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Pernille Parmer, Steinar Strøm, Helge Sandvig Thorsen, Inger Ubbe, Bjørnar Andreas Kvinge

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Investments on the Norwegian Continental Shelf – An Empirical Analysis

Abstract

Investments in oil and gas fields are regressed against variables on panel field-data from the start of oil and gas production on the Norwegian continental shelf in 1968 until 2016. Two alternative models track the observed investments aggregated across fields from 1970 until 2016 relatively accurately, except for the period 2012-2015. These years were marked by an almost world-wide recession in the aftermath of the financial crisis in 2008 and by the increase in production of shale-gas in the US. However when using data until 2010 in the estimation of the model, the fixed effect regression predicts rather accurately the development of aggregated across fields from 2011-2016. By using data only from 1995 until 2016 in the estimation of the fixed effect model the observed development after 2011 is also well tracked. The models imply rather strong and significant effect of the lagged oil price (Brent Blend) on investments. When data for the shorter period 1995-2016 is used, we get significant asymmetric price effects on investments, implying that an increase in the oil price has more positive effects on investments in periods with rising oil prices. In periods with declining prices the price history has a rather strong dampening impact on the effects of prices increases on investment. We also find strong and significant negative effects of lower expected remaining reserves on investments.

JEL-Codes: C230, D220, D250.

Keywords: oil and gas investments, prices of oil, panel-data.

Pernille Parmer
Vista Analyse AS & Agency for Public Management and eGovernment
Oslo / Norway

Steinar Strøm
The Ragnar Frisch Centre of Economic Research, University of Oslo / Norway
s.o.strom@econ.uio.no

Helge Sandvig Thorsen
The Norwegian Petroleum Directorate
Stavanger / Norway

Inger Ubbe
The Norwegian Petroleum Directorate
Stavanger / Norway

Bjørnar Andreas Kvinge
The Norwegian Petroleum Directorate & Vista Analyse AS / Norway

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1. Introduction

We use a unique dataset collected from the Norwegian Petroleum Directorate that allow us to apply a field-level panel data analysis. The panel dataset is an unbalanced dataset covering all oil and gas fields on the Norwegian continental shelf for the period 1968-2016. In total, there are 112 unique producing fields included in the dataset and more than 1900 observations. This opens for new empirical approaches in the analysis of investments related to oil and gas production. To our knowledge, there exists no comparable empirical study of such investments at field level.

We have applied two models for the relation between investments in oil and gas fields and a selection of variables that may affect these investments. In the first model, we assume that investments in period *t* depend on investments in the previous period, together with other variables. In the second model, we have no lagged investments, but we include oil and gas field fixed effects, together with the same explanatory variables as in the first model. The most notable result is that our models perform very well. They both track the observed investments from 1970 until 2016 relatively accurately, except for the period 2012-2015. In this period, both of our models overestimate the investments. These years were marked by an almost world-wide recession in the aftermath of the financial crisis in 2008 and by the increase of shale-gas production in the US. To make a prediction out of sample we have excluded the years 2011-2016 from our sample in the estimation of our two models. The out of sample predictions based on the fixed effect model fits remarkable well the observations for the out of sample period 2011-2016. Moreover, we have estimated the fixed effect model also on the most recent data, covering the period 1995-2016. Again, the estimated model tracks the observed development rather well.

The models, estimated on longer and shorter panel data, imply rather strong and significant effect of the lagged oil price (Brent Blend) on investments. We have also tried to include price volatility and future prices in the regressions. Both proved to have the expected sign, but they have no significant effect on investments. In the models we allow for asymmetric price effects. As expected, we find that the investment response to an increase in the oil price is stronger if this increase occurs in periods when oil prices have been increasing relative to periods when it has been decreasing. When data for the whole period 1968-2016 is used, the effects are not significant. However, when data for the shorter time period, 1995-2016, is used, the effects are significant.

The results also reflect that investment behavior changes over the lifetime of the field. Whereas the start-up of a field is investment intensive, production at the end of field life involves lower investments. When using data for the shorter period in the estimation of the model we have access to estimates of remaining reserves. The less reserves there are left, the lower are the investments. The impact is rather sizeable.

2. Previous research

The modelling of investment behavior is complex due to several uncertainties, such as discoveries of petroleum resources, future oil and gas prices and costs of production. For this reason the empirical literature on investment behavior in the oil and gas industry is rather limited, probably due to the lack of reliable and relevant field data. Most empirical studies, with some exceptions, are aggregate time series analysis, with a focus mainly on investments in exploration activities rather than on investments during production periods. The two are closely related, but reasons to invest in exploration may differ from the reasons to invest in a field after the initial decision to develop the field has been taken.

Fisher (1964), a pioneer in analyzing oil investments, published two econometric studies related to the U.S. petroleum industry. He studied the effect of oil prices, seismic crews and drilling costs on the rates of oil drilling, drilling success, and petroleum discoveries. Later, several time series and cross sectional studies have been published in the field of petroleum exploration (Pesaran (1990), Favero and Pesaran (1994), Farzin (2001), Mohn (2008), Mohn and Osmundsen (2008), Ringlunda, Rosendahl, and Skjerpen, (2008)).

The number of empirical panel data works in this field are few, but growing. So far published panel data studies use panels that are aggregated up to region- and country level or company level. Iledare and Pulsipher (1999) run a region-specific panel regression of drilling activity on different economic variables from 1977-1994. Although the dataset is small, it is sufficient to include regional fixed effects in the regression. They include explanatory variables that describe depletion, technical progress, economic and market conditions, industry structure and conduct, and taxation policy. Their results indicate diminishing marginal returns to exploration and development drilling with increasing drilling effort. The results also indicate that while technical progress significantly reduced the negative effects of depletion on petroleum reserve additions, its overall impact on reserve additions has not dominated the effects of depletion in Louisiana state jurisdiction.

Another panel data analysis is by Kemp and Kasim (2006). They run a three-stage least square regression in the analysis of exploration costs and efficiency. The model is disaggregated along regional lines and utilizes data from the UK Continental Shelf over the period 1964–2002, divided into five regions. They examine the effect of several explanatory variables; oil and gas prices, technology (time trend), resource depletion, taxes and expected reserves. The results indicate that resource depletion has a negative influence on exploration activity. Technological progress (time trend) seems to have a positive effect. Oil and gas prices also have a positive effect on drilling activity, but the effect is not statistically significant for all regions. Expected reserves have a positive effect on drilling activity in some of the regions. Kemp and Kasim (2006) conclude that the effect of tax policy on cost and income varies across regions.

Nuhu, Kim and Heo (2014) run a cross country fixed effect regression that examines the influence of competition, uncertainty, and geological factors in exploration investments in OPEC countries from 1980 to 2011. They find a significant positive effect of oil prices, production, reserves replacement, and the geological potential of petroleum basins. The results also indicate a significantly negative effect of resource depletion on exploration expenditure.

Other related empirical studies have used panel data at regional levels from the Norwegian continental shelf. The study by Mohn and Osmundsen (2011) is probably the most relevant in our context. They use data on drilling activities, discoveries and exploration acreage for three Norwegian offshore regions over the period 1966 to 2004. They investigate if there are asymmetric price effects and other effects of uncertainty on the investments indicators. The results show support for both asymmetric price dynamics and uncertainty in oil and gas investments. Osmundsen, Roll, and Tveterås (2010) also utilize a dataset on drilled wells, for three major regions. Although they analyze the development in drilling productivity in exploration wells, the data makes it possible to control for regional fixed effects.

Other studies use datasets at a company level. Kellogg (2014) employs a dataset combining data on well-level oil drilling with expected oil price volatility data from the NYMEX futures options market. He tests the sensitivity of firms' investment decisions to changes in the uncertainty of their economic environment. Firms reduce their drilling activity when expected volatility rises. Misund and Mohn (2006) estimate four different specifications of the *q* model of investment based on data for 115 companies over the period 1992–2005. They find robust results for the two uncertainty variables, represented by historical volatility measures for the S&P 500 index and the oil price.

However, there are many studies of price uncertainty on firms' investment in other industries than in the oil and gas industry. For example, Fuss and Vermeulen (2004) estimate the effect of demand and price uncertainty on firms' investment decisions from a panel of large Belgian manufacturing firms. The investment plans sample contains 977 observations for 114 firms. Uncertainty measures are derived from firms' subjective qualitative expectations. They find that demand uncertainty depresses planned and realized investment, while price uncertainty is insignificant. Controlling for the degree of competition, Ghosal and Loungani (1996) find a significant negative impact of price uncertainty on investment only in competitive industries. In another study Ghosal and Loungani (2000) find that the price uncertainty has a negative impact on investment in industries dominated by small firms. Bulan (2000) measures total firm uncertainty as the realized volatility of the firm's equity returns and finds that uncertainty reduces investment. Bloom et al. (2003) also use the variance of stock returns to measure uncertainty and find that uncertainty depresses investment. The problem with these two and other similar studies is that equity returns and stock returns are quite noisy.

3. Model and estimations methodology

3.1 Oil and gas investments: Two models

Our dataset allows for estimation of panel data models using field data. Estimation within fields controls for time invariant field specific effects like location (distance from shore, north vs. south, water depth, geological factors[6]) and field size. Investments in the petroleum sector are associated with high risk because of the volatile oil price, and are therefore expected to be sensitive to market conditions. Current and past market conditions may affect the expected value of an investment, and influence companies' access to capital.

We estimate two models, with and without a lagged dependent variable. It may be argued that the current level of investment is affected by past investments, and that lagged investments should be included as an explanatory variable. However, including a lagged investment variable as an explanatory variable in a fixed-effect (FE) regression may lead to endogeneity issues. We therefore run an Arellano-Bond GMM model (AB), with lagged investment. The Arellano-Bond method ensures consistency of the estimated parameters by utilizing earlier lags as instruments for the lagged dependent variable (Woolridge, 2006). A drawback with the Arellano-Bond method is that it is not efficient for data sets with large time dimensions. Our panel data consist of data for more than 45 years. We try to compensate for this by restricting the number of instruments to five lags; i.e., lagged investments from time *t-2* through *t-6*. In the second model, we have no lagged investments, but fixed field effects.

Our dependent variable is total investments at field level. Total investments include all capital costs related to facilities, wells and subsea equipment. All investments from development to cessation are included, whereas exploration costs are not included. Both past and present fields are included in the dataset[7]. Figure 1 plots the aggregated total investments against the historical Brent Blend oil price. The plot illustrates that the real investments at the shelf has grown over the production period. There are however some periods with a negative growth in aggregated investments. We observe that, with some delay, the investments seem to follow the oil price.

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[6] Geological uncertainty varies over time with accumulated information. The perceived field size may also change over time.

[7] Investments in fields under development are included, even if production has not yet started.

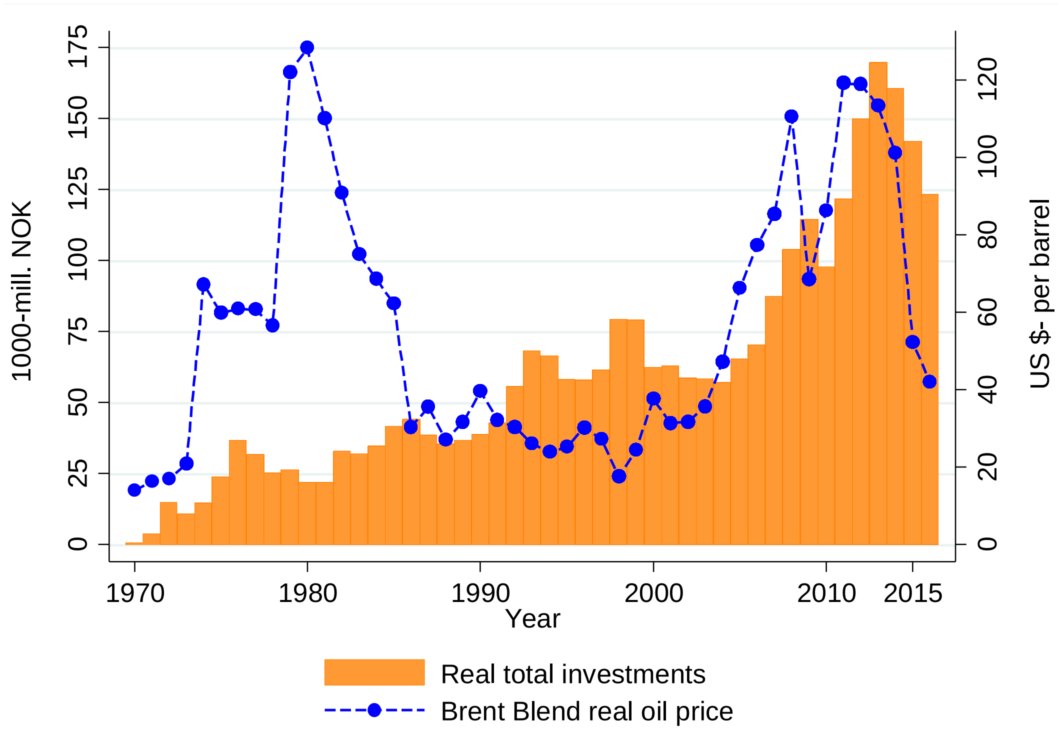

Figure 1: Aggregated real total investments aggregated across fields on the Norwegian continental shelf and the Brent Blend real oil price.

Let I_{jt} be investments in MNOK 2015 prices in field *j* in period *t.* An increase in the oil price is expected to have a positive effect on investment, e.g. due to increased expectations of future revenues. We utilize the Brent Blend oil price per barrel, a major benchmark price for purchases of oil worldwide.

Let $f(p_t, p_{t-1}, p_{t-2})$ be a function of current and lagged prices to be specified below, and let $g(x_{jt}, x_{jt-1})$ be a function of vectors of explanatory variables. ε_{jt} are random (white noise) variables. In the Arellano-Bond (AB) model, investments I_{jt} are given by the following linear relation:

$$(1)\quad I_{jt} = a + \rho I_{jt-1} + f(p_t, p_{t-1}, p_{t-2}) + g(x_{jt}, x_{jt-1}) + \varepsilon_{jt}$$

In the alternative fixed effect (FE) model, investments are given by the following model:

$$(2)\quad I_{jt} = b_j + f(p_t, p_{t-1}, p_{t-2}) + g(x_{jt}, x_{jt-1}) + \varepsilon_{jt}$$

The price function

The *f*-function is given by the following structure:

$$(3)\quad f(p_t, p_{t-1}, p_{t-2}) = \beta_1 p_{t-1} + \beta_2(100\frac{p_{t-1}-p_{t-2}}{p_{t-2}}) + \beta_3(p_{t-1}J(p_t, p_{t-1}) + \beta_4(100\frac{p_{t-1}-p_{t-2}}{p_{t-2}}J(p_t, p_{t-1}))$$

where

$$(4)\quad J(p_t, p_{t-1}) = \begin{cases} 1 & if\ \ p_t \le p_{t-1} \\ 0 & if\ \ p_t > p_{t-1} \end{cases}$$

We thus assume that lagged prices and lagged relative price change (in percent) may have an impact on current investments in a field. Moreover, we interact each of these two with a dummy that equals 1 if the oil price has declined from period *t-1* to the current period *t*, and equal 0 otherwise. The *J-function* captures asymmetric price effects. It accounts for the possibility that the price effect depends on earlier price movements, that is price history. Historical price movements in combination with present price movements may affect expectations of future prices and thus future revenue streams.

We observe that in both models we have the following marginal impact of a change in the lagged price on current investments:

$$(5)\quad \frac{\partial I_{jt}}{\partial p_{t-1}} = \beta_1 + \beta_3 J(p_t, p_{t-1}) + 100\frac{\beta_2 + \beta_4 J(p_t, p_{t-1})}{p_{t-2}}$$

If (β_3, β_4)<0, then a marginal increase in the lagged price has a stronger effect on current investments if this marginal price increase occurs in a period with increasing oil prices relative to an increase in a period with declining oil prices.

In the AB-model the marginal impact given in (5) will be the short run effect, while the long run effect is given by

$$(6)\quad \frac{1}{1-\rho}\frac{\partial I_{jt}}{\partial p_{t-1}} = \frac{1}{1-\rho}\left[\beta_1 + \beta_3 J(p_t, p_{t-1}) + 100\frac{\beta_2 + \beta_4 J(p_t, p_{t-1})}{p_{t-2}}\right]$$

If say, ρ equals 0.5, the long run effect will be the double of the short run effect.

3.2 Explanatory variables

The explanatory variables are collected from different sources. See Table A1 in the Appendix for source and a short description. Note that all variables are in real values, deflated by the Norwegian consumer price index (2015=100). Summary statistics are given in the Appendix, see Table A2.

Operating costs

Operating costs per field comes from the Norwegian Petroleum Directorates' (NPD) database. According to NPD's experience, operating costs per field are normally relatively insensitive to production level, and thus fairly constant over time.

Decline phase

Investments are likely to change over the different phases of the field life. Although a declining production rate may involve investments to prevent cessation, lower remaining reserves may reduce the incentives to invest. To capture the characteristics of mature fields, we include a dummy variable for production relative to peak production. The dummy equals 1 if current production is less than 30 per cent of the maximum production (in oil equivalents)[8] in the year when maximum production occurred.

Startup index

To capture that startups are probably more investment intensive, we include a dummy variable that equals 1 for the years with investments up to and including the first year of production.

$$(7)\quad J(Startup_{jt}) = \begin{cases} 1 & if\ I_{jt} > 0\ and\ aggregate\ production = 0 \\ 0 & otherwise \end{cases}$$

#Wells

Number of drilled wells with a positive discovery may be an indicator for optimism and new information about future possible resources in the field. We include a variable (#*Wells)* that

[8] We have run unreported regressions with alternative cut-off values. Main results are robust to such different specifications of the variable.

gives the number of drilled wells that had a petroleum discovery. The variable is defined by year and field, whereas estimated discovery size is not captured by the variable.

Company concentration – number of oil companies and the Herfindahl-index (HHI)

To test if owner diversity affects the investment behavior, we include two variables. First, we include a control for the number of oil companies (#Firms) within an oil field. We define all companies with the same mother company as one company, regardless of its resident country.

Second, we construct a Herfindahl index to measure the concentration of companies. This is an indicator of influence/ownership concentration at the field level. Let n_{jt} be the number of shareholders of field j at time t. The Herfindahl index, *HHI*, is:

$$(8)\ HHI_{jt} = \sum_{i=1}^{n_{jt}} (Share_{ijt})^2$$

If $HHI=1$, there is only one shareholder at the oilfield. If the $HHI=0.5$ there are two equal shareholders at the field, and so on. The summary statistics for the Herfindahl index reports an average value equal to 0.38.

Sector-specific cost inflation

We include a variable to represent sector-specific cost inflation. In periods where oil price is high, high investments in new developments typically lead to higher pressures in the economy and sector-specific inflation. The time series is published by Statistics Norway in their Norwegian National Accounts and is the price index related to annual investment statistics for Norwegian oil and gas activities.

Changes in fiscal terms

Before 1975 the fiscal regime included a royalty tax in addition to company tax. In 1987 the royalty tax was removed for new fields and the outline of the current system was established. Since then, there have been smaller revisions and amendments, including changes in the tax rate, but not major modifications. To capture the effect of the major changes in the fiscal regime, we include dummy variables for a trend change in 1975 and 1987.

Reserves

Investments in new or existing fields depend on remaining resources to carry the investment. Expected, remaining resources decreases with production of reserves. However, new technology, tie-back of additional resources, higher oil price and better understanding of the reservoir may increase the known remaining resources. To capture this effect, we include a variable to control for expected remaining known reserves and the accumulated produced share of reserves up to time *t*. Data on reserves are available from 1995. We estimate the FE model on this limited dataset. The results are reported in Table 3.

3.2 Other explanatory variables – robustness tests

We have also included other explanatory variables to test the robustness of our regressions. None of the following variables were significant in the regressions.

Analytic prices

Petroleum prices are highly volatile and notoriously hard to predict. There are several ways to model future oil prices. One way is random walk-models, another is to use financial market data from future markets, and a third way is to use market intelligence projections at each point in time. An argument against random walk-models is the lack of reversal to mean. Future markets for petroleum products are limited and may not represent market expectations very well. Our experience from the industry indicate that market intelligence is used to build a forecast for petroleum prices. Based on market intelligence and own analyses, oil companies make price forecasts that are used as base assumptions in investment decision and business planning. NPD has gathered this information from companies on the Norwegian Continental Shelf (NCS).

Analytic prices are in general less volatile than actual oil price, following a more stable and conservative price path. A regression was performed, substituting oil price with analytic prices. The results were insignificant and did not influence other parameters very much. Analytic prices are not included in the main model specifications.

Indicator for uncertainty

Following recent literature, we have tried to include an indicator for market uncertainty (Mohn and Osmundsen (2011), Kellogg (2014)). First, we included lagged yearly historic price volatility. The regression results indicate that the effect is insignificant. Second, Kellogg (2014) finds that a forward-looking measure of expected price volatility derived from futures options is a more powerful determinant of drilling behavior than backward-looking measures based on historic volatility. We test this by including a variable for price volatility for 4 months-futures. As for historical price volatility, the estimator turns out to be insignificant and is not included in the results reported here.

These results are interesting as they contradict the findings of both Mohn and Osmundsen (2011) and Kellogg (2014). Field level data might give different results than more aggregated data. Market uncertainty does probably affect the investments decisions, but price volatility does not capture this effect in our analysis. This result is in line with the findings reported in Section 2 above related to investments in other sectors than the petroleum sector.

Indicator for technological change and learning

Several papers have used a linear time trend to control for unobserved technological progress (Iledare and Pulsipher (1999), Kemp and Kasim (2006), Mohn et.al. (2011)). However, in our context this is not a good proxy. Total investments at the field level are affected by technological change, but the direction of the effect is ambiguous. Technological change can reduce costs and investments, but also stimulate investments because of new opportunities and increased success probability. Another drawback by using time trend as proxy is that it implicitly assumes that technological progress is time invariant. Although included in the model, the variable turned out not to be significant in all regressions. The proxy is therefore not included in the final models.

We also tried an alternative measure/index for learning. Following Iledare and Pulsipher (1999) and Kemp and Kasim (2006) we included a variable for the cumulative number of wells as a proxy for learning and information (both at field level and shelf level). The variable turned out to be insignificant and the result is not reported here.

4. Results

4.1 Estimates

In Table 1 we give the estimates of the two models. Note that the *J(.)* functions are representing dummy variables, see the relevant equations in Section 3.

Table 1: Estimates of oil field investments in $MNOK_{2015}$. The Norwegian Continental Shelf[9], 1968-2016.

	(1) AB	(2) FE
$Investments_{t-1}$	0.464***	
	(0.048)	
Oil $price_{t-1}$	7.641*	11.754*
	(4.213)	(6.705)
Relative oil $price_{t-1}$	-2.244	-3.498
	(2.802)	(2.310)
$Oilprice_{t-1}$* J(PriceNeg)	-2.370	-0.431
	(1.842)	(2.079)
Relative oil $price_{t-1}$ *J(PriceNeg)	-0.967	-3.799
	(3.955)	(4.214)
Operating costs	-0.580***	0.093
	(0.178)	(0.245)
Operating $costs_{t-1}$	-0.444***	-0.987***
	(0.114)	(0.226)
$\#Wells_{t-1}$	341.283*	363.891
	(197.351)	(228.089)
J(Startup)	1718.530***	1719.608***
	(271.716)	(274.754)
J(Tax75)	-1103.429*	-1231.895
	(617.315)	(1631.024)
J(Tax87)	-784.419	-102.469
	(757.874)	(503.497)
#Firms	239.484	-4.016
	(149.801)	(117.323)
Herfindahl index	2479.172	1138.807
	(1602.126)	(1529.530)
J(Decline phase)	-69.135	-355.464**
	(87.231)	(171.233)
Sector-specific cost inflation	45.008**	12.330
	(17.873)	(23.158)
Constant	-4524.526	692.407
	(2816.779)	(2806.590)
N	1647	1752

* p<.10, ** p<.05, *** p<.01

[9] Standard deviation in parentheses, AB is the Arellano-Bond regression and FE is the fixed-effect regression.

Generally, both models give, with a few exceptions, similar results, which is an argument in favor of the simpler fixed effect specification.

We observe that the lagged oil price has a significant effect on investment. To illustrate the effect we have calculated the marginal effect of lagged price on investments, see equations (5) and (6) above. Table 2 gives the effects on investment per field when the oil price is increased by USD 10 per barrel, lagged one year back. Because the asymmetric price effects, terms with $J(p_t , p_{t-1})$, are not significant we show the result without these terms. Note that when *J(.)* equals zero this occurs when the oil price has been increasing. The investment response per field to an increase in the lagged oil price of 10 USD per barrel in the fixed effect regression is between the short and long run effects in the Arellano-Bond regression. The response is plus-minus 100 MNOK per field, which is around 6-7 percent of the mean investment per field in the period. The effect of a price increase on investments is thus sizeable.

Table 2. The effect of an increase in lagged oil price of USD 10 per barrel on current investments per field. MNOK$_{2015}$.

Arellano-Bond regression		Fixed effect regression
Short run	Long run	
76	141	117

In the FE model the operating costs, lagged one period, has a negative impact on current investments. According to the estimate, an increase in operating costs of MNOK 100 per field lagged one period implies a reduction in current investment of MNOK 100 per field. Based on our knowledge of the characteristics of operating costs at field level, this result appears surprisingly strong. We will discuss this further in the section below where remaining reserves are included as a covariate and where we only use recent data, starting from 1995.

Investments vary according to the phase of production. Before production start and through the startup phase investments are typically significant. To capture this effect, we included a variable startup which is significant. On the other hand, investments are typically low when production reaches tail production. This effect is captured by the tail production dummy, which is significantly negative. These effects are rather sizeable.

The other variables, fiscal regime, number of wells, number of firms and the Herfindahl index have no significant effect on investment in the FE regression.

Reserves

As mentioned above, for recent years we have access to annual estimates of remaining reserves on field level. We know that the phase of production is important for field investments. Higher remaining reserves can allow for investments to recover the remaining volumes, whereas a field can be within the 30 percent threshold of maximum production for a long time. In our opinion, the estimates for remaining reserves is a better indicator than the defined decline phase variable. Thus, we replace the decline phase variable with the reserves variables. However, as the dataset on reserves is limited to 1995 and onwards, this severely limits the number of observations included in the analysis.

We have estimated both the AB and the FE models on the limited data set covering the period 1995-2016. However we could not reject the hypothesis of autocorrelation in the AB model and we thus only show the result based on the FE model. Table 3 gives the estimates. The coefficient attached to (lagged) operating costs is not significant. This is mainly due to the exclusion of observations before 1995. An unreported regression of the same FE model discussed above and estimated on the shorter time series also yields similar results, strengthening our suspicion that the operating cost effect in the main model is a result of poor data quality related to operating cost in the early years.

We observe that there is a significant negative relationship between investments and share of remaining reserves, as well as the magnitude of remaining reserves. This corresponds with the finding from our main analysis, where investments are significantly lower in the decline phase. A reduction in remaining reserves of 10 MSm^3 is estimated to give a reduction in investment in a field of 51 MNOK, while a reduction in the share of remaining reserves of 10 percentage point is estimated to give a reduction in investment in a field of 130 MNOK.

The sector-specific cost inflation has a significant and positive impact on investment, which reflects that the increase in prices related to the inputs in oil investments exceeds the average rate of inflation in the economy.

An interesting result when investment is regressed on more recent data is that there are some significant asymmetric price response. The interaction of relative price changes and whether this took place in periods with increasing or decreasing oil prices has a significant impact on investments. In periods with decreasing oil prices the marginal effect of a shift to higher oil prices is substantially lower, even negative, than in periods where oil prices have been increasing. In periods where oil prices have been increasing, the marginal effect is 7.63, irrespective of the size of the lagged oil price. This is very similar to the short run effect reported above for the AB regression based on the panel data covering the longer period 1968-2016.

Table 3. Fixed effect estimates when including reserves. data for the period 1995-2016

Oil price$_{t-1}$	7.630**
	(3.312)
Relativ oil price$_{t-1}$	2.867
	(2.840)
Oilprice$_{t-1}$* J(PriceNeg)	0.514
	(1.983)
Relativ oil price$_{t-1}$ *J(PriceNeg)	-12.378**
	(4.766)
Operating costs	-0.279
	(0.171)
Operating costs$_{t-1}$	-0.299
	(0.308)
#Wells$_{t-1}$	97.070
	(171.113)
J(Startup)	1793.712***
	(398.274)
#Firms	91.564
	(103.266)
Herfindahl index	1094.184
	(1515.603)
Remaining reserves$_{t-1}$	-5.144*
	(2.909)
Share of reserves remaining$_{t-1}$	-1300.111**
	(522.968)
Sector-specific cost inflation	34.935**
	(15.434)
Constant	-2754.494
	(2227.328)
N	1234

* p<.10, ** p<.05, *** p<.01

4.2 Graphical illustration of the regression results

Figure 2 plots the observed investments aggregated across fields, and the predicted aggregated investments across fields derived from the FE model. We observe that both models perform relatively well, although they clearly over-estimate the investment level in the period 2012-2015.

The graphs do not imply a clear difference between the performances of the two models. With some exceptions, they follow each other over the estimation period.

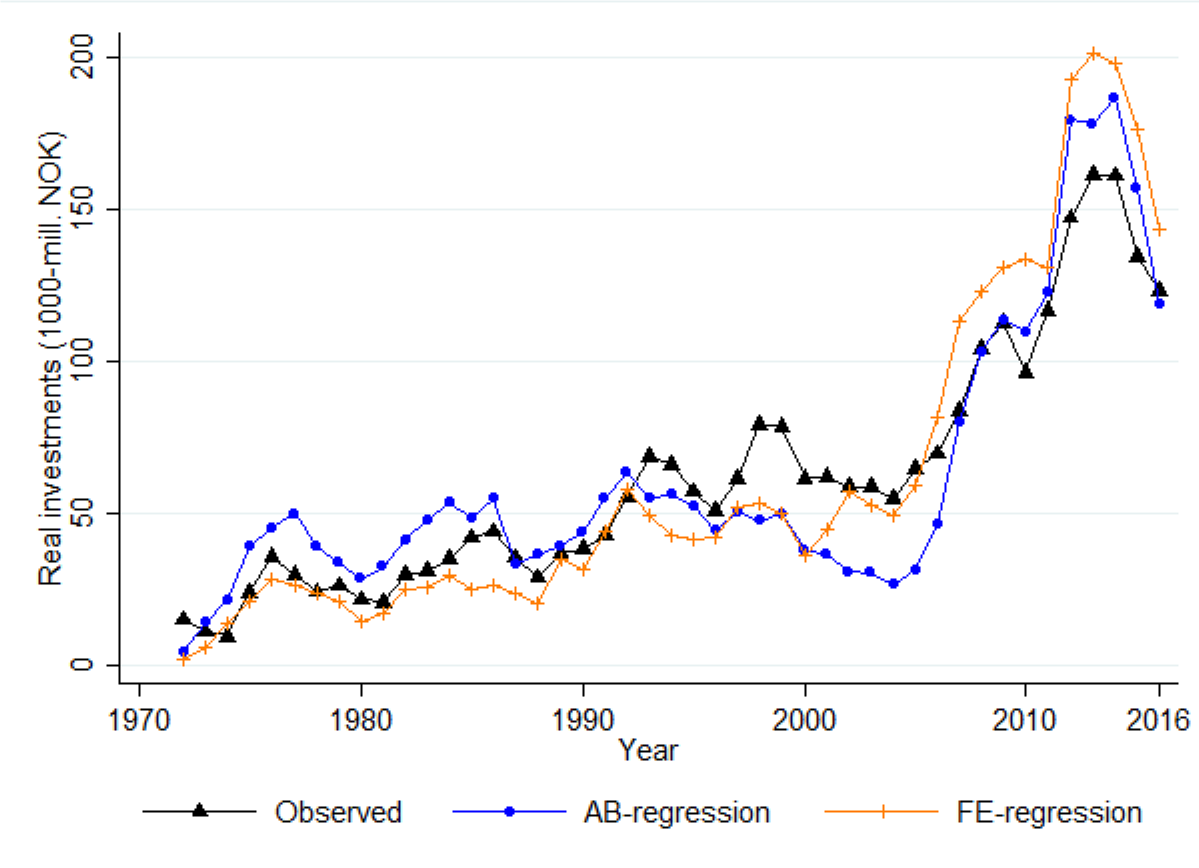

Figure 2: Aggregated investments across fields on the Norwegian continental shelf derived from the estimation on field data, plotted against observed aggregated values, aggregated over the observations used in the regressions.

As an experiment, we ran the regression on a subsample of the data. We use data until year 2010 and then make an out of sample prediction for the period 2011 until 2016. The results are shown in Figure 3. The graphs show that the FE-model outperforms the AB-model.

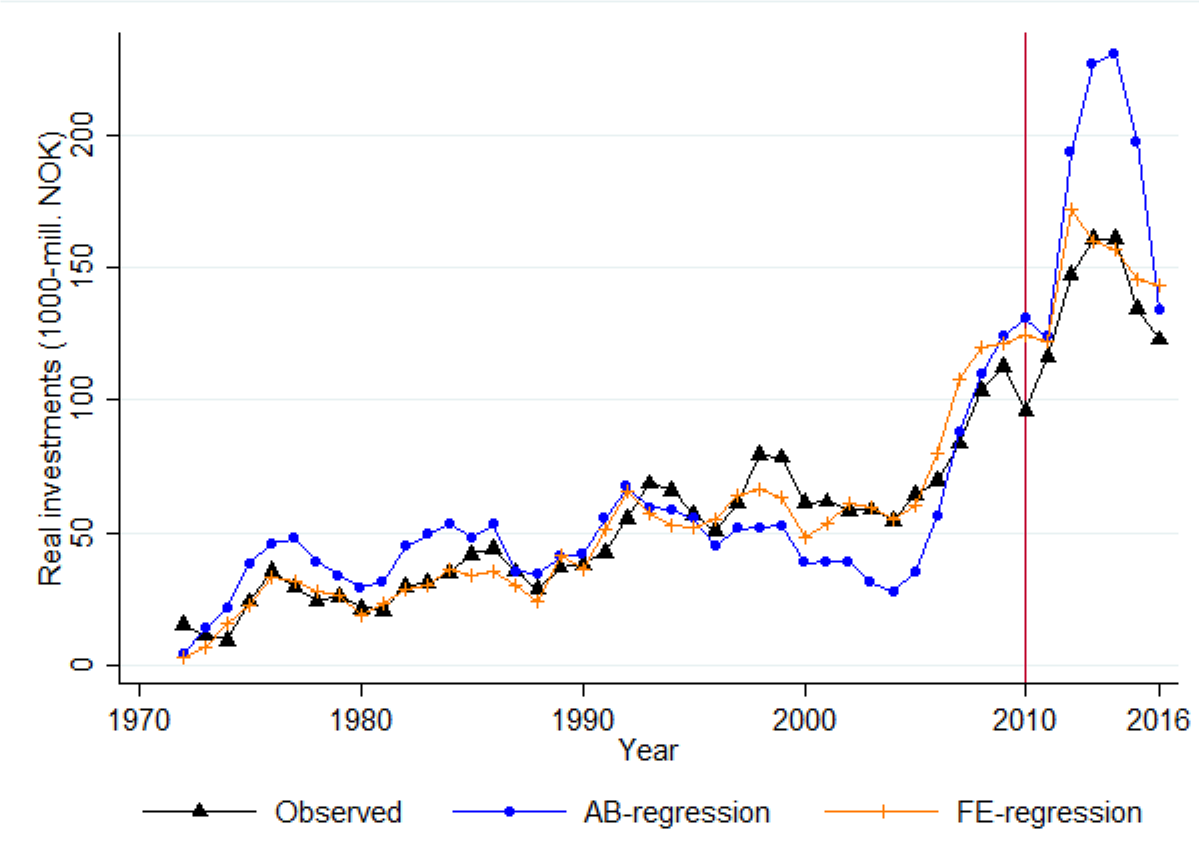

Figure 3: Same figure as Figure 2, but the regressions are applied on data until 2010, the values for year 2011-2016 are predicted values from the regressed model.

In Figure 4 we compare the observed investments with the prediction based on FE regression, estimated on data from the shorter period 1995-2016. We see that the FE regression fits data rather well, except for the later years in the aftermath of the financial crisis.

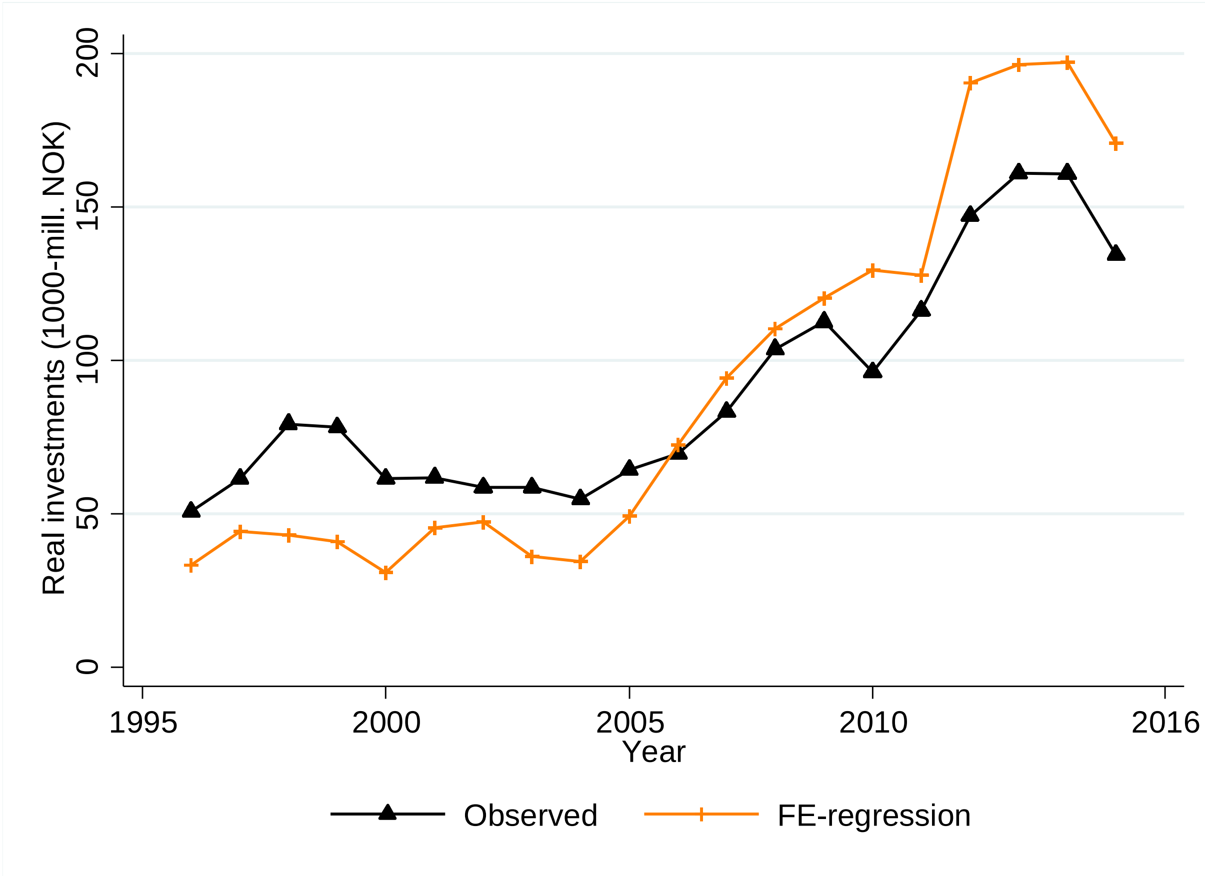

Figure 4. Aggregated investments across fields on the Norwegian continental shelf derived from the estimation on field data for the period 1995-2016 only, plotted against observed aggregated values, aggregated over the observations used in the regressions.

5. Conclusion

Our models track the observed investments from 1970 until 2016 relatively accurately, except for the period 2012-2015, when there was an almost world-wide recession in the aftermath of the financial crisis in 2008 and an increase of shale-gas production in the US. The models imply rather strong and significant effect of the lagged oil price (Brent Blend) on investments. When the model is estimated on recent data, 1995-2016, we find that the investment response to an increase in the oil price is stronger if this increase occurs in periods when oil prices have been increasing relative to periods when it has been decreasing. When using data for the shorter period in the estimation of the model we have access to estimation of remaining reserves. A decline in expected remaining reserves and in the share of remaing reserves have a strong negative imapct on investments.

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Appendix

A.1: Variable description

Table A1: Variable description of variables included in the analysis

Variable	Description	First year
$Investments_{it}$	Yearly investments per oil field, real. Deflated by CPI. Million NOK 2015 prices. Source: The Norwegian petroleum Directorate	1968
$Oilprice_{t}$	Brent Blend oil price, real, yearly average. Deflated by CPI. $ pr. barrel. Source: EIA	1970
Asymmetric $oilprice_{t}$ **-Price (+)** **-Price (-)**	See Section 1 for description.	1971
Relative $price_{t}$	Relative price compared to last period. See Section 3.1 for description for different price variables.	1971
Operating $costs_{jt}$	Yearly operating costs per field, real. Deflated by CPI. Million NOK 2015 prices. Source: The Norwegian petroleum Directorate	1970
Decline $phase_{jt}$	Indicator with value 1 when a field produces less than 30% of its peak production, and the peak is elapsed.	1971
$Startup_{it}$	Dummy =1; prior to production, including year for start of production. In other words: indicator for years with positive investments, but with cumulative production of 0 up until t-1. *See section 3.2 for description.*	1968

Herfindahl index$_{it}$	Describes the company concentration at the oil field. *See section 3.2 for description.* Source: The Norwegian Petroleum Directorate	1970
#Wells$_{jt}$	Number of drilled wells with a discovery. Source: The Norwegian Petroleum Directorate	1968
#Selskaper$_{jt}$	Number of oil companies per felt. Source: The Norwegian Petroleum Directorate	1970
CPI$_{t}$	Consumer price index. 2015=100. Source: Statistics Norway	1968
Tax dummies$_{t}$	Two dummies for change in the fiscal system, in 1975 and 1987.	1968
Cost index$_{t}$	Price index for annual investments for Norwegian oil and gas activities. Source: Statistics Norway. See section 3.2 for further description.	1971
Remaining reserves$_{jt}$	Remaining known reserves. A control for the produced share of total reserves at any point in time is also included. Data on reserves are available from 1995. See section 3.2 for further description.	1995
Share of reserves remaining$_{jt}$	A control for the produced share of total reserves at any given point in time is also included. Data on reserves are available from 1995. See section 3.2 for further description.	1995
Analytic price$_{t}$	Forecast prices that are used as base assumptions for investment decision and business planning. See section 3.2 for further description.	1980

A.2: Descriptive statistics

Table A2: Descriptive statistics

Variable	Mean	Min.	Max	Std.
Investments (MNOK2015)	1487	-178[10]	24298	2555
Oil price (USD/barrel)	64	14	128	34
Relative Price Change	3.76	-51.18	221.28	31.35
PriceNeg	0.55	0	1	0.50
Relativ_price_PriceNeg	-8.00	-51.18	221.28	20.20
Oil price_priceNeg	34.66	0	119.25	40.37
Operating costs (MNOK2015)	653	-6	7900	1003
Tax75	0.99	0	1	0.10
Tax87	0.90	0	1	0.30
Decline Phase	0.26	0	1	0.44
Startup	0.24	0	1	0.43
#wells	0.12	0	5	0.48
#firms	5.2	1	14	2.68
Herfindahl Index	0.38	0.14	1	0.16
Sector-specific cost inflation	110.07	96.94	124.52	7.76
Remaining reserves (MSm^3 oe)	50.30	0	1553.50	150.29
Share of reserves remaining	0.51	0	1	.038
Analytic price (USD/barrel)	50	15	100	34

[10] In the yearly revised national budget reporting, investments on existing fields are reported as addable delta profiles to give the most realistic production scenario.