Shifting Sentiments in Firm Investment: An Application to the Oil Industry[1]

by

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Abstract

Recent developments in the oil and gas industry suggest that investment behaviour is not necessarily changeless over time. We propose a micro-econometric procedure to investigate the stability of investment behaviour. Applying system GMM methods on a panel data set for 253 oil and gas companies over 14 years, we estimate accelerator models of investment with error-correction. Robust econometric evidence indicates a structural break in oil and gas investment in 1998. The process of capital formation over the last years is more flexible than before, with significant and material changes in the role of explanatory factors like cash flow and uncertainty.

JEL classification: C32, G31, L72

Key words: Capital formation, dynamic panel data models, structural break

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1. Introduction

The process of company investment expenditure and capital formation is influenced by a range of internal and external variables, covering aspects of economics, policies, institutions and technology. Changes and shocks in prices, liquidity and uncertainty may carry over to management mentality. Moreover, substantial shifts in the economic environment of the firm may also induce changes in the underlying models of investment behaviour. We propose a micro-econometric framework to assess how the process of capital formation at the firm-level might be affected by a period of far-reaching industrial upheaval and restructuring.

This is the first study to apply company data in a micro-econometric assessment of investment behaviour in the oil and gas industry. Based on accounting information for 253 companies over the period 1992-2005, we specify the process of capital formation as an accelerator model with error-correction (Bean, 1981), whereby investment is explained as a continuous adjustment process towards a long-term equilibrium relation between capital and output. The error-correction process is disturbed by temporary shocks, and by variation in a set of financial and operational control variables. The dynamic panel data model is estimated with *GMM* techniques introduced by Arrellano and Bond (1991). Based on the industrial restructuring of the late 1990s, we apply a flexible dummy-variable technique to test for the presence of a structural break in oil and gas company investment.

Our results provide robust evidence for two historical regimes of investment behaviour in the international oil and gas industry over the last 15 years; one from 1992 to 1997, and one from 1998-2005. Interesting insights are revealed by the shift in various coefficients of our model. Specifically, the late rise in oil price and cash-flows has had a far smaller impact on investment rates than what was typical before 1998, suggesting that financial market pressures in the aftermath of the Asian economic crisis have caused tightened capital discipline in recent years (Osmundsen et al., 2006). Moreover, the early 1990s were characterised by a negative relationship between investment and uncertainty, whereas the recent increase in oil price volatility has spurred investment over the last few years. This result is at odds with the vast majority of previous studies of investment and uncertainty (Dixit and Pindyck, 1994; Carruth et al., 2000), but well in line with recent development of theories of compound options and strategic investment (Abel et al., 1996; Smit and Trigeorgis, 2004). As far as we can see, this kind of robust empirical support for a positive investment/uncertainty relationship is unprecedented in econometric studies.

From around 1985 and towards the end of the 1990s, the international oil and gas companies were exposed to extensive changes in their market, business and political environment. Oil and gas production temporarily lost its former national, political and strategic superstructure, and financial principles gained ground. Processes commonly referred to as globalisation advanced rapidly, with far-reaching implications in terms of economic and financial integration, intensified restructuring and improvement efforts, accelerating technology diffusion, enhanced competition and increased uncertainty.

International oil and gas companies were hesitant in responding to these changes, and were outpaced by the emerging industries of telecom, media and technology (TMT).

Figure 1. Investment indicators in the oil and gas industry
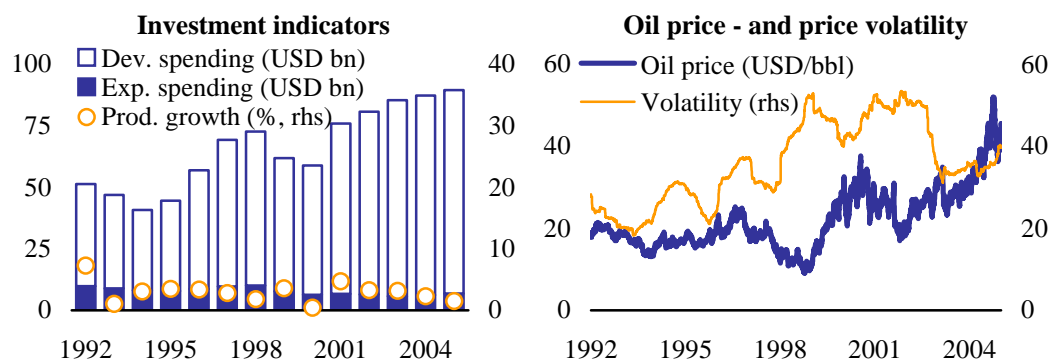
Oil price volatility: Annualised standard deviation of daily price change (260 days rolling data window). See Section 4 for details.
Sources: Investment indicators: Deutsche Bank *Major Oils* (2004), oil price and stock market data: Reuters Ecowin (http://www.ecowin.com).

Towards the end of the 1990s, oil companies' failure to deliver satisfactory investment returns triggered a massive pressure for restructuring, strategic change and improved financial performance (Weston et al., 1999). A combined result of these developments was a wave of mergers and acquisitions that erased former prominent independent names such as Elf, Fina, Mobil, Amoco, Arco, YPF, Texaco, Phillips, Lasmo – and recently also Unocal. The international oil and gas industry entered a new stage towards the end of the 1990s, with heavy focus on production growth, cost-cutting, operational efficiency and short-term profitability. Scorecards of key performance indicators were presented to the financial market, as an implicit incentive scheme between investors and senior management in the companies. Osmundsen et al. (2007) discuss potential implications for capital formation and oil supply, but an empirical analysis of investment behaviour through the period is yet to be published.

Due to strengthened capital discipline (Dobbs et al., 2006), oil and gas exploration and production activities has failed to respond to increasing oil prices over the last years. Figure 1 illustrates that production growth among international oil and gas companies has remained low in the aftermath of the Asian Economic Crisis in 1998. The figure also shows that the share of exploration spending in total E&P investments has been cut back substantially since 1990. However, an increasing share of oil industry investments has been directed at short and medium term development projects rather than long-term reserve replacement.

These developments clearly suggest that the mechanisms of investment behaviour are not necessarily stable over time. Financial friction may both be raised and resolved by exogenous disturbances. Similarly, demand and price shocks, changes in industry structure and competition, financial market pressures and policy changes may change company managers' attitudes to risk and uncertainty. The role of these variables in investment behaviour should therefore be addressed in terms of regime-shifting

behaviour. The paper is organised as follows. Section 2 provides a selective overview of recent contributions to the micro-econometric investment literature, with a special focus on financial friction, real options and uncertainty, dynamic panel data models, and oil and gas applications. The econometric model is derived in Section 3, whereas the data set is introduced and discussed in Section 4. Estimation and results are presented in Section 5, before some concluding remarks are offered in Section 6.

2. Previous research

Based on early theoretical contributions from pioneers like Haavelmo (1960), Jorgenson (1963) and Tobin (1969), empirical interest in investment behaviour has a long tradition in economic research. Chirinko (1993) offers a survey of modelling strategies and results up to the early 1990s, exploring a range of applications of neo-classical models, models with explicit dynamics and various reduced-form models. An essential conclusion from Chirinko's (1993) study is that user cost variables tend to be less important for capital formation at the firm level than revenue and cash-flow variables, casting doubt on the empirical performance of the standard neo-classical investment model. The development of dynamic panel data techniques has resulted in a number of micro-econometric investment studies, developed for general representations of investment behaviour,[2] but also for topical studies like capital market imperfections (Hubbard, 1998) and irreversibility/uncertainty issues (Carruth et al., 2000).

In more recent years, important questions have been raised regarding the role of cash-flow variables in structural models of investment. Critics argue that the common interpretation of cash-flow effects as evidence of capital market imperfections (Hubbard, 1998) is seriously flawed, due to measurement error in market valuation variables (Erickson and Whited, 2000), model specification, and identification problems (Kaplan and Zingales, 1997; Gomes, 2001). Consequently, the attraction has increased for non-structural models (Bean, 1981; Mairesse et al., 1999; Bond et al., 2003), with less theoretical restrictions and without the standard source of measurement error from traditional q models. In a reconciling modelling approach, Moyen (2004) asserts that financially constrained firms actually require another investment model than non-constrained firms. Our econometric approach extends this line of thought, investigating the possible regime-shifting behaviour in the oil and gas industry between periods with more and less financial restriction.

Theories of irreversible investment and real waiting options imply a negative investment-uncertainty relationship (Dixit and Pindyck, 1994), contesting the traditional neoclassical "desirability of price instability" argument (Oi, 1961; Hartman, 1972; Abel, 1983). However, a reconciling study by Abel et al. (1996) illustrates how both these perspectives can be accommodated in modern theories of investment. Adding future put options of contraction to the traditional call options of deferral, ambiguous results are produced for the sign of the investment/uncertainty relationship. Recent applications in management and finance (e.g., Kulatilaka and Perotti, 1998;

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[2] See Bond and Van Reenen (2007) for a general overview.

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Panayi and Trigeorgis, 1998; Smit and Trigeorgis, 2004) also stress that investment implies not only the sacrifice of a waiting option, but also a potential reward from the acquisition of future development options. Increased uncertainty will increase the value of both waiting and development options. Moreover, the value of waiting options is also eroded by imperfect competition and strategic investment (Grenadier, 2002; Akdogu and MacKay, 2007). Empirical studies are therefore required to settle the investment-uncertainty relationship.[3]

In terms of econometric specification, there is a separation in the empirical investment literature between structural models and reduced-form models. Structural models are derived directly from the firm's dynamic optimisation problem, with explicit mechanisms for adjustment costs and intertemporal behaviour. On the other hand, reduced-form models are usually derived from general auto-regressive distributed-lag (ADL) models, relating current and lagged investment to current and lagged values of various explanatory variables. As these models are not linked explicitly to an underlying theory of investment behaviour, their coefficients do not have a straightforward interpretation. However, several researchers (e. g., Oliner et al., 1995); Mairesse et al., 1999) note that reduced-form models tend to perform better for forecasting purposes than structural models. Consequently, ADL models remain the preferred choice among forecasters. Chirinko et al. (1999) conclude that "the applied econometrician must choose between distributed lag models that are empirically dependable but conceptually fragile and structural models that have a stronger theoretical foundation but an unsteady empirical superstructure".

The development of panel data methods has facilitated a change of perspective from macroeconomic to microeconomic behaviour. Panel data sets enable the researcher to account not only for the dynamics of the investment process, but also for cross-sectional variation between companies. A key challenge with dynamic panel data models concerns the simultaneity issues that arise in models with fixed effects and lagged dependent variables. Starting with Anderson and Hsiao (1981), a variety of instrumental variable techniques has been suggested to resolve this issue. A widely employed approach is the generalised method of moments (*GMM*) procedure originally suggested by Arrellano and Bond (1991), refined in a range of subsequent contributions, and applied in the majority of modern micro-econometric investment studies. See Bond (2002) and Arrellano (2003) for updated reviews.

The typical panel data set for company data contains information for a relatively large number of companies (large *N*) over a limited number of time periods (small *T*). This restricts the potential for a robust portrayal of dynamic behaviour over longer time periods. Small *T* panels also reduce our ability to uncover trends and shifts in parameters over time, and to study structural breaks in the data set with stringent methods. With 253 companies over 14 years, our data set is generated over a full financial and oil market cycle, covering periods of consolidation, restructuring, stability, vulnerability, suppression – and "irrational exuberance" (Shiller, 2000).

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[3] According to Carruth et al. (2000), the vast majority of econometric studies are supportive of a quite robust negative link between investment and uncertainty.

Previous studies of oil and gas investment have been occupied with various types of aggregate data (e.g., Pesaran, 1990) or field-specific data (e.g., Hurn and Wright, 1988; Favero et al., 1992; Favero and Pesaran, 1994), with a more or less explicit concern for the exhaustibility issues of oil and gas resources. The capital stock in each of our data units represents a portfolio of reserves and fixed assets at various stages of development, and with various regional, technological and product characteristics. Consequently, our investment figures capture total investment in each company in a range of different projects. With such a genuine company perspective on oil and gas investments, the non-renewable properties of oil and gas investment become less apparent than in field-specific data and regional time series data.

3. An accelerator model with error-correction

The dynamics of capital formation is complex, and even more so when we consider investment at the company level as an aggregate of many types of capital. The vast empirical literature on structural investment models has not been convincing in terms of results. Bond and van Reenen (2007) survey empirical investment models derived from economic theory, and discuss a variety of the challenges and shortcomings related to models derived directly from the producer's dynamic optimisation problem. Our data set does also not offer the richness in variables required for a full-blown structural modelling approach. As the accelerator model is also not plagued by the problems of measurement error in the traditional q models, we therefore base our study on a reduced-form approach.

A common alternative is to rely on a dynamic econometric specification for the data-generating process that is not explicitly derived from structural relations for optimal adjustment behaviour. An example of such an approach is the accelerator model with error-correction, introduced into the investment literature by Bean (1981). More recent applications include Driver and Moreton (1991), Darby et al. (1999) and Mairesse et al. (1999). Their common point of departure is a long-term relation between the desired capital stock (K_{it}^{*}), output (Y_{it}) and the user cost of capital (J_{it}):

$$K_{it}^{*} = A_i Y_{it} J_{it}^{-\sigma} .$$ [1]

This formulation is consistent with profit maximisation under CES production technology. According to common practice in the literature, we assume a long-term capital-output elasticity at unity. The special case of Cobb Douglas production technology would imply $\sigma = 1$. On the other hand, a fixed captial-output ratio implies that $\sigma = 0$. Imperfect competition with firm-specific mark-up can be reflected by the constant term A_i. Alternatively, the constant term may reflect a company-specific distribution parameter in the production function. Letting small-caps indicate natural logarithms, Equation [1] implies for the long-term equilibrium relation:

$$k_{it}^{*} = a_i + y_{it} - \sigma j_{it} .$$ [2]

The property of a unity long-term elasticity between desired capital and output can now be exploited by letting the production level serve as a proxy for the desired capital stock. Our next step is to envelope Equation [2] in a general dynamic model, accounting for the sluggishness of adjustment of the actual capital stock. As noted by Bond et al. (2003), an implicit assumption of this approach is that the desired level of capital without adjustment costs is proportional to the desired capital level in the presence of adjustment costs. Further, we assume that any variation in the user cost of capital can be captured by the combination of firm-specific effects and time-specific dummy variables.[4] Bearing this in mind, our point of departure is a standard 2nd order autoregressive distributed lag (ADL) for the capital stock (k_{it}):

$$k_{it} = \alpha_1 k_{it-1} + \alpha_2 k_{it-2} + \beta_0 y_{it} + \beta_1 y_{it-1} + \beta_2 y_{it-2} + u_{it} , \qquad [3]$$

where u_{it} is an error term. Our assumption of a long-run unit elasticity of capital with respect to output requires that $(\beta_0 + \beta_1 + \beta_2)/(1-\alpha_1-\alpha_2) = 1$. We may therefore take differences and rearrange Equation [3] to obtain a standard error-correction model:

$$\Delta k_{it} = (\alpha_1 - 1)\Delta k_{it-1} + \beta_0 \Delta y_{it} + (\beta_0 + \beta_1)\Delta y_{it-1}$$
$$+ (\alpha_1 + \alpha_2 - 1)[k_{it-2} - y_{it-2}] + u_{it} , \qquad [4]$$

where the bracketed term ($k_{it-2} - y_{it-2}$) represents the error-correction term (e_{it-2}). Error-correcting behaviour now implies that its coefficient is negative. This means that any deviation between the actual and the desired capital stock will be corrected through investment. To arrive at a specification in the investment rate (I_{it}/K_{it-1}), we follow the mainstream literature and approximate the change in the desired capital stock as $\Delta k_{it} = (I_{it}/K_{it-1}) - \delta_i$, where δ_i is a company-specific depreciation rate. For simplicity of exposition, we also define the investment rate (i_{it}) as: $i_{it} \equiv I_{it}/K_{it-1}$. Further, we include x_{it} as a set of control variables, to allow for the influence of cash flow measures, uncertainty proxies and operational indicators that may have an influence on investment. Finally, we include fixed effects (η_i) and time-specific error-components (ζ_t) in the error-term according to the following structure: $u_{it} = \eta_i + \zeta_t + \varepsilon_{it}$, yielding for the equation to be estimated:

$$i_{it} = \rho i_{it-1} + \gamma_0 \Delta y_{it} + \gamma_1 \Delta y_{it-1} + \lambda e_{it-2} + \pi x_{it} + \eta_i + \zeta_t + \varepsilon_{it} , \qquad [5]$$

where ρ is an autoregressive coefficient on the lagged dependent variable, λ is the error-correction coefficient, indicating the speed of adjustment towards the long-term

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[4] The treatment of the user cost is in line with previous applications of accelerator models with error-correction for investment studies. Our specification allows for differences in user costs between companies, but the implicit assumption is that changes over time in the user costs are common to all companies. At this point it should also be noted that a key result from the empirical investment literature is that price and volume variables are far more important for capital formation than variables affecting user costs (Chirinko, 1993). Casual observation also suggests that capital costs play a subordinate role in the investment process of oil and gas companies. Management and financial market attention is rather focused oil price expectations, reserve and production potentials (in addition to various risk indicators).

equilibrium. The deviation from the long-term equilibrium is represented by $e_{it-2} = k_{it-2} - y_{it-2}$.

The scope of our study is to investigate if investment behaviour among international oil and gas companies has changed over the last 14 years. To explore for structural breaks in the data-generating process, we need techniques that allow for parameter instability across historical sub-samples. Moreover, our model should be sufficiently flexible to account for a structural break that applies only to a subset of the variables involved. As an example, the autoregressive structure of the model (i_{t-1}) may well be stable, whereas behavioural change is observable for uncertainty variables (x_{it}), and possibly also for the speed of adjustment, as measured by the estimated response to changes in the equilibrium error (e_{it-2}). To open for this kind of instability, we employ a flexible dummy-variable technique on the parameters of the models. We illustrate the technique for the π vector of the control variables (x_{it}). Letting t^* represent the year of the structural break, dummy variables are defined as follows:

$$d_t = \begin{cases} 0 & if \quad t < t^* \\ 1 & if \quad t \geq t^* \end{cases}$$ [6]

Equation [6] introduces the shift variable to be applied for the subsequent years after the structural break. Now, the πx_{it} term of Equation [5] is replaced by a composite term:

$$\pi x_{it} = \pi_0 x_{it} + \pi_1 d_t x_{it} ,$$ [7]

A null of stability implies $\pi_1 d_t = 0$, and the total impact of a change in the x_{it} variable is represented by the parameter π_0 for the full sample period. On the other hand, if π_1 is statistically significant, the null is rejected, and we have evidence of a structural break for the variable in question. For this case, the sensitivity of investment rates with respect to changes in x_{it} is still given by π_0 for the first period ($t < t^*$). However, an additional shift parameter (π_1) is introduced at the point of the structural break ($t = t^*$), and the full effect is therefore $\pi_0 + \pi_1$ for the subsequent years of the sample. Statistical tests may now be applied to test for these structural breaks for each of the variables, and simultaneously for any (sub-) set of variables of our model.[5]

In addition to dynamic part of the model (i_{it}, i_{it-1}, Δy_{it}, Δy_{it-1}) and the error-correction term (e_{it}) of Equation [5], our estimated models also include four financial and operational indicators in the vector of control variables (x_{it}). The first is a cash-flow measure ($c_{it}=CF_{it}/K_{it-1}$), to test for the impact of financial factors in the investment process (Schiantarelli, 1996; Hubbard, 1998). In addition, the cash-flow variable will capture the effect of oil price variation, including changes in adaptive oil price

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[5] Based on the result from preliminary estimation, the shift is restricted to the error-correction term (e_{it}) and the vector of control variables (x_{it}). Econometric tests are not supportive of a structural shift for the dynamic part of the model (i_{it-1}, Δy_{it}, Δy_{it-1}).

expectations.[6] The next variable is included to capture industry-specific risk, as proxied by oil price volatility (σ_{it}). As with the cash-flow variable, the econometric performance of this volatility variable is improved when divided by lagged capital stock ($v_{it} = \sigma_{it}/K_{it-1}$), and this scaling procedure is therefore adopted in the estimated model. We also include a measure for individual company exposure to oil vs natural gas. Our o_{it} variable represents the share of oil in total oil and gas reserves, and the variable is lagged one period in the estimated models, to capture the lag structure in the development of oil and gas reserves. Finally, the reserve replacement rate (r_{it}) is included to test for the specific influence on investment from reserve replacement efforts.[7]

4. Data

Our data sample is an unbalanced panel of oil and gas companies (1991-2005) drawn from John S. Herold Company's (JS Herold) oil and gas financial database.[8] The JS Herold database consists of financial and operating data from annual financial statements of more than 500 publicly traded energy companies worldwide. From this universe we select firms mainly engaged in exploration and production (E&P or upstream) activities. This leaves us with 253 companies and a sample of 3290 potential firm-years.

On this initial sample we apply a screening procedure. First, we exclude all firms with less than 100 employees in the first year of observation. Second, we require at least six years of data from each firm, and firms not meeting this requirement are excluded. Third, firms that have undergone major restructuring, such as mergers and acquisitions or de-mergers, need to be excluded as the usual models of investment may not characterize these discrete adjustments well. We therefore remove observations where the change in sales from any one year to the next exceeded a factor of three.[9] Missing observations, lagged variables, and the screening procedure reduce the number of firm years to 1765, a total reduction of 46%.

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[6] A range of control variables has been tested, including various oil price variables, result variables and cash-flow variables. The best econometric results were obtained in a model with the described cash-flow indicator as the financial variable. Joint significance of model parameters of this version outperformed alternative specifications, and the sign and magnitude of the estimated coefficients allowed the most reasonable interpretation. We therefore assume that all relevant financial information, including oil price variation, is captured by the cash-flow variable retained in the preferred model version.

[7] The key differentiating factor of the production technology among oil and gas companies is the reserve concept. The stock of oil and gas reserves represents a crucial input in this production process. But oil and gas reserves are not readily available in well-functioning input markets, like the case is for most other traditional inputs. Rather, oil and gas companies have to invest in very risky exploration activities, to support and grow the base of oil and gas reserves. Thus, our reserve replacement variable is included to capture the impact on total investment from companies' efforts to sustain production activity over the longer term.

[8] Founded in 1948, John S. Herold Inc. is an independent research firm that specialises in the analysis of companies, transactions, and trends in the global energy industry (http://www.herold.com/).

[9] A factor of 3 is only slightly higher than the maximum year-to-year change in oil price in our sample. A lower factor may therefore exclude observations not affected by a major restructuring, where annual sales growth is simply induced by oil price changes.

Following Miller (1990), the majority of investment studies combines stock and flow information using the perpetual inventory method to construct capital stocks ($p_t^I K_t$):[10]

$$p_t^I K_{it} = (1-\delta) p_{t-1}^I K_{it-1} \frac{p_t^I}{p_{t-1}^I} + p_t^I I_{it}, \qquad [8]$$

K_{it} is the capital stock at current replacement cost, p_t^I is the price of investment goods,[11] I_{it} represent real investment, and δ is the constant rate of depreciation, assumed at 8 per cent.[12] In line with previous research, we use the net book value of tangible fixed capital assets in the first observation in the sample period (adjusted for previous years' inflation) as our initial value. Our proxy for the price of investment goods (p_t^I) is the implicit price deflator for non-residential gross private domestic investment (structures, equipment and software) from the US national accounts. Subsequent estimates of capital stocks were calculated according to Equation [8].

Table 1. Descriptive statistics for data sample

	Obs.	Mean	St. dev.	Min.	Max.
i_{it}	1765	0.288	0.600	-0.913	12.801
y_{it}	1765	0.140	0.355	-0.837	5.300
k_{it}	1765	7.004	2.297	1.082	12.179
c_{it}	1765	0.211	0.323	-5.170	3.593
v_{it}	1765	0.372	1.079	0.000	17.549
r_{it}	1765	1.426	1.552	-14.490	19.171
o_{it}	1765	0.438	0.271	0.000	1.000

Data source: JS Herold (http://www.herold.com).

Our investment variable (I_{it}) is based on financial statement data on capital expenditure and additions to property, plant and equipment (PP&E), acquisitions and proceeds from sales of PP&E (disposals). We apply a measure of investment including M&A (acquisitions and disposals) as this provides the best econometric results. The investment rate is calculated as investment divided by lagged capital stock. As Table 1 shows the mean investment rate is 0.288, which is higher than comparable studies of investment behaviour. In a study of European manufacturing companies, Bond et al. (2003) document investment rates of 0.110 to 0.125. With comparable rates of depreciation, this suggests a slightly higher rate of capital

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[10] See Terregrossa (1997) for a comparative analysis of variuos depreciation patterns and investment demand.

[11] Our proxy for the price of investment goods is the implicit price deflator for non-residential gross private domestic investment (structures, equipment and software) from the US national accounts.

[12] Bond et al. (2003) also assume a constant rate of depreciation of 8 per cent for manufacturing companies. For comparability, we assume the same rate of depreciation.

accumulation in our sample than in previous studies of manufacturing industries. This assertion is also supported by the fact that our sample reveals a higher average change in production (0.140) and cash flow rates (0.211) than comparable studies. Our estimated models also include four financial and operational indicators in the vector of control variables (x_{it}). Cash-flow (CF_{it}) is computed by adding back depreciation (as reported in the financial statements) to net income (as reported). In order to improve econometric performance, we scaled this cash flow with lagged capital, resulting in the c_{it} variable of our econometric analysis. While the mean c_{it} in our sample is 0.211, the investment rate i_{it} is 0.288 (Table 1). This indicates that the average oil and gas firm in our sample have been investing more money than it has been able to generate internally.

The product mix (o_{it}; oil exposure) is calculated as the ratio of oil reserves to total oil and gas reserves, as reported in the oil companies' supplementary oil and gas disclosures. While oil is reported in million barrels (mmbbl), gas is reported in billion cubic feet (bcf). In order to calculate oil and gas reserves in barrels of oil equivalent (boe), a conversion factor of 6 is used (i.e. 6 bcf = 1 mmbbl). Our sample reveals that the mean oil share of total reserves is approximately 44 per cent.

The reserve replacement ratio (r_{it}) is calculated as the ratio of annual reserve additions to annual extraction. A reserve replacement ratio of 1.0 implies full replacement of the annual production volume (through exploration and/or acquisitions). A mean r_{it} of 1.426 in our sample indicates that the average firm has generated more reserves than they have decimated through production over the period (Table 1).

Carruth et al. (2000) survey the variety of approaches to the measurement of uncertainty in empirical investment studies. To approach the most important source of uncertainty for international oil and gas companies, our point of departure is the historical volatility of the oil price.[13] Based on daily price (p_{kt}) data for the brent blend quality for each of the last 15 years, we calculate annualised standard errors of daily returns ($r_{kt} = \Delta p_{kt}$, $k = 1, 2 .. N$, $t = 1992\text{-}2005$):

$$\sigma_t = \sqrt{\frac{1}{N}\sum_{k=1}^{N}\left(r_{kt} - E(r_{kt})\right)^2}, \tag{9}$$

where N is the annual number of trading days (~ 260) and the average daily change in each year is used as a proxy for $E(r_{kt})$. This methodology is according to financial market practice, and in line with previous related studies (e.g., Paddock et al., 1988;

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[13] A range of options is available for uncertainty indicators, and no consensus is yet obtained for the appropriate way to proxy uncertainty in empirical models of investment. Forward-looking volatility forecasting models (Engle, 1982) are common in early empirical studies of investment and uncertainty. However, this strategy also introduces model uncertainty in two stages. Furthermore, ARCH and GARCH models estimated on high-frequency data will usually imply a low persistence of shocks for our purpose. The majority of recent work therefore relies more directly on observed uncertainty measures (Carruth et al., 2000).

Hurn and Wright, 1994). A running daily calculation of this volatility measure is illustrated in Figure 1 in the Introduction (p. 3). Oil price volatility has increased from an annualised level of 20-30 per cent during the early 1990s to 40-50 per cent during 1998-2002, when the oil industry endured substantial restructuring and a severe oil price drop during the Asian economic crisis (Weston et al., 1999). Since then, oil price volatility has fallen to levels just below 40 per cent, which is slightly higher than average levels from the 1990s.

5. Estimation and results

Our econometric model is a dynamic panel data model for investment behaviour, to be estimated with micro data for international oil and gas companies over the period 1992-2005. The introduction of the lagged dependent variable on the right hand side of the econometric equation introduces a potential endogeneity bias. The standard approach to potentially endogenous explanatory variables is to augment the estimation procedure with additional exogenous instrumental variables. Bond (2002) show that a range of instruments is available in the lagged differences and levels of endogenous and predetermined variables. As additional instrument variables we also include total revenue, as well as annual dummy variables. We apply the general method of moments (*GMM*) approach initially suggested by Arellano and Bond (1991), and refined by a range of subsequent contributions. See Arellano (2003) for an updated overview.

Our point of departure for the econometric estimation is the model specified in Equation [5]. Specifically, we regress the investment rate (i_{it}) against lagged investment (i_{it-1}), current and lagged production growth (Δy_{it}, Δy_{it-1}) and an error-correction term ($e_{it-2} = k_{it-2} - y_{it-2}$) that captures the hypothesised equilibrium-correcting adjustment in the data-generating process. In addition to the dynamic part of the model (i_{it}, i_{it-1}, Δy_{it}, Δy_{it-1}) and the error-correction term (e_{it}), we include four variables to control for the influence of cash-flow variations (c_{it}), oil price uncertainty (v_{it}), reserve-replacement efforts (r_{it}) and product mix (o_{it}).

As pointed out by Bond (2002), the instruments available for the equations in first differences are likely to be weak when the individual time series have near unit root properties. Differenced unit root variables approach random walks, offering limited information as instrumental variables. The original Arellano Bond estimator therefore requires autoregressive parameters to be significantly less than one in simple autoregressive specifications. Our specification of an error-correction model also requires that the variables of the estimated equation are stationary. We therefore estimate a simple AR(1) specification for the variables in our estimated equation to test the dynamic properties of our model variables.

Table 2. AR(1) estimates for model variables

| Depvar	OLS	Fixed Effects	System GMM
i_{it}	0.063*** (0.000)	-0.037 (0.477)	-0.253** (0.012)
y_{it}	0.972*** (0.000)	0.767*** (0.000)	0.960*** (0.000)
k_{it}	0.965*** (0.000)	0.840*** (0.000)	0.956*** (0.000)
e_{it} (= k_{it} - y_{it})	0.873*** (0.000)	0.724*** (0.000)	0.748*** (0.000)
c_{it}	0.347*** (0.000)	0.013** (0.011)	0.005 (0.935)
v_{it}	0.723*** (0.000)	0.598*** (0.000)	0.574*** (0.000)
r_{it}	0.039* (0.086)	-0.024 (0.648)	-0.141*** (0.001)
o_{it}	0.914*** (0.000)	0.469*** (0.000)	0.784*** (0.000)

*) Significant at 90, **) 95 and ***) 99 per cent confidence level, respectively.

Table 2 reports *OLS*, *fixed-effects* and *GMM* results for the estimated auto-correlation coefficient from the AR(1) regression for all our model variables. The hypothesis of an exact unit root is rejected for all variables. These results are consistent with our dynamic modelling approach. Observe also that the derived error correction term e_{it} (= k_{it} – y_{it}) is clearly less persistent than both of its two constituents k_{it} and y_{it}. As suggested by the error-correction literature (e.g., Engle and Granger, 1987; Hendry and Juselius, 2000), the combination of highly persistent variables in a cointegrating vector produces a variable with improved stationarity properties for econometric estimation. We take these results as support for our specification of investment as an accelerator model with error-correction.

Our next step is to test for the structural break we are hypothesising. At this point, our approach draws on a flexible dummy-variable approach equivalent to the framework introduced by Chow (1960), and refined in a series of subsequent contributions (e.g., Holtz-Eakin et al., 1988; Andrews and Lu, 2001). Equation [5] is estimated with all control variables and all shift parameters (cf. Equations [6]-[7]). We then test the joint significance of all shift parameters, with a null of no structural break. Rejection implies statistical support for the presence of a structural break. Further, our testing procedure implies that the point of the structural break (t^*) is endogenised, as the described stability test is repeated for all the possible break points (years) granted by our data set. We test for structural breaks in our model for all the years between 1995 and 2004, one by one.[14] Results from these tests provide valuable guidance in our selection of year for the structural break (t^*), which we suspect took place sometime in the late 1990s. Relevant χ^2 test statistics from this procedure are illustrated in Figure 2, along with their respective p values.

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[14] The presence of lagged variables in the model, and the application of deeply lagged instruments, reduces the quality of this test procedure for breaking points further back than 1995.

Figure 2. Detection of structural break
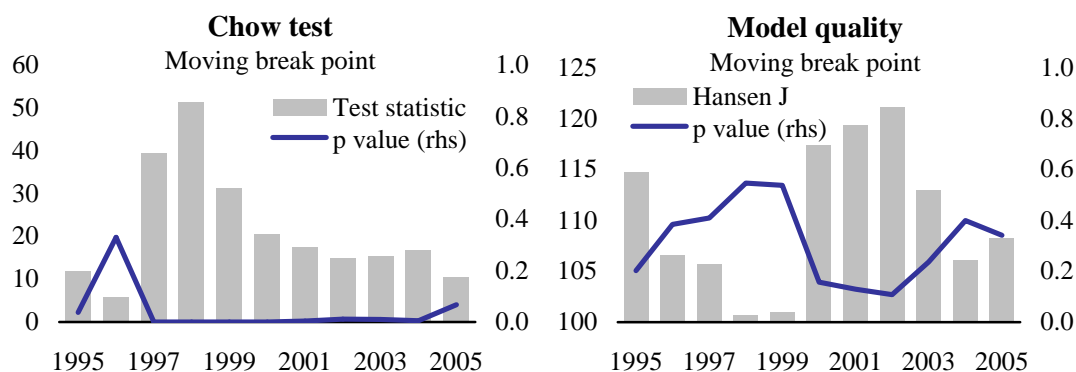
GMM estimation of Equation [5] with shift parameters for error correction term (e_{it}) and the four control variables ($x_{it} = [\, c_{it},\, v_{it},\, r_{it},\, o_{it}\,]$).

Figure 2 illustrates that the likelihood of a structural break is at its maximum in 1997/1998. We also report the Hansen's *J* statistic, from a test for the exogeneity properties of our instrument matrix. Rejection of the null implies that the validity of our over-identifying restrictions is threatened, which would be an indication of model misspecification. The power of this test is at its minimum in 1998, implying that the validity of our over-identifying restrictions is at its highest for the model with a structural break in 1997/1998. We take this as further support for the hypothesis of a structural break in investment behaviour. The assumption of a structural break in oil and gas investment in 1997/1998 is therefore adopted in the following econometric analysis.

We now proceed to the estimation of our accelerator model with error-correction, as stated by Equation [5]. Table 3 presents the result for three different model versions. Model 1 is the model in its simplest for, without any control variables (x_{it}). Model 2 includes four financial and operational control variables as described above. The shift dummies of Equation [6] are applied in Model 3, to allow for variable-specific structural breaks in investment behaviour in the error-correction term (e_{it}) as well as the control variables (x_{it}), whereas stability over the period is assumed for the dynamic part of the model (i_{t-1}, Δy_t, Δy_{t-1}).[15]

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[15] This assertion is supported by statistical inference from preliminary estimations, where the structural shift was allowed also for the dynamic part of the model. These full-fledged models produced more insignificant parameter estimates, and their overall quality diagnostics proved them inferior to the presented estimated models.

Table 3. Estimated accelerator models with error-correction

System GMM estimates obtained with Stata 9.0

	Model 1	Model 2	Model 3
Estimated coefficients [a]			
Intercept	2.116*** (0.000)	2.382*** (0.001)	1.175*** (0.004)
i_{it-1}	-0.077* (0.081)	-0.083** (0.027)	-0.127* (0.016)
Δy_{it}	0.613*** (0.000)	0.504*** (0.000)	0.443*** (0.000)
Δy_{it-1}	0.258*** (0.001)	0.204*** (0.005)	0.162** (0.033)
e_{it-2}	-0.184*** (0.000)	-0.201*** (0.001)	-0.059 (0.170)
$d_t \cdot e_{it-2}$			-0.055*** (0.001)
c_{it-1}		0.200*** (0.001)	0.979*** (0.000)
$d_t \cdot c_{it-1}$			-0.787** (0.027)
v_{it}		-0.241 (0.314)	-0.554*** (0.000)
$d_t \cdot v_{it}$			1.128*** (0.000)
o_{it}		-0.247*** (0.005)	-1.162*** (0.000)
$d_t \cdot o_{it}$			1.392*** (0.000)
r_{it}		0.028*** (0.005)	0.069*** (0.006)
$d_t \cdot r_{it}$			-0.058* (0.072)
Model diagnostics			
Wald χ^2	119.94*** (0.000)	220.77*** (0.000)	292.88*** (0.000)
Hansen J	176.84 (0.133)	158.50 (0.364)	100.70 (0.546)
AB AC(1)	-5.00 (0.000)	-4.72 (0.000)	-5.25 (0.000)
AB AC(2)	-0.01 (0.996)	0.03 (0.972)	-0.37 (0.709)
Firms (#)	232	232	232
Obs (#)	1737	1737	1737

[*] Significant at 90, [**] 95 and [***] 99 per cent confidence level, respectively.
[a] p-values in brackets.
Dependent variable: Investment rate (i_{it}). Explanatory variables: lagged investment rate (i_{it-1}), production growth (Δy_{it}, Δy_{it-1}) error-correction term ($e_{it-2} = y_{it-2} - k_{it-2}$), cash-flow variable ($c_{it}$), oil price volatility (v_{it}), reserve replacement efforts (r_{it}) and relative oil exposure (o_{it}). See Section 3 and 4 for definition and description of model variables.

Table 3 also presents a selection of model diagnostics, which indicate satisfactory performance for all the three model versions. The Wald χ^2 statistic is a test for joint signficiance of all model parameters. Arellano and Bond (1991) recommend the Sargan statistic to test the exogeneity properties of the instruments as a group, with a null of validity. However, the Sargan statistic is sensitive to heteroskedasticity and autocorrelation, and tends to over-reject in the presence of either. We therefore

follow follow Roodman's (2006) advise and report the more robust Hansen *J* statistic as an indicator for the validity of the over-identifying restrictions.[16] *AB AC(n)* is the Arrellano-Bond test for n^{th}-order autocorrelation in the differenced residuals, with a null of no autocorrelation. Non-rejection of 1st order autocorrelation is as expected, and not critical for the validity of the differenced equations. 2nd order autocorrelation in the residuals of the differenced model would be more troublesome, as it would imply a breach of the assumption of well-behaved residuals in the level representation of our model.

The lagged investment rate (i_{it}) takes a small, negative and statistically significant coefficient, indicating that periods of high investment are normally followed by a downward correction, and vice versa. According to our results, production growth (Δy_t, Δy_{t-1}) is an especially important driver for investments among oil and gas companies, with sizeable, positive, and highly significant parameter estimates. On average, an increase in oil and gas production growth by one percentage point yields an increase in the investment rate of 0.67 percentage points (p value < 0.01) in our preferred model.

Our choice of model specification is supported by the plausible and significant estimate for the error-correction coefficient (Kremers et al., 1992), except in Model 3. The parameter estimate of the error-correction term (e_{it}) suggests that 12-20 per cent of any equilibrium error is adjusted every year. This may seem sluggish, but compares well with previous empirical studies for manufacturing industries (e.g., Mairesse et al., 1999; Bond et al., 2003). The structural break parameter suggests that the pace of adjustment was slower in the early 1990s than over the last years of the sample. This agrees well with industrial developments over the last 10 years or so; intensified restructuring and improvement efforts, accelerating technology diffusion, enhanced competition and increased uncertainty (Weston et al., 1999). Consequently, industrial upheaval contributed to a more flexible investment process, with higher rates of adjustment than in previous years.

We also obtain material precise parameter estimates for the cash-flow variable (c_{it}). A common interpretation used to be that these coefficients represent signals of capital market imperfection and financial friction (Hubbard, 1998). However, we recommend caution in the interpretation of these coefficients. Even without the common source of measurement error from the structural models (Erickson and Whited, 2000), critics have argued that significant cash-flow coefficients might be due to model misspecification (e.g., Kaplan and Zingales, 1997; Gomes, 2001). Moreover, the fact that our reduced-form model is not explicitly linked to an underlying theory of investment behaviour also implies that the cash-flow coefficient does not have a straightforward interpretation. Still, our results provide econometric evidence that access to internal funds plays a role in the data-generating process of firm investment. Prior to the structural break in 1998, when the oil price was low, earnings were modest and profitability was moderate, our results suggest that availability of internal funds played a material and statistically significant role in

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[16] The Hansen *J* statistic is the minimised value of the two-step *GMM* criterion function (Hansen, 1982).

capital formation. The estimated coefficient of 0.98 implies that variations in the cashflow rate produced similar changes in the investment rate during this period. This also corresponds well to casual observation across the industry in the aftermath of the Asian economic crisis and the subsequent oil price drop in 1997-1998. However, sentiments changed in 1998, and the response in oil and gas investment to the subsequent oil price increase was muted. The shift parameter for our cashflow variable cuts the original coefficient by 0.79, suggesting that the connection between investment and internal funds has become weaker over the last 10 years. A likely interpretation is that financial market pressures for capital discipline in the aftermath of the Asian economic crisis put a lid on oil and gas investments from the late 1990s (Osmundsen et al. 2006, 2007).

The economic results may seem even more thought-provoking for our uncertainty indicator (v_{it}). Table 3 suggests that the role of uncertainty in the investment process has changed markedly over the 15 years of our data sample. During the first period, an increase in uncertainty gives a statistically significant dampening effect on oil and gas investment, as implied by standard theory of irreversible investment and real waiting options (Dixit and Pindyck, 1994; Carruth et al., 2000). However, recent theoretical contributions (Kulatilaka and Perotti, 1998; Smit and Trigeorgis, 2004) point out that investment implies not only the sacrifice of a waiting option, but also a potential reward from the acquisition of future development options. For the oil and gas industry, an increase in oil price volatility will increase the value of both these types of real options. Aguerrevere (2003) also notes that long construction lags, which are typical for the oil and gas industry, tend to undermine the net effect of uncertainty on investment. The reason is that the time-to-build factor increases the value and relevance of future development and growth options in the investment decision. Thus, the theory of compound options may give rise to a positive relationship between investment and uncertainty. With a positive and highly significant coefficient for the period after 1998,[17] an increase in uncertainty seems to have had a stimulating effect on capital formation over the last few years. This result should be interpreted in the context of imperfect competition, resource scarcity and strategic investments, which have become increasingly important in the international oil and gas industry (see also Weston et al., 1999).[18]

The estimated models also provide evidence that gas-prone companies are characterised by a higher rate of capital accumulation than companies dominated by oil reserves. This effect is captured by our o_{it} variable, which represents the share of oil in the total reserve base. We see this as an indication of the huge investment requirements on the companies who shifted production from oil to natural gas over

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[17] Based on the far-right column of Table 3 (Model 3), the sum of the two estimated volatility coefficients is $-0.554 + 1.128 = 0.574$, with $p < 0.01$.
[18] Boyle and Guthrie (2003) also suggest that financial frictions may increase the risk of future funding shortfalls. This will reduce the general value of waiting, and may therefore increase investment beyond the optimal level. Moreover, an additional source of a positive investment/uncertainty relationship is introduced. Based on this idea, an interaction term between cashflow and uncertainty has also been tested in our model. However, this combined variable did not produce significant parameter estimates, and could therefore not be included in the preferred model.

the 1990s. However, the difference in investment rates between oil-prone and gas-prone companies seems to be a phenomenon of the 1990s. More specifically, our results indicate that average investment rates of oil-prone companies have caught up with gas-prone companies since the turn of the century.

Finally, our results suggest that reserve replacement efforts drew capital resources beyond the requirements of production growth over the first period of our sample. On the other hand, the effect is largely outweighed by the shift parameter for this variable, implying that no specific investment impulse can be attributed distinctly to reserve replacement in the period after 1998. The background for this development is related to the fact that accessible oil and gas reserves have become increasingly scarce. International oil and gas companies struggle to replace their production, at increasing access cost for new reserves. Even though reserve replacement rates have turned down, the involved capital requirements are probably upheld. This constitutes a likely explanation for the negligible impact on oil and gas investment from reserve replacement efforts over the last few years.

6. Conclusion

The process of capital formation in the oil and gas industry is and important part of the supply side dynamics in the oil market. Understanding how oil and gas companies think in terms of investment is therefore essential to develop and maintain the required insights for meaningful analyses of oil price formation. Over the last 15 years, international oil and gas companies have gone through a period of industry upheaval, restructuring and escalating market turbulence. Since the beginning of the 1990s, business principles have gradually gained ground, and today competition among international oil companies is more aggressive than ever. Easily accessible oil and gas reserves in market-oriented economies like USA, Canada and United Kingdom are faced with depletion. Oil and gas investments are now gradually redirected in a rat race for increasingly scarce oil and gas resources. On this background it should come as no surprise that investment behaviour among international oil and gas companies has changed gears.

We provide firm econometric evidence that the investment process among international oil and gas companies changed significantly towards the end of the 1990s. The investment process over the last years is more flexible than before, with significant changes in the role of explanatory factors like uncertainty, reserve replacement efforts and product mix. We find robust statistical support for cash-flow effects, with recent investment rates less sensitive to changes in oil price and cash flow than in the early 1990s. More surprisingly, we find that the investment uncertainty relationship changed sign in the late 1990s. Whereas an increase in oil price volatility would reduce investments in the early years of our sample, investment over the last few years has gained stimulus from increasing oil price uncertainty. We see this as empirical support for recent contributions on investment and compound options. Finally, our results suggest that operational factors like

product mix and reserve replacement efforts have lost some of their historical influence on the investment process.

Industrial leaders and their companies respond continuously to changing political and market environments. Their mindset and models may be stable for periods. However, from time to time their way of thinking is also challenged by external forces. And sometimes these pressures even bring about deeper changes. Our study demonstrates that such a change took place in the oil and gas industry in the 1ate 1990s, in response to the industrial upheaval and massive pressure from financial markets. A fruitful direction for future research would be to relate these changes to company characteristics, possibly within a structural model framework.

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