment by testing whether investment follows a Self Exciting Threshold Autoregressive (SETAR) process, in accordance with (S,s) theoretical models of investment under uncertainty, and allows uncertainty to enter the model in a manner which permits the effects of uncertainty to differ depending on the SETAR regime. The SETAR model is introduced in Section 9.1. Section 9.2 presents the results of BDS (Brock et al., 1996) and McLeod-Li (McLeod and Li, 1983) linearity tests applied to the First Release and National Accounts investment series when estimated using linear AR processes, this is in order to determine the suitability of a non-linear model, such as the SETAR specification, for modelling investment. SETAR models are then estimated for the First Release and National Accounts data in 9.3, where neglected non-linearity is tested for to determine the success of this estimation. Section 9.4 allows the uncertainty measures produced in Chapter 7 to enter the investment equation, and 9.5 summarises the chapter.

9.1 – SETAR Models

Research has shown that firms adjust their capital stocks in a lumpy fashion, with periods of inaction followed by large investment spikes (for example Doms and

Dunne, 1998; Nilsen and Schiantarelli, 1997; Gelos and Isgut, 2001; Carlsson and Laseen, 2005). This pattern of investment therefore suggests that a firm's investment may be best modelled by some form of threshold model such as the (S,s) model (see Section 3.2). Sub-section 9.1.1 introduces the SETAR model, while sub-section 9.1.2 examines the implications for investment patterns when modelled using the SETAR specification. Sub-section 9.1.3 revisits the results of the preceding chapters to present the evidence for the suitability of imposing a non-linear specification when modelling the First Release and National Accounts investment series. The implications for the investment-uncertainty relationship are introduced briefly in sub-section 9.1.4.

9.1.1 – Introducing the SETAR Model

A Threshold Autoregressive (TAR) process (Tong, 1978) allows a series to follow an autoregressive process, but this process changes when a certain threshold (c) within a state variable (q_t) is reached:

$$(9.1) \qquad y_t = \begin{cases} \phi_{0,1} + \sum_{i=i}^{p_1} \phi_{i,1} y_{t-i} + \varepsilon_t & \text{if } q_{t-d} \leq c \\ \phi_{0,2} + \sum_{j=i}^{p_2} \phi_{j,1} y_{t-j} + \varepsilon_t & \text{if } q_{t-d} > c \end{cases}$$

The value d in the subscript of the state variable (q) is the delay variable. This represents the fact that changes in regime may not be immediate but take place after a number of periods have passed. The AR processes within each regime can be restricted to be of the same order or of different AR orders. Although the example above includes only two regimes and one threshold value, the model can be extended to include more than one threshold, and multiple regimes. A Self Exciting Threshold Autoregressive (SETAR) model is where the state variable is simply a lagged value of the dependant variable. As before the dependent variable follows an AR process, but the exact process followed depends upon the value of the dependant variable in some preceding period, as determined by the delay variable.

Non-linear models have a number of advantages over their linear counterparts. A linear ARMA(v,w) specification can be used represent any stationary endogenous variable, y_t, with the stationarity resulting in fixity of mean, variance and autocorrelation in y. The choice of v and w is typically to ensure that the disturbance terms are 'white'. This may not, however, ensure that the model is an appropriate representation of the underlying process for y_t. In order to ensure linearity the disturbance term needs to be strictly independent random variables (Priestley, 1981). The ARMA representation may, therefore, allow a non-linear structure to remain within the disturbance terms, if for example asymmetry was present in the series, and therefore a non-linear representation is required to account for this structure and produce truly independent random disturbances.

While, the unit roots of a linear AR process must be within the unit circle to allow estimation, this is not the case for the SETAR model. Series characterised by explosive and contractive regimes can be represented using the SETAR model, as the SETAR model can accommodate variables displaying limit cycle behaviour, rather than being confined to limit point behaviour. This means rather than collapsing to a limiting point in the long run, a variable can have an asymptotic periodic form, so a variable would follow an endogenous cycle without the presence of disturbances. The ability to account for non-linearities within disturbances, and model limit cycles has been shown to improve the out-of sample forecasts for macroeconomic variables such as unemployment (Peel and Speight, 2000), and in-sample forecasting of output (Peel and Speight, 1998). These properties suggest that the SETAR model should be an appropriate representation of the First Release and National Accounts investment series.

9.1.2 – Modelling Investment Data

This is the model that is used in estimating the investment series from the First Release and National Accounts datasets. In these models investment will be determined by past values of investment, but the exact process that this model follows will depend upon where a past investment value was above or below a certain level. One threshold will be used to determine two separate regimes, as although there is potential for more regimes than two it is not always possible to estimate these models as the greater number of regimes the fewer observations that are available to identify the AR process in each regime.[158] This will create a model where the investment decisions of firms will be made in such a way that firms will either operate in a low investment regime (regime 1) or a high investment regime (regime 2). The delay variable, *d*, will initially be set at 1, so investment in the previous period will determine the regime that is used to estimate current investment. This assumption is later relaxed to allow the delay to take a value greater than 1.

The investment data used are the growth rates of investment used in the linearity tests (see Section 9.2). The growth rates of the First Release data are also used to re-estimated the investment-uncertainty relationship tested in Chapter 8. The maximum orders of the AR processes will be limited to the orders selected by the AIC when

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[158] Authors such as Abel and Eberly (1994) suggest that firms will operate with three investment regimes, divest, no investment activity, invest. Whilst this does not translate directly to the aggregate it may be possible that more than one regime is required to accurately model aggregate investment when using SETAR processes, (see Chapter 3 for discussion of non-linear investment decision processes with irreversible investment).

using a simple linear AR process to model the investment series.[159] The correct order of the AR processes in each regime, are selected using the AIC.[160] No restriction is placed upon the regimes having the same orders. As noted above the delay variable is initially fixed at 1, but this assumption is relaxed for further estimation allowing the delay to take a value between 1 and 4 with the most appropriate model selected, as before, using the AIC. This allows for the possibility that switches in regime take a long period to occur, rather than in the quarter immediately following the threshold being breached.

9.1.3 – Testing the Suitability of the SETAR Representations

The *TR* tests in Chapter 6, provide evidence that certain industry groups and most investment good categories are not accurately represented using a linear AR process, as they display asymmetry. As described at the beginning of this chapter if this asymmetry is due to irreversible investment some form of non-linear threshold model may be best utilised to estimate the series. BDS and McLeod-Li linearity tests are used in the following section to determine whether the asymmetry detected by the *TR* tests results in neglected non-linearity being present when estimating the investment series using linear AR processes. However just because non-linearity is present it is not necessarily due to irreversible investment and therefore an alternative non-linear representation to the SETAR model may be more appropriate. One method of testing the suitability of a threshold model is to use an LM test of linearity against TAR

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[159] See Table 6.4 for linear AR orders used to represent First Release growth rates, and Table 6.10 for National Accounts growth rate AR orders.

[160] It was found that even using the AIC some regimes were estimated to have low orders or simply a constant value. This implies that the log-level of investment follows a random walk about trend, where the best prediction of firm's investment is the previous periods investment level, plus a component following an upward or downward trend, and an unforecastable shock component. This perhaps characterises periods of investment 'inaction' with relatively 'tranquil' investment growth rates, when only replacement investment is undertaken.

(Chan, 1990). This test is applied to the investment series and the results also reported in the following section. The test statistic is equivalent to the (conditional) likelihood ratio test statistic when errors are normally distributed. An alternative description is that the test statistic is the normalised reduction in the sum of squares due to the introduction of the additional variables to create a second regime. The tests are conducted with the null of a linear AR process selected by the AIC against the alternative of a TAR model. The tests are repeated with delays of 1, 3, and 4 quarters to give an indication of the sluggishness of changes in investment.[161] If those series displaying asymmetry and non-linearity are found to reject the null of linearity for the alternative of TAR then it is more likely that the asymmetry and non-linearity are due to irreversible investment.

An alternative is to reapply the linearity tests used in the following section to the residuals produced by the SETAR models to determine whether any neglected non-linearity remains. If no neglected non-linearity apparent it suggests that this is an appropriate form for modelling the investment series (Stanca, 1999). If, however, neglected non-linearity remains this could be due to one of two reasons: either the threshold approach is not the correct approach for modelling the neglected non-linearity, suggesting irreversible investment is unlikely to be the main cause of the results found in Chapters 5 and 6; or, alternatively, the SETAR specification with only one threshold is not appropriate and the data should be estimated with models incorporating more than two regimes.

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[161] Delays of 1 and 4 quarters were selected to represent relatively fast changes in decision making process, and slower adjustments only taking place after a year has past. The delay of 3 quarters was utilised to represent the longer delay for the series where the longest AR process was of order 3, and therefore a delay of 4 quarters was not possible to test for.

9.1.4 – Uncertainty and SETAR Estimations

In Chapter 8 it was found that few industry groups displayed significant investment-uncertainty relationships, but a small number did (Engineering, Textiles and Food). It was also found that Textiles in particular showed changes in the strength of this relationship depending upon whether the economy was in an expansionary or contractionary phase of the business cycle. This means that it might be expected that uncertainty would follow a different relationship depending upon which of the SETAR regimes the industry group was operating in. Having identified the SETAR processes governing investment the models are re-estimated with the threshold being fixed at the value found previously but allowing the industry group specific and aggregate uncertainty measures described in Chapter 8 to affect the investment regimes.

9.2 – Non-Linearity Tests

As discussed in the previous section whilst a threshold model would be appropriate for modelling investment when irreversible investment has a strong effect, there is only moderate evidence that investment is irreversible in even those industries display asymmetry.[162] This means that further tests must be conducted to determine the appropriateness of a SETAR representation. Authors such as Psaradakis and Sola (2003) directly, and Stanca (1999) and Cook (2000) indirectly, have found that tests for asymmetry such as the deepness and steepness tests and time irreversibility tests have low power to reject the null of asymmetry. An alternative to attempting to detect

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[162] Remember that the TR-tests conducted in Chapter 6 are only capable of identifying longitudinal asymmetry, rather than the transversal asymmetry most likely to be produced by irreversible investment in the form of 'highness'. The Sichel and Triples tests capable of identifying this form of asymmetry could not detect it other than when the data was not used in natural logarithm form (see Chapter 5).

irreversibilities in series through asymmetry is to test for non-linearity in the series directly (Stanca, 1999). As discussed in Section 3.2, lumpy investment patterns may well be best modelled with the use of some kind of threshold model. Although a number of LM-tests can be utilised to detect particular types of non-linearity, the exact form of non-linearity that would best model the investment series is not known, so two more general tests of non-linearity are therefore utilised, the McLeod and Li (1983) test, and Brock et al.'s (1996) BDS test. Sub-section 9.2.1 introduces the McLeod and Li test and 9.2.2 the BDS test, with the results of these tests presented in sub-section 9.2.3. The McLeod-Li and BDS tests only identify the presence of neglected non-linearity not the form that this non-linearity takes, therefore, sub-section 9.2.4 presents the results of an LM-test of linearity against the alternative of TAR.

9.2.1 – McLeod-Li Test

The McLeod and Li (1983) test generates a portmanteau test statistic based upon the autocorrelation function of the squared residuals $\left(\hat{\varepsilon}_t^2\right)$generated by an AR process. If the linear specification is adequate and correctly specified, then the squared residuals should exhibit no autocorrelation. The squared residuals autocorrelation function $\left(\hat{r}_{\varepsilon\varepsilon}(k)\right)$ is given by:

$$(9.2) \qquad \hat{r}_{\varepsilon\varepsilon}(k) = \sum_{t=k+1}^{n}\left(\hat{\varepsilon}_t^2 - \hat{\sigma}^2\right)\left(\hat{\varepsilon}_{t-k}^2 - \hat{\sigma}^2\right) \Big/ \sum_{t=1}^{n}\left(\hat{\varepsilon}_t^2 - \hat{\sigma}^2\right)^2$$

where:

$$(9.3) \qquad \hat{\sigma}^2 = \sum \hat{\varepsilon}_t^2 / n$$

And the test statistic is therefore constructed as:

(9.4) $$Q^{*}_{\varepsilon\varepsilon} = n(n+2)\sum_{i=1}^{M} \hat{r}^{2}_{\varepsilon\varepsilon}(i)/(n-i)$$

where $Q^{*}_{\varepsilon\varepsilon}$ is asymptotically distributed as $\chi^2(M)$ if the errors are independent. Stanca (1999) reports the values when $M = 1$ and $M = 4$, this approach is followed in this study.

9.2.2 – BDS Test

The BDS test is a statistic based on the correlation dimension of the residuals from a fitted AR process, and can be used to test for non-linear dependence after an AR model has been fitted. This is defined as:

(9.5) $$BDS(m,\varepsilon) = b_{m,n}(\varepsilon)/\left(\sigma/\sqrt{T}\right) = \left\{c^{m}(\varepsilon) - \left[c^{1}(\varepsilon)\right]^{m}\right\}/\left(\sigma/\sqrt{T}\right)$$

where σ^2 is the sample variance of the data, and $c^m(k)$ is the sample correlation integral given 'embedding dimension', m, and 'distance', ε. This is derived from where a time series y_t ($t = 1, 2, \ldots, T$) of scalars, can be broken down into a number of shorter series with overlapping entries with m values each (a series of 'm-histories', such that:

(9.6) $$y^{m}_{t} = \left(y_{t}, y_{t+1}, \ldots, y_{t+m-1}\right)$$

where m is the 'embedding dimension' mentioned above. The distance between two m-histories is given by:

(9.7) $$D^{m}_{t,s} = \max_{1 \le i \le m} \left| y^{m}_{t-i} - y^{m}_{s-i} \right|$$

The cumulative distribution function of D^m is the 'correlation integral', $C^m(\varepsilon)$, (Grassberger and Procaccia, 1983):

(9.8) $$C^{m}(\varepsilon) = P\left(D^{m} < \varepsilon\right)$$

Under the null of an i.i.d. data generating process for y_t, D^m has an asymptotic distribution such that $C^m(d) \rightarrow [C^1 \le \varepsilon]$ as $T \rightarrow \infty$ (Brock et al., 1987). When the following holds:

$$(9.9) \qquad C^m(d) = [C^1(d)]^m$$

the probability that two time trajectories which have remained with a distance of ε of each other for m- 1 periods will continued to do so for an additional period is given by the correlation integral at embedding dimension 1:

$$(9.10) \qquad P[(D^m \le \varepsilon)|(D^{m-1} \le \varepsilon)] = C^m(\varepsilon)/C^{m-1}(\varepsilon) = C^1(\varepsilon)$$

which under the 'U-statistics' theory (Serfling, 1980), it follows asymptotically:

$$(9.11) \qquad (\sqrt{T})\{C^m(\varepsilon) - [C^1(\varepsilon)]^m\} \sim N(0, \sigma_m^2)$$

by selecting $\varepsilon_k = \sigma\delta^{k-1}$ (k = 1, 2, ..., K) where $0 < \delta < 1$, the estimate, $c^m(\varepsilon)$, of the correlation integral is given by the proportion of the distances less than ε_k. For larger samples (T = 1000) the asymptotic normality for the null hypothesis of i.i.d. is appropriate for $\sigma < \varepsilon < 2\sigma$ and $m \le 5$, including when skewness and kurtosis are present in the distribution (Hsieh, 1989). However, when $T < 500$ the finite sample distribution does not approximate an asymptotic normal, (Brock et al., 1991), and therefore it is suggested that embedding dimensions of m = 2, 3, and, 4 are utilised in order to confirm the robustness of results, this approach is the approach followed here. The distance parameter (ε) can be chosen by a number of different criteria, but in this study it is chosen to ensure that a certain fraction (0.7) of pairs within the sample lie within ε of each other.[163] The models used to estimate the series will be the

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[163] 0.7 is accepted as a reasonable fraction of pairs to utilise in the BDS test when testing shorter dimensions, but should be increased when testing longer dimensions.

AR-processes selected by the AIC and SIC identified when applying the *TR* tests in Chapter 6 using logarithmic first differences of the investment series.

9.2.3 – Tests for Linearity

Previous chapters have attempted to identify asymmetry present in the investment series using three different approaches, with varying degrees of success. However, a number of previous studies have utilised another approach when examining time series, the application of linearity tests. This sub-section presents the results of applying two tests of general linearity upon the investment series, the McLeod-Li and BDS tests described above.

The McLeod-Li test results for National Accounts data are presented in Table 9.1.

Table 9.1

McLeod and Li Test Results for Growth Rates of National Accounts Data

Investment Good Category	AIC[a]		SIC	
	Q1[bc]	Q4	Q1	Q4
Gross Fixed Capital Expenditure	**10.731** (0.001)	**17.571** (0.001)	**12.631** (0)	**17.895** (0.001)
New Building Work	0.4246 (0.515)	1.0555 (0.901)	1.043 (0.307)	2.5883 (0.629)
Vehicles Expenditure	0.5108 (0.475)	1.4355 (0.838)	0.5108 (0.475)	1.4355 (0.838)
Other Investment Expenditure	1.9586 (0.162)	7.1496 (0.128)	**5.7643** (0.016)	**11.649** (0.02)

(a) Information criterion used to select the correct order of autoregressive process used to estimate the investment series.

(b) Q1, and Q4 represent the McLeod-Li statistic taken at maximum lags of M=1, and M=4 respectively.

(c) Emboldened figures are significant at the 5% level with p-values shown in parenthesis.

Linearity is rejected for Fixed Capital Expenditure, and less strongly for New Building Work and Other Investment. Table 9.2 displays BDS results for the National Accounts investment growth rate series.

Table 9.2

BDS Test Results for First Differenced National Accounts Data

		M = 2	M = 3	M = 4
Fixed Capital Expenditure	AIC	0.010986	0.004528	-0.00768
		(0.0802)	(0.6517)	(0.5225)
	SIC	**0.015757**	0.017136	0.01095
		(0.0068)	(0.0643)	(0.3208)
New Building Work	AIC	0.000641	0.010839	0.0101
		(0.9134)	(0.2468)	(0.3645)
	SIC	0.008533	**0.021583**	0.015956
		(0.1605)	(0.0257)	(0.1667)
Vehicle Expenditure	AIC	**0.013248**	0.013517	0.013084
		(0.0387)	(0.1854)	(0.283)
	SIC	**0.013248**	0.013517	0.013084
		(0.0387)	(0.1854)	(0.283)
Other Investment Expenditure	AIC	-0.00119	0.001753	-0.00266
		(0.8234)	(0.8354)	(0.7911)
	SIC	0.001837	0.002205	-0.00339
		(0.7283)	(0.7933)	(0.7356)

(a) M=2 to M=4 are the embedding dimensions of the BDS test.
(b) Emboldened figures are significant at the 5% level, with p-values shown in parenthesis.
(c) AIC and SIC represent the information criterion used to select the order of autoregressive process appropriate for estimating the investment series.

As with the McLeod-Li test results linearity can be rejected for Fixed Capital Expenditure and New Building Work, but also for Vehicles Expenditure, whilst linearity cannot be rejected for Other Investment.[164]

The results for the National Accounts data show the advantage of utilising both the McLeod-Li, and BDS tests. Whilst non-linearity is most strongly detected in Fixed Capital Expenditure and New Building Work by the McLeod-Li test the BDS test finds stronger evidence for non-linearity in New Building Work and Vehicles Expenditure, but not the Gross Fixed Capital Expenditure. Use of only one of the tests would have lead to the assumption that either Gross Fixed Capital Expenditure or Vehicles Expenditure is linear.

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[164] The null of linearity can only be rejected under a single embedding value for each of the investment good categories. Brock et al. (1991) suggest that when using a small sample ($T < 500$), the alternative of non-linearity is better confirmed with use of a number of different embedding values. Therefore the conclusion that linearity should be rejected for Fixed Capital Expenditure, Vehicle Expenditure and Other Investment should be approached with caution.

Table 9.3 presents the McLeod-Li results for the First Release investment growth rates, with neglected non-linearity found for the Food Processing, Fuels, Metals and Textiles industry groups.

Table 9.3

McLeod and Li Results for Growth Rates of First Release Data

Industry Group	AIC[a]		SIC	
	Q1[bc]	Q4	Q1	Q4
Aggregate	3.1753	6.3699	3.1753	6.3699
	(0.075)	(0.173)	(0.075)	(0.173)
Chemicals	0.3846	0.7785	0.0285	0.5175
	(0.535)	(0.941)	(0.866)	(0.972)
Engineering	1.2728	1.8198	1.2728	1.8198
	(0.259)	(0.769)	(0.259)	(0.769)
Food Processing	0.9135	3.0607	2.4449	4.2515
	(0.339)	(0.548)	(0.118)	(0.373)
Fuels	0.0094	4.5661	3.2233	**12.747**
	(0.923)	(0.335)	(0.073)	(0.013)
Metals	**3.8996**	6.5888	**4.8539**	**9.5429**
	(0.048)	(0.159)	(0.028)	(0.049)
Textiles	**8.1846**	**10.347**	**11.6**	**19.618**
	(0.004)	(0.035)	(0.001)	(0.001)
Other Manufacturing	0.006	1.8906	0.0283	8.2696
	(0.938)	(0.756)	(0.866)	(0.082)

(a) Information criterion used to select the correct order of autoregressive process used to estimate the investment series.
(b) Q1 and Q4 represent the McLeod-Li statistic taken at maximum lags of M=1, and M=4 respectively.
(c) Emboldened figures are significant at the 5% level with p-values shown in parenthesis.

The BDS test results presented in Table 9.4 finds evidence of neglected non-linearity for the same industry groups, and also generates significant results for the Engineering and Other Manufacturing industry groups. As with the National Accounts data the results are not in many cases for all embedding values, and results differ greatly between the AR processes selected by the AIC and those selected by the SIC, with the lower order processes selected by the SIC generally displaying more evidence of neglected non-linearity.

Table 9.4

BDS Test Results for Growth Rates of First Release Data

Industry Group		M = 2[ab]	M = 3	M = 4
Aggregate	AIC[c]	0.003759 (0.4075)	0.00327 (0.6515)	-0.00741 (0.3916)
	SIC	0.003759 (0.4075)	0.00327 (0.6515)	-0.00741 (0.3916)
Chemicals	AIC	0.000729 (0.9212)	-0.00884 (0.4542)	-0.01335 (0.3464)
	SIC	-0.00957 (0.2229)	-0.01433 (0.2536)	-0.0238 (0.1135)
Engineering	AIC	-0.00012 (0.9874)	0.006059 (0.6148)	0.025685 (0.0744)
	SIC	-0.00012 (0.9874)	0.006059 (0.6148)	0.025685 (0.0744)
Food Processing	AIC	-0.00983 (0.1689)	-0.01705 (0.1355)	-0.02021 (0.1394)
	SIC	**-0.01443** (0.0493)	**-0.02938** (0.0123)	**-0.03333** (0.0177)
Fuels	AIC	0.007857 (0.3427)	0.011053 (0.4038)	0.018766 (0.2367)
	SIC	**0.01999** (0.029)	**0.031835** (0.0302)	**0.053315** (0.0025)
Metals	AIC	0.011109 (0.1685)	0.020906 (0.1058)	0.019771 (0.2026)
	SIC	0.013472 (0.0706)	**0.028388** (0.0171)	0.025701 (0.0714)
Textiles	AIC	0.012981 (0.1216)	0.023421 (0.0811)	0.027451 (0.0883)
	SIC	0.006056 (0.4665)	0.017814 (0.1805)	0.009768 (0.5402)
Other Manufacturing	AIC	0.003997 (0.5676)	0.007915 (0.4788)	-0.00734 (0.5835)
	SIC	-0.00426 (0.5236)	-0.00968 (0.3624)	**-0.03014** (0.0175)

(a) M=2 to M=4 are the embedding dimensions of the BDS test.

(b) Emboldened figures are significant at the 5% level, with p-values shown in parenthesis.

(c) AIC and SIC represent the information criterion used to select the order of autoregressive process appropriate for estimating the investment series.

Taken with the asymmetry identified in earlier chapters the linearity test results presented in this sub-section do suggest that there is a case for using a SETAR model to represent all of the investment good categories, and a majority of the industry groups, with the exceptions being the Aggregate and Chemicals industry group, where no evidence of neglected non-linearity is found. From the results presented within this sub-section seem to be a link between those industry groups found to exhibit asymmetry, time irreversibility and neglected non-linearity, with the Textiles and Fuels industry groups being the most prominent of these.

9.2.4 - LM-Tests of Linearity Against the Alternative of TAR

The results of the LM-test described in sub-section 9.1.3 are presented in Table 9.5 for the National Accounts Data and 9.6 for the First Release data.

Table 9.5

LM-Linearity Tests Against Alternative of TAR Representation (National Accounts Data)

Delay[a]	1		3		4	
Investment Good Category	Test Statistic[b]	Critical Value[c]	Test Statistic	Critical Value	Test Statistic	Critical Value
Fixed Capital Expenditure	14.67	22.65	14.63	22.65	12.4	22.65
New Building Work	3.55	27.57	**33.52**	27.57	11.04	27.57
Vehicles Expenditure	7.85	11.18	n/a		n/a	
Other Investment	2.51	15.42	11.74	15.42	n/a	

(a) Delay value for TAR alternative model to linear AR process.
(b) Emboldened values are those significant at the 5% level.
(c) All critical values are those for the 5% level.

Table 9.6

LM-Linearity Tests Against Alternative of TAR Representation (First Release Data)

Delay[a]	1		3		4	
Industry Group	Test Statistic[b]	Critical Value[c]	Test Statistic	Critical Value	Test Statistic	Critical Value
Aggregate	9.27	15.42	**17.24**	15.42	n/a	
Chemicals	10.53	20.93	**21.34**	20.93	10.07	20.93
Engineering	**15.44**	11.18	n/a		n/a	
Food	7.54	15.42	6.07	15.42	n/a	
Fuels	4.45	22.65	3.87	22.65	**29.72**	22.65
Metals	**32.55**	29.15	**34.94**	29.15	**60.36**	29.15
Textiles	**33**	17.33	16.4	17.33	14.59	17.33
Other Manufacturing	19.42	24.32	**26.38**	24.32	16.37	24.32

(a) Delay value for TAR alternative model to linear AR process.
(b) Emboldened values are those significant at the 5% level.
(c) All critical values are those for the 5% level.

The growth rates of the First Release industry groups reject the null of linearity for all but the Food industry group. The results for the industry groups therefore suggest there is strong evidence for using a SETAR representation when modelling investment growth rates. In contrast for National Accounts data the rejection of the null is restricted to growth rates of New Building Work. With the implication that SETAR models are more appropriate for modelling the First Release data than the National Accounts data, the results of the TAR LM-Tests imply the reverse to the more general McLeod-Li and BDS tests of linearity where greater evidence of neglected non-linearity was found for the National Accounts investment good categories. The two groups of tests therefore make a case between them for SETAR modelling of both sets of investment growth rates, which are presented in the following section.

9.3 – SETAR Models of Investment

The TAR LM-Tests, and the McLeod-Li and BDS linearity tests presented in the previous section suggest that arguments exist for using SETAR models to estimate the investment growth rates of both the investment good categories of the National Accounts data, and the industry groups of the First Release data, in order to account for neglected non-linearity, and provide a better fitting representation of the data. The following sub-section presents the estimated SETAR models for the National Accounts and First Release data. Sub-section 9.3.2 repeats the McLeod-Li and BDS linearity tests utilised in Section 9.2, but using the residuals of the SETAR models to determine whether the neglected non-linearity previously found when using AR models has been accounted for with the SETAR models.

9.3.1 – SETAR Model Estimations

The SETAR models are estimated with two different assumptions relating to the delay variable. In the first specification the delay is restricted to one period whilst the second specification allows the delay to be up to four periods long. Tables 9.7 and 9.8 summarises the orders of the AR processes selected for the First Release and National Accounts growth rates.

Table 9.7

Delay Variables and Orders of Autoregressive Processes in Estimated SETAR Models for National Accounts Data

Investment Good Category	Max Delay 1[a]			Max Delay 4		
	Delay	Regime 1	Regime 2	Delay	Regime 1	Regime 2
Fixed Capital Expenditure	1	5	1	1	5	1
New Building Work	1	3	8	2	3	3
Vehicles Expenditure	1	1	1	3	0	1
Other Investment	1	3	0	4	3	1

(a) Regime 1 and Regime 2 refer to the order of autoregressive process selected for each model.

Table 9.8

Delay Variables and Orders of Autoregressive Processes in Estimated SETAR Models for First Release Data

	Maximum Delay = 1[a]			Maximum Delay = 4		
Industry Group	Delay	Regime 1	Regime 2	Delay	Regime 1	Regime 2
Aggregate	1	3	3	3	0	0
Chemicals	1	6	0	3	1	6
Engineering	1	0	1	4	0	0
Food Processing	1	3	1	2	3	0
Fuels	1	7	3	4	7	7
Metals	1	11	0	1	11	0
Textiles	1	1	4	1	1	4
Other Manufacturing	1	5	8	2	8	0

(a) Regime 1 and Regime 2 refer to the order of autoregressive process selected for each model.

When the assumption that the delay variable was equal to 1 was relaxed it is noticeable that a majority of the selected specifications took a delay variable of a higher value, suggesting that firms are relatively slow to adjust investment in response to changes in economic conditions.

The order of the AR processes is in most cases not the same in both regimes suggesting that for a majority of the investment good categories and industry groups there is a degree of asymmetry between the two regimes. Although not the case for all, it is evident that a number of the series that are represented by a low order AR process or even simply a constant, in the high investment regime 2, this is particularly the case where the assumption that the delay is only one period has been relaxed, Tables 9.9 and 9.10 presents the full estimated SETAR models when the assumption that $d = 1$, has been relaxed for the National Accounts and First Release investment series respectively.

Table 9.9

SETAR Model Estimates of National Accounts Investment Growth Rates

	Threshold	Constant[a]	ΔY_{t-1}	ΔY_{t-2}	ΔY_{t-3}	ΔY_{t-4}	ΔY_{t-5}	ΔY_{t-6}	ΔY_{t-7}	ΔY_{t-8}	Var(ε_t)
Gross Fixed Capital Expenditure	$\Delta Y_{t-1} \leq 0.02736$	0.00673 (0.0028)	-0.05639 (0.1039)	0.20113 (0.0825)	0.18609 (0.076)	0.082 (0.0776)	-0.11072 (0.0778)	–	–	–	0.00071
	$\Delta Y_{t-1} > 0.02736$	0.0428 (0.0186)	-0.79797 (0.3742)	–	–	–	–	–	–	–	0.00172
New Building Work	$\Delta Y_{t-2} \leq -0.06763$	-0.02777 (0.0375)	-0.57179 (0.1562)	-0.3056 (0.2377)	0.3299 (0.2028)	–	–	–	–	–	0.01286
	$\Delta Y_{t-2} > -0.06763$	-0.01404 (0.0098)	-0.04212 (0.0882)	0.12671 (0.1199)	0.239 (0.0839)	–	–	–	–	–	0.00868
Vehicles Expenditure	$\Delta Y_{t-3} \leq -0.08307$	-0.05284 (0.0232)	–	–	–	–	–	–	–	–	0.01237
	$\Delta Y_{t-3} > -0.08307$	0.00366 (0.0071)	-0.28426 (0.0753)	–	–	–	–	–	–	–	0.00646
Other Investment	$\Delta Y_{t-4} \leq 0.049$	0.00482 (0.0037)	0.02131 (0.0722)	0.17488 (0.0754)	0.26364 (0.0746)	–	–	–	–	–	0.00175
	$\Delta Y_{t-4} > 0.049$	0.01042 (0.0184)	-1.01944 (0.4628)	–	–	–	–	–	–	–	0.0045

a) Standard errors in parenthesis

Table 9.10

SETAR Model Estimates of First Release Investment Growth Rates

	Threshold	Constant[a]	ΔY_{t-1}	ΔY_{t-2}	ΔY_{t-3}	ΔY_{t-4}	ΔY_{t-5}	ΔY_{t-6}	ΔY_{t-7}	ΔY_{t-8}	Var(ε_t)
Aggregate	$\Delta Y_{t-3} \leq 0.0105$	-0.01486 (0.0045)	–	–	–	–	–	–	–	–	0.00172
	$\Delta Y_{t-3} > 0.0105$	0.02142 (0.0059)	–	–	–	–	–	–	–	–	0.0022
Chemicals	$\Delta Y_{t-3} \leq 0.00018$	-0.01433 (0.0095)	-0.21556 (0.1225)	–	–	–	–	–	–	–	0.00475
	$\Delta Y_{t-3} > 0.00018$	0.00024 (0.0185)	-0.0462 (0.1471)	0.13038 (0.166)	-0.06937 (0.1944)	-0.65203 (0.1609)	-0.05031 (0.1966)	0.46252 (0.146)	–	–	0.007
Engineering	$\Delta Y_{t-4} \leq 0.07849$	0.00889 (0.0089)	–	–	–	–	–	–	–	–	0.00654
	$\Delta Y_{t-4} > 0.07849$	-0.05456 (0.0257)	–	–	–	–	–	–	–	–	0.00925
Food Processing	$\Delta Y_{t-2} \leq 0.03553$	-0.0157 (0.0089)	-0.45262 (0.115)	-0.40653 (0.1793)	0.27369 (0.1126)	–	–	–	–	–	0.00351
	$\Delta Y_{t-2} > 0.03553$	0.0038 (0.0084)	–	–	–	–	–	–	–	–	0.00198
Fuels	$\Delta Y_{t-4} \leq -0.18292$	0.49106 (0.0942)	0.01922 (0.1834)	0.70425 (0.2349)	0.36503 (0.2049)	1.73559 (0.2688)	0.79283 (0.2158)	1.6358 (0.3112)	0.57498 (0.1382)	–	0.01071
	$\Delta Y_{t-4} > -0.18292$	0.00267 (0.0166)	-0.48108 (0.0935)	-0.09617 (0.0967)	0.02434 (0.102)	-0.48078 (0.1267)	-0.37112 (0.0977)	-0.03764 (0.098)	0.18065 (0.1031)	–	0.0193
Metals	$\Delta Y_{t-1} \leq -0.09295$	0.18936 (0.0704)	1.04795 (0.4512)	-0.06391 (0.2467)	0.10923 (0.2437)	-0.07555 (0.3463)	-0.75412 (0.3168)	0.00807 (0.2857)	-0.98361 (0.2634)	-0.90548 (0.2218)	0.00371
	$\Delta Y_{t-1} > -0.09295$	-0.00205 (0.0111)	–	–	–	–	–	–	–	–	0.00917

a) Standard errors in parenthesis

Table 9.10 continued

	Threshold	Constant	ΔY_{t-1}	ΔY_{t-2}	ΔY_{t-3}	ΔY_{t-4}	ΔY_{t-5}	ΔY_{t-6}	ΔY_{t-7}	ΔY_{t-8}	Var(ε_t)
Textiles	$\Delta Y_{t-1} \leq 0.09812$	-0.01712 (0.0179)	-0.2394 (0.1165)	–	–	–	–	–	–	–	0.01898
	$\Delta Y_{t-1} > 0.09812$	0.28382 (0.0824)	-1.75345 (0.3664)	-0.34958 (0.1865)	-0.85039 (0.213)	-0.51724 (0.1619)	–	–	–	–	0.02259
Other Manufacturing	$\Delta Y_{t-2} \leq 0.07687$	0.00063 (0.0099)	-0.14766 (0.1033)	0.11317 (0.1393)	0.31599 (0.1121)	-0.12072 (0.1099)	0.02049 (0.1098)	0.31258 (0.1167)	0.12595 (0.122)	-0.5263 (0.118)	0.00571
	$\Delta Y_{t-2} > 0.07687$	0.00172 (0.0159)	–	–	–	–	–	–	–	–	0.00506

a) Standard errors in parenthesis

One explanation for this could be that when higher rates of investment have been experienced in the *d* periods previously (an 'investment spike') firms will only under take replacement investment represented by the lower order AR processes (or even simply a constant), when modelling the investment growth rate, as investment growth rates become more tranquil.

9.3.2 – SETAR Models and Neglected Non-Linearity

The threshold-LM tests suggested that the First Release data in particular is most appropriately modelled with a TAR process of some kind, but a question that remains is will the adoption of a SETAR specification remove the neglected non-linearity detected by the BDS and McLeod-Li tests in applied to AR model residuals.

Starting with the National Accounts data Tables 9.11 and 9.12 show the McLeod-Li and BDS test results respectively, with panel (a) of each table showing the results when the delay variable, *d*, is restricted to 1, and panel (b) showing the results when the restriction on the delay variable is relaxed to allow a maximum value of 4. When modelled using linear AR processes evidence of neglected non-linearity for all four investment good categories, but when using the SETAR models neglected non-linearity is only found for Fixed Capital Expenditure and New Building Work when using the McLeod-Li tests, and only Fixed Capital Expenditure when using the BDS test.[165]

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[165] It should be noted that the BDS test only produces a significant result for one embedding value when using the SETAR model to represent Gross Fixed Capital Expenditure, which Brock et al. (1991) suggest is not reliable when using small sample sizes.

Table A9.11

McLeod-Li Test Results for National Accounts Growth Rates Estimated with SETAR Models

Panel (a) Maximum Delay = 1[a]

Investment Good Category	Q1[bc]	Q4
Fixed Capital Expenditure	**8.1144**	**17.588**
	(0.004)	(0.001)
New Building Work	**4.2829**	4.9412
	(0.038)	(0.293)
Vehicles Expenditure	3.00E-05	1.5722
	(0.995)	(0.814)
Other Investment	2.5506	6.0238
	(0.11)	(0.197)

Panel (a) Maximum Delay = 4

Investment Good Category	Q1	Q4
Fixed Capital Expenditure	**8.1144**	**17.588**
	(0.004)	(0.001)
New Building Work	0.0121	6.0098
	(0.912)	(0.198)
Vehicles Expenditure	8.10E-03	0.4535
	(0.928)	(0.978)
Other Investment	1.1007	9.4591
	(0.294)	(0.051)

(a) Refers to the maximum value that can be taken by the delay parameter within the SETAR model.

(b) *Q*1, and *Q*4 represent the McLeod-Li statistic taken at maximum lags of *M*=1, and *M*=4 respectively.

(c) Emboldened figures are significant at the 5%level, with p-values in parenthesis.

Table A9.12

BDS Test Results for National Accounts Growth Rates Estimated with SETAR Models

Panel (a) Maximum Delay = 1[a]

Investment Good Category	M = 2[bc]	M = 3	M = 4
Fixed Capital Expenditure	**0.01712**	0.017278	0.009385
	(0.0062)	(0.0841)	(0.4331)
New Building Work	0.00592	0.014848	0.004006
	(0.3155)	(0.1148)	(0.7221)
Vehicles Expenditure	0.004117	0.00041	-0.00386
	(0.528)	(0.9685)	(0.756)
Other Investment	-0.00207	0.001694	-0.0019
	(0.6885)	(0.8373)	(0.8474)

Panel (b) Maximum Delay = 4

Investment Good Category	M = 2	M = 3	M = 4
Fixed Capital Expenditure	**0.01712**	0.017278	0.009385
	(0.0062)	(0.0841)	(0.4331)
New Building Work	8.91E-05	0.006997	0.008831
	(0.9891)	(0.5028)	(0.4797)
Vehicles Expenditure	0.003565	0.001943	0.000376
	(0.5889)	(0.8535)	(0.9761)
Other Investment	-0.00513	0.001206	-0.00282
	(0.3187)	(0.883)	(0.7729)

(a) Refers to the maximum value that can be taken by the delay parameter within the SETAR model.
(b) M=2 to M=4 are the embedding dimensions of the BDS test.
(c) Emboldened figures are significant at the 5% level, with p-values shown in parenthesis.

Comparing the results of the linearity tests presented in Tables 9.11 and 9.12 with those discussed in Section 9.2 it appears that the use of a SETAR model has removed much of the neglected non-linearity in the National Accounts residuals compared to when estimating with AR models.

The First Release investment series displayed less evidence of neglected non-linearity compared to the National Accounts data when represented by AR models (see Section 9.2), but as with the National Accounts data the McLeod-Li and BDS tests of linear when using SETAR models to represent the data show a reduction of the neglected non-linearity present. This is particularly the case where the assumption that delay is limited to 1 period is relaxed, (see Tables 9.13 and 9.14).

Table 9.13

McLeod-Li Test Results for First Release Growth Rates Estimated with SETAR Models

Panel (a) Industry Group	Maximum Delay = 1[a] Q1[bc]	 Q4
Aggregate	0.4673 (0.494)	4.9353 (0.294)
Chemicals	0.1959 (0.658)	1.1569 (0.885)
Engineering	0.4069 (0.524)	4.9623 (0.291)
Food Processing	0.7359 (0.391)	3.5636 (0.468)
Fuels	0.1966 (0.657)	0.4984 (0.974)
Metals	0.905 (0.341)	2.1679 (0.705)
Textiles	1.45 (0.229)	2.2129 (0.697)
Other Manufacturing	1.1755 (0.278)	1.6958 (0.791)

Panel (b) Industry Group	Maximum Delay = 4 Q1	 Q4
Aggregate	3.2241 (0.073)	4.0195 (0.403)
Chemicals	0.3562 (0.551)	1.058 (0.901)
Engineering	0.6079 (0.436)	0.7119 (0.95)
Food Processing	0.8436 (0.358)	2.8321 (0.586)
Fuels	0.1631 (0.686)	2.2159 (0.696)
Metals	0.905 (0.341)	2.1679 (0.705)
Textiles	1.45 (0.229)	2.2129 (0.697)
Other Manufacturing	0.0123 (0.912)	1.0163 (0.907)

(a) Refers to the maximum value that can be taken by the delay parameter within the SETAR model.

(b) *Q*1, and *Q4* represent the McLeod-Li statistic taken at maximum lags of *M*=1, *M*=4 respectively.

(c) Emboldened figures are significant at the 5%level, with p-values in parenthesis.

Table 9.14

BDS Test Results for First Release Growth Rates Estimated with SETAR Models

Panel (a) Maximum Delay = 1[a]

Industry Group	M = 2[bc]	M = 3	M = 4
Aggregate	0.000626	-0.00212	-0.01147
	(0.8976)	(0.7844)	(0.2162)
Chemicals	-0.00142	-0.00727	-0.00999
	(0.8561)	(0.5616)	(0.5059)
Engineering	0.000382	-0.00425	0.005496
	(0.9624)	(0.7428)	(0.7234)
Food Processing	-0.01039	-0.02066	-0.02587
	(0.147)	(0.0715)	(0.0596)
Fuels	-0.00369	-0.01214	-0.01375
	(0.6178)	(0.3038)	(0.3294)
Metals	0.003418	0.009787	0.004091
	(0.6744)	(0.451)	(0.7921)
Textiles	**0.015131**	**0.021001**	**0.025276**
	(0.0196)	(0.0425)	(0.0413)
Other Manufacturing	**0.012408**	0.016535	0.002938
	(0.038)	(0.0832)	(0.7968)

Panel (b) Maximum Delay = 4

Industry Group	M = 2	M = 3	M = 4
Aggregate	0.004151	0.008113	0.003721
	(0.4314)	(0.3342)	(0.7104)
Chemicals	0.002213	-0.00317	-0.00066
	(0.7796)	(0.8022)	(0.9651)
Engineering	-0.00124	0.005519	0.015896
	(0.8686)	(0.6439)	(0.2661)
Food Processing	-0.00807	-0.02179	-0.02921
	(0.3103)	(0.0871)	(0.0558)
Fuels	5.03E-05	-0.00874	-0.00462
	(0.9948)	(0.4786)	(0.7543)
Metals	0.003418	0.009787	0.004091
	(0.6744)	(0.451)	(0.7921)
Textiles	**0.015131**	**0.021001**	**0.025276**
	(0.0196)	(0.0425)	(0.0413)
Other Manufacturing	0.000304	0.005193	-0.01221
	(0.963)	(0.6204)	(0.3313)

(a) Refers to the maximum value that can be taken by the delay parameter within the SETAR model.
(b) M=2 to M=4 are the embedding dimensions of the BDS test.
(c) Emboldened figures are significant at the 5% level, with p-values shown in parenthesis.

With the delay restriction relaxed neither the McLeod-Li or BDS test detect neglected non-linearity for any of the industry groups with the exception of the Textiles industry group,[166] suggesting that the use of SETAR models when estimating the First Release data are appropriate. When delay is allowed to take a value up to 4 periods, only the Textiles industry group displays neglected non-linearity for the BDS test. Overall the use of SETAR models are successful in reducing the neglected non-linearity, found when using linear AR models, for both the National Accounts and First Release data.

9.4 – Thresholds and Uncertainty

As discussed in sub-section 8.4.4 the investment-uncertainty relationship studied in Chapter 8 was found to be generally negative, which is consistent with the Bernanke hypothesis of irreversible investment encouraging firms to delay investment as uncertainty increases. The previous section found that a SETAR specification with delay greater than one was able to remove non-linearity in the investment data for nearly all series considered, confirming the threshold-LM tests which suggested that a large number of the First Release industry groups should be modelled with some form of TAR model rather than a linear representation. Combining the findings on the investment-uncertainty relationship of the previous chapter with the evidence that some form of threshold model should be applied when modelling the investment series, this section re-estimates the investment-uncertainty relationships using the SETAR specifications from above, with the expectation that certain industry groups

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[166] The best fitting model as determined by the AIC for the Textiles industry group when the delay variable was allowed to take a value up to 4 periods, selected a model using a delay of 1 period, and therefore no alternative model with a longer delay was estimated where neglected non-linearity may have been reduced.

are likely to show differing relationships within each regime.[167] Given the greater ability to account for neglected non-linearity when the restriction that $d = 1$ is relaxed the SETAR models with delay allow to be up to four periods are utilised in this section.[168]

The industry groups displaying a significant investment-uncertainty relationship when using a SETAR model are similar to those found in Chapter 8 using linear models. When output growth is excluded from the uncertainty equation, Textiles displays a negative industry group specific investment-uncertainty relationship, and Food Processing a negative influence from aggregate uncertainty, as under the linear representations (see Table 9.15). In addition however Metals also generates positive aggregate uncertainty coefficients. I have suggested that it both the Black and Bernanke hypotheses hold for certain industry groups the Black hypothesis is more likely to operate through the aggregate uncertainty measure (see Chapter 8). Allowing output growth to enter the uncertainty equation generally moves the significance towards the aggregate uncertainty measure, as was found to be the case when using the linear representations in Chapter 8, (see Table 9.16). Most of industry group specific uncertainty terms lose their significance at the 5% level, but are still significant at the 10% in many cases. As was often found in Chapter 8 Engineering produces a significant negative coefficient for industry group specific uncertainty, this occurs when in the low investment regime, whilst on the other hand Other Manufacturing produced a significant positive investment-industry group uncertainty relationship when in the low investment regime.[169]

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[167] Particularly, it was also found that the Textiles industry group showed considerable evidence that the investment-uncertainty relationship changed in strength over the business cycle.

[168] The results when using SETAR models with delay restricted to one period produce similar conclusions to those when the restriction is lifted.

[169] This unusual result was found for Other Manufacturing in the linear specifications. The fact that the Other Manufacturing industry group is a heterogeneous collection of industries, which means that

Table 9.15

Investment-Uncertainty Relationships with SETAR Models (Output Growth Excluded From Uncertainty Equation, Maximum Delay 4 Quarters)

Investment Group		Regime 1		Regime 2	
		Agg Unc[a]	Ind Unc[b]	Agg Unc	Ind Unc
Aggregate	AIC[cd]	-0.69226 (0.3437)	n/a	-1.11813 (0.1717)	n/a
	SIC	-0.69226 (0.3437)	n/a	-1.11813 (0.1717)	n/a
Chemicals	AIC	1.50686 (0.7341)	-2.86314 (0.1295)	-11.5229 (0.0833)	-3.08564 (0.2828)
	SIC	2.142232 (0.6735)	-2.99696 (0.1582)	-11.53 (0.0806)	-3.93334 (0.2204)
Engineering	AIC	-4.39101 (0.2402)	0.514292 (0.8936)	16.88826 (0.3124)	-10.6979 (0.1037)
	SIC	0.490217 (0.896)	-4.58728 (0.1713)	18.97402 (0.2846)	-13.1051 (0.1047)
Food Processing	AIC	**-4.21407** (0.0347)	94.47816 (0.4452)	-3.30531 (0.4025)	119.0678 (0.5419)
	SIC	**-4.71208** (0.0083)	4.767358 (0.1215)	-2.86498 (0.4308)	2.895532 (0.5866)
Fuels	AIC	-57.7913 (0.4008)	-5.25446 (0.0765)	1.554174 (0.77)	0.277267 (0.5343)
	SIC	-57.7913 (0.4008)	-5.25446 (0.0765)	1.554174 (0.77)	0.277267 (0.5343)
Metals[e]	AIC	**114.1889** (0.0306)	-23.3604 (0.0612)	-10.3285 (0.0814)	3.72577 (0.0708)
	SIC	**114.1889** (0.0306)	-23.3604 (0.0612)	-10.3285 (0.0814)	3.72577 (0.0708)
Textiles[e]	AIC	-1.63269 (0.6528)	**-6.78762** (0.014)	5.038222 (0.805)	**-25.4956** (0.0103)
	SIC	-0.59005 (0.8715)	**-7.69709** (0.0036)	4.340322 (0.8304)	**-27.956** (0.0154)
Other Manufacturing	AIC	-0.46022 (0.9022)	1.843478 (0.5654)	-0.30614 (0.9762)	0.96372 (0.8829)
	SIC	-0.46022 (0.9022)	1.843478 (0.5654)	-0.30614 (0.9762)	0.96372 (0.8829)

(a) Agg Unc is output growth uncertainty for the aggregate of the manufacturing sector, as calculated by the conditional variance of an APARCH-M model.
(b) Ind Unc is output growth uncertainty for the industry group, as calculated by the conditional variance of an APARCH-M model.
(c) Information criterion used to select the order of AR process in the output equation.
(d) Emboldened figures are significant at the 5% level, with p-values in parenthesis.
(e) Model selected when maximum delay was increased to four quarters was same as selected when the delay was limited to one quarter.

industry group specific uncertainty is unlikely to be particularly specific to any of the component industries of the industry group. This means that, in some respects, the Other Manufacturing industry group is effectively estimated with two different 'aggregate' uncertainty terms.

Table 9.16

Investment-Uncertainty Relationships with SETAR Models (Output Growth Allowed to Enter Uncertainty Equation, Maximum Delay 4 Quarters)

Investment Group		Regime 1		Regime 2	
		Agg Unc[a]	Ind Unc[b]	Agg Unc	Ind Unc
Aggregate	AIC[cd]	**-3.03039** (0.002)	n/a	**-2.1676** (0.0299)	n/a
	SIC	**-3.03039** (0.002)	n/a	**-2.1676** (0.0299)	n/a
Chemicals	AIC	-2.40894 (0.5702)	-1.62979 (0.2518)	-5.26794 (0.3494)	-1.00636 (0.652)
	SIC	-2.51887 (0.5408)	-1.78267 (0.2413)	-5.63402 (0.3161)	-0.31407 (0.8949)
Engineering	AIC	-2.04989 (0.5704)	-2.12672 (0.4279)	15.30219 (0.3482)	-7.76115 (0.2353)
	SIC	-0.42378 (0.8838)	**-3.28336** (0.0477)	23.95499 (0.1387)	-11.645 (0.0675)
Food Processing	AIC	**-5.4884** (0.0017)	0.189285 (0.9282)	-4.59309 (0.3269)	1.393649 (0.6379)
	SIC	**-5.31882** (0.0022)	-0.3712 (0.8421)	-4.6185 (0.3279)	1.146675 (0.6536)
Fuels	AIC	-35.5268 (0.599)	-2.49971 (0.7644)	4.279604 (0.4885)	0.408484 (0.6465)
	SIC	-35.5268 (0.599)	-2.49971 (0.7644)	4.279604 (0.4885)	0.408484 (0.6465)
Metals[e]	AIC	**118.0533** (0.0201)	**-20.7118** (0.0248)	-8.91128 (0.066)	2.356531 (0.1557)
	SIC	**118.0533** (0.0201)	**-20.7118** (0.0248)	-8.91128 (0.066)	2.356531 (0.1557)
Textiles[e]	AIC	**-8.75521** (0.042)	-4.21137 (0.094)	19.77352 (0.2244)	-12.0393 (0.0591)
	SIC	**-8.80795** (0.0418)	-4.15617 (0.0929)	18.62769 (0.2566)	-9.06501 (0.1738)
Other Manufacturing	AIC	-4.75008 (0.2268)	**10.38402** (0.0483)	-12.1104 (0.1831)	6.937751 (0.3517)
	SIC	-4.75008 (0.2268)	**10.38402** (0.0483)	-12.1104 (0.1831)	6.937751 (0.3517)

(a) Agg Unc is output growth uncertainty for the aggregate of the manufacturing sector, as calculated by the conditional variance of an APARCH-M model.
(b) Ind Unc is output growth uncertainty for the industry group, as calculated by the conditional variance of an APARCH-M model.
(c) Information criterion used to select the order of AR process in the output equation.
(d) Emboldened figures are significant at the 5% level, with p-values in parenthesis.
(e) Model selected when maximum delay was increased to four quarters was same as selected when the delay was limited to one quarter.

A greater number of significant uncertainty terms are found within the low investment regime 1 compared to the high investment regime 2, which is to be expected, as firms are unlikely to start new projects if the Bernanke hypothesis holds and uncertainty rises. If, however, many firms are already undertaking projects a rise in uncertainty will in many cases not be enough to induce a firm to abandon a project in which sunken costs have already been incurred.[170]

Wald tests were used to test for symmetry in the investment-uncertainty relationships across regimes, (Table 9.17). The null of symmetry for the uncertainty terms cannot be rejected at the 5% level for the Engineering and Textiles industry groups. The Metals industry group on the other hand can reject the null of symmetry at the 5% level due to the large positive aggregate and large negative industry specific uncertainty terms estimated for the low investment regime 1, compared to the small uncertainty terms of the opposing signs in regime 2. In Chapter 7 the Metals industry group (industry sector J) was consistently found to display a positive output growth-output growth uncertainty relationship, while Chapter 8 found little evidence of a significant investment-uncertainty relationship. These contradictory results may be explained by the results found in this chapter, where Section 9.2 found strong evidence from the threshold-LM test that a threshold approach to estimation was appropriate, and, when a SETAR approach is applied, the neglected AR residual non-linearity detected in Section 9.2 by both the McLeod-Li and BDS test is accounted for. The insignificant investment-uncertainty relationship becomes understandable when it is observed that only when operating in the low investment regime 1 is a significant relationship found. The large positive aggregate uncertainty term also shows how the Black hypothesis result found in Chapter 7 could be entering the investment decision.

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[170] It was noted in the previous chapter that the Textiles industry group was found to significantly change its investment-uncertainty relationship depending upon whether an expansion was present in the economy or not. Looking at the results presented in Table 9.14, when output growth is excluded from the uncertainty equation, Textiles is actually more negatively affected by industry specific uncertainty when operating in the high investment regime.

Table 9.17

Wald Tests of Symmetry of Uncertainty Terms Across SETAR Regimes (Maximum Delay 4 Quarters)

Industry Group		Output Growth Excluded		Output Growth Allowed to Enter	
		Agg Unc[a]	Ind Unc[b]	Agg Unc	Ind Unc
Aggregate	AIC[cd]	0.151912 (0.6973)	n/a	0.391623 (0.5324)	n/a
	SIC	0.151912 (0.6973)	n/a	0.391623 (0.5324)	n/a
Chemicals	AIC	2.706286 (0.1038)	0.004254 (0.9482)	0.166174 (0.6846)	0.056036 (0.8135)
	SIC	2.744309 (0.1015)	0.060174 (0.8068)	0.202138 (0.6542)	0.272953 (0.6028)
Engineering	AIC	1.560454 (0.2148)	2.203604 (0.1412)	1.089704 (0.2993)	0.64367 (0.4245)
	SIC	1.052325 (0.3077)	0.967251 (0.328)	2.238603 (0.1381)	1.654051 (0.2017)
Food Processing	AIC	0.042788 (0.8366)	0.01141 (0.9152)	0.032599 (0.8571)	0.110701 (0.7401)
	SIC	0.211304 (0.6469)	0.093589 (0.7604)	0.019719 (0.8886)	0.231871 (0.6313)
Fuels	AIC	0.748811 (0.3897)	3.498439 (0.0654)	0.347305 (0.5575)	0.121143 (0.7288)
	SIC	0.748811 (0.3897)	3.498439 (0.0654)	0.347305 (0.5575)	0.121143 (0.7288)
Metals[e]	AIC	**5.709008** (0.0195)	**4.734009** (0.0329)	**6.472293** (0.0131)	**6.314228** (0.0142)
	SIC	**5.709008** (0.0195)	**4.734009** (0.0329)	**6.472293** (0.0131)	**6.314228** (0.0142)
Textiles[e]	AIC	0.104204 (0.7476)	3.439921 (0.0671)	2.917182 (0.0913)	1.338765 (0.2505)
	SIC	0.057701 (0.8107)	3.055008 (0.0841)	2.648992 (0.1073)	0.485181 (0.488)
Other Manufacturing	AIC	0.000201 (0.9887)	0.014673 (0.9039)	0.561514 (0.4559)	0.145503 (0.7039)
	SIC	0.000201 (0.9887)	0.014673 (0.9039)	0.561514 (0.4559)	0.145503 (0.7039)

(a) Agg Unc is the Wald statistic for symmetry of aggregate output growth uncertainty over the two SETAR regimes.
(b) Ind Unc is the Wald statistic for symmetry of industry group specific output growth uncertainty over the two SETAR regimes.
(c) Information criterion used to select the order of AR process in the output equation.
(d) Emboldened figures are significant at the 5% level, with p-values in parenthesis.
(e) Model selected when maximum delay was increased to four quarters was same as selected when the delay was limited to one quarter.

The results found in this section are consistent with those found in Chapter 8 on the whole with the Engineering and Textiles industry groups displaying a negative investment-uncertainty relationship with the industry specific measures of uncertainty, and investment within the Food Processing industry group being negatively affected by aggregate uncertainty. These three industry groups, therefore throw their weight firmly behind the Bernanke irreversible investment hypothesis.

The Metals industry group on the other hand displays patterns that possibly suggest both the Black and Bernanke hypotheses holding, and operating through the two different uncertainty measures. This may well explain the strongly positive relationship found between output growth and output growth uncertainty in Chapter 7 for the Metals industry group when no significant investment-uncertainty relationship was found in Chapter 8.

9.5 – Summary of Chapter

This chapter attempted to draw together the findings of the first four empirical chapters. Taking the evidence of asymmetry and time irreversibility from Chapters 5 and 6, it suggested that a number of the investment series were best modelled by some form of threshold model. An LM test of linearity against TAR non-linearity found considerable evidence of threshold effects in the data. A SETAR specification was used to model the National Accounts and First Release data, and the estimated SETAR models were then used to examine further the findings of Chapters 7 and 8 concerning the investment-uncertainty relationship for the First Release industry groups. As with the linear specifications, the Engineering, Food and Textiles industry groups were found to exhibit significant investment-uncertainty relationships. Although it is the case for a number of series that the investment-uncertainty relationship is much stronger when operating in the low investment regime, the difference between the effect of uncertainty across the regimes is not statistically significant with the exception of the Metals industry group, which shows the Black hypothesis operating through aggregate uncertainty measure and the Bernanke hypothesis operating through industry group uncertainty when in the low investment regime. This explains why the Black hypothesis was found to hold for the industry group in Chapter 7, but no further evidence in Chapter 8.

Conclusion

The purpose of this study has been to attempt to identify the presence and effect of irreversible investment within disaggregated UK manufacturing investment data. The empirical chapters of this study have taken different approaches in order to achieve this. Chapters 5 attempted to identify the presence of asymmetry, within the investment series that may have been caused by firms adjusting capital stocks in lumpy fashions, as is to be expected under irreversible investment conditions (see Section 3.3). Chapter 6 used Ramsey and Rothman's (1996) time reversibility (*TR*) Test to look directly for irreversible investment. Chapters 7 and 8 examined the investment-uncertainty relationship. This has traditionally been thought to be a positive relationship due to the convexity of the profit function in prices and demand (see Section 4.2). However, irreversible investment considerations suggest that the 'option value of waiting' increases with uncertainty (see sub-section 3.3.2) encouraging firms to delay investment and therefore leading to a negative relationship (see Section 4.3). Chapter 9 attempted to draw these two themes together by using a SETAR specification to accommodate the irreversible investment induced lumpy patterns identified in chapters 5 and 6, before re-examining the investment-uncertainty relationships observed in Chapters 7 and 8.

Previous empirical work examining the affects of irreversible investment has mainly concentrated upon the aggregate or, where available, firm and plant level data, (see Sections 3.4 and 4.4). Whilst plant level data has revealed strong evidence for the presence of irreversible investment (for example, Doms and Dunne, 1998, also see sub-sections 3.4.1 and 3.4.3), studies of the aggregate have found little evidence of asymmetry induced into the investment pattern by irreversible investment (see sub-section 3.4.2). Empirical work on the investment-uncertainty relationship has also produced mixed results, whether examining the relationship indirectly through the output growth-uncertainty relationship, or directly though the investment-uncertainty relationship (see Section 4.4).

This study has utilised investment data disaggregated either by industry group or investment good category, as it may be expected that greater evidence of irreversible investment should be apparent when using disaggregated data than in aggregate data (see Chapter 5 for a full data description). Whilst Chapters 5 and 6 found evidence that some industry groups and investment good categories display asymmetry typical of the presence of irreversible investment, this is by no means the case for all of the investment series studied, whilst asymmetry was detected by the *TR* test in Chapter 6 for a number of investment series.

Chapters 7 and 8 concentrated upon the investment-uncertainty relationship, where the presence of irreversible investment has been posited to have the effect of reversing the traditionally positive sign of this relationship (see Chapter 4). Whilst past empirical studies of the relationship for aggregate investment have produced mixed results, with neither relationship dominating, it is possible that both effects are present and cancel one another out (see Chapter 4). Moreover if certain industries/industry groups are more strongly affected by irreversible investment then different signs might be found for the uncertainty relationship for these industries than those less strongly affected.

Indirect examination of the relationship was made in Chapter 7 using the output growth-output growth uncertainty relationship, theoretically driven by the investment decision (see sub-section 4.3.3 and Chapter 7), and two opposing hypotheses governing which sign is to be found in this relationship: the Black hypothesis (positive), and the Bernanke hypothesis (negative). The latter of these two is attributable to the presence of irreversible investment dissuading firms from making investments as uncertainty rises, therefore lowering output growth. APARCH-M models were used to model the relationship for UK manufacturing industry sectors and industry groups. Whilst some industry sectors displayed relationships of one sign or the other consistently, for a majority of the industry sectors no significant relationship was found. As production data are available for a much lower level of aggregation, 4-digit industries comprising three of the industry sectors that had shown the most evidence of a relationship existing were further examined using the APARCH-M approach. These industry sectors were Metal Production (industry sector J), Plastics Production (industry sector H), and Electrical Good Production (industry sector L), the first two displaying a positive relationship and the latter a negative relationship at the industry sector level. The finding from this disaggregated data was that the component industries showed relationships of both signs with little dependence upon the parent industry sectors' relationship. There was some evidence of 4-digit industries within the same 2 or 3-digit industries having the same sign on the relationship, but this was not always the case.

Given the lack of clarity in the results from Chapter 7 the investment-uncertainty relationship was then modelled directly in Chapter 8, where the output growth uncertainty measures established in Chapter 7 were used as the uncertainty measures in the investment equations of Chapter 8. As with the output growth-uncertainty relationship, certain industry groups displayed evidence of a significant investment-uncertainty relationship, whilst for the majority the relationship was found to be statistically insignificant. However, unlike the results found in Chapter 7, which were mixed, the relationship was found to be negative in a majority of cases, implying that the industry groups most strongly affected by uncertainty are influenced by irreversible investment. A further interesting finding was that whilst some industry groups are most strongly affected by industry specific uncertainty (Textiles and Engineering) others are more strongly affected by aggregate uncertainty (Food Processing).[171]

The adoption of non-linear SETAR specifications in modelling investment in Chapter 9 had moderate success. The results of linearity tests suggest that some neglected non-linearity is present in the investment series, particularly those identified by the *TR* test used in Chapter 6 as being time irreversible. These were the Engineering, Fuels, and Textiles industry groups, and the Gross Fixed Capital Expenditure, New Building Work and Vehicles Expenditure investment good categories. The most important finding perhaps of these chapters was not in identifying the three industry groups above as being most strongly affected by irreversible investment, but the importance of not only disaggregating investment data by industry but also by investment good category given the differing patterns identified by the *TR* tests in Chapter 6.[172] The introduction of uncertainty into the SETAR models also met with moderate success. Whilst more significant uncertainty terms were found in the low investment regime, it was generally not possible to establish a statistically significant asymmetry in the uncertainty relationship, across the regimes.

In conclusion, overall, it has been found that there is some evidence that irreversible investment has an affect at the industry group level in UK manufacturing,

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[171] Inclusion of dummy variables to represent expansions was found to have a considerable affect upon the investment-uncertainty relationships for the Textiles industry group. When no expansion was present the negative affect of industry group specific uncertainty was greater, but the negative effect of aggregate uncertainty was strengthened by an expansion. This asymmetry across phases of the business cycle in the investment-uncertainty relationship, partially led on to the work in Chapter 9.

[172] Ideally if the data were available it would be most appropriate for future work to model investment disaggregated by investment good category for individual industry groups or even lower industry aggregation levels.

but this is relatively weak. It is found to be more strongly present when examining the investment-uncertainty relationship, but even then only for certain industry groups. Although not providing an answer for all of the conflicting studies of aggregate investment of the past, this study has identified perhaps the main reason for these conflicting results. The reason lies in the very different characteristics of the industry groups' investment patterns, and this is perhaps the direction that should be followed in the future, through examination of individual industry groups, for which it may also be wise to make international comparisons.

There are a number of possible directions for future study. The results found particularly in Chapter 7 where data at a lower aggregation level were used suggest that, if available, there could be much gained from repeating much of the work in this study on either 2 or 4-digit industry data. The difficulty in this is likely to lie with the availability of a long enough span of data. However, with data disaggregated by industry and investment good category it may be possible to detect lumpy investment patterns more clearly through tests for asymmetry or non-linearity. As well as using 4-digit industry data to repeat the output growth-uncertainty modelling in Chapter 7, other alternatives are possibilities for further work. Whilst it is assumed that the relationships examined in Chapter 7 are driven by the investment-uncertainty relationship alone, this is always likely to be clouded by short-term capacity usage decisions. Inclusion of either a capacity usage variable, or alternatively breaking the uncertainty component down into short and long term components, may shed more light on the longer term implications, as well as any difference in the relationship amongst these variables.

Appendix

Table A1

SIC(92) – Listing of 4-Digit Industries

DA – Manufacture of food products, beverages and tobacco

15 – Manufacture of food products and beverages

15.1 – Production processing and preserving of meat and meat products
15.11 – Production and preserving of meat
15.12 – Production and preserving of poultry meat
15.13 – Production and preserving of meat and poultry meat products
15.2 – Processing and preserving of fish and fish products
15.3 – Processing and preserving of fruit and vegetables
15.31 – Processing and preserving of potatoes
15.32 – Manufacturing of fruit and vegetable juice
15.33 – Processing and preserving of fruit and vegetables not elsewhere classified
15.4 – Manufacture of vegetable and animal oils and fats
15.41- Manufacture of crude oils and fats
15.42 – Manufacture of refined oils and fats
15.43 – Manufacture of margarine and similar edible fats
15.5 – Manufacture of dairy products
15.51 – Operations of dairies and cheese making
15.52 – Manufacture of ice cream
15.6 – Manufacture of grain mill products, starches and starch products
15.61 – Manufacture of grain mill products
15.62 – Manufacture of starches and starch products
15.7 – Manufacture of prepared animal feeds
15.71 – Manufacture of prepared feeds for farm animals
15.72 – Manufacture of prepared pet foods
15.8 – Manufacture of other food products
15.81 – Manufacture of bread; manufacture of fresh pastry goods and cakes
15.82 – Manufacture of rusks and biscuits; manufacture of preserved pastry goods and cakes
15.83 – Manufacture of sugar
15.84 – Manufacture of cocoa, chocolate and sugar confectionary
15.85 – Manufacture of macaroni, noodles, couscous and similar farinaceous products
15.86 – Processing of tea and coffee
15.87 – Manufacture of condiments and seasonings
15.88 – Manufacture of homogenised food preparations and dietetic food
15.89 - Manufacture of other food products not elsewhere classified
15.9 - Manufacture of beverages
15.91 - Manufacture of distilled potable alcoholic beverages
15.92 - Production of ethyl alcohol from fermented materials
15.93 - Manufacture of wines
15.94 - Manufacture of cider and other fruit wines
15.96 - Manufacture of beer
15.97 - Manufacture of malt
15.98 - Manufacture of mineral waters and soft drinks

16 – Manufacture of tobacco products

DB - Manufacture of textiles and textile products

17 – Manufacture of textiles

17.1 - Preparation and spinning of textile fibres
17.11 - Preparation and spinning of cotton-type fibres
17.12 - Preparation and spinning of woollen-type fibres
17.13 - Preparation and spinning of worsted-type fibres
17.14 - Preparation and spinning of flax-type fibres
17.15 - Throwing and preparation of silk including from noils and throwing and texturing of synthetic or artificial filament yarns
17.16 - Manufacture of sewing threads
17.17 - Preparation and spinning of other textile fibres
17.2 - Textile weaving
17.21 - Cotton-type weaving
17.22 - Woollen-type weaving
17.23 - Worsted-type weaving
17.24 - Silk-type weaving
17.25 - Other-type weaving
17.3 - Finishing of textiles
17.4 - Manufacture of made-up textile articles, except apparel
17.5 - Manufacture of other textile
17.51 - Manufacture of carpets and rugs
17.52 - Manufacture of cordage, rope, twine and netting
17.53 - Manufacture of non-wovens and articles made from non-wovens, except apparel
17.54 - Manufacture of other textiles not elsewhere classified
17.6 - Manufacture of knitted and crocheted fabrics
17.7 - Manufacture of knitted and crocheted articles
17.71 - Manufacture of knitted and crocheted hosiery
17.72 - Manufacture of knitted and crocheted pullovers, cardigans and similar articles

18 - Manufacture of wearing apparel; dressing and dyeing of fur

18.1 - Manufacture of leather clothes
18.2 - Manufacture of other wearing apparel and accessories
18.21 - Manufacture of workwear
18.22 - Manufacture of other outrwear
18.23 - Manufacture of underwear
18.24 - Manufacture of other wearing apparel and accessories not elsewhere classified
18.3 - Dressing and dyeing of fur; manufacture of articles of fur

DC - Manufacture of leather and leather products

19 - Manufacture of leather and leather products

19.1 - Tanning and dressing of leather
19.2 - Manufacture of luggage, handbags and the like, saddlery and harness
19.3 - Manufacture of footwear

DD - Manufacture of wood and wood products

20 - Manufacture of wood and wood products

20.1 - Saw milling and planing of wood, impregnation of wood
20.2 - Manufacture of veneer sheets; manufacture of plywood, laminboard, particle board, fibre board and other panels and boards
20.3 - Manufacture of builders' carpentry and joinery
20.4 - Manufacture of wooden containers
20.5 - Manufacture of other products of wood; manufacture of articles of cork, straw and plaiting materials
20.51 - Manufacture of other products of wood
20.52 - Manufacture of articles of cork, straw and plaiting materials

DE - Manufacture of pulp, paper and paper products; publishing and printing

21 - Manufacture of pulp, paper and paper products

21.1 - Manufacture of pulp, paper and paperboard
21.2 - Manufacture of articles of paper and paperboard
21.21 - Manufacture of corrugated paper and paperboard and of containers of paper and paperboard
21.22 - Manufacture of household and sanitary goods and of toilet requisites
21.23 - Manufacture of paper stationery
21.24 - Manufacture of wallpaper
21.25 - Manufacture of other articles of paper and paperboard not elsewhere classified

22 - Publishing, printing and reproduction of recorded media

22.1 – Publishing
22.11 - Publishing of books
22.12 - Publishing of newspapers
22.13 - Publishing of journals and periodicals
22.14 - Publishing of sound recordings
22.15 - Other publishing
22.2 - Printing and service activities related to printing
22.21 - Printing of newspapers
22.22 - Printing not elsewhere classified
22.23 - Bookbinding and finishing
22.24 - Composition and plate-making
22.25 - Other activities related to printing
22.3 - Reproduction of recorded media
22.31 - Reproduction of sound recording
22.32 - Reproduction of video recording
22.33 - Reproduction of computer media

DF - Manufacture of coke, refined petroleum products and nuclear fuel

23 - Manufacture of coke, refined petroleum products and nuclear fuel

23.1 - Manufacture of coke oven products
23.2 - Manufacture of refined petroleum products
23.3 - Processing of nuclear fuel

DG - Manufacture of chemicals, chemical products and man-made fibres

24 - Manufacture of chemicals, chemical products and man-made fibres

24.1 - Manufacture of basic chemicals
24.11 - Manufacture of industrial gases
24.12 - Manufacture of dyes and pigments
24.13 - Manufacture of other inorganic basic chemicals
24.14 - Manufacture of other organic chemicals
24.15 - Manufacture of fertilizers and nitrogen compounds
24.16 - Manufacture of plastics in primary forms
24.17 - Manufacture of synthetic rubber in primary forms
24.2 - Manufacture of pesticides and other agro-chemical products
24.3 - Manufacture of paints, varnishes and similar coatings, printing inks and mastics
24.4 - Manufacture of pharmaceuticals, medicinal chemicals and botanical products
24.41 - Manufacture of basic pharmaceuticals
24.42 - Manufacture of pharmaceutical preparations
24.5 - Manufacture of soap and detergents, cleaning and polishing preparations, perfumes and toilet preparations
24.51 - Manufacture of soap and detergents, cleaning and polishing preparations
24.52 - Manufacture of perfumes and toilet preparations
24.6 - Manufacture of other chemical products
24.61 - Manufacture of explosives
24.62 - Manufacture of glues and gelatine
24.63 - Manufacture of essential oils
24.64 - Manufacture of photographic chemical material
24.65 - Manufacture of prepared unrecorded media
24.66 - Manufacture of other chemical products not elsewhere classified
24.7 - Manufacture of man-made fibres

DH - Manufacture of rubber and plastic products

25 - Manufacture of rubber and plastic products

25.1 - Manufacture of rubber products
25.11 - Manufacture of rubber tyres and tubes
25.12 - Retreading and rebuilding of rubber tyres
25.13 - Manufacture of other rubber products
25.2 - Manufacture of plastic products
25.21 - Manufacture of plastic plates, sheets, tubes and profiles
25.22 - Manufacture of plastic packing goods
25.23 - Manufacture of builders' ware of plastic
25.24 - Manufacture of other plastic products

DI - Manufacture of other non-metallic mineral products

26 - Manufacture of other non-metallic mineral products

26.1 - Manufacture of glass and glass products
26.11 - Manufacture of flat glass
26.12 - Shaping and processing of flat glass
26.13 - Manufacture of hollow glass
26.14 - manufacture of hollow fibres
26.15 - Manufacture and processing of other glass including technical glassware
26.2 - Manufacture of non-refractory ceramic goods other than for construction purposes
26.21 - Manufacture of ceramic household and ornamental articles
26.22 - Manufacture of ceramic sanitary fixtures
26.23 - Manufacture of ceramic insulators and insulating fittings
26.24 - Manufacture of other technical ceramic products
26.25 - Manufacture of other ceramic products
26.26 - Manufacture of refractory ceramic products
26.3 - Manufacture of ceramic tiles and flags
26.4 - Manufacture of bricks, tiles and construction products, in baked clay
26.5 - Manufacture of cement, lime and plaster
26.51 - Manufacture of cement
26.52 - Manufacture of lime
26.53 - Manufacture of plaster
26.6 - Manufacture of articles of concrete, plaster and cement
26.61 - Manufacture of concrete products for construction purposes
26.62 - Manufacture of plaster products for construction purposes
26.63 - Manufacture of ready-mixed concrete
26.64 - Manufacture of mortars
26.65 - Manufacture of fibre cement
26.66 - Manufacture of other articles of concrete, plaster and cement
26.7 - Cutting, shaping and finishing of stone
26.8 - Manufacture of other non-metallic mineral products
26.81 - Production of abrasive products
26.82 - Manufacture of other non-metallic mineral products not elsewhere classified

DJ - Manufacture of basic metals and fabricated metal products (ECSC)

27 - Manufacture of basic metals

27.1 - Manufacture of basic iron and steel and of ferro-alloys

27.2 - Manufacture of tubes

27.21 - Manufacture of cast iron tubes
27.22 - Manufacture of steel tubes

27.3 - Other first processing of iron and steel and production of non-ECSC ferro alloys

27.31 - Cold drawing
27.32 - Cold rolling of narrow strip
27.33 - Cold forming or folding
27.34 - Wire drawing
27.35 - Other first processing of iron and steel not elsewhere classified; production of non-ECSC ferro-alloys

27.4 - Manufacture of basic precious and other non-ferrous metals

27.41 - Precious metals production
27.42 - Aluminium production
27.43 - Lead, zinc and tin production
27.44 - Copper production
27.45 - Other non-ferrous metal production

27.5 - Casting of metals

27.51 - Casting of iron
27.52 - Casting of steel
27.53 - Casting of light metals
27.54 - Casting of other non-ferrous metals

28 - Manufacture of fabricated metal products, except machinery and equipment

28.1 - Manufacture of structural metal products

28.11 - Manufacture of metal structures and parts of structures
28.12 - Manufacture of builders' carpentry and joinery of metal

28.2 - Manufacture of tanks, reservoirs and containers of metal; manufacture central heating radiators and boilers

28.21 - Manufacture of tanks, reservoirs and containers of metal
28.22 - Manufacture of central heating radiators and boilers

28.3 - Manufacture of steam generators, except central heating hot water boilers

28.4 - Forging, pressing, stamping and roll forming of metal; powder metallurgy

28.5 - Treatment and coating of metals; general mechanical engineering

28.51 - Treatment and coating of metals
28.52 - General mechanical engineering

28.6 - Manufacture of cutlery, tools and general hardware

28.61 - Manufacture of cutlery
28.62 - Manufacture of tools
28.63 - Manufacture of locks and hinges

28.7 - Manufacture of other fabricated metal products

28.71 - Manufacture of steel drums and similar containers
28.72 - Manufacture of light metal packaging

28.73 - Manufacture of wire products
28.74 - Manufacture of fasteners, screw machine products, chains and springs
28.75 - Manufacture of other fabricated metal products not elsewhere classified

DK - Manufacture of machinery and equipment not elsewhere classified

29 - Manufacture of machinery and equipment not elsewhere classified

29.1 - Manufacture of machinery for the production and use of mechanical power, except aircraft, vehicle and cycle engines
29.11 - Manufacture of engines and turbines, except aircraft, vehicle and cycle engines
29.12 - Manufacture of pumps and compressors
29.13 - Manufacture of taps and valves
29.14 - Manufacture of bearings, gears, gearing and driving elements
29.2 - Manufacture of other general purpose machinery
29.21 - Manufacture of furnaces and furnace burners
29.22 - Manufacture of lifting and handling equipment
29.23 - Manufacture of non-domestic cooling and ventilation equipment
29.24 - Manufacture of other general purpose machinery not elsewhere classified
29.3 - Manufacture of agricultural and forestry machinery
29.31 - Manufacture of agricultural tractors
29.32 - Manufacture of other agricultural and forestry machinery
29.4 - Manufacture of machine tools
29.5 - Manufacture of other special purpose machinery
29.51 - Manufacture of machinery for metallurgy
29.52 - Manufacture of machinery for mining, quarrying and construction
29.53 - Manufacture of machinery for food, beverage and tobacco processing
29.54 - Manufacture of machinery for textile, apparel and leather production
29.55 - Manufacture of machinery for paper and paperboard production
29.56 - Manufacture of other special purpose machinery not elsewhere classified
29.6 - Manufacture of weapons and ammunition
29.7 - Manufacture of domestic appliances not elsewhere classified
29.71 - Manufacture of electric domestic appliances
29.72 - Manufacture of non-electric domestic appliances

DL - Manufacture of electrical and optical equipment

30 - Manufacture of office machinery and computers

30.01 - Manufacture of office machinery
30.02 - Manufacture of computers and other information processing equipment

31 - Manufacture of electrical machinery and apparatus not elsewhere classified

31.1 - Manufacture of electric motors, generators and transformers
31.2 - Manufacture of electricity distribution
31.3 - Manufacture of insulated wire and cables
31.4 - Manufacture of accumulators, primary cells and primary batteries
31.5 - Manufacture of lighting equipment and electric lamps

31.6 - Manufacture of electrical equipment not elsewhere classified

31.61 - Manufacture of electrical equipment for engines and vehicles not elsewhere classified

31.62 - Manufacture of electrical equipment not elsewhere classified

32 - Manufacture of radio, television and communication equipment and apparatus

32.1 - Manufacture of electronic valves and tubes and other electronic components

32.2 - Manufacture of television and radio transmitters and apparatus for line telephony and line telegraphy

32.3 - Manufacture of television and radio receivers, sound or video recording or reproducing apparatus and

33 - Manufacture of medical, precision and optical instruments, watches and clocks

33.1 - Manufacture of medical and surgical equipment and orthopaedic appliances

33.2 - Manufacture of instruments and appliances for measuring, checking, testing, navigating and other purposes, except industrial process control equipment

33.3 - Manufacture of industrial process control equipment

33.4 - Manufacture of optical instruments and photographic equipment

33.5 - Manufacture of watches and clocks

DM - Manufacture of transport equipment

34 - Manufacture of motor vehicles, trailers and semi-trailers

34.1 - Manufacture of motor vehicles

34.2 - Manufacture of bodies (coachwork) for motor vehicles; manufacture of trailers and semi-trailers

34.3 - Manufacture of parts and accessories for motor vehicles and their engines

35 - Manufacture of other transport equipment

35.1 - Building and repairing of ships and boats

35.11 - Building and repairing of ships

35.12 - Building and repairing of pleasure and sporting boats

35.2 - Manufacture of railway and tramway locomotives and rolling stock

35.3 - Manufacture of aircraft and spacecraft

35.4 - Manufacture of motorcycles and bicycles

35.41 - Manufacture of motorcycles

35.42 - Manufacture of bicycles

35.43 - Manufacture of invalid carriages

35.5 - Manufacture of other transport equipment not elsewhere classified

DN - Manufacture not elsewhere classified

36 - Manufacture of furniture; manufacturing not elsewhere classified

36.1 - Manufacture of furniture
36.11 - Manufacture of chairs and seats
36.12 - Manufacture of other office and shop furniture
36.13 - Manufacture of other kitchen furniture
36.14 - Manufacture of other furniture
36.15 - Manufacture of mattresses
36.2 - Manufacture of jewellery and related articles
36.21 - Striking of coins and medals
36.22 - Manufacture of jewellery and related articles not elsewhere classified
36.3 - Manufacture of musical instruments
36.4 - Manufacture of sports goods
36.5 - Manufacture of games and toys
36.6 - Miscellaneous manufacturing not elsewhere classified
36.61 - Manufacture of imitation jewellery
36.62 - Manufacture of brooms and brushes
36.63 - Other manufacturing not elsewhere classified

37 – Recycling

37.1 - Recycling of metal waste and scrap
37.2 - Recycling of non-metal waste and scrap

Source: Report on Census of Production – Summary Volume PA1002 (2000)

Table A2 – UK Manufacturing Industry Groups

Industry Group Name	Full Title	ONS Code	Sectors Included	Sector Names	SIC(92) 2-digit Industries	Industry names
Chemicals	Chemicals and Man Made Fibres	INLA	DG	Manufacture of chemicals, chemical products and man-made fibres	24	Manufacture of chemicals, chemical products and man-made fibres
Engineering	Engineering and Vehicles	INKQ	DK	Manufacture of machinery and equipment not elsewhere classified	29	Manufacture of machinery and equipment not elsewhere classified
			DL	Manufacture of electrical and optical equipment	30	Manufacture of office machinery and computers
					31	Manufacture of electical machinery and apparatus not elsewhere classified
					32	Manufacture of radio, television and communication equipment and apparatus
					33	Manufacture of medical, precision and optical instruments, watches and clocks
			DM	Manufacture of transport equipment	34	Manufacture of motor vehicles, trailers and semi-trailers
					35	Manufacture of other transport equipment
Food	Food products, beverages and tobacco	INKV	DA	Food products, beverages and tobacco	15	Manufacture of food products and beverages
					16	Manufacture of tobacco products
Fuels	Manufacture of coke, refined petroleum products and nuclear fuel	INKZ	DF	Manufacture of coke, refined petroleum products and nuclear fuel	23	Manufacture of coke, refined petroleum products and nuclear fuel

Table A2 continued

Metals	Manufacture of basix metals and fabricated metal products	INLC	DJ	Manufacture of basic metals and fabricated metal products	27	Manufacture of basic metals
					28	Manufacture of fabricated metal products, except machinery and equipment
Other	Other Manufacuting Not Classified Elsewhere	JZKM	DD	Manufacture of wood and wood products	20	Manufacture of wood and wood products
			DE	Manufacture of pulp, paper, and paper products; publishing and printing	21	Manufacture of pulp, paper and paper products
					22	Publishing, printing and reproduction of recorded media
			DH	Manufacture of rubber and plastic products	25	Manufacture of rubber and plastic products
			DI	Manufacture of other non-metallic mineral products	26	Manufacture of other non-metallic mineral products
			DN	Manufacture not elsewhere classified	36	Manufacture of furnature; manufacturing not elsewhere classified
					37	Recycling
Textiles	Textiles, clothing, leather and footware	INKW	DB	Manufacture of textiles and textile products	17	Manufacture of textiles
					18	Manufacture of wearing apparel; dressing and dyeing of fur
			DC	Manufacture of leather and leather products	19	Manufacture of leather and leather products

Source: Report on Census of Production – Summary Volume PA1002 (2000)

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