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Investment Under Price Uncertainty

An Empirical Study of the Norwegian Petroleum Industry

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Summary

Investments are based on expectations of future profits. The common perception of the investment and uncertainty relationship is that increased uncertainty reduces willingness to invest. Uncertainty is here defined as deviation from the expected outcome. In uncertain conditions, it may be difficult to establish a clear profit expectation. However, from the early development of investment theory the sign has been debated. Uncertainty can also be exploited for profit seeking and the sign may therefore be positive. Petroleum extraction is a complicated, slow and expensive process. Historically petroleum prices have been quite volatile, and it is a major uncertainty factor for petroleum producers. The forward looking nature of investment behavior creates several issues for investment theories and empirical modeling. Expectations of return and uncertainty are unobserved and challenging to quantify. When controlling for dynamic panel bias I find a negative relationship between investment and price uncertainty. If price uncertainty increases, investors on the Norwegian continental shelf are more likely to postpone or drop new investments.

Acknowledgements

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Magnus Tjøstheim

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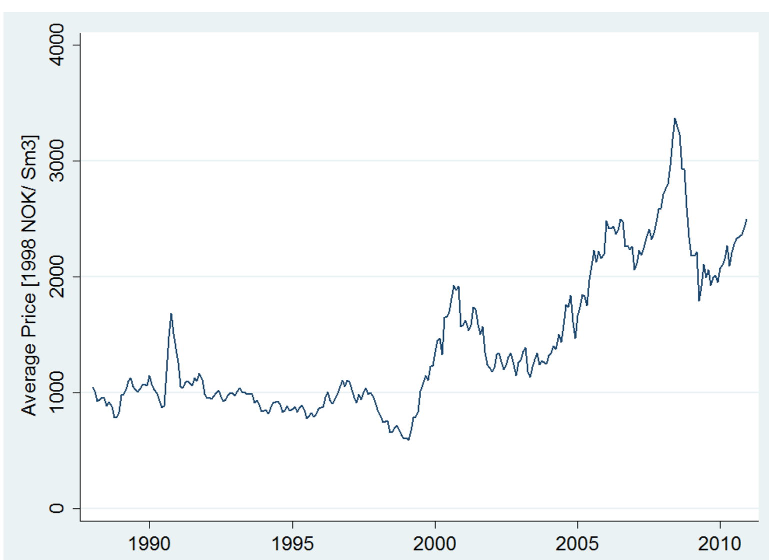
1 Introduction

1.1 Background

Petroleum extraction has had an enormous impact on the Norwegian society the last couple of decades. In 2010 the petroleum industry represented 21 % of total GDP, 26 % of total investments and 47 % of all exports. Today about 50 national and international companies are active on the Norwegian continental shelf (NPD, 2012). The petroleum industry has some unique characteristics. Development of a petroleum field is a slow and comprehensive process. First the resource must be located, and then massive infrastructure is required to extract the oil and gas. It takes several years and is very expensive. In addition the resources are nonrenewable and depletion of a petroleum field gets more difficult as time passes. Nevertheless, the petroleum industry has historically, without a doubt, been extremely profitable.

An investment implies taking on an immediate cost in expectancy of a future reward. The key element to an investment decision is forward-looking expectations. There are several relevant uncertainty aspects in a petroleum project. The most dominant are: how much oil and gas can be expected in the ground, and what could it possibly be sold for? Petroleum prices are known to be volatile, and represent a major uncertainty factor for petroleum companies. Figure 1 shows the average real sales price on the Norwegian continental shelf between 1988 and 2010. It is clearly unstable and possibly difficult to predict.

Figure 1 Average Price on the Norwegian Shelf



Note: Based on monthly data. Weighted average of Oil, Condensate, NGL and Gas. Source: SSB (2013)

The relationship between investments and uncertainty is a debated issue. The majority of the literature predicts a negative sign. If uncertainty increases the desire to invest is reduced. In uncertain conditions an investor cannot know for sure whether to expect a future reward or not. The investor may then postpone or drop the investment until better information is available. On the other hand, uncertainty can also be exploited for profit seeking. A number of studies find a positive relationship between investments and uncertainty and argue that a positive sign is equally plausible as a negative.

1.2 Research Problem

The main purpose of this paper is to investigate in how petroleum investments are affected by price uncertainty. The relationship may be positive or negative, strong or weak. My research problem is as follows:

What is the effect of price uncertainty on investment in the Norwegian petroleum industry?

1.3 Modeling

I will use an econometric model to identify the drivers for investment and the effect of uncertainty. The data is a panel of all fields on the Norwegian shelf in between 1988 and 2010. There are two main problems that must be handled. First, expectation of return and uncertainty are unobserved variables and therefore challenging to quantify. Secondly, the model may suffer from dynamic panel bias. I therefore explore three different estimation techniques for panel data. I start by using a fixed effects model. Further I apply Anderson-Hsiao estimator and Generalized Methods of Moments (GMM) to control for dynamic panel bias.

1.4 Structure

Chapter 2 provides some characteristics of the petroleum industry. Theoretical aspects and previous research of investments and uncertainty are covered in chapter 3. Chapter 4 gives an overview of the data set. The econometric model and different estimation techniques are discussed in chapter 5. Estimated results are presented in chapter 6. Finally, chapter 7 offers some concluding remarks.

2 Characteristics of the Petroleum Industry

2.1 Industrial Organization

2.1.1 Licenses

The petroleum industry is heavily regulated by the Norwegian government. The Ministry of Petroleum and Energy is the main regulating authority in cooperation with the Norwegian Petroleum Directorate (NPD). The Ministry regulates which areas that may be operated and the activity in the different fields. Before an area is opened to petroleum activity it must be granted in Stortinget. An impact assessment review must be carried out to evaluate factors such as the economic effects, social effects and the environmental impact the activity could have for other industries and the adjacent districts (NPD, 2012). For example, today there is a huge political discussion going on whether the areas outside Lofoten and Vesterålen in the northern part of Norway should be opened. Until now they have been closed due to vulnerable nature and a possible negative effect on fish stocks, even though they are expected to be profitable.

To do business on the shelf one needs a production license from the government. The production license regulates rights and obligations vis-à-vis the government and the producer. It grants companies exclusive rights to seismic surveys[1], exploration drilling and production of petroleum within the geographical area covered by the license for a given time period (NPD, 2012). For new fields there is an initial period up to 10 years granted for exploration. Production licenses are normally awarded through licensing rounds. The government announces a certain number of blocks that are available for award of production (NPD, 2012). Interested parties must apply to each block they wish to operate in. While holding the license, the produce is obligated to work towards implementing new projects.

2.1.2 Joint ventures

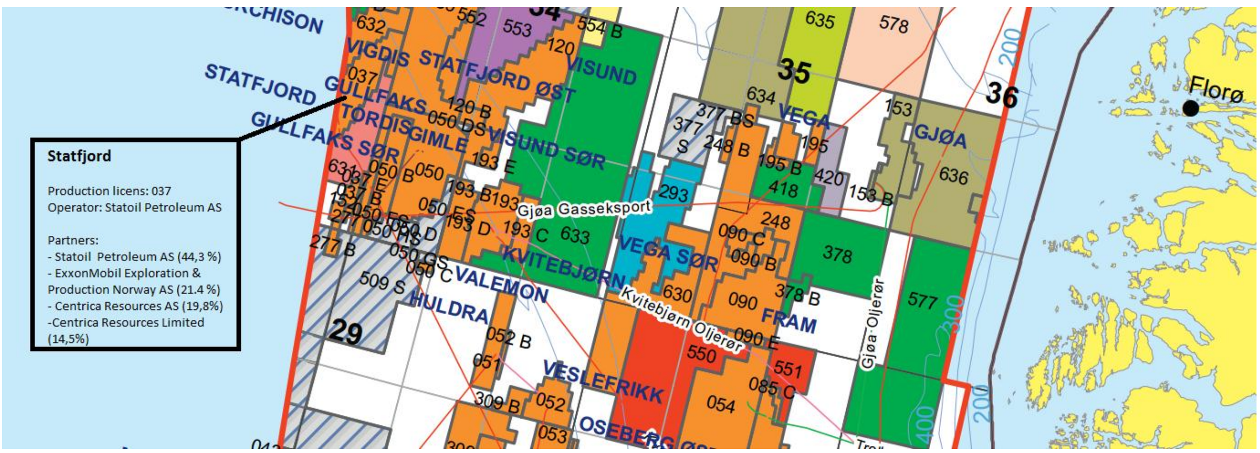
The producer holding the license is called an operator. The operator may sell ownership in the license to other parties. Most oil fields are therefore operated as joint ventures. Distribution of costs and revenues are normally done every month. However, the obligations of the license are the operator's responsibility

[1] Seismic survey is a sea bead map. Sound waves are shot against the ocean bottom and the characteristics in the reflection make it possible to perform an educated guess to where oil and gas may be located. Geologist analyses the sea ground for possible "oil traps" where hydrocarbons are locked inside porous rock by a layer of solid rock. Seismic surveying is developed for most of the southern Norwegian shelf and is now being explored in the northern parts.

alone. The incentive for a joint venture is obviously to spread risk. Petroleum production is a risky business. It is difficult to determine the production potential of a petroleum field. The information about the field is developing as more wells are drilled and the production is evolving. Hence, one never knows for certain how much of the resources that are economically extractable.

In figure 2 I have illustrated production license 037, more commonly known as Statfjord. Statfjord is the largest petroleum field on the Norwegian continental shelf. Statoil Petroleum AS is the operator and owns 44.3 % of the license. Three additional companies own the remaining 55.7 %. The square sections in the figure are the blocks that are made available through licensing rounds.

Figure 2 Statfjord - Joint Venture



Source: NPD (2013)

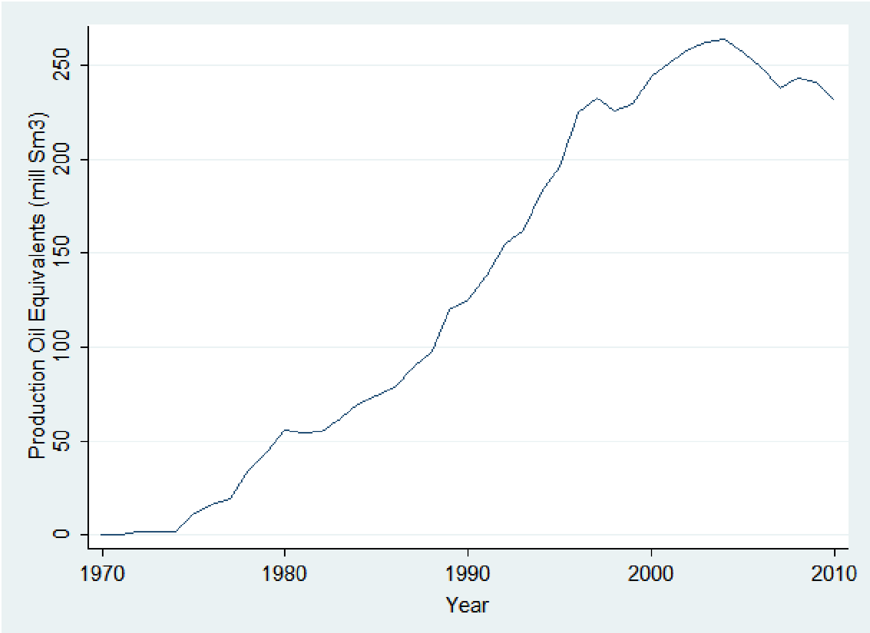
2.2 Historical Trends

2.2.1 Production

The Norwegian oil exploration and production started in the late 60s. The first discovery was Ekofisk in December 1969. Production from Ekofisk started in 1971 and the rest of the 70s was characterized by huge discoveries. Most of the large petroleum fields on the shelf were discovered early. Investments and production increased quickly the first two decades (NPD, 2012). There are two common measures of petroleum production; Standard Cubic Meters (Sm^3) and Barrels [2].Barrels are the most common in the North America, while Sm^3 are used in the rest of the world. I.e. production from the Norwegian continental shelf is usually given in Sm^3. The production, as may be seen in Figure 3, increased until 2004 and so decreased until 2010.

[2] Standard Cubic Meter (Sm^3): Oil, Gas and Condensate is measured to a reference condition of 15 °C and 1,01325 bar. Barrels: 1 barrel = 42 US Gallons ≈ 159 liters ≈ 0,159 Sm^3 (Energilink, 2008).

Figure 3 Annual Production



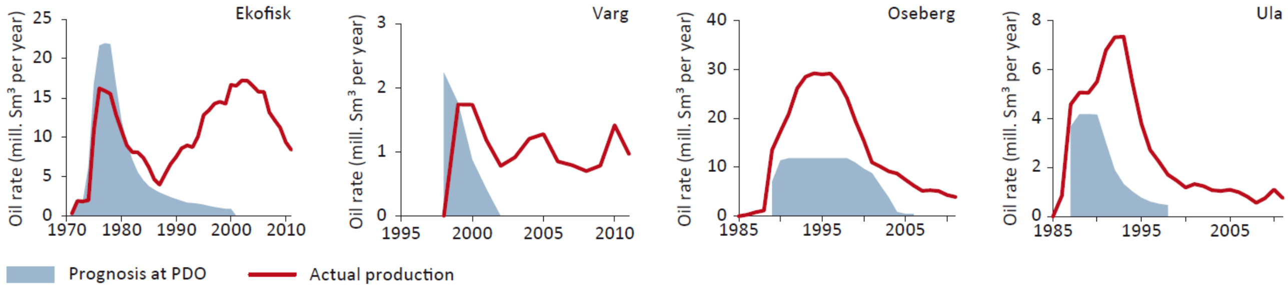
Source: NPD (2013)

Because petroleum is a nonrenewable resource, it will sooner or later be fully exploited. A "bell shaped" parabolic pattern is therefore intuitive. The resources that are easiest to find and extract will be developed first. Hence, as time passes resources will be both harder to find and extract. A theory is developed on the matter, called peak oil. Modern discussion of the theory relates to whether world oil production has reached its peak and will decline in the future (Odell, 2004). Figure 3 indicates that Norway might be in a peak oil situation. However, in 2010 a huge discovery, called Johan Sverdrup[3], was made in the North Sea, and annual production is expected to increase again in the years to come.

The parabolic production profile is traditionally also expected for each field. However, new technology and discoveries within the surrounding area often extends the production phase. The traditional parabolic pattern is common, but not true for all fields. Some examples are shown in Figure 4. Ekofisk increased its production rapidly again in the early 90s due to new technology. Ula and Oseberg share the traditional peak oil characteristics.

[3] There were two separate, but geographically close, findings. They were at first called Avaldsnes and Aldous. The area is now jointly called Johan Sverdrup

Figure 4 Production Development for Ekofisk, Varg, Oseberg and Ula



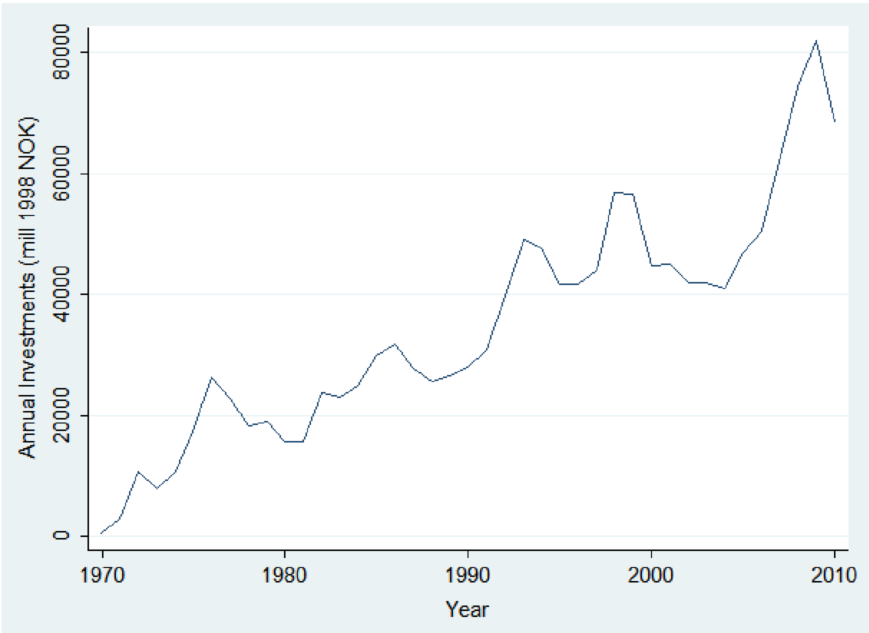
Source: NPD (2012)

Figure 4 also show the expected prognosis before production has started. PDO means plan for development and operation. A PDO has to be submitted by the operator to the government before any drilling may start. It is clear that the estimates for all these examples are way off. The imprecise estimates have two main sources. First of all, it is difficult to know how much petroleum recourses that is in the ground before several wells are drilled. Seismic surveys give some information, but not the full story. The more wells drilled, the more precise knowledge of the field. Secondly, new technology is developed over time and has made more of the resources economically extractable.

2.2.2 Investments

Figure 5 shows the total annual investments on the Norwegian continental shelf from 1970 to 2010. To make the observations comparable between years they are inflation adjusted to 1998 NOK by Statistics Norway's (SSB) consumer price index. Investments increased rapidly after the first discovery in 1969 and have had a long term increasing trend. Nevertheless, there is some visible short term volatility between years.

Figure 5 Total Annual Investments



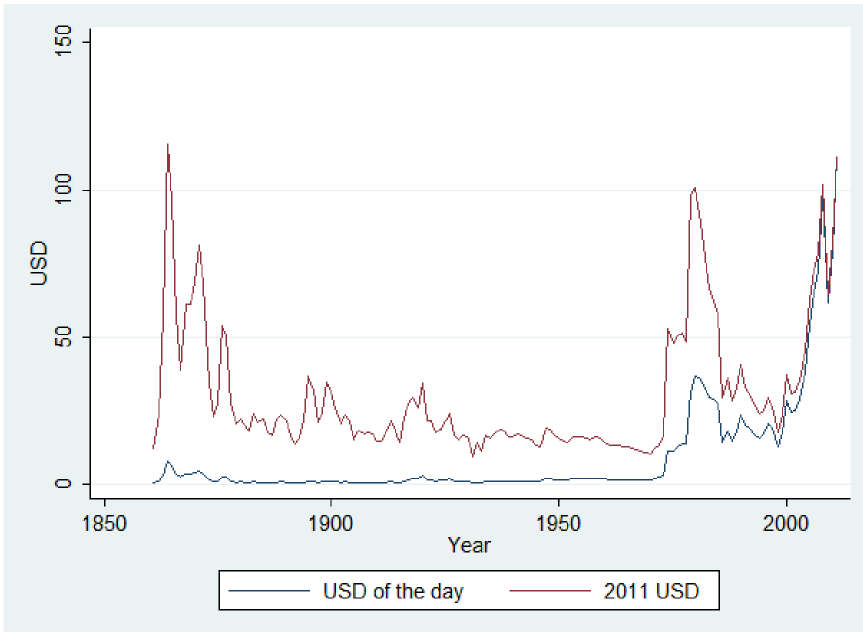
Source: NPD (2013)

2.2.3 Price

Petroleum prices are known to be volatile. Figure 6 shows the international crude oil price index in USD/ barrel from 1861 -2011, both in nominal and real terms. There are 4 main price regimes after 1950. From 1950-73 the price was stable and slightly declining. The period 1973-85 was characterized by extreme spikes in the price caused by international conflicts and the market power of the Organization of the Petroleum Exporting Countries (OPEC). From 1985-2003 OPEC's market power shrank, and until 1999 prices declined. After 2004 the oil price increased rapidly before plummeting during the financial crises, starting in 2008. Afterwards the price has increased again and stabilized around 100 USD/barrel.

The volatile petroleum prices cause uncertainty for the oil producers (and consumers). Inelastic demand makes the price move relatively much in response to changes in supply. The price has historically been dominated by imperfect competition caused by OPEC, international conflicts and speculation bubbles. In the following I will look closer into the different periods after 1950 and try to identify some main price drivers.

Figure 6 Historical Crude Oil Price Index



Note: Three different price indexes included.1861-1944 US Average, 1945-1983 Arabian Light, 1984-2011 Brent Blend. Source: BP (2012)

2.2.3.1 OPEC

OPEC was founded in 1960. OPEC has since the beginning been dominated by Middle East countries[4]. The Middle East region has the greatest quantity, easiest accessible and cheapest petroleum resources in the world. From 1973-85 OPEC had great influence on the price (Hannesson, 1998). OPEC caused the sharp incline in price in 1973, often referred to as OPEC I. A slight decline in production led to a quadrupling of the price. OPEC I was caused by the war between Israel and Egypt in 1973. OPEC imposed an oil embargo on the US and the Netherlands because they supported Israel in the war. Thereafter the price was relatively stable for 5 years from 1973-78. The second oil price spike in 1978, called OPEC II, was caused by the Iranian revolution. Iran's production shrank dramatically and created shortage in the market.

The dramatic spikes in the price indicate inelastic demand. Whether demand is inelastic in the long run is debated, but it is definitely inelastic in short terms. Some different estimates are done. The International Energy Agency (IEA) estimates a price elasticity of 0.03 in short terms and 0.15 in long terms (IEA, 2006).

[4] The first members of OPEC were Saudi Arabia, Iran, Iraq, Kuwait and Venezuela. Today also Angola, Algeria, United Arab Emirates, Ecuador, Libya, Nigeria and Qatar are members (OPEC, 2013).

Griffen (2009) calculates 0.09 in short terms, and argues for the elasticity to approach one in the long run. Griffin claims that even though there is no realistic replacement to petroleum today, new solutions will be developed in a long perspective. An example is the sudden profitability of offshore petroleum areas in the 1970s. As the oil price was spiking new petroleum resources were developed. Before the OPEC I, profitable offshore petroleum production was regarded as unrealistic (Hannesson, 1998).

Offshore production decreased OPEC's market power and the world dependence on oil from the Middle East between 1985 and 2003. Until 1999 the price declined. From 1999-2003 it increased slowly and stabilized. The galloping oil price in the 70s has suddenly made expensive areas, such as the North Sea and the Gulf of Mexico, very profitable. Hence, OPEC's share of world production shrank. In 1974 and 1985 OPEC's share of world production was respectively 50 % and 28 % (BP, 2012).

OPEC's initial target was to help host governments to raise tax revenue from oil production (Hannesson, 1998). Today OPEC has the following objective:

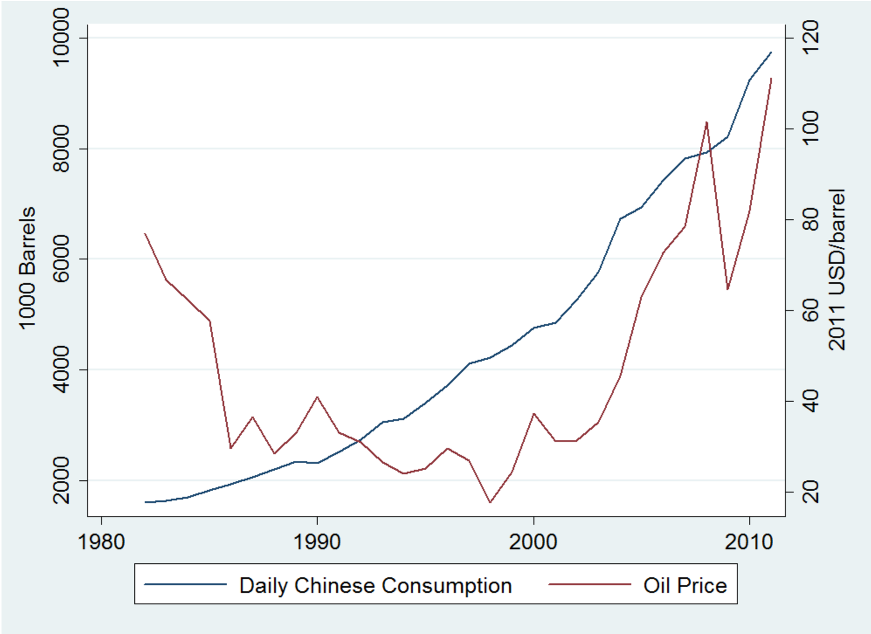
"OPEC's objective is to co-ordinate and unify petroleum policies among Member Countries, in order to secure fair and stable prices for petroleum producers; an efficient, economic and regular supply of petroleum to consuming nations; and a fair return on capital to those investing in the industry. (OPEC, 2013)".

Many nonmember states view OPEC as a cartel that destroys competition in the petroleum market and causes unbalance in the world economy. As stated in OPEC's objective, they want to control the price. In 2011 OPEC had 42 % of total world production and controlled 72 % of proven reserves (BP, 2012). So, OPEC's market power is rising and they can to a certain degree affect the world price (NPD, 2012) .

2.2.3.1 The 21st century

After 2003 the oil price increased rapidly until the financial crises in 2008. There are several factors to explain the dramatic increase. First of all, oil consumption has increased and especially in Asia. China is now the second largest consumer of petroleum products after the US (BP, 2012). Figure 7 shows the daily consumption in China and the real price of oil. The Chinese consumption has increased tremendously since 1980, and especially in the two latest decades. Because China is a huge market, the increased usage of petroleum pushes up the long term price.

Figure 7 Chinese Oil Consumption



Note: Brent Blend price. Source: BP (2012)

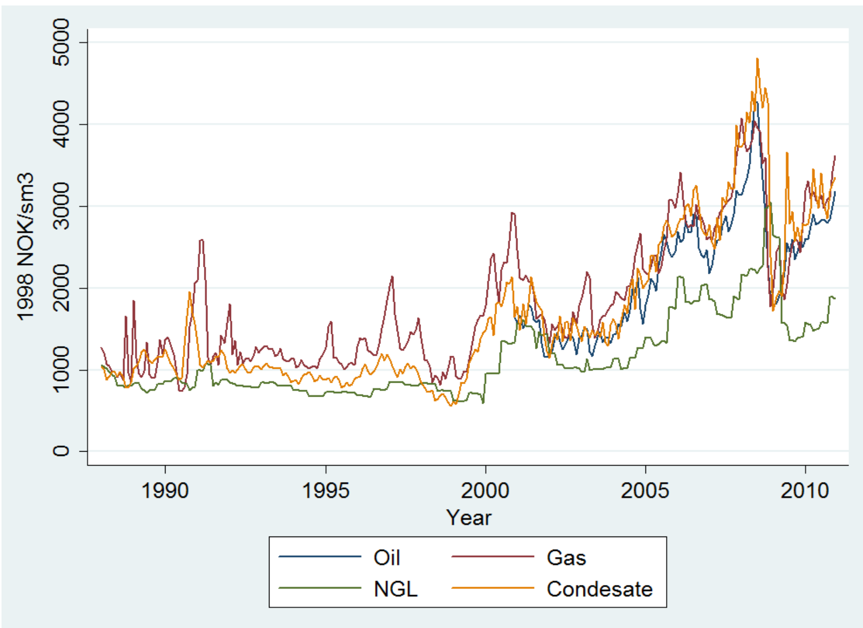
Secondly, modern oil production is more expensive. New petroleum resources are harder and more expensive to find and extract, such as deepwater offshore drilling, tar sand in Canada and shale gas in the US[5]. In the period 2000-07 development and finding costs increased by 70 % in real USD (IEA, 2008). Thirdly, petroleum is to a greater extent than before affected by movements in the financial markets (NPD, 2012). The world economy was boosting in until the summer of 2008. The price fall afterwards was dramatic. In six months the price fell from almost 150 to 40 USD/barrel (nominal). From 2009 the price increased again and stabilized around 100 USD/barrel.

[5] Tar sand refers to bitumen-impregnated sands that yield mixtures of liquid hydrocarbon. It requires advanced mechanical and chemical processing becoming finished petroleum products. Shale gas refers to natural gas that is trapped within shale formations. Shales are fine-grained sedimentary rocks that can be rich sources of natural gas. In the past decade new technology has made extraction economically possible for both (EIA, 2013).

2.2.3.2 The Norwegian Market

The prices for producers in Norway follow the same trend as the world oil price indexes, but there are some differences between products. In figure 8 I have plotted the average sales price of the 4 main product categories that are exported from the Norwegian continental shelf. The four products are Oil, Condensate, Natural Gas Liquids (NGL) and Natural Gas. The main difference between them is density. In the listed order oil is the heaviest and gas is the lightest. For the same volume unit oil carries more energy than gas.

Figure 8 Average Prices



Note: Based on monthly observations. Before 2001 Condensate and Oil statistics were not separated. Source: SSB (2013)

I have calculated the average sales price for producers in the Norwegian market based on SSB's export statistics from 1988-2010. Prices on different petroleum products follow the same trend, but there are some individual differences. The oil price is very similar all around the world because oil is fairly easy to transport. Gas is much more difficult to handle and transport. The majority of gas is transported in pipelines. The alternative is to liquefy the gas (LNG) and transport it in special tank ships, but that is very costly. Most of the Norwegian gas is transported in pipelines to central Europe. The difference between Oil and Gas price is in general small in Europe. In North America gas has historically been much cheaper than oil (BP, 2012).

3 Theoretical Framework & Previous Research

In economics investment is defined as the act of incurring an immediate cost in the expectation of future rewards (Dixit & Pindyck, 1994). The forward looking nature of investment behavior creates several issues for investment theories and empirical modeling. Expectations are unobserved and it is therefore challenging to find solid empirical evidence on investment behavior. There are several different investment theories and approaches to modeling.

Today's common perception of the investment and uncertainty relationship is that increased uncertainty reduces willingness to invest. Uncertainty is defined as deviation from the expected. However, from the early development of investment theory the sign of the relationship has been debated. Basic finance theory says that there is a tradeoff between uncertainty/risk and profits. One cannot have both low risk and high returns. An investor will demand compensation to take on risk. If risk increases, the investor will demand higher expected return on the investment. There are two possible implications of this. In uncertain conditions it is more difficult to know whether to expect a future reward or not. Uncertainty then decreases the desire to invest. At the same time, more uncertainty will possibly generate greater returns. Uncertainty could then increase the desire to invest. Thus, the effect of uncertainty on investment is regarded as a somewhat unresolved issue.

3.1 Previous Research

Some of the early contributions to investment theory emphasized the convexity of a profit function (e.g. Oi (1961) Hartman (1972) and Abel (1983)), and found empirical evidence for a positive effect of uncertainty on investments. Volatility can be exploited for profit seeking and indicates a positive effect of uncertainty on investment. Other early studies emphasized the option to wait (e.g. Cukierman (1980) , Bernanke (1983) and McDonald and Siegel (1986)), and found empirical evidence of a negative relationship. If an investment is postponed the investor may get better information to resolve the uncertainty aspects. The value of waiting will increase if uncertainty increases, indicating a negative effect on willingness to invest. Sandmo (1971) show how response to price uncertainty is dependent on risk tolerance. Relatively risk averse firms are more likely to postpone or drop an investment. From the early contributions to investment and uncertainty research it is not possible to find any consensus. The results are relying heavily on the assumptions of investment behavior.

The option methodology is most common in modern literature (e.g. Bloom *et al.* (2007), Leahy and Whited (1996) and Drakos and Konstantinou (2013)). Most investment decisions share three important characteristics. First of all they are partly or fully irreversible, meaning that a possible large fraction of the investment in sunk cost and cannot be utilized in any other form later on. Secondly, there is uncertainty connected to the investment's future payoff. Thirdly, timing is important and one has the option to postpone investments in search of more information and reduce uncertainty (Dixit & Pindyck, 1994).

Uncertainty aspects in the project development are the key factor to the investment timing. The option of waiting is an opportunity cost that affects the investment decisions. Both the opportunity to invest and the opportunity to wait have a certain value. An investment today generates an immediate expected cash flow. At the same time one gives up the opportunity to wait for more and better information about the project and market conditions. New information may change the timing aspect and the desirability to invest. However, if the investment is postponed (or dropped) today, the immediate cash flow is not generated.

3.1.1 Real Option Theory

To illustrate the concept of a real option I will in the following present a stylized example collected from Dixit and Pindyck (1994)[6]. The full mathematical treatment can be reviewed in Appendix A. Assume a basic irreversible investment option that requires a sunk investment cost and yields a future income value *V*.*V* includes all future income. *V* is assumed to be a stochastic process. A stochastic process is a variable that evolves over time in a way that is at least in part random, indicating that there is uncertainty connected to the future income (Dixit & Pindyck, 1994). More precisely *V* is assumed to evolve according to the following geometric Brownian motion

$$dV = \alpha V\, dt + \sigma V\, dz \tag{3.1}$$

Where *t* is the time, *dz* is a Wiener process[7] , σ is the represents the variance/uncertainty and α represents a drift/growth parameter. Equation (3.1) implies that the change in future income value, dV, is given by a growth and uncertainty parameter to the current known value of V.The current value of the

[6] The example is collected from chapter 5. For a richer theoretical explanation of real options the reader is advised to Dixit & Pindyck (1994), especially chapter 5 and 6.

[7] A Wiener Process - also called a standard Brownian motion – is a continuous-time stochastic process with three important properties. First, it is a Markov process, meaning that all predicted values of the variable depends only on its value today and thereby independent of previous values. Secondly, the probability distribution has independent increments, meaning that any interval Δz are independent of each other. Thirdly, change in the process over any finite time is normally distributed with a variance that grows linearly over any time interval. (Dixit & Pindyck, 1994)

project in known, but future values are lognormally distributed with a variance that grows linearly with the time horizon. I.e. a change in the logarithmic value of *V* is normally distributed. Information about *V* improves over time, but there is always some uncertainty related to future income.

The value of the option to invest is given by

$$F(V) = \max \mathrm{E}[(V_T - I)e^{-\rho T}] \tag{3.2}$$

Where *E* denotes the expectation, *I* is the sunk investment cost, *T* is the future time when the investment is made and ρ is the discount rate. For (3.2) to make sense it is assumed that $\alpha < \rho$. If not, the integral of (3.1) could be made infinitely large by choosing a larger *T*. Equation (3.2) maximizes the projects value, *V* , by investing at the right time. So, the decision of when to invest is decided by maximizing equation (3.2) with respect to time.

As there always is some uncertainty present for the future value of an investment, $\sigma > 0$. The problem is to determine the optimal *T* to invest given the expected uncertainty, σ. However, since *V* is defined as a stochastic process the optimal solution with respect to time cannot be solved. Hence, the investment problem is to find a critical value *V** where it is optimal to invest if $V \geq V^*$. The critical value is give by

$$V^* = \frac{\beta_1}{\beta_1 - 1} I \tag{3.3}$$

where $\beta_1 > 1$ and dependent on the parameters σ, ρ and α of the differential equation. The main implication from this result is; because $\beta_1 > 1$, the critical value $V^* > I$ and $\beta_1 / (\beta_1 - 1) > 1$. Thus uncertainty, growth and discount rate (represented by β_1 dependence on σ,α and ρ) drives a wedge between investment, I, and the optimal expected benefit value, *V**.The size of the wedge is given by $\beta_1 / (\beta_1 - 1)$.

Further it may be shown that the effect of increased uncertainty is negative;

$$\frac{\partial \beta_1}{\partial \sigma} < 0 \tag{3.4}$$

i.e. if uncertainty σ increases, β_1 decreases. Consequently, $\beta_1 / (\beta_1 - 1)$ increases. The wedge between I and V^* increases if uncertainty increases. An investor is therefore more likely to postpone or drop investments if uncertainty increases. The greater uncertainty, the higher expected return is required to make the investment. So, if uncertainty increases the willingness to invest decreases.

Resent theoretical literature has, however, questioned the negative effect of uncertainty in the real option perspective. Smit and Trigeorgis (2004) discuss traditional real option theory in a long term strategic perspective. By dropping or postponing an investment one gives up the opportunity of waiting, but also a possible future reward. The future reward consists of two parts, the expected income from the investment made today and the possibility to invest further in the next period. Investments often have a substantial strategic impact. The market develops over time and the value of being in position to invest in the next step is often undermined by traditional real option theory. In a competitive market there is a constant fight for positions. If the investor is very sensitive to uncertainty and do not invest, the possibility of losing competitiveness occurs. For this reason Smit and Trigeorgis (2004) argue that a positive relationship between investments and uncertainty is equally reasonable as a negative.

3.1.2 Further Empirical Findings

In sum, investment theory cannot give a clear answer to the effect of uncertainty on investment. Empirical research is historically incoherent, but in the past two decades the vast majority of empirical research finds a negative relationship. Nevertheless, there is still no strong consensus to a negative sign.

Bond *et al.* (2005) and Carruth *et al.* (2000) present a nice overview of historical contributions to investment and uncertainty research. For a further discussion on different studies on investment under uncertainty the reader is advised to these two papers. Some of the most influential studies the past two decades are Bloom *et al.* (2007) and Leahy and Withed (1996). Both studies document a significant negative relationship between investment and uncertainty. Because of irreversibility in investments, uncertainty increases the value of waiting, and thereby reduces the willingness to invest.

The impact of uncertainty may differ between industries. Ghosal and Loungani (2000) find a negative relationship, but industries dominated by small firms are more sensitive to uncertainty. The petroleum industry is dominated by large firms. Hence, a small negative impact of uncertainty may be expected. Drakos and Konstantinou (2013) investigate the effect of oil price volatility in the Greek manufacturing sector. They find that increasing oil price and increasing price uncertainty significantly reduce the likelihood of investment action. However, oil price represents an input factor for the manufacturing sector. The price effects may be different for petroleum producers.

There have been done a few empirical researches on investment and uncertainty specific to the petroleum industry. The results are inconclusive. Favero *et al*. (1992) investigate petroleum fields on the British continental shelf and conclude that uncertainty has a significant impact on delaying investments.

I.e. uncertainty has a negative effect on willingness to invest. Hurn and Wright (1994) also use data from petroleum fields in the North Sea and find that the price level has a positive effect while price uncertainty is insignificant. Mohn and Misund (2009) use worldwide data on publicly traded firms in the petroleum industry. They distinguish between financial market uncertainty measured by stock index volatility, and price uncertainty measured by oil price index volatility. Both measures of uncertainty are statistically significant, but have opposite signs. Price uncertainty has a positive effect on investments while financial uncertainty has a negative effect.

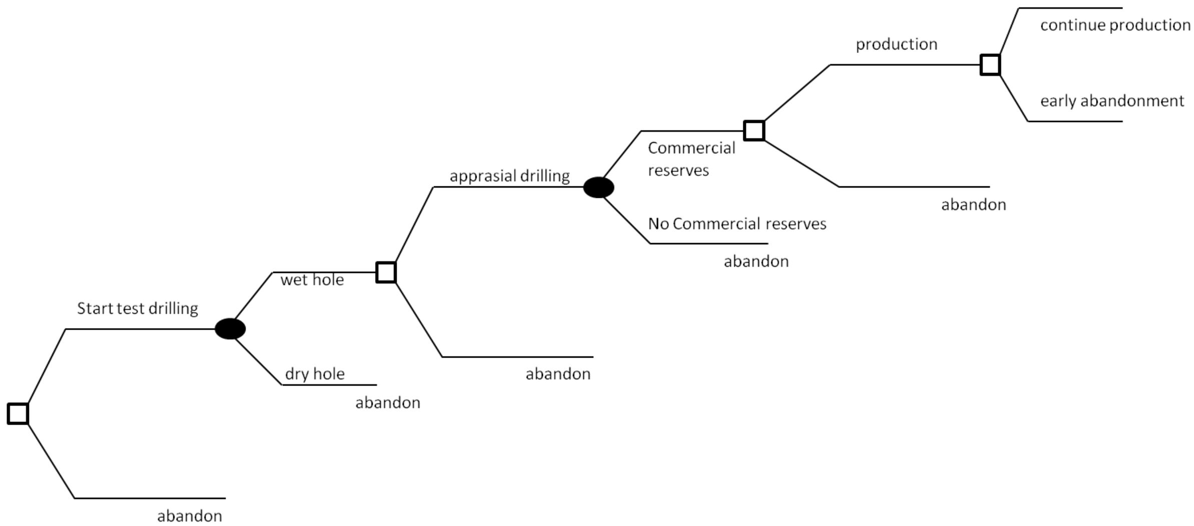
In total previous research gives no clear indication to what result I may expect from my empirical model. The most resent broad literature predicts a negative sign. However, the research specific to the petroleum industry is highly inconclusive.

3.2 Real Options in a Petroleum Investment

Development of a petroleum field may be viewed as a series of real options. A petroleum reserve represents an opportunity, but not an obligation to develop the field (Bjerksund & Ekern, 1990). The project must have a certain probability to be economically profitable. As the project develops outlooks on profitability may change. The value of postponing an investment might therefore be substantial. In general, an investment will not be made before the net benefit rise substantially above long run average cost (Dixit & Pindyck, 1994).

A petroleum fields development phases may be divided in three main parts; test drilling, appraisal drilling and production (Smit, 1997). Generalized there are two main sources of uncertainty; how much petroleum reserves that is in the ground and the market price. Figure 9 illustrates how the different phases and its connected options to proceed and uncertainties. Investors have to make decisions, illustrated by "□" in the figure. At the same time price and quantity uncertainties evolves over time, illustrated by "●" in the figure.

Figure 9 Real Options in a Petroleum Project



Source: Smit (1997)

To start test drilling there it must be probable to find significant petroleum reserves. An accumulation of oil and gas in the ground is called a reservoir. Companies study seismic surveying to allocate possible reservoirs. If it is likely that there will be significant oil resources in the ground, test wells are drilled or further accurate seismic is retrieved. Both are expensive investments. One can obtain much information by seismic, but one cannot know for sure if there is reserves in the ground before wells are drilled. Test drilling is aimed to ensure the finding of a reservoir.

When a reservoir is located by test drilling, further development must be planned in detail and reserves large enough for commercial production confirmed. The number of production wells that are drilled and their location is vital to maximize the depletion of the reservoir and profits. To decide on these questions several appraisal wells are drilled to acquire information.

If the proven reserves are large enough, production starts. The produced quantity increases fast in the beginning as more production wells are drilled. In the production phase there are many real option decisions. Commercial factors, such as sales price and production costs, are critical to the profits. When to start up and when to close down are key decisions. When a project is abandoned, there is no realistic possibility to open it again. Also, there are several investments that can be done along the way to increase production and the lifetime of the project.

When the production is shut down depends on several factors. A negative demand shock can make production unprofitable, extractable reserves may be less than expected or more expensive than expected. In addition there are high abandonment costs. If production is shut down, one is required by law to remove all equipment and plug all wells.

3.2.1 Sources of Uncertainty in a Petroleum Project

In this paper I only consider price risk in my model. Price volatility is a central uncertainty factor, but far from the only one. Bøhren and Ekern (1985) list 5 different sources of uncertainty in a petroleum project: reservoir, development, production, revenue and political risk.

Every reservoir has individual properties. One may get some pleasant or unpleasant surprises along the way. Volume and mixture of oil and gas may not be as expected. The mixture of oil and gas affects how much of the reservoir that can be economically extracted. In addition, gas is more difficult to handle. Gas requires more a sophisticated transport system. Development is difficult to plan because the information and characteristics of the reservoir may change as development evolves. When resources are extracted, reservoir pressure drops and makes it more difficult to extract the rest. The production profile and how much of the resources that can be extracted depend on previous actions. The consequence of productions choices to the reservoir structure are to some extent uncertain.

The revenue risk is largely based on the oil price movements. The oil price has historically been very volatile and represents a large fraction of the total uncertainty picture. Revenue risk is related to political risk. Many petroleum producing countries have unstable and/or undeveloped government. The greatest resources are located in the Middle East, which is known to be an unstable area of the world. Iran, Iraq and Syria are examples of countries that have been dominated by dictatorship and conflict for several decades. Also other large producers, such as Nigeria, Venezuela and Sudan, have large resources, but their governments are dominated by poor institutions, dictatorship and conflicts. Political instability can affect the supply of petroleum and thereby the price. There are several examples of how political risk affected the oil price, such as the OPEC I and II crises. Political uncertainty also includes regulations for producers. In countries with poor institutions regulation uncertainty may be considerable. The Norwegian political framework must though be regarded as very stable. The political risk for oil producers in Norway is low in terms of regulation. The main regulations have been more or less the same since the beginning.

3.3 Formation of Expectations

There are several theories of how expectations in economics are formed. The two most common are rational and adaptive expectations. Adaptive expectations say that expectations are dependent solely on events in the past (Evans & Honkapohja, 2001). Expectations will change by time and be affected by current events. E.g. if the oil price is plummeting today, expectations of future oil price will be degraded. In economic models adaptive expectations takes the form of a lag regime. The simplest assumption is the naive or static expectation

$$X_t^e = X_{t-1} \tag{3.5}$$

Where *X* is an economic variable (e.g. asset price, inflation or production), *t* is the time and X^e denotes the expectation *X*. The more sophisticated form of adaptive expectations can be written in the form

$$X_t^e = \alpha \sum_{i=0}^{\infty} (1-\alpha)^i X_{t-1-i} \tag{3.6}$$

Which is a distributed lag model with declining weights where $0 < \alpha < 1$. The most recent periods are most important in forming today's expectations.

Rational expectations say that the agents form their decisions on a rational outlook. The rational outlook is based on previous experience and all available information, assuming that all agents are fully informed (Evans & Honkapohja, 2001). If rational experience is true, all forecasting errors are random and the population prediction is equivalent to the actual future outcome. Random errors mean that there are no systematic over- or under-estimation in the expectation formation. The population will jointly *not* have a misperception of the market. To implement rational expectations some sort of lead formation or equilibrium modeling is required. The simplest version of rational expectation is modeled as perfect foresight where

$$X_{t+1}^e = X_{t+1} \tag{3.7}$$

Lag regimes in equilibrium modeling is another way to incorporate rational expectations, e.g. error correction or partial adjustment models. A growing literature on behavioral economics questions rational expectations. Agents are not always rational and are not necessarily fully informed. If they are irrational, their interpretation of market information may be incorrect. Hence, a systematic bias in expectations is possible. If rational expectations hold, one should not observe global meltdowns such as the financial crises in 2008. For a further discussion on behavioral economics the reader could look into Kahneman (2003).

3.4 Different Modeling Strategies

There are several possible modeling strategies for investment behavior. There are several ways to incorporate expectations of return and uncertainty. The fact that expectations are unobserved blurs the research. One has to make strong assumptions to how expectations of return and uncertainty are formed. The results may differ significantly depending on modeling strategy.

Investment models are characterized as dynamic. Dynamic models describe the relationship between variables for different points in time (Verbeek, 2012). An investment is made on expectancy of the future. These expectations may change depending on current and past events. Timing between the different variables is essential to get a correct understanding of the causal relationship between investment and explanatory variables. Historically there have been many different approaches to understanding investment spending. Chirinko (1993) offers an overview of different modeling strategies. The key elements that must be handled and is treated different between models are:

1. consistency of the theoretical model,
2. characteristics of the technology,
3. treatment of expectations, and
4. the impact of investment spending of prices, quantities and shocks
   (Chirinko, 1993)

Chirinko (1993) divides investment models into two main categories, explicit and implicit. The difference relates to how dynamics are included in the model. For an explicit model the dynamic variables are directly included in the optimization problem for the optimal investment and estimated coefficient are directly connected to the underlying expectation parameter. Implicit models to not include dynamics directly and expectations are therefore static. Implicit models discussed by Chirinko are neoclassical models, vector autoregressive (VAR), effective tax rate and return over cost models. Modern research finds explicit models more useful. Explicit models give better understanding of adjustments to changes in expectations by including relevant parameters directly in the model. Modern investment theory is focused around the opportunity to invest and the opportunity to hold back. Explicit models more suited to capture the instant changes to both opportunities. Hence, I will not go into more detail on implicit models.

Explicit models in Chirinko's overview include Tobin's q, Euler-equation and Direct Forecasting. They are all based on that changing the capital stock has a cost. The difference between these models is the treatment of expectations. Tobin's q model is one of the most popular models in empirical investment research. q is defined as the ratio of market value of capital and the value to replace it (Tobin, 1969).The intuitive interpretation of q is; the marginal market value of one unit capital relative to its replacement cost is the driver for investment. The firm will invest as long as the market value of invested capital is greater than the investment (replacement) cost. Tobin's q model uses information from financial markets to define expectations. However, the market value of assets is not always easy to observe. Empirical studies often rely on companies traded on public stock markets. In Stock markets one observes the market value of a company and its assets. In addition volatility of the stock price is a direct indicator of uncertainty.

Much of the resent research (e.g. Bloom *et al.* (2007) and Mohn and Misund (2009)) use some version of the q model where the investment rate, $\left(\frac{investment}{total\ capital}\right)$, is modeled as the dependent variable and the optimal investment rate. The q model implies equilibrium for the investment rate, which the firm will eventually reach. The principle that the investment rate will converge against equilibrium and any diversion from the equilibrium is short term, assumes rational expectations. Partial adjustment or error correction modeling is commonly used in the q model framework. They are both autoregressive distributed lag (ADL) models. An ADL model means that both lagged versions of the dependent variable and other (possibly lagged) explanatory variables are included. An ADL model without the equilibrium modeling assumes adaptive expectations.

The firm's total capital value is also used in Euler-equation and direct forecasting model. They both implement a lead structure and thereby an extreme version of rational expectation. If lead variables are included, perfect foresight is assumed.

Expectation of return on investment its uncertainty is in any case unobserved. Good proxy variables[8] are therefore needed to make the empirical model believable. Assumptions on how expectations are made and how variables are quantified may have a significant effect on the results.

[8] A proxy variable control for an unobserved variable that should be include in the analysis. If not included, the analysis might suffer from an omitted variable bias. The proxy variable needs to be closely related to the unobserved effect (Wooldridge, 2009)

3.5 Quantifying Uncertainty

Financial uncertainty is typically measured by some volatility measure. The underlying variable may vary based on available data and modeling purpose. An uncertainty measure ideally captures both time and individual specific effects. Volatility of directly observed variables, such as firm stock price, is most common in resent literature (e.g. Bloom et al. (2007) and Leahy and Withed (1996)). Stock price volatility captures the individual specific effect of each firm over time. The beauty of the stock price volatility is that the movement of the stock price reflects future expectations of the firm’s performance. The stock price move by the markets aggregated expectation. That is very useful in an investment analysis where future expectations of return and uncertainty are the key explanatory variables. Volatility of other directly observed variables, such as sales or cost, may also be used. These will also capture individual effects.

If individual specific effects are irrelevant, volatility of macroeconomic indicators can be used as uncertainty measure, e.g. GDP or price indexes. Drakos and Konstantinou (2013) measure oil price index uncertainty. First they calculate monthly return on the oil price. Then they measure a forecast of the conditional standard deviation for 12 months by a GARCH(1,1) model[9]. The annual average of the forecast is used as an uncertainty measure.

Another possible approach is to us the volatility of a profit, price, sales or cost forecast as an uncertainty measure. Ghosal and Loungani (1996) measure the uncertainty of a price forecast, and Ghosal and Loungani (2000) use a profit forecast measured as $\frac{sales\ revenue - variable\ cost}{sales\ revenue}$. They assume adaptive expectations and measure an autoregressive (AR) model with a linear trend to get a forecast. Uncertainty is measured as the standard deviation of the residuals in the forecast model.

[9] Generalized Autoregressive Conditional Heteroscedasticity (GARCH) is a common application in forecasting time series volatility. See for example Enders (2010) for more information.

4 Data

The data is an unbalanced panel data set from 84 petroleum fields on the Norwegian continental shelf. All together there are 1139 annual observations. Petroleum fields are organized as joint ventures and each field has a unique ownership structure. The operator of each joint venture reports to NPD, so "petroleum field" serves well as a panel variable. A panel data set contains several observations from the same individual (in this case petroleum field) over time. The advantage of panel data versus cross sectional or time series data is that it allows for constant differences between the individuals. A model that control for individual effects gives more efficient and realistic estimations of economic relationships (Verbeek, 2012). The data is collected from the NPD and SSB in the period 1988-2010. The minimum, average and maximum numbers of observations for each field are 2, 14 and 23 All data input is inflation adjusted by SSB's consumer price index to 1998 NOK. Appendix D offers some descriptive statistics.

My dependent variable is *investments* per field and collected from NPD .NPD only offers annual observations of investments and the rest of my data is therefore fitted to annual observations. From NPD I also collected annual observations of *variable costs.* Both investments and variable costs are reported in million NOK.

I also need an income measure per field as driver for investment, but I have no direct observations of s*ales revenue*. Sales revenue is estimated from average sales prices in SSB's export statistics and multiplied by production data (per field) from NPD. Both price and production data are available for the main product categories; Oil, NGL, Gas and Condensate. Thus, sales revenue picks up income variation between fields caused by the product mix. The sales revenue estimation is done on monthly data, then summarized and merged together with the annual investment and variable cost data. The fact that I do not have direct observations of sales opens the possibility for measurement bias. However, as my approximation is specified for each product each month, it should be a minor problem.

The investment and production data available in the NPD database only includes oil fields where there is, or is planed, production. Fields that are abandoned before production has started are not included. So, my data can only give an indication of the relationship between investments and uncertainty in successful fields. Figure 9 in section 3.2 I illustrated the different phases of a petroleum project. My dataset can only indicate further investments in the production phase. However, the data set includes observations for the selected fields before production started and sufficient reserves were proven.

Below in Table 1 observations for the field Grane are displayed as an example of typical development for a petroleum field and the data characteristics.

Table 1 Grane Observations

Year	Investments (Mill NOK)	Sales Revenue (Mill NOK)	Variable Costs (Mill NOK)	Production (Mill Sm3)
1999	87.00	0.00	0.00	0.00
2000	869.00	0.00	74.00	0.00
2001	3299.00	0.00	152.00	0.00
2002	5200.00	0.00	152.00	0.00
2003	2537.00	1231.96	395.00	0.75
2004	746.00	13802.56	464.00	7.09
2005	710.00	27017.81	534.00	10.31
2006	829.00	39136.06	630.00	12.61
2007	1052.00	38227.78	658.00	11.99
2008	989.00	40667.36	681.00	10.04
2009	1097.00	30572.72	655.00	10.72
2010	1170.00	35135.72	743.00	9.65

As Table 1 shows, it takes long time to develop a petroleum field for production. In this case there were heavy investments for four years before it actually generated an income. I will only use the observations from where the field starts to produce. In the Grane example from 2003. First of all, I need observations of sales revenue to create a driver for investments when using a lag structure. Consequently, all observations before production started are excluded in my estimated models. Secondly, there is a sample selection bias in the data. The dataset only includes successful fields. Early investments, in the test and appraisal drilling phase (before 2003 for Grane), for fields that eventually was *not* developed for production, are not included in the dataset. Hence, the data may only be used to investigate fields *in production*. I started with 1139 observations from 84 fields, but because of the sample selection bias and needed lag structure I can only utilize about 520 observations from 57 fields in my estimated models.

The data example illustrate some important features of the offshore petroleum industry. Payoff from investments and development of a field is a slow process. In addition offshore installations require massive investments, but the payoff is potentially very large. Given the complexity of developing an oil field investment decisions are likely to be made long before the investment is executed. Hence, Investments decisions are made quite some time before the actual investment cost appears in the data and even longer before the companies can expect revenue on the investment. Timing between the variables is therefore essential to construct a believable empirical model.

5 Econometric Model

In my data I have no collection of firms accounting value or market value. I investigate joint venture's connected to specific petroleum fields. There is no collected market value or accounting value for these. Hence, I cannot implement a q model, Euler-equation or direct forecasting to my data.

I assume adaptive expectations in my model. Rational expectations are in my opinion a too strong assumption. Investment in the petroleum industry depends on factors that are hard to predict. The oil price is moving up and down by factors that are highly unpredictable, such as imperfect competition, international conflicts and speculation bubbles. To assume that agents in the petroleum industry somewhat jointly forecast future outcomes seems implausible. Hence, I will not use an error correction or partial adjustment model. Though, I will use an ADL model.

My starting point is the following dynamic panel data model, where *i* represents each petroleum field and *t* represents the time (year).

$$\mathrm{invest}_{\mathrm{i,t}} = \beta_0 + \beta_1\,\mathrm{invest}_{\mathrm{i,t-1}} + \beta_2\,cf_{i,t-2} + \beta_3 sd_{i,t-2} + a_i + \gamma_t + u_{i,t} \qquad (5.1)$$

$$where\ t = 1,2,3 \ldots .T$$

$\mathrm{invest}_{\mathrm{i,t}}$ is the natural logarithm of annual investment in million 1998 NOK. $cf_{i,t}$ is the natural logarithm of cash flow in million 1998 NOK measured as; sales revenue – variable costs. $sd_{i,t}$ is the price uncertainty. a_i represents the field specific effects and γ_t is time specific effects represented by year dummies in the model. $u_{i,t}$ is the idiosyncratic error term.

I choose to transform both investments and cash flow to a logarithmic scale for the sake of more desirable interpretation. By log-transforming the relationship may be interpreted as elasticities. An interpretation in 1998 NOK is harder to relate to than relative percentage movements.

Investments in the petroleum industry are likely to be correlated from one year to another (Mohn & Misund, 2009). Investment projects often stretch out over several years. If an investment project is started today, a commitment for several years is often necessary. The petroleum industry is characterized by huge projects and it is therefore plausible to observe investment dynamics. I have therefore included lagged investment, $\mathrm{invest}_{\mathrm{i,t-1}}$, as an explanatory variable. I am mainly interested in the causal effects of uncertainty and cash flow on investment. Lagged investment indicates correlation, but not causality to a new investment. However, I must include lagged investment as an explanatory variable to control for the dynamics and get a believable estimation of the cash flow and uncertainty parameters. The dynamics in $\mathrm{invest}_{i,t}$ introduces some modeling difficulties, which I will come back to in section 5.3.

5.1 Driver for Investment and Timing

Since I only use data from where the field has started to produce, it makes sense that the resent performance of the field is a driver for further investment. Cash flow captures the short time profit and today's performance. Cash flow indicates both the cost and revenue level. Increasing revenue, decreasing variable costs and increasing volume all give a better cash flow. If the field is making nice profits today it is more attractive to invest further to make an even larger profit. Cash flow is the best indicator for the field specific performance in my data. Revenue varies with macro price movements and the mixture of oil and gas in the reservoir. Variable cost indicates how complicated the field is to operate. A relatively large variable cost indicates a complicated reservoir.

Other functional forms of "drivers for investment" could be relevant for the model. A first differenced term of sales revenue or cash flow would capture the movement trend. Increasing sales revenue would indicate an upward trend in income and be positive for willingness to investment. Also, there might be nonlinearity in cash flow, and a squared term could be appropriate. Nevertheless, neither the squared nor first differenced term turns out significant in my model and is therefore excluded. However, the weak significance may be an effect of a relatively small sample size.

The investment decision is made before the investment cost appears in the data set. Timing between the variables is therefore essential to get a believable model. Offshore petroleum investment is a slow process. Before a field stats to produce there are often investments for several years. Offshore investment requires massive planning. First, offshore installations are huge and needs a lot of different contributors when changes are going to be made. In addition there are capacity constraints on everything. The fact that the installation is lying in the middle of the ocean complicates planning and execution of a project. Number of beds, available personnel and equipment are examples of issues. For that reason I have lagged cash flow and uncertainty by two periods. That indicates that investment decisions are made two years before the investment is executed.

5.2 Price Uncertainty

There is no stock price connected to joint ventures in the petroleum sector. However, the current and historical ownership of the licenses are publicly available. An alternative approach could therefore be to use companies instead of joint ventures as a panel variable. Then I would have to split income, cost and investments for each field between the owners. However, there are two core problems to such an approach. First, few of the owners on the Norwegian shelf are registered on the Norwegian stock market. To get a license on the Norwegian shelf one must start a subsidiary in Norway, but very few register on the stock market. If I then use the company's stock market value, it would reflect the company's performance in the whole world and not exclusively on the Norwegian shelf. Secondly, the field specific heterogeneity would then not be captured. The uncertainty would reflect each company's ownership portfolio. So, stock prices are not an option for my estimations.

I want to use an uncertainty measure that captures both time and field specific effect. I got both sales revenue and variable cost observations for each field I my dataset. I could therefore use the approach in Ghosal and Loungani (2000) by estimating the volatility of a profit forecast. However, I only have annual observations of variable costs. The standard deviation in Ghosal and Loungani (2000) is based on the past 5 years. A standard deviation based on 5 observations is not very believable. My best option to measure uncertainty is therefore to look solely on price volatility.

I use the volatility of a simple price forecast as an uncertainty measure, based on Ghosal and Loungani (1996). By only looking at price uncertainty I can use monthly data instead of annual to measure volatility. The oil price varies significantly within the year. A price uncertainty measure based on annual observations would not give a realistic picture of the price volatility. I use average sales price from the Norwegian shelf based on SSB's export statistics to calculate the price volatility. The observations are adjusted for inflation to 1998 NOK.

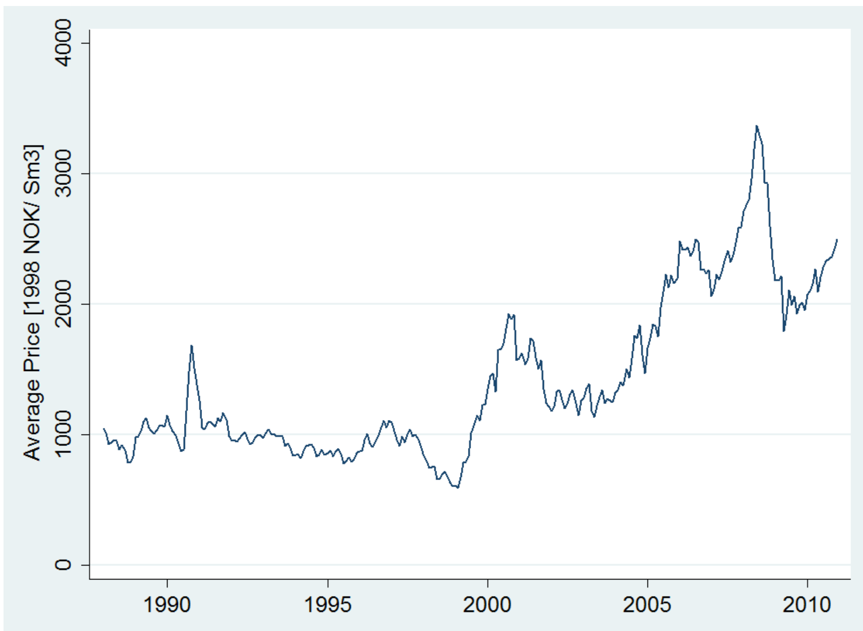
The oil price is known to be quite volatile and a large fraction of the total uncertainty is captured by the sales price. Petroleum products are homogenous and sold in the same market. The market price is the same for each joint venture. However, there are differences in the price between products (see figure 8 in chapter 2), and every petroleum field has its own mixture of petroleum products. Oil is in general valued more than gas. Therefore I will calculate the average sale price for each field. It is essential to my panel data model to have a field specific uncertainty measure to control for heterogeneity between fields. If I had used the same price for all fields the efficiency of the model would shrink. If the price uncertainty only varied with time it would also pick up other time specific effects. I will use a full set of year dummies to control for time specific effects that is common to all fields. If the price only varied with time and not the panel variable, the dummies and the price uncertainty would measure some of the same effects, resulting in a less efficient model.

5.2.1 Stationarity and Logarithmic Transformation

I will in the following present a simple price forecasting equation where I use the standard deviation of the residuals as my uncertainty variable. There are several issues to modeling a time series variable such as price. Price data is likely to be non stationary and a transformation into logarithmic first difference may be appropriate (Ghosal, 1996).

To evaluate the stationarity and growth properties I will look at a weighted average of the four main products as price variable. The average price is displayed in Figure 10 below.

Figure 10 Average Price on the Norwegian Shelf



Note: Based on monthly data. Weighted average between Oil, Condensate, NGL and Gas. Source: SSB (2013)

There is some variability of the price level between products. However, the price follows the same trends. I believe that an exponential growth rate of the price is more plausible than a linear given Figure 10. A linear growth pattern will increase or decrease at a constant amount, while an exponential growth pattern will increase by multiplying the previous observation by a constant factor. The variability in growth from one year to another indicates an exponential growth pattern in this case. Hence, the price variable is transformed to logarithmic scale

$$p_m = \ln(P_m) \tag{5.2}$$

where P is the price in 1998 NOK in and *m* is the time (months). By log-transforming a percentage change for a “high” price gives the same effect to the uncertainty as for a “low” price.

The price series, logarithmic or not, is clearly nonstationary. Stationarity is an important assumption when dealing with time series variables. A stationary process is such that the mean variance and covariance of the residual is constant over time (Verbeek, 2012). Visually a stationary process is “mean reverting”; that is moving over its own mean frequently. Mean reversion is clearly not the case in Figure 10. If the series is nonstationary, regressions might be spurious. A spurious regression will indicate a significant relationship between variables when there in reality is none (Verbeek, 2012).

Stationarity of time series may be tested with a Dickey-Fuller test (Dickey & Fuller, 1979). Figure 10 indicates a growing trend over time and a constant term. Hence, I first perform the Dickey-Fuller test with trend and a constant on p_m. Dickey-Fuller tests the null hypotheses “non stationary”. p_m fails to reject H_0 with a p-value of 0.4. Further I first difference p_m to see if the process is integrated of order one (I[1]), i.e. whether Δp_m is stationary. Δp_m rejects H_0 with a p-value of zero. p_m is then I[1]. Consequently, I use Δp_m in the price forecast. Δp_m is interpreted as the continuous *monthly* return of the price. The Dickey-Fuller tests and a figure of Δp_m can be reviewed in Appendix B.

Uncertainty is in this case defined as deviation from the expected price. I assume that the joint ventures use a simple AR forecasting model with a time trend and two lags to predict the price

$$\Delta p_{i,m} = \alpha_0 + \alpha_1 m + \alpha_2 \Delta p_{i,m-1} + \alpha_3 \Delta p_{i,m-2} + \varepsilon_{i,m} \quad (5.3)$$

$$m = 1,2,3 \dots M$$

Further I collect all the residuals, $\varepsilon_{i,m}$. Uncertainty is calculated as the estimated standard deviation, $\sigma(\varepsilon_{i,m})$, for the past three years, i.e. the past 36 months.

$$sd'_{i,m} = \sigma(\varepsilon_{i,m}, \varepsilon_{i,m-1}, \dots \ \varepsilon_{m-35}) \quad (5.4)$$

For the sake of a more desirable interpretation I transform the price uncertainty to *annual* percentage point[10].

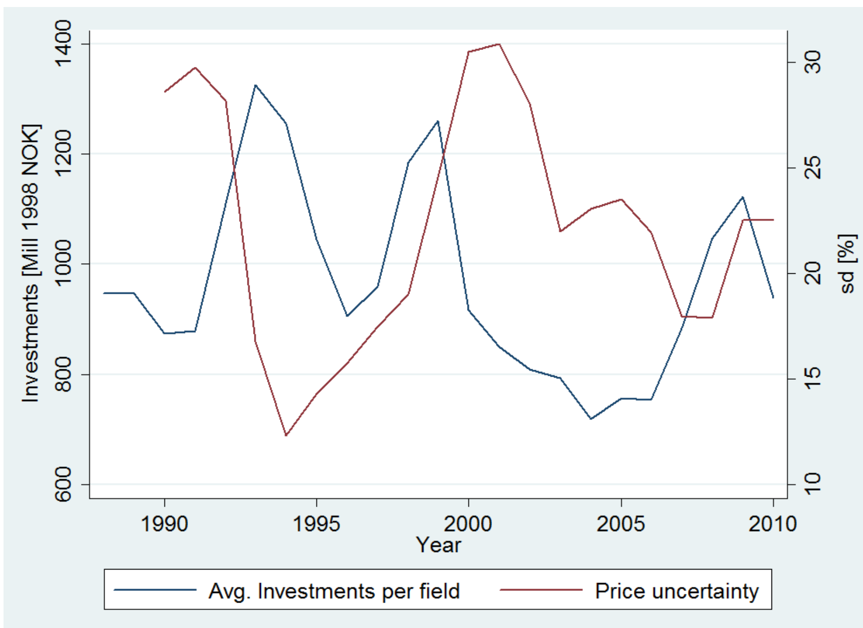
$$sd_{i,m} = 100 * \sqrt{12} * sd'_{i,m} \quad (5.5)$$

[10] Return and volatility is commonly referred to in annual terms in finance. Annualizing standard deviation by multiplying with $\sqrt{12}$ assumes independence; i.e. no covariance between months. Independence is a simplifying assumption, but well suited for interpreting purpose.

To merge the monthly data with my annual investment and sales data I use the December observation each year. Ghosal and Loungani (2000) and (1996) measure the standard deviation over 5 years. I use 3 years for the sake of keeping more observations. By using 3 years instead of 5 I keep 2 more annual observations for each field. Also, I do not believe that a 5 year perspective of uncertainty is very different from a 3 year perspective for petroleum prices.

Figure 11 shows the calculated average price uncertainty against average investments per field on the Norwegian shelf[11].

Figure 11 Investments vs. Price Uncertainty



Note: Uncertainty calculated as in equation (5.5) on average price for all fields. Uncertainty is lagged two periods in accordance to the model in equation (5.1). Sources: NPD (2013) *and SSB (2013)*

It is not possible to spot a clear relationship between price volatility and investment from this figure. Before 1999 price and average investments seems to be positively correlated. In the periods 1999-2003 it looks negative. From 2003-2007 it is positive again and turning negative in the period 2007-2010. In total, there are a large amount of years after 1999 that indicate a negative relationship, while it is positive before 1999. Because of the possible shift in correlation I will look into whether the effect of uncertainty is different after 1999 in my model. I will do that by including an interaction term consisting

[11] The figure is made on the time series of price, which is displayed in figure10. There are some individual heterogeneity caused by field specific product mix. The field specifics will be included in my econometric models. However, the trend is the same and Figure 11 gives a nice overall picture.

of a dummy after 1999 and uncertainty; $sd_{i,t-2}\gamma_{1999+}$. Figure 11 is, though, a rough indication. One should be careful to interpret such a figure for casual effect. There are other factors besides price uncertainty that effect the investment decision.

It is also worth pointing out that a spiking as well as a dropping price gives large standard errors in the price forecast. For example around 2000 the oil price was high and increasing rapidly. Uncertainty is here defined as diversion from the expected. In the theoretical real option model I established the rule that a critical expected value of a project in decisive for whether an investment is made today or postponed. If the price is high, volatility will intuitively have less effect on the investment decision because the investors expect a great profit no matter what. Because the oil price in the period 1988 -2010, where I have collected my data, has had a upward sloping trend, it is believable that the price uncertainty has been more critical to investment decisions in the beginning of the period.

5.3 Estimation Techniques

Because I have a panel data set, a traditional Ordinary Least Squares (OLS) without controlling for the field specific effect will be biased (given that the field specific effect is significant). OLS estimation violates the zero conditional mean assumption by including a_i in the error term. In addition OLS and the standard panel data estimators (First Difference, Fixed Effects and Random Effects) will be biased because of the AR(1) specification of investment (Bond, 2002). For my panel data specification in equation (5.1) to be consistent the zero conditional mean assumption in (5.6) must hold; for all time periods, the expected value of the idiosyncratic error given the explanatory variables is zero. If the assumption holds the model is strictly exogenous. If not, there is an endogeneity problem.

$$E\left(u_{i,t} \middle| \mathrm{invest}_{\mathrm{i,t}}, cf_{i,t}, sd_{i,t}, \gamma_t, a_i\right) = 0 \tag{5.6}$$

$$t = 1,2 \ldots T$$

A consistent estimator means; if the model is specified correctly the estimate converges to the true coefficient as the sample size goes to infinity (Hansen, 1982). Because of dynamics in investment, a standard panel data estimator violates the zero conditional mean assumption and is biased. Hence, I must use an instrumental variables (IV) method to cope with the endogeneity. A more detailed explanation of the dynamic bias is included in Appendix C.

By instrumenting $\mathrm{invest}_{\mathrm{i,t-1}}$ the zero conditional mean assumption in (5.6) may hold. Both the Anderson-Hsiao and GMM estimator is *consistent* under the appropriate conditions (Verbeek, 2012). These estimators cannot in any case be unbiased, but the endogeneity problem is reduced. Hence, Anderson-Hsiao and GMM will give a better indication on the relationship between investments and uncertainty. The idea that today's observations are strongly correlated with observations in the near past, but uncorrelated with observations further in the past. Defined as an AR(1) process[12]:

$$corr(\mathrm{invest}_{\mathrm{i,t}}, \mathrm{invest}_{\mathrm{i,t-1}}) \neq 0 \quad and \quad corr(\mathrm{invest}_{\mathrm{i,t}}, \mathrm{invest}_{\mathrm{i,t-2}}) = 0 \tag{5.7}$$

$\mathrm{invest}_{\mathrm{i,t-2}}$ may then serve as an instrument for $\mathrm{invest}_{\mathrm{i,t-1}}$. Instruments must fulfill two requirements:

1. Relevance $corr(\mathrm{invest}_{\mathrm{i,t-1}}, \mathrm{invest}_{\mathrm{i,t-2}}) \neq 0$
2. Exogeneity $corr(\mathrm{invest}_{\mathrm{i,t-2}}, u_{i,t}) = 0$ (5.8)

The relevance may easily be tested, while the exogeneity requirement cannot be directly tested. To fulfill the exogeneity requirement the instrument, $\mathrm{invest}_{\mathrm{i,t-2}}$, should not have a partial effect on the dependent variable.

If it is believe that today's observations only are correlated with observations one period in the past and not further back, the exogeneity requirement is fulfilled. If so, the zero conditional mean assumption holds. For an AR(1) process of investment;

$$E(\mathrm{invest}_{\mathrm{i,t-2}}\, u_{i,t}) = 0 \tag{5.9}$$

and the exogeneity requirement is fulfilled. The question is then whether it is believable that investment is an AR(1) process. Table 2 shows a relevance test in column (1). In column (2) I have added a further lagged variable of investments, to see whether it has a partial effect on the dependent variable.

[12] Note that I am talking about the *direct* autocorrelation coefficient, often called the partial autocorrelation. For an AR(1) model, the autocorrelation between $\mathrm{invest}_{\mathrm{i,t}}$ and $\mathrm{invest}_{\mathrm{i,t-n}}$ will be ρ^n since $corr(\mathrm{invest}_{\mathrm{i,t-1}}, \mathrm{invest}_{\mathrm{i,t-2}}) = \rho$ .The autocorrelation function for an AR(1) decays exponentially with ρ^n and the partial autocorrelation function will die after one lag (Enders, 2010)

Table 2 Instrument Requirements

	(1) $\text{invest}_{i,t-1}$	(2) $\text{invest}_{i,t-1}$
$\text{invest}_{i,t-2}$	0.196***	0.216***
	(0.008)	(0.006)
$\text{invest}_{i,t-3}$		-0.0827
		(0.131)
No. observations	527	517

Note:FE estimates robust to heteroscedasticity
*p-values in parentheses. * p < .1, ** p < .05, *** p < .01*
Included but not reported variables: $cf_{i,t-2}$, $sd_{i,t-2}$,
a full set of year dummies, constant

The instrument, $\text{invest}_{\text{i,t}-2}$, is highly significant when defined as an AR(1) process in column (1), and serves well as an instrument concerning relevance. In column (2) I have added $\text{invest}_{\text{i,t}-3}$ to the regression, i.e. defining investments as an AR(2) process. It does not have a significant effect on $\text{invest}_{\text{i,t}-1}$. Investment only seems to be significantly correlated one year back. In other words, $\text{invest}_{\text{i,t}-2}$ has no partial effect on $\text{invest}_{\text{i,t}}$ and the exogeneity requirement is fulfilled. This is not a statistical *proof*, but insignificance of the AR(2) term gives an indication of exogeneity, and thereby justifies using an AR(1) specification of the instrument.

5.3.1 Anderson-Hsiao

Anderson-Hsiao is a first differenced two stage least square IV-estimator (Anderson & Hisao, 1982). By transforming the variables in first difference the unobserved field specific effect is removed. I.e. if equation (5.1) is first differenced, a_i disappears;

$$\Delta\text{invest}_{\text{i,t}} = \beta_1\, \Delta\text{invest}_{\text{i,t}-1} + \beta_2\, \Delta cf_{i,t-2} + \beta_3 \Delta sd_{i,t-2} + \underbrace{(a_i - a_i)}_{=0} + \Delta\gamma_t + \Delta u_{i,t} \qquad (5.10)$$

A least square estimate to equation (5.10) would then not violate the zero conditional mean assumption by including a_i in the error term. Further I use $\Delta\text{invest}_{\text{i,t}-2}$ as an instrument for $\Delta\text{invest}_{\text{i,t}-1}$ to deal with the endogeneity caused by dynamics in investment; $\Delta invest_{i,t-1} = \Delta invest_{i,t-2} + e_{i,t}$. It is possible to use the instrument in both level and difference form, and it may affect the efficiency of the estimation. One should in general choose the most efficient instrument (Arellano, 1989). Typically the level instrument is preferred to maximize the sample size. $\Delta invest_{i,t-2}$ is not available before *t = 3*, while $invest_{i,t-2}$ is available at *t =2* (Roodman, 2009). Nevertheless, in my case the difference instrument gives the most efficient estimates.

Assuming that $corr(\Delta \text{invest}_{\text{i,t}-2}, \Delta u_{i,t}) = 0$, Anderson-Hsiao is strictly exogenous and thereby consistent. In addition it is assumed that the idiosyncratic error term is independent and identically distributed (IID). Hence, Anderson-Hsiao imposes the following moment condition for *T* time periods

$$E \sum_{t=3}^{T} \Delta invest_{i,t-2} \Delta u_{i,t} = 0 \quad (5.11)$$

A moment condition is a restriction to the model in terms of expectations. The moment condition is used to identify the unknown parameters in the model; $\beta_1, \beta_2 \, and \, \beta_3$ in equation (5.1) (Verbeek, 2012). Basically, the estimation is fitted as close as possible to zero for the moment condition.

6.3.2 GMM

The Generalized Method of Moment (GMM) estimator also uses lagged observations as instruments to cope with endogeneity problems caused by dynamics. GMM is frequently used in the literature on investment and uncertainty (e.g. Bloom et al. (2007), Bloom (2009) and Mohn and Misund, (2009)). The main difference between Anderson-Hsiao and GMM is that GMM imposes several moment conditions, while Anderson-Hsiao only imposes one. The additional moment conditions give some extra advantages. It is known that imposing more moment conditions increases the efficiency of the estimation, given that the conditions are relevant, exogenous and free of second order autocorrelation (Roodman, 2009).

There are many possible versions of a GMM estimator. At first GMM usually was a two-step linear model (e.g. Arellano and Bond (1991)), estimated in first difference to deal with bias caused by a_i. However, the first difference GMM procedure performs poorly on dynamic panel data with a moderately small *T* (Blundell & Bond, 1998). As I have a quite small *T* (maximum observations for one field is 23) I use a one-step system GMM to increase the efficiency of the estimator as proposed in Blundell and Bond (1998). The one step estimator implies the assumption of homoscedasticity while a two step estimator is robust to heteroscedasticity. The one step estimator is however popular in empirical research. Simulation models indicate small efficiency gains from a two step estimator, even in presence of severe heteroscedasticity (Bond, 2002).

Field specific effects are not removed for a system GMM (as it is not first differenced), but instruments that are considered to be uncorrelated with a_i are used. A system GMM uses instruments both in first difference and level form. Endogenous variables in level are instruments in difference, and endogenous variables on difference form are instrumented in level (Arellano & Bover, 1995). I.e. I use $\Delta invest_{i,t-2}$ as an instrument for $invest_{i,t-1}$.

It is possible and common to use several instruments on one endogenous variable. However, by including more instruments there might be an overidentification of restriction problem. By adding several instruments more moment conditions are added to the model. Some of the instruments may be weak. In general one is better off with few strong instruments than many weak ones. Especially in small samples, such as mine, overidentification may lead to biased results (Blundell & Bond, 1998). For the simplicity of the model and to avoid any weak instrument problem I will only use $\Delta invest_{i,t-2}$ as instrument and not further lags.

The moment conditions for GMM exploit the imposed orthogonal restrictions for every *i* and *t.* For my specification, with only one instrument for each period and assuming IID errors, the moment conditions are as in equation (5.12). $\mathrm{invest}_{\mathrm{i,t}}$ is for illustration purpose defined as $\mathrm{y}_{\mathrm{i,t}}$ The rows of the instrument matrix, Z_i, represent the main model from equation (5.1) in period 3, 4 … T.

$$E(Z_i' \, u_i) = 0 \qquad for \ i = 1,2, \dots N \tag{5.12}$$

where $$Z_i = \begin{bmatrix} \Delta y_{i,1} & 0 & 0 & \dots & 0 \\ 0 & \Delta y_{i,2} & 0 & \dots & 0 \\ . & . & \ddots & \dots & 0 \\ 0 & 0 & 0 & \dots & \Delta y_{i,T-2} \end{bmatrix} \quad \text{and} \quad u_i = (\, u_{i,3}, \, u_{i,4}, \dots \, u_{i,T})'$$

The one step GMM estimator minimizes the criterion

$$J_N = \left(\frac{1}{N}\sum_{i=1}^{N} Z_i' \, u_i\right) W_N \left(\frac{1}{N}\sum_{i=1}^{N} Z_i \, u_i{}'\right) \tag{5.13}$$

where W_N is a weight matrix. The weight matrix for a one step estimate is

$$W_N = \left[\frac{1}{N}\sum_{i=1}^{N}(Z'{}_i HZ)\right]^{-1}$$

where *H* is a *(T-2)x(T-2)* matrix of the form

$$H = \begin{bmatrix} 2 & -1 & 0 & \cdots & 0 \\ -1 & 2 & -1 & \cdots & 0 \\ 0 & -1 & 2 & \cdots & 0 \\ \cdots & \cdots & \cdots & \cdots & . \\ 0 & 0 & 0 & \cdots & 2 \end{bmatrix}$$

The empirical results could differ to some extent by the choice of instrument matrix, Z_i , in equation (5.12) and whether a one or two step weight matrix is used. For a general theoretic discussion on GMM, I recommend Bond (2002), Blundell and Bond (1998) and Arellano and Bover (1995).

6 Results

Table 3 shows the suggested model in equation (5.1) for OLS, Fixed Effects (FE), Anderson-Hsiao and GMM estimators presented in the previous chapter. I estimate robust standard errors for all thee estimators. A robust standard error is a valid estimator in the presence of any kind of heteroscedasticity (Wooldridge, 2009). Hence, the reported p-values are based on heteroscedasticity-robust standard errors. The GMM standard errors are also robust to autocorrelation within fields.

Table 3 Results

	(1) OLS	(2) Fixed Effects	(3) Anderson-Hsiao	(4) GMM	(5) GMM
	$invest_{i,t}$	$invest_{i,t}$	$invest_{i,t}$	$invest_{i,t}$	$invest_{i,t}$
$invest_{i,t-1}$	0.642***	0.201***	0.424*	0.332*	0.366*
	(0.000)	(0.005)	(0.085)	(0.065)	(0.077)
$cf_{i,t-2}$	0.307***	-0.011	0.318	0.580***	0.535**
	(0.000)	(0.903)	(0.151)	(0.001)	(0.010)
$sd_{i,t-2}$	-0.013	-0.004	-0.091**	-0.043**	-0.021
	(0.268)	(0.805)	(0.019)	(0.047)	(0.190)
$sd_{i,t-2} * \gamma_{1999+}$					-0.074
					(0.378)
Constant	-0.108	3.862***	-1.759**	-0.335	1.217
	(0.799)	(0.003)	(0.013)	(0.656)	(0.637)
Overidentification (p-value)				0.704	0.536
Autocorrelation AR(1)	0.032	0.000	0.002	0.002	0.002
Autocorrelation AR(2) (p-value)	0.316	0.000	0.543	0.543	0.536
No. observations	522	522	452	520	520
No. groups	-	57	-	57	57

*Note: p-values in parentheses. * $p < .1$, ** $p < .05$, *** $p < .01$. A full set of year dummies is included in all specifications.*
OLS and Fixed Effects estimates robust to heteroscedasticity
Anderson-Hsiao: fist differenced estimates robust to heteroscedasticity
$\Delta invest_{i,t-1}$ instrumented with $\Delta invest_{i,t-2}$
GMM: One step system GMM estimates robust to heteroscedasticity and autocorrelation within panels (fields). $invest_{i,t-1}$ instrumented with $\Delta invest_{i,t-2}$
Overidentification : Sargan- Hansen test as in Hansen (1982). H_0: no overidentification problem
Autocorrelation: Arellano-Bond test for OLS, Anderson-Hsiao and GMM as introduced by Arellano and Bond (1991). Arellano-Bond test is not appropriate for FE. For FE a standard linear AR(2) regression is preformed on the idiosyncratic error term. The given p-values refer to a standard t-test of the coefficients. H_0: no autocorrelation
Programmed for STATA.11. Syntax included in Appendix E

The OLS does not control for field specific effects, a_i. FE controls for the field specific effect. Anderson-Hsiao and GMM control for the field specific effect and instruments are used on $invest_{i,t-1}$ to control for dynamic panel bias. The difference number of observations is due to different estimation techniques. Naturally the first difference procedure in Anderson-Hsiao consumes more observations than the level estimates for OLS, FE and GMM. Number of groups is the number of petroleum fields that is included and adjusted for. For Anderson-Hsiao the field specific effect disappears by first differencing. Thus, no adjustment for field specific variation is done. OLS does not adjust for field specific effects.

All specifications show a positive correlation between today's investment and previous investments. The $invest_{i,t-1}$ coefficient may be interpreted as an elasticity, as the variable is on logarithmic form. All others equal, if investment increased by 1 % last year, it will increase by 0.33 % this year, according to the GMM estimator in column (4). However, it makes no sense to interpret this result as causal. It simply shows path dependence and commitment to investment projects. Whether to invest or not in the first place, is determinate by expectations of profits and uncertainty, which in this model is represented by cash flow and price volatility. $invest_{i,t-1}$ is highly significant for the OLS and FE model, while the effect is diminishing when I introduce instruments in the Anderson-Hsiao and GMM estimation. For the instrumented variables approaches investments is only significant on a 10 % level. Nevertheless, concerning the relatively small sample size, I believe 10 % is an acceptable significance level. These results confirm my expectations. There is time dependence in investment.

Both the OLS and FE estimation must be regarded as biased. In addition to the dynamic bias caused by $invest_{i,t-1}$, OLS includes the field specific effect in the error term. By including a_i in the error term the zero conditional mean assumption is violated, making the OLS estimates heavily biased. The dynamic bias is visible in the FE results. Lagged investments block the effect of cash flow and uncertainty. $invest_{i,t-1}$ is the only significant variable. There are no indicated relationship between investment and uncertainty nor investments and performance levels represented by cash flow. It is not plausible that neither explain investments. When I control for the dynamic bias in Anderson-Hsiao and GMM, both cash flow and uncertainty are significant. OLS and FE coefficient for $invest_{i,t-1}$ still have an interesting interpretation. Estimates on autoregressive variables in panel data tend to be downward biased for FE and upward biased for OLS (Bond, 2002). FE gives a lower limit for the true coefficient of $invest_{i,t-1}$ while OLS gives an upper limit. That indicates that the true coefficient for $invest_{i,t-1}$ is greater than 0.20 but less than 0.64. Both Anderson-Hsiao and GMM estimates of $invest_{i,t-1}$ fits to this interval.

Both Anderson-Hsiao and GMM are regarded as consistent estimates. The difference of Anderson-Hsiao and GMM is a matter of efficiency. The estimated coefficients have the same sign and the magnitude is quite similar, but the significance of the GMM is better than the Anderson-Hsiao estimator. For GMM both uncertainty and cash flow is significant on a 5 % level. For Anderson-Hsiao uncertainty is significant on a 5 % level, while cash flow is insignificant even on a 10 % level. My GMM results are the most trustworthy.

The price uncertainty and cash flow coefficients are interpreted as causal effects. Assuming adaptive expectations previous observations of cash flow and uncertainty will be decisive for a new investment decision. Both cash flow and investments are on logarithmic form, and may therefore be interpreted as elasticities. Everything else equal, a 1 % increase in cash flow will cause a 0.58 % increase in investment, according to my GMM estimator in column (4). This result is in accordance to real option theory and adaptive expectations. If the performance of the field is improving, either by increasing prices, lower costs or greater volume, the willingness to invest further in the field increases. The maximization problem of real options says that one needs a certain expected return to invest. The expected return of the field is increasing if performance is improving.

Price uncertainty is measured as a standard deviation of a continuous return adjusted to percentage point. The interpretation of the coefficient is; a 1 % point increase in uncertainty/standard deviation will decrease investment by 0.04 % ceteris paribus according to my GMM in column (4). The sign is negative, as predicted by real option theory. The value of waiting increases when uncertainty increases. In uncertain conditions it is harder to form a clear expectation of return. Willingness to invest thereby decreases if price uncertainty increases. An investor will use the waiting option to get better information and see how the market evolves.

Both GMM in column (4) and Anderson-Hsiao predict a significant negative relationship between price uncertainty and investment. Some may find this relationship hard to believe for the petroleum industry. In the period 1988 – 2010 the oil price has had a long term increasing trend and been booming on several occasions. The price uncertainty is also increasing when the price is booming, not only when the price is dropping. If the price is booming, it is plausible that the willingness to invest should increase and not decrease. Some may therefore argue that a positive relationship is more plausible than a negative, for the petroleum industry in the period 1988-2010. However, it is important to evaluate the model as a whole. In my model price level is captured by cash flow. If one consider the scenario of a price boom. A high price increases cash flow and thereby willingness to invest. Uncertainty picks up the natural skepticism of a boom; how long will it last? In the scenario of a stable price, the standard deviation parameter is small and gives a relatively small contribution to the investment decision.

The included year dummies will capture much of the time specific effects of investment, cash flow and uncertainty. The dummies capture variation between years that is common to all joint ventures. Hence, unobserved macro economic shocks and trends in the given time period are captured by these dummies. If the uncertainty or cash flow parameter changes a lot from one year to another, the effect will mostly be picked up by the dummies. Hence, my uncertainty measure shows response to "normal" price volatility between years and fields. The price uncertainty between fields is related to the product mix in the reservoir.

In column 5 I look into whether there has been a change in response to price uncertainty in the period 1998-2010. The interaction term $sd_{i,t-2}\gamma_{1999+}$ captures any general change in response to uncertainty. The interpretation is as follows: Before 1999 the uncertainty coefficient is -0.021, while -0.021 + -0.074 = -0.095 after 1999. However, neither $sd_{i,t-2}\gamma_{1999+}$ nor $sd_{i,t-2}$ is significant alone. The joint coefficient of -0.095 is also insignificant with a p-value of 0.23. In total I find no significant change in response to uncertainty after 1999, and uncertainty as a whole seems insignificant when I split the period. The low significance could be affected by the year dummies. The included time dummies pick up variation between years. Thus, I have tried to run the model with the interaction term, but without time dummies. However, excluding the dummies results in a less efficient model and I therefore keep them in the regression in column (5).The fact that uncertainty as a whole turns out insignificant when the interaction term is introduced weakens my result. In column (3) and (4) I find a significant effect of uncertainty, but it disappears in column (5). Nevertheless, the weak significance is likely to be an effect of the small sample size. It is more difficult to separate effects of different parameters in a small sample. When I introduce the interaction term, the uncertainty parameter is included twice and causes lower significance, even though it is included in a different functional form. Conclusively, I still believe that there is a significant negative effect of price uncertainty based on column (3) and (4). There are individual differences between fields and between years, but the overall trend show a negative response in investments when price uncertainty increases.

6.1Robustness

I have added two model specification tests. One test for autocorrelation for all specification, and one test for overidentification of restrictions in GMM. Neither the Anderson-Hsiao nor GMM estimations are bothered with an autocorrelation problem. The used Arellano-Bond test for autocorrelation in Anderson-Hsiao and GMM has a first difference approach. Because $\Delta u_{i,t}$ is mathematically related to $\Delta u_{i,t-1}$ in the joint $u_{i,t-1}$ term, first order autocorrelation of the residuals is expected (Roodman, 2009). I am therefore only interested in the second order autocorrelation. The high p-values for AR(2) autocorrelation indicate no autocorrelation problem. Sargan-Hansen test for overidentification check whether the added instruments are uncorrelated with the field specific effects in GMM. That is the main criteria for a system GMM. The test's high p-value indicates no overidentification problem. Hence, a system GMM is an appropriate estimator.

It is important to highlight that my results cannot be generalized to other industries or all investment decisions in the petroleum industry. My data is only fields *in production.* I only look at one specific investment scenario; whether to expand and invest further in an already producing field. The decision to stat up a field in the first place may show a different relationship to price uncertainty. Price uncertainty is likely to be a smaller fraction of the total uncertainty in the early stages of a petroleum project. Uncertainty of volume potential is the main uncertainty factor before a field has started to produce. When a field is in production there is a lot more knowledge of the reservoir potential. Hence, price uncertainty represents a greater fraction of the total uncertainty for an established field.

Empirical studies find varying results for both sign and magnitude of uncertainty's effect on investments. The opportunity to hold back investments and risk appetite differs between industries. Every industry has its own characteristics of capital structure and market conditions. If a firm has no opportunity to hold back further investments due to large sunk cost, the value of waiting is low. The petroleum industry is extremely capital intensive relative to other industries. The capital cost of existing will not be affected by changes in uncertainty. For negative uncertainty shocks one has to do business as usual to minimize the damage. Nevertheless, negative shocks will strongly affect *new* investments for a capital intensive industry such as petroleum.

7 Concluding Remarks

In this paper I have discussed the implications of uncertainty to an investment decision. I look into the specific scenario; whether to invest further in an already producing petroleum field. Investments are based on expectations of future profits. I assume adaptive expectations and find a positive correlation between the field's performance, measured by cash flow, and investments. If a fields performance is improving, either by increasing prices, lower costs or greater volume, the willingness to invest further in the field increases.

Previous research does not give a strong consensus on the relationship between investments and uncertainty. The sign and magnitude varies between studies. Uncertainty makes it difficult to establish a clear expectation of future profitability, but may also be exploited for profit seeking. The price has historically been quite volatile. Price uncertainty is a major uncertainty factor for petroleum producers.

Petroleum extraction is a complicated, slow and expensive process. A petroleum project typically stretches over long period of time. Investments are therefore correlated between years. This correlation complicates the estimation. Standard panel data estimators are biased and I therefore use instrumental variable methods. I explore both Anderson-Hsiao and GMM estimator. GMM is more efficient than Anderson-Hsiao and therefore most trustworthy of the two.

When I control for dynamic panel bias, my estimations show a significant negative effect of uncertainty on investments. In a situation of increased uncertainty, a new investment is more likely to be dropped or postponed. The specific properties to each petroleum field are different and each joint venture would respond different to increased uncertainty. However, the overall trend is a negative effect of uncertainty on willingness to invest.

There are numerous versions of GMM and the estimated result may differ depending on how the instruments are specified. It could be worth exploring other GMM estimators in future work. I use adaptive expectations in my model. A model assuming rational expectations could give different results and be worth looking into. Another issue in my model is how uncertainty is measured. A study including other uncertainty measures could be of interest.

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Appendix

A) Real Option Maximization Problem

The future income value of the option to invest evolves according to the following geometric Brownian motion

$$dV = \alpha V\, dt + \sigma V\, dz \tag{A.1}$$

Where t is the time, *I* is a sunk investment cost and *dz* is a Wiener process, σ is the represents the variance/uncertainty and α represents the drift/growth parameter. The value of the option to invest is given by

$$F(V) = \max \mathrm{E}[(V_T - I)e^{-\rho T}] \tag{A.2}$$

Where *E* denotes the expectation, *T* is the future time when the investment is made and ρ is the discount rate. For (A.2) to make sense it is assumed that $\alpha < \rho$. If not, the integral of (A.1) could be made infinitely large by choosing a larger *T*. Equation (A.2) maximizes the projects value *V* by investing at the right time. So, the decision of when to invest is decided by maximizing equation (A.2) with respect to time.

As there always is some uncertainty present for the future value of an investment; $\sigma > 0$. The problem is to determine when the right time *T* to invest given the expected uncertainty σ. However, since *V* is defined as a stochastic process the optimal solution with respect to time cannot be solved. Hence, the investment problem is to find a critical value *V** where it is optimal to invest if $V \geq V^*$. This investment problem may be solved in two ways; either by cointegrated claims analysis or by dynamic programming. I present the latter.

By using Ito's Lemma[13] it can be shown that the following differential equation, that must be satisfied by *F(V),* solves the maximization problem in equation (A.2)

$$\frac{1}{2}\sigma^2 V^2 F''(V) + \alpha V F'(V) - \rho F = 0 \tag{A.3}$$

In addition *F(V)* must satisfy boundary conditions

$$F(0) = 0 \tag{A.4}$$

[13] Ito's Lemmas is widely used application in calculus of a stochastic process in continuous time.

$$F(V^*) = V^* - I \tag{A.5}$$

$$F'(V^*) = 1 \tag{A.6}$$

Condition (4) must hold in order to satisfy that if *V* goes to zero, it will stay at zero, which is an implication of the stochastic process in (1).Obviously, there will be no investment if the future benefit of investing is zero. Hence, the value of the option to invest *F(V)* is zero if *V=0*. Condition (5) is the "value matching condition". It states that the firm will receive a net payoff if invested at the critical expected value V*. Condition (6) is a "smooth pasting condition". The "Smooth pasting condition" says that if *F(V)* were not continuous and smooth at the critical exercise point V*, one could be better off exercises the option at a another time.

To find *F(V)* equation (A.3) must be solved with respect to the (A.4)-(A.6) conditions. To satisfy (A.4) the solution must be on the form

$$F(V) = AV^{\beta_1} \tag{A.7}$$

Where *A* is a constant and $\beta_1 > 1$ and dependent on the parameters σ, ρ and α of the differential equation.

Condition (A.5) and (A.6) can then be used to define V* and A. By substituting (A.7) into (A.5) and (A.6) and rearranging one gets

$$V^* = \frac{\beta_1}{\beta_1 - 1} I \tag{A.8}$$

and

$$A = \frac{V^* - I}{(V^*)^{\beta_1}} = \frac{(\beta_1 - 1)^{\beta_1 - 1}}{{\beta_1}^{\beta_1}\, I^{\beta_1 - 1}} \tag{A.9}$$

The main implication from this result is that since $\beta_1 > 1$, $V^* > I$ and $\beta_1 / (\beta_1 - 1) > 1$. Hence, uncertainty, growth and discount rate (represented by β_1 dependence on σ,α and ρ) drives a wedge between investment, *I*, and the optimal expected benefit value *V*.*The size of the wedge is given by $\beta_1 / (\beta_1 - 1)$.

Since I am mainly interested in the effect of uncertainty in this paper, I only discuss the effect of σ on the wedge further. To determent the effect of σ on *V** one must examine the differential equation in (A.3) in more detail. Equation (A.3) is linear in the dependent variable *F(V)* and the general solution of the differential equation may therefore be expressed as a linear combination of any two independent solutions. AV^{β} satisfies as a general solution of (A.3) given that β is a root of the following quadratic equation

$$\frac{1}{2}\sigma^2\beta(\beta-1)+\alpha\beta-\rho=0 \tag{A.10}$$

The two roots are

$$\beta_1=\frac{1}{2}-\frac{\alpha}{\sigma^2}+\sqrt{\left[\frac{\alpha}{\sigma^2}-\frac{1}{2}\right]^2+\frac{2\rho}{\sigma^2}}\ >\ 1 \tag{A.11}$$

$$\beta_2=\frac{1}{2}-\frac{\alpha}{\sigma^2}+\sqrt{\left[\frac{\alpha}{\sigma^2}-\frac{1}{2}\right]^2+\frac{2\rho}{\sigma^2}}\ <\ 0 \tag{A.12}$$

Then the general solution may then be written as

$$F(V)=A_1V^{\beta_1}+A_2V^{\beta_2} \tag{A.13}$$

where A_1 and A_2 are constants to be determined.

To get an economic interpretation concerning the size of the wedge with respect to σ I look closer into the quadratic expression in (A.10). I only focus of the positive root β_1. The left hand side of equation (A.10) is defined as *Q*. Q is dependent on the parameter β as well as ρ, σ and α. Hence, equation (A.10) may be written as

$$\frac{\partial Q}{\partial \beta}\frac{\partial \beta_1}{\partial Q}+\frac{\partial Q}{\partial \sigma}=0 \tag{A.14}$$

where all derivatives are valued at β_1. At $\beta_1>1$ the derivative of Q with respect to σ is

$$\frac{\partial Q}{\partial \sigma}=\sigma\beta(\beta-1)>0 \tag{A.15}$$

thus

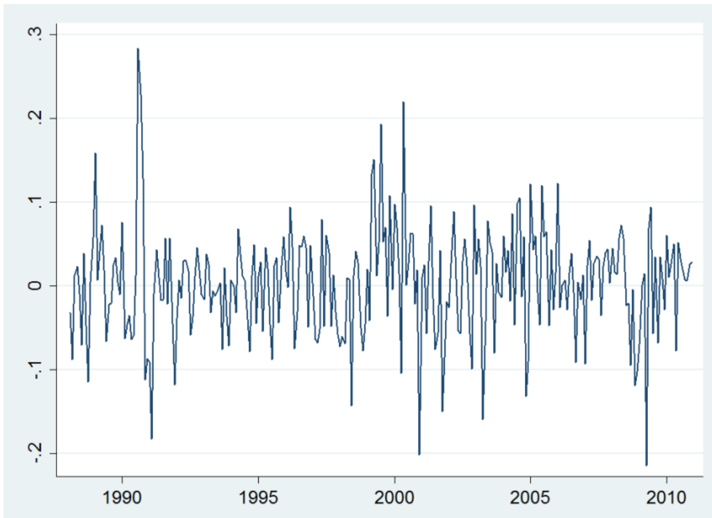
$$\frac{\partial \beta_1}{\partial \sigma}<0 \tag{A.16}$$

i.e. if uncertainty σ increases, β_1 decreases. Consequently, $\beta_1/(\beta_1-1)$ increases. The wedge between I and V^* increases if uncertainty increases.

B) Stationarity of Price

Figure 12 shows the series Δp_t. It clearly looks mean revering and the trend and constant (obviously) disappears when the series is first differenced. Consequently I have not included trend and constant in my Dickey-Fuller test of Δp_t. Dickey-Fuller is based on the regression in Table 4 below. The t-value of the lagged tested variable is the Dickey Fuller test statistic. H_0: “non stationary time series”.

Figure 12 First Differenced Price Series



Note: Based on monthly data. Source: SSB (2013)

Table 4 Dickey-Fuller Test

	Level	**First Differeice**
	Δp_t	Δp_t
Δp_{t-1}		-0.836***
		(-14.01)
p_{t-1}	-0.0375**	
	(-2.38)	
Trend	0.0002**	
	(2.29)	
$Constant_t$	0.247**	
	(2.35)	
Dickey-Fuller:		
Test statistic	-2.38	-14.01
p-value	0.392	0.000

*Note:t-values in parentheses. * p < .1, ** p < .05, *** p < .01*
Critical Values for Dickey-Fuller: -3.989 (1%), -3.429 (5%) -3.130 (10 %).

C) Dynamic Panel Bias

An Ordinary Least Squares (OLS) without controlling for the field specific effect a_i is likely to be biased. The unobserved field specific effect will then be included in the error term. If it is significant the zero conditional mean assumption will be violated[14]. A panel data model controls for the unobserved field specific effect. There are three basic panel data models; Fixed Effects (FE), Random Effects (RE) and First Difference (FD). The estimators have some different properties. FD is less efficient than a FE estimator. RE is more efficient than FE, but assumes that a_i is uncorrelated with all other explanatory variables. No correlation between a_i and explanatory variables is hard to prove. Because the FE model allows for arbitrary correlation between a_i and other explanatory variables, it is often regarded as more trustworthy and preferred to the RE model (Verbeek, 2012). I will only consider FE.

My suggested model (from (5.1)) is

$$\mathrm{invest}_{\mathrm{i,t}} = \beta_0 + \beta_1\,\mathrm{invest}_{\mathrm{i,t-1}} + \beta_2\, cf_{i,t-2} + \beta_3 sd_{i,t-2} + a_i + \gamma_t + u_{i,t} \qquad \text{(C.1)}$$

$$where\ t = 1,2,3 \ldots .T$$

The FE model removes the field specific effect by transforming the data. The field mean is subtracted from the model in equation (C.1). The field mean may be written as

$$\overline{\mathrm{invest}}_{\mathrm{i}} = a_i + \beta_1\,\overline{\mathrm{invest}}_{\mathrm{i}} + \beta_2\,\overline{cf_i} + \beta_3\,\overline{sd}_i + \bar{u}_i \qquad \text{(C.2)}$$

By subtracting (C.2) from (C.1) the field specific effect is removed, resulting in

$$\mathrm{invest}_{\mathrm{i,t}} - \overline{\mathrm{invest}}_{\mathrm{i}} = \beta_1\left[\,\mathrm{invest}_{\mathrm{i,t-1}} - \overline{\mathrm{invest}}_{\mathrm{i}}\right] + \qquad \text{(C.3)}$$

$$\beta_2\left[cf_{i,t-2} - cf_{\mathrm{i}}\right] + \beta_3\left[sd_{i,t-2} - \overline{sd_i}\right] + \gamma_t + \left[u_{i,t} - \bar{u}_i\right]$$

When estimating the FE model it is equation (C.3) that is estimated.

[14] Without controlling for a_i the cross sections (fields) would be pooled leaving only the time dimension under the assumption that $E(a_i|X_{t1}, X_{t2} \ldots X_{tk}) = 0$ .Assumptions to get unbiased (Pooled) OLS estimates of time series: 1) The true model can be written as $y_t = \beta_0 + \beta_1 X_{t1} + \beta_2 X_{t2} \ldots \beta_k X_{tk} + u_t$. 2) No perfect collinearity. 3) Zero conditional mean; $E(u_t|X_{t1}, X_{t2} \ldots X_{tk}) = 0$. (Wooldridge, 2009). If a_i is not controlled for it is included in the error term u_t. i.e. if $E(a_i|X_{t1}, X_{t2} \ldots X_{tk}) \neq 0 \quad \rightarrow \quad E(u_t|X_{t1}, X_{t2} \ldots X_{tk}) \neq 0$

Under assumptions similar to OLS assumptions FE estimates is unbiased [15]. The main consideration in this case is whether FE is *consistent*; if the model is specified correctly the estimate converges to the true coefficient as the sample size goes to infinity (Hansen, 1982). For FE to be consistent the zero conditional mean assumption must hold; for all time periods, the expected value of the idiosyncratic error given the explanatory variables is zero. If the assumption holds the model is strictly exogenous. If not, there is an endogeneity problem.

$$E\left(u_{i,t} \middle| \text{invest}_{\text{i,t}}, cf_{i,t}, sd_{i,t}, \gamma_t, a_i\right) = 0 \tag{C.4}$$

$$t = 1,2 \ldots T$$

However, my model is dynamic in investment, and a FE estimation will therefore biased. Today's investments are likely to be Autoregressive (AR). In my model I have defined investments as an AR(1) process by including on lagged dependent variable.

Strict exogeneity from equation (C.4) has the following implication to the transformed equation in (C.3)

$$\text{Cov}\left(\text{invest}_{\text{i,t}-1} - \overline{\text{invest}}_{\text{i}}, u_{i,t} - \bar{u}_i\right) = 0 \tag{C.5}$$

though;

$$\underbrace{\text{E}\left(\text{invest}_{\text{i,t}-1} u_{i,t}\right)}_{=0} - \underbrace{\text{E}\left(\text{invest}_{\text{i,t}-1} \bar{u}_i\right)}_{\neq 0} - \underbrace{\text{E}\left(\overline{\text{invest}}_{\text{i}}\, u_{i,t}\right)}_{\neq 0} + \underbrace{\text{E}\left(\overline{\text{invest}}_{\text{i}} \bar{u}_i\right)}_{\neq 0} \neq 0 \tag{C.6}$$

Hence, for FE estimation on dynamic panel data the transformed dependent variable will be correlated with the transformed error term. FE is then endogenous and therefore biased (Bond, 2002).

If both $T \to \infty$ and $N \to \infty$ FE will be consistent (Verbeek, 2012). However, both the time frame and number of fields are fixed and quite small in this case.

[15] Assumptions for unbiased FE estimates: 1) The true model can be written as $y_t = \beta_0 + \beta_1 X_{1i,t} + \beta_2 X_{2i,t} \ldots \beta_k X_{ki,t} + a_i + u_{i,t}$. 2) Random sample from cross sections. 3) Each explanatory variable changes over time (for at least some i) and no perfect linear relationship exists among the explanatory variables. 4) Zero conditional mean; $E\left(u_{i,t} \middle| X_{1i,t}, X_{2i,t} \ldots X_{ki,t}, a_i\right) = 0$. (Wooldridge, 2009).

D) Descriptive Statistics

Table 5 Regression Variables Summary

	Variable	Mean	Std. Dev.	Min	Max
Full dataset	$invest_{i,t}$	5.454	2.079	-0.645	9.763
	$cf_{i,t}$	7.932	1.722	-0.052	11.822
	$sd_{i,t}$	28.933	11.218	13.042	100.857
Year < 1999	$invest_{i,t}$	5.028	2.378	-0.645	9.763
	$cf_{i,t}$	7.500	1.760	-0.052	10.719
	$sd_{i,t}$	30.907	18.793	13.042	100.857
Year ≥ 1999	$invest_{i,t}$	5.647	1.898	-0.253	9.495
	$cf_{i,t}$	8.169	1.653	0.707	11.822
	$sd_{i,t}$	27.978	5.221	13.467	59.866

Table 6 Raw Data Summary

	Variable	Mean	Std. Dev.	Min	Max
Full dataset	Investments	811.673	1461.639	0.000	17371.060
	Variable Costs	531.982	645.746	0.000	4995.025
	Sales	8879.269	14577.040	0.000	137890.800
	Cash Flow	8347.287	14226.420	-466.670	136236.500
Year < 1999	Investments	764.474	1812.708	0.000	17371.060
	Variable Costs	563.285	792.978	0.000	4995.025
	Sales	6085.871	9156.945	0.000	48046.130
	Cash Flow	5522.586	8543.424	-466.670	45195.470
Year ≥ 1999	Investments	835.976	1243.875	0.000	13296.190
	Variable Costs	515.864	554.990	0.000	2716.695
	Sales	10317.590	16519.060	0.000	137890.800
	Cash Flow	9801.727	16217.800	-26.540	136236.500

Note: Numbers in mill 1998 NOK

E) STATA Syntax

The following syntax is used for estimated regressions in table 3.

```
* Variables Explanation*
        * id = field identification
        * invest = ln of real investments in mill NOK
        * cf = ln of real cash flow in mill NOK
        * sd = Annualized 3 year standard deviation of ln and first differenced price forecast
        * D = year dummies
        * sd_after1999 = interaction term between dummy after 1999 and sd

* Declaring panel data set
xtset id year

* OLS
reg invest l.invest ll.cf ll.sd D* , robust

* FE
xtreg invest l.invest ll.cf ll.sd D* , robust fe cluster(id)

* Anderson-Hsiao
ivreg d.invest (dl.invest = dll.invest) dll.ln_cf dll.sd D* , robust

* GMM
        *column (4)
xtabond2 invest l.invest ll.cf ll.sd D*, gmm(invest, eq(diff) lag(2 2)) iv( cf sd D* ) robust artests(5) h(3)
        *column (5)
xtabond2 invest l.invest ll.cf ll.sd ll.sd_after1999 D*, gmm(invest, eq(diff) lag(2 2)) iv( cf sd sd_after1999 D* )
robust artests(5) h(3)
```