University of
Stavanger

Faculty of Science and Technology

MASTER'S THESIS

Study program/Specialization: Industrial Economics Petroleum Technology and Risk Management	**Spring semester, 2020** Open access
Author: Erlend Fjelstad Berget	Erlend Berget ………………………………………. (Signature of author)

Faculty supervisor:
Reidar Brumer Bratvold

Title of master's thesis:
Redevelopment Projects on the NCS: A Statistical Analysis of the Norwegian Petroleum Industry's Ability to Generate Unbiased Production Forecasts

Credits: 30

Keywords: Forecast performance Oil production Bias Redevelopments Value erosion Delusion Deception	Number of pages: 99 + supplemental material/other: 0 Stavanger, 01.07.2020 Date/year

Abstract

Petroleum companies operating on the Norwegian Continental Shelf (NCS) must receive authority approval of the Plan for Development and Operation (PDO – also called the FID – Final Investment Decision) before a development project can be initiated. In the PDO, the companies present probabilistic forecasts for cost, schedule – and production, which are used to demonstrate the profitability of their projects through the calculation of a value metric, typically the net present value. However, it is well-documented that the Norwegian petroleum industry struggle to complete development projects without budget overruns and schedule delays, and recently Bratvold *et al.* (2019) established that field developments on the NCS tend to produce significantly less volumes in the early phase than expected at project sanction.

Despite the contribution of Bratvold *et.al.*, the literature on production forecast performance in the oil and gas industry is much less extensive than for cost and schedule. This is due to the fact that operators are neither obliged nor willing to share their production forecasts with the public. As such, this work forms the first public study on probabilistic production forecasting that focus on redevelopment projects, i.e. projects initiated after first oil. The main purpose is to assess the quality of the industry's production forecasts, which is accomplished by statistically comparing the FID production forecasts for 32 redevelopments with their actual annual production.

The results of the statistical analysis show that the forecasts used in the investment appraisal for redevelopment projects are both optimistic and overconfident. Consistent poor performance relative to the forecasts suggest that the forecasts are biased, which is incompatible with good, economically efficient, decision making. In total, the redevelopments in the study produced 8.3 percent less than the mean forecasted volumes, which translates to a revenue loss of approximately 102 billion 2019-NOK. It is observed that access to historical production data is correlated with forecasts quality, as the redevelopment forecasts improves slightly with years of historical production prior to project approval, while also being less biased than forecasts for new field developments. Flawed human decision making in terms of delusion (honest mistakes) and deception (strategic misrepresentation) is presented as the root cause of the forecasting inaccuracies, and how to improve forecasting by overcoming delusion and deception is also briefly discussed.

Acknowledgements

First and foremost, I would like to offer a special thanks to my supervisor, professor Reidar B. Bratvold, for his valuable and constructive suggestions during the planning and development of this thesis. His willingness to give of his time has been very much appreciated. In addition, I owe my appreciation to the Norwegian Petroleum Directorate for making the operators' production forecasts available to the University of Stavanger under a non-disclosure agreement, thus facilitating this research.

I would also like to express my gratitude to fellow students and friends. The five years spent at the University of Stavanger has been an excellent experience because of you. Huge thanks.

Finally, I want to express my love and appreciation to my family. Your advice and support led me to pursue engineering, and your unwavering in faith my abilities have been a source of encouragement over the course of the master's degree.

Table of Contents

List of figures

List of tables

1 Introduction

Reviews of megaprojects[1] worldwide have shown that cost- and schedule overruns is the rule rather than the exception. This applies to the Norwegian petroleum industry as well, where the average field development has experienced cost escalations in excess of 20 percent over the last two decades while project execution exceeded schedule by an average of 25 percent (Oglend *et al.*, 2016, Mohus, 2018).

Historically, production attainment relative to forecast has been subject to significantly less scrutiny than cost – and schedule performance. The difficulty to obtain verifiable production estimates from the time of the final investment decision (FID) has contributed to the discrepancy in research focus. For instance, for less than half of the petroleum development projects included in the IPA[2] database, the project teams could provide the FID production forecasts, whereas almost all teams could provide the cost – and schedule forecasts (Nandurdikar & Wallace, 2011). In Norway, cost estimates are in the public domain, while the production estimates are confidential. The result is that few studies have been carried out using rigorous forecast verification and statistical analysis to assess the quality of the industry's production forecasts.

One study conducted on production attainment considered field developments on the Norwegian Continental Shelf (NCS) exclusively. Bratvold *et al.* (2019) demonstrated that the development decisions made for fields on the NCS are based on production forecasts that tend to be biased. Biased forecasts cause the fields to consistently fail to produce the forecasted volumes at project sanction. Obviously, selling hydrocarbons is how revenue is generated, thus every barrel of reduced production relative to the forecasts causes value erosion of the project. In addition, underproduction leads to overcapacity in installations and infrastructure, which point to inefficient capital allocation as resources could have been invested elsewhere.

1.1 Objectives

In Bratvold *et al.* (2019), the projects featured were new field developments. For these fields, the statistical analysis was primarily focused on the first four years of production. This limitation is mainly due to regular investments into redevelopment projects not accounted for in the original forecast, rendering comparison of actual vs estimated production later in field

---

[1] Megaprojects is defined by Merrow (2011) as projects with total cost of $ 1 billion.

[2] Independent Project Analysis

life mute. As new petroleum discoveries become more infrequent, the ability to extend the lifespan of aging fields is becoming increasingly relevant for the industry. Drawing upon forecast data from petroleum fields on the NCS, this thesis will extend the work of Bratvold *et al*. by analysing the quality of oil production forecasts for Norwegian redevelopment projects. Herein, redevelopments are defined as investment projects initiated on a field after first oil with the purpose of increasing production. As with the original FID, the production forecasts supporting these redevelopment decisions should be unbiased as any bias will lead to poor decisions and suboptimal use of capital. Also, the financial impact of any production shortfalls will be assessed.

A second significant issue to be addressed is whether the forecasters have improved their predictions for redevelopments compared to the original development. An improvement should be expected on technical merits, as the forecasters should have better understanding of the fields relative to the initial forecast.

1.2 Background

1.2.1 Nandurdikar & Wallace (2011)

In 2011, Nandurdikar & Wallace (2011) studied the production attainment relative to FID forecast for 147 international petroleum developments. The forecasted distribution of outcomes was significantly different from the actual outcomes, heavily skewed toward overestimation as shown in figure 1. Thus, the average field in the sample produced only 81 percent of the forecasted volumes, with 75 percent of the projects failing to meet their expected production. In fact, the petroleum industry's ability to deliver on its production forecasts was the worst across all industrial sectors monitored by the IPA. However, because of higher than estimated commodity prices, most development projects made great profits despite the reduced production volumes. The authors therefore speculate that most companies are unaware that poor production attainment is an issue (Nandurdikar & Wallace, 2011).

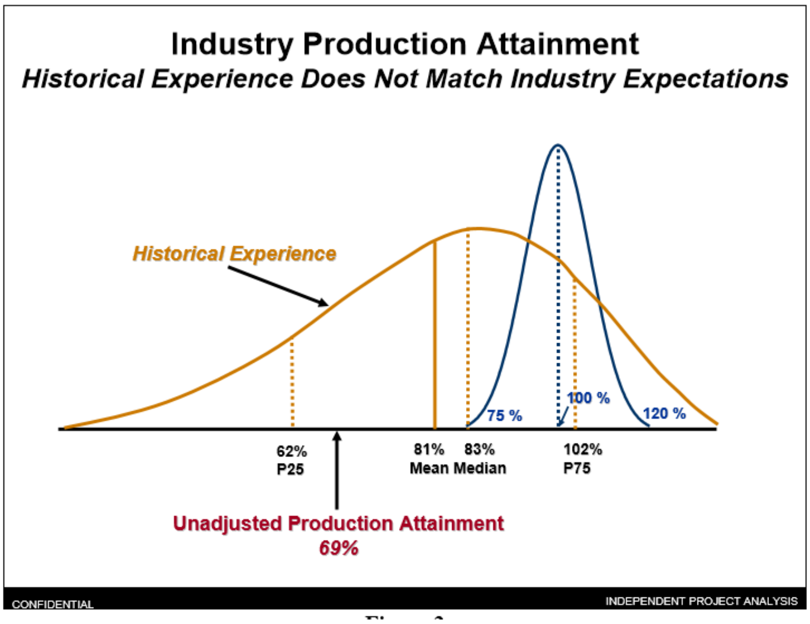


Figure 1: Historical – and forecasted distribution of production (Nandurdikar & Wallace, 2011).

In the paper, optimistic subsurface assumptions, failure of assurance processes, and lack of accountability for production volumes are cited as the main causes for the poor performance. To improve performance, the companies are advised to adopt a conservative appraisal strategy in order to collect sufficient quality data. This recommendation is based on data showing that 70 percent of the projects achieving production attainment above 90 percent of forecasted were conservative in their appraisal strategy, whereas only 10 percent applied an aggressive appraisal strategy (Nandurdikar & Wallace, 2011).

1.2.2 Mohus (2018) and Bratvold *et al.* (2019)

Mohus and Bratvold *et al*. studied the production attainment from petroleum developments on the NCS over the past one and a half decade. The core analysis was presented in Mohus (2018) and further refined in Bratvold *et al.* (2019). The latter citation will primarily be used to reference the research in this thesis.

By gaining access to the production forecasts submitted annually to Norwegian authorities by the operators on the NCS, the authors identified 32 fields, from a sample of 56, with valid P10 – mean – P90[3] estimates over the first four production years (F4Y). Comparing the production

---

[3] Norwegian authorities require the operator of a petroleum field on the NCS to submit three estimates of production. Here P10 is the low estimate, meaning that the operator assesses the likelihood of production being less than this estimate at 10 percent.

forecast with the cumulative production over the F4Y for each field, they obtained the results presented in table 1 (Bratvold *et al.*, 2019).

Table 1: Percentage of fields with actual production less than P10, P50 and P90 forecast over the F4Y (Bratvold et al., 2019).

	Under P10	Under P50	Under P90	Inside P10-P90
Unbiased forecasts	10%	50%	90%	80%
Actual forecasts	59%	84%	90%	31%

Although the forecasts presented to the Norwegian authorities are supposed to be unbiased to support unbiased decision making, the conclusion is that they are anything but. Only a third of the development projects have actual production that are within their proclaimed 80 percent confidence interval, while 59 percent of the fields, as opposed to 10 percent, are underperforming the P10. Furthermore, the authors found no hard evidence of forecast improvement in the 22-year period investigated, as seen by the plot of production excess or shortfall relative to the mean estimate in figure 2.

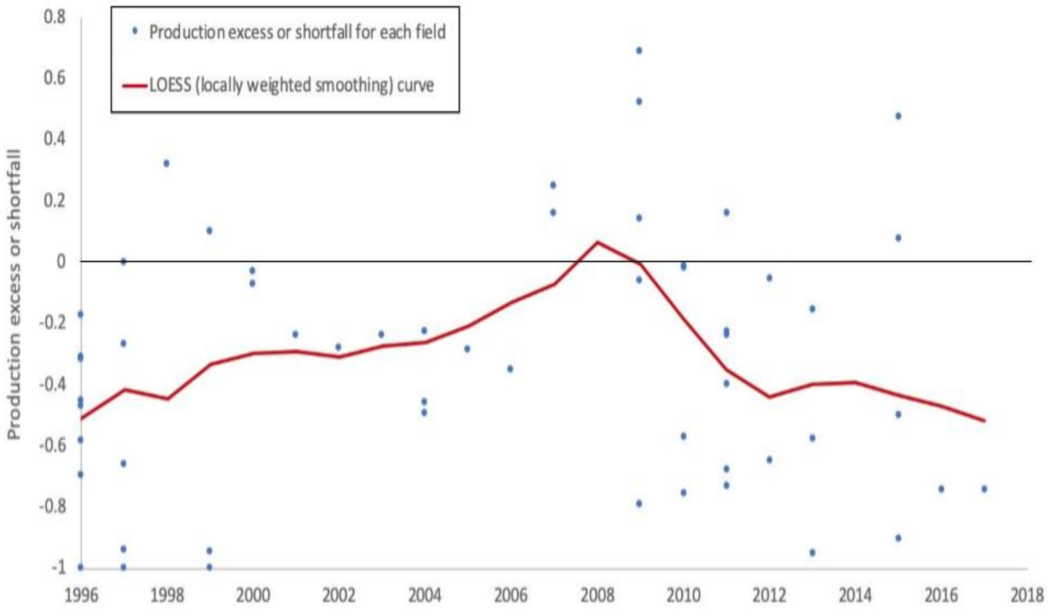


Figure 2: Production excess or shortfall relative to mean estimate for each field sorted according to year of FID (Bratvold et al., 2019).

In the publication, it is argued that the root cause of the consistent forecasting inaccuracies is flawed decision making attributed to delusion and deception. Delusion is honest mistakes that stem from optimism – and overconfidence bias, while deception is the strategic misrepresentation of a project.

1.3 Structure

This thesis is divided into eight chapters. The current chapter, chapter one, outlines the thesis objectives and serves as an introduction to the topics covered herein. Next, chapter two describes the lifecycle of a petroleum development on the NCS and review the technical uncertainties that affect production forecasting. Following this, the results from previous research on megaprojects in the petroleum industry will be presented. Chapter three is dedicated to explaining the dataset and describing the procedure employed to analyse the data statistically. The limitations and uncertainties of the analysis will also be addressed. Chapter four presents the results of the analysis on production attainment for redevelopments, while chapter five consider the value loss caused by not meeting forecasted production.

Motivated by the analytical results, chapter 6 presents two models that explain inaccurate forecasts in terms of flawed human decision making. The first models focus on the cognitive biases that affects human judgement, while the second model consider factors that can cause people to strategically misrepresent forecasts. Chapter seven address the quality of production forecasts for redevelopments in relation to original field developments. In addition, the importance of unbiased forecasting will be highlighted along with different approaches for improving the forecast quality. Finally, chapter eight concludes.

2 Theory

2.1 The Petroleum Act

Norway is fortunate be rich in natural resources, and the hydrocarbon deposits located offshore on the NCS has played a key role in developing the Norwegian welfare state. Since the initiation of petroleum activities on the NCS, the state has worked to provide a framework for profitable production of oil and gas, while simultaneously ensuring that the majority of the value accrues to the public. At the present time, this ideology is enforced through the Petroleum Act of 1996, which is the legalisation governing petroleum activities on the shelf. The petroleum act establishes that "The Norwegian State has the proprietary right to subsea petroleum deposits and the exclusive right to resource management" (NPD, n.d).

With respect to resource management, the legislation stresses that the production of petroleum shall be conducted to maximize the resources in the reservoirs, and that waste of petroleum or reservoir energy should be avoided. To achieve this objective, the organizations operating on the shelf must continuously evaluate their production strategy and technical solutions (NPD, n.d).

2.2 Timeline of a petroleum field development

The Norwegian authorities in charge of managing the petroleum industry is the Ministry of Petroleum and Energy (MPE). They have established a framework for the development of petroleum deposits designed such that the state maintains control of the industry by demanding organizations to apply for licences and receive approval from the authorities in every phase of a development. In figure 3, the official ministry requirements related to each phase of a petroleum development is given.

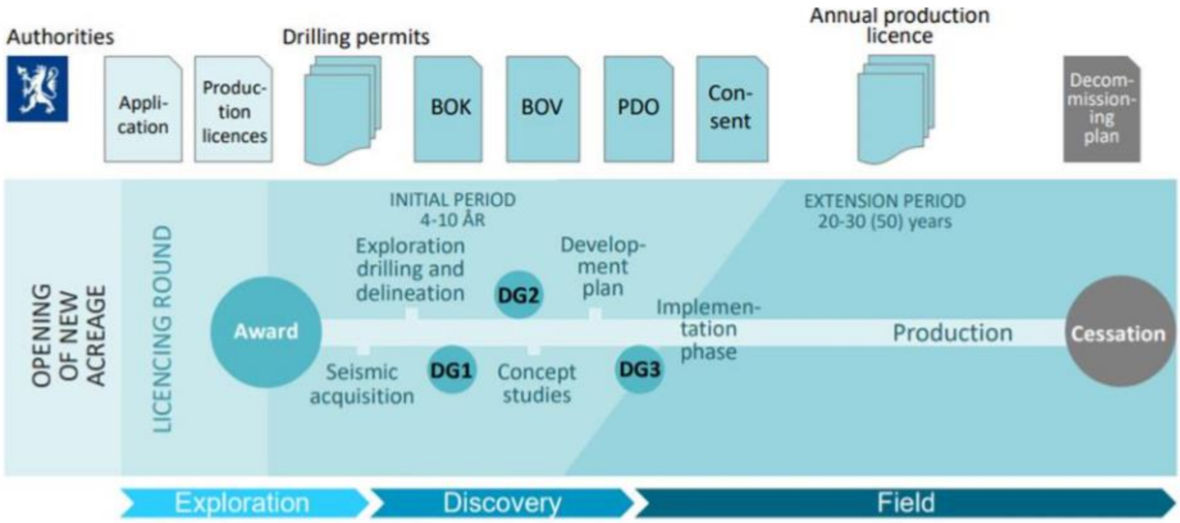


Figure 3: Ministry requirements for each phase of a petroleum development (NPD, cited in Hatlestad, 2019).

The next subsections will elaborate on the major milestones of a Norwegian petroleum development outlined in the figure above.

2.2.1 The licence system and opening of acreage

Before any petroleum related activity can be performed on the NCS, the authorities must formally open the area for industrial purposes. It is the Norwegian parliament that ultimately decides which areas that are made available for the industry at any given time. To aid their decision, the Ministry of Petroleum and Energy provide an impact assessment that consider the economical, societal – and environmental consequences of petroleum activities in the area (Norwegian Petroleum, n.d).

Should the decision be made to open areas for the industry, petroleum companies are invited to apply for survey – or production licences. Survey licenses are non-exclusive rights to conduct exploration in an area. However, exploration drilling is not allowed under this licence, nor does it provide any preferential rights when production licenses are granted. Therefore, it is often companies specialized in selling data to operators on the shelf that are awarded this licence to perform seismic surveys (Alvik, 2016).

Companies that are awarded a production licence are given exclusive rights to perform seismic surveys, exploration drilling, and production of petroleum in that block for an initial period of 10 years. The companies may apply for the licence individually, but the MPE will award the licence to a group of suitable companies based on objective, pre-announced criteria and select an operator for the joint venture. The joint venture functions as an internal control system where the licensees monitor the performance of the ministry appointed operator to ensure prudent resource management on the shelf (NPD, 2012).

2.2.2 Exploration and discovery

When awarded a production licence, the licensees will perform exploration activities where the objective is to quantify the recoverable hydrocarbons in the region. Exploration drilling is conducted based on information from seismic surveys and provide information about a prospect in the form of well logs, pressure tests, reservoir cores, etc. This data can be combined to provide information about essential reservoir properties, which are used as inputs in reservoir models (Demirmen, 2007). Models are the basis for most reservoir evaluation and engineering decisions and are used to generate reserve estimates for a prospect (Ringrose & Bentley, 2015). If an economically feasible discovery is made, the licensees can require the production licence to be extended to develop the discovery commercially.

2.2.3 Development

If a discovery made during exploration is economically possible to produce, the project enters the development phase. In this phase, the licensees will explore different technical solutions to determine the development concept that generates the most value. The Norwegian authorities oversee the project development process and the licensees must receive authority approval of the Plan for Development and Operation (PDO) before detailed engineering and construction can commence. Prior to submitting the PDO, the project has passed several milestones where the project has matured such that it is, according to the companies, ready for implementation. The authorities are involved at every milestone, providing feedback to the licensees to ensure the development plans meet the authorities' quality requirements. The timeline for government approval of a petroleum development is given in figure 4 (MPE, 2018).

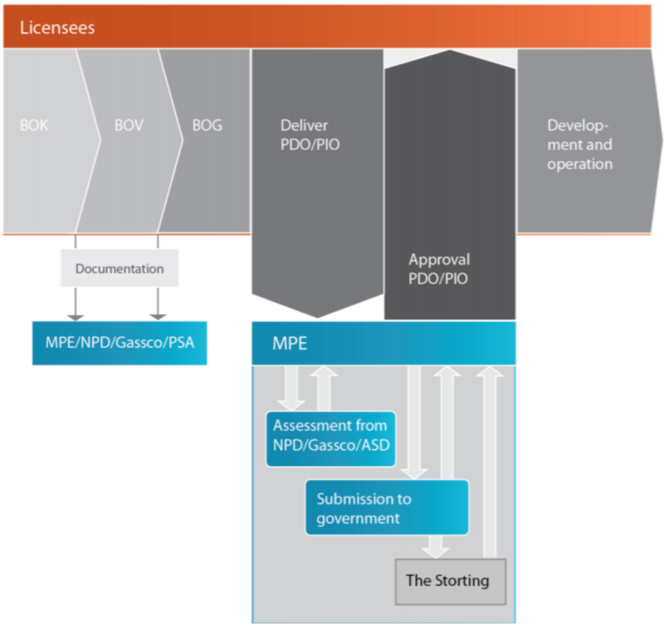


Figure 4: Timeline for government approval of a development plan (MPE, 2018).

To aid the companies on the NCS in developing PDO applications according to the authorities' standards, the Ministry of Petroleum and Energy has issued a PDO guidance document that specifies the topics that must be covered in the PDO. According to the guidelines, a reservoir technical description of the field shall be given. Key elements included in the description are the estimated reserves in the reservoir and the forecasted production schedule. The MPE also require that the uncertainties in the estimates should be assessed both qualitatively and quantitatively (MPE, 2018).

2.2.4 Operation

When a field is in operation, hydrocarbons are produced from the reservoir and revenue is generated. As volumes are extracted from the reservoir, the pressure differential between the surface and the reservoir decreases, which results in decreasing production rate as time progresses towards abandonment. The expected lifetime and production profile of a field is stipulated in the PDO, but most fields on the shelf have extended their producing lifetime compared to the initial estimate. Figure 5 shows the commercial life of selected fields on the NCS compared with the expectation at project sanction.

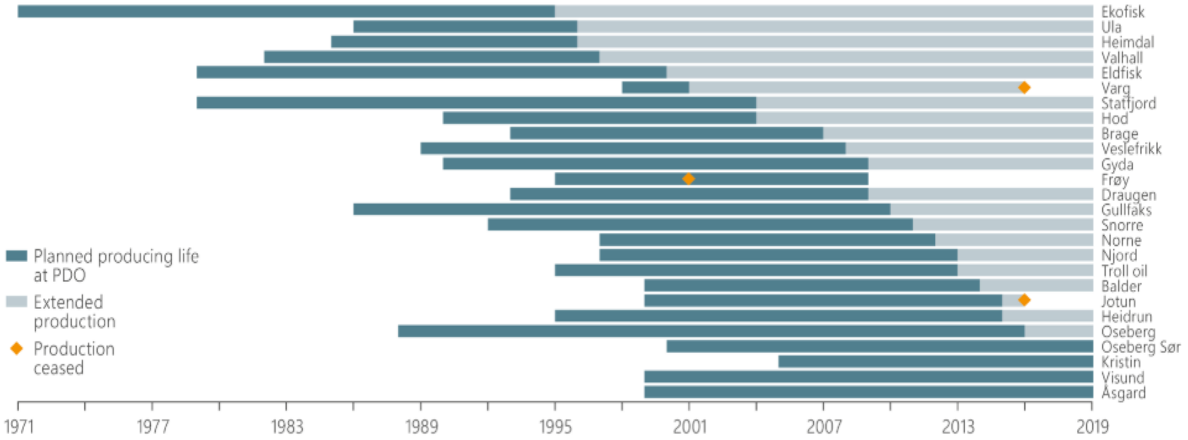


Figure 5: Commercial life for fields on the NCS compared with the estimate in the original PDO (NPD, 2019).

2.2.5 Redevelopment

The extended operational period of the fields in figure 5 is due investments into redevelopment projects, i.e. projects initiated after first oil to increase the ultimate recovery and production rate from the fields. These projects resonate with the resource management strategy of the Norwegian state of maximizing the resources on the shelf. Technical advances and exploration around existing infrastructure are important drivers facilitating redevelopments and is encouraged by the state through opening of exploration acreage and funding of research into enhanced oil recovery methods (EOR).

The maturing state of the NCS makes discoveries of new giant fields less probable and phasing smaller developments into existing infrastructure is expected to be the most common development solution in the future. Redevelopment projects will therefore likely be increasingly important to the Norwegian oil production. There is a great potential for improved recovery on the shelf in the form of drilling campaigns, low pressure production, and EOR methods. This is illustrated in figure 6, where the residual oil after planned cessation under current development plans is given for selected fields. Only considering EOR methods, which is the use of advanced techniques to produce “immobile oil”, the Norwegian Petroleum Directorate (NPD) estimates a resource potential of 350 million Sm^3 of oil factoring in technical – and economic feasibility (NPD, 2019).

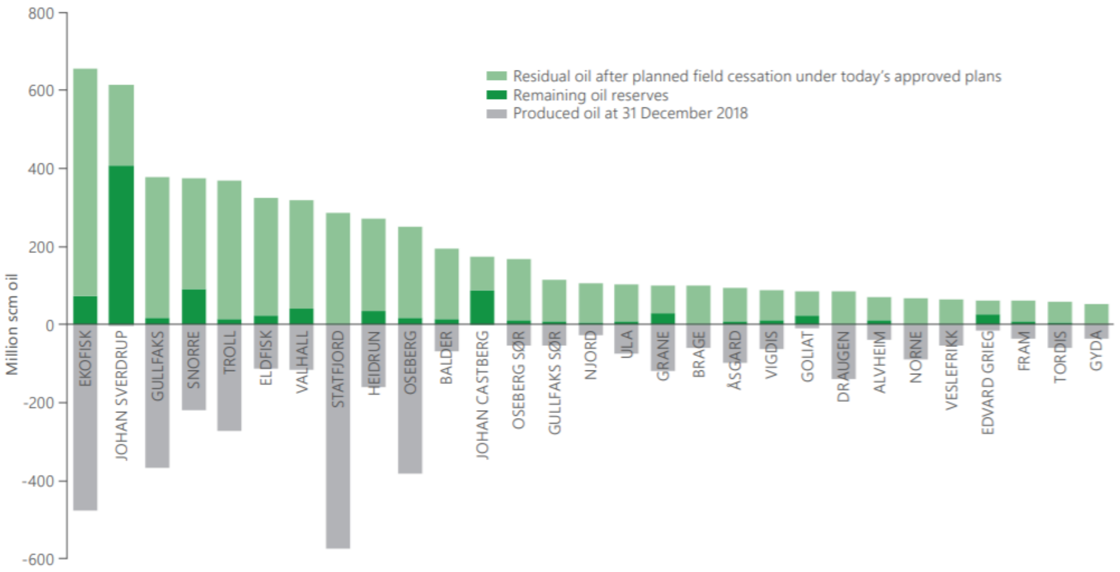


Figure 6: Remaining oil reserves, produced oil, and residual oil after planned cessation of operations under current plans as of December 31 2018 (NPD, 2019).

For a redevelopment to be approved, the licensees must demonstrate that the project have a positive socioeconomic contribution, thus redevelopments are subject to the same PDO approval process as original field developments. Updated production forecasts for the field must be generated since the redevelopment will cause the field production to increase such that the forecast presented in the original PDO no longer holds any validity. The difference in the production forecasts for the field with – and without the redevelopment investment provide the basis to calculate the expected profits from the project. If significant deviations from the PDO is experienced during project execution, the licensees must inform the MPE who can demand the submission of an amended PDO that account for the new circumstances (MPE, 2018).

For projects that meet the criteria listed below, the MPE can grant project approval without the submission of a PDO. These are categorized as PDO exemption projects and are primarily relevant for the development of smaller deposits in connection with existing facilities (MPE, 2018, p. 9).

1. The project cannot have societal aspects of significance
2. The upper investment limit is 20 billion NOK
3. The project must show acceptable socioeconomic profitability

2.2.6 Decommissioning

Decommissioning of facilities and permanent abandonment of wells are conducted when recovery of the remaining hydrocarbons in the reservoir is deemed uneconomical. As more fields on the NCS are reaching the end of their life cycle, abandonment activities will become increasingly relevant. Prior to cessation of operations, the operator must submit a decommissioning plan to the ministry which consists of an impact assessment and the plan for disposing of installations. Also, it must be shown that continued operation is uneconomical, as the authorities aim to maximize the resources on the shelf. An abandoned field can later be reopened if new technological solutions provide basis for renewed profitable production. Because of the significant costs associated with decommissioning and well abandonment[4], the licensees must stipulate the costs in the PDO and demonstrate that sufficient funds have been allocated for this purpose (MPE, 2018, Saasen & Khalifeh, 2020).

2.3 Producible reserves

The two key factors in determining revenue from a petroleum field are the commodity prices and the amount of production. The estimated recoverable volumes of hydrocarbons in a reservoir and the expected rate of production therefore dictate development decisions in the absence of cost considerations. However, without a common procedure to report these estimates, comparing the economic attractiveness of different petroleum developments would be challenging. For this reason, the players on the NCS are required to follow NPD's standards when reporting volume estimates in the PDO.

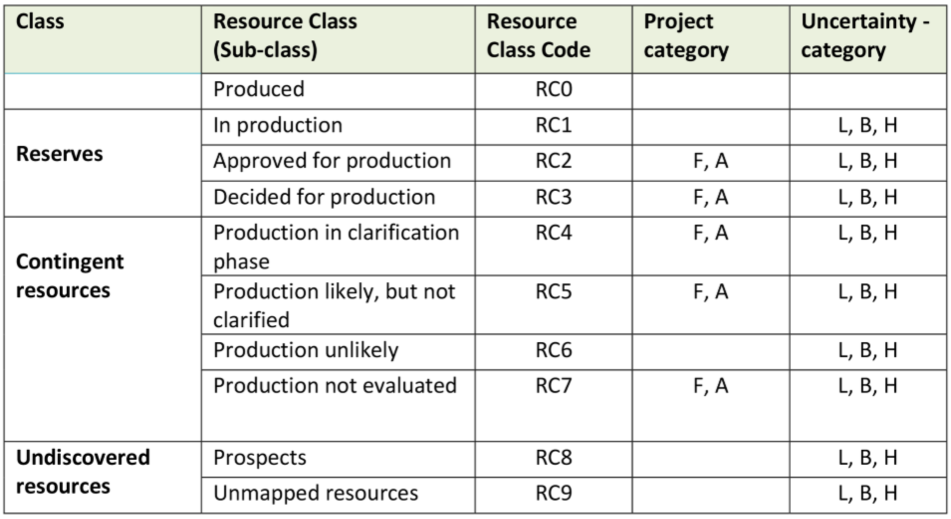
2.3.1 Resource classification

The hydrocarbons initially in place (HCIIP) in the reservoir prior to production start is the complete resource base for a petroleum development project. However, the entirety of this volume is not producible due to technical limitations and economic considerations. Therefore, the resources are divided into several categories depending on their recoverability, with the Norwegian Petroleum Directorate opting for the classification scheme shown in table 2.

---

[4] Plugging a well may account for 25 % of total drilling costs

Table 2:Overview over the NPD's resource classification scheme (NPD, 2016).



Class	**Resource Class (Sub-class)**	**Resource Class Code**	**Project category**	**Uncertainty - category**
	Produced	RC0		
Reserves	In production	RC1		L, B, H
	Approved for production	RC2	F, A	L, B, H
	Decided for production	RC3	F, A	L, B, H
Contingent resources	Production in clarification phase	RC4	F, A	L, B, H
	Production likely, but not clarified	RC5	F, A	L, B, H
	Production unlikely	RC6		L, B, H
	Production not evaluated	RC7	F, A	L, B, H
Undiscovered resources	Prospects	RC8		L, B, H
	Unmapped resources	RC9		L, B, H

The producible reserves are a subset of the complete resources and is defined as "Those quantities of petroleum which are anticipated to be commercially recovered from known accumulations from a given date forward" (SPE, 2001, p. 14). In NPD's classification scheme, the reserves are further subdivided into resource classes RC1 through RC3 and it is the accumulated volumes from these resource classes that make up the reserve estimates reported in the PDO. The hydrocarbons in the reservoir that do not satisfy the definition of reserves are categorized as contingent resources, meaning potentially recoverable volumes that are either non-profitable or not possible to produce under current conditions. However, as a field matures through its life cycle, the classification of volumes is subject to change. The general trend is for contingent resources to move towards reserves as a response to new technological solutions and increased understanding of reservoir characteristics (Demirmen, 2007). The new reserves are then extracted from the reservoir by initiating redevelopment projects. An illustration of the typical development of the classification of petroleum resources is given in figure 7, while figure 8 shows the reserve growth from the original PDO estimate for all fields on the NCS with absolute change in reserves greater than two million Sm^3 of oil equivalent.

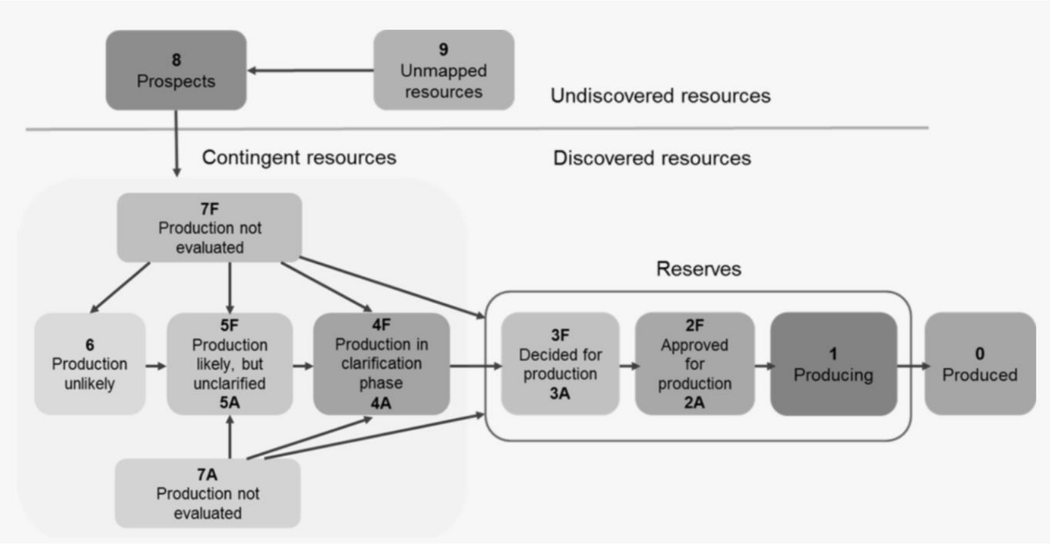


Figure 7: Schematic overview over the NPD's resource classification system (NPD, 2016).

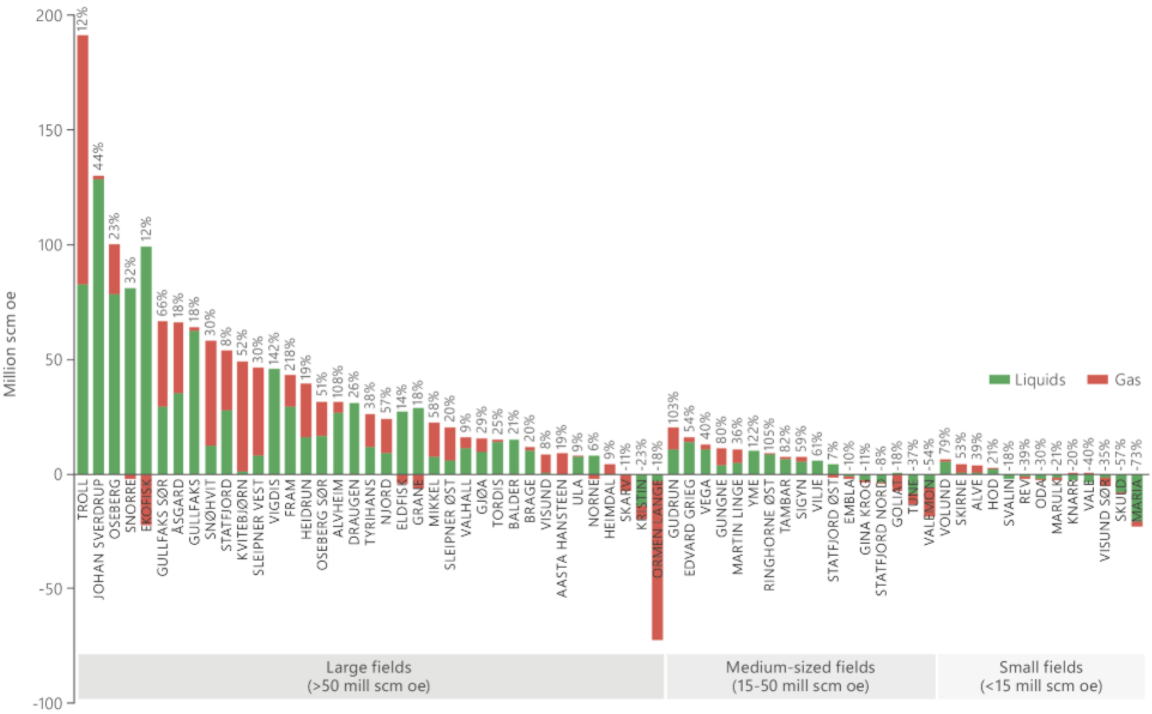


Figure 8: Reserve growth for fields on the NCS (NPD, 2019).

2.3.2 Sources of technical uncertainty when estimating reserves and production rate

Demirmen (2007) argues that three levels of technical uncertainty affect the estimation of reserves and production schedule for new field developments. First, it is a challenge for the operators to obtain sufficient quality data about the reservoirs. The only way to access the reservoirs and gain direct information on the subsurface conditions is by drilling appraisal wells and collect data in the form of well logs, core samples, pressure tests, etc. While this data provides valuable insight on different reservoir parameters such as porosity, permeability, and oil viscosity, uncertainty will inherently accompany the collection of data and thus introduce the first level of uncertainty in the volumetric estimates. Moreover, because the significant costs of appraisal wells limit the number that can be drilled, especially for economically marginal developments, the data from appraisal wells are extrapolated to other reservoir sections. This data is not necessarily representative of the entire reservoir, only the near well region, and when it is used to build reservoir models that are applied in the estimation process, a second level of uncertainty is introduced. A final level of uncertainty arises in the estimation process itself when "Shortcomings in estimation procedures compound imperfections in the reservoir model" (Demirmen, 2007, p. 81). The three levels of uncertainty are illustrated in figure 9.

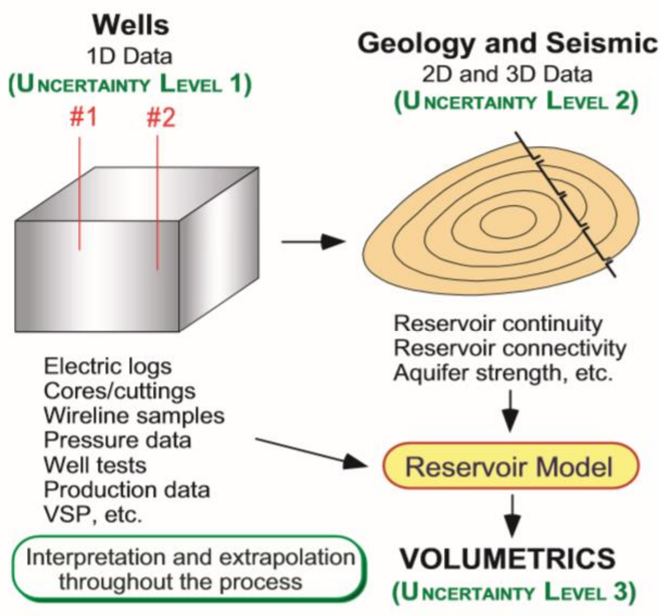


Figure 9: Three levels of technical uncertainty (Demirmen, 2007).

In a redevelopment setting, the forecasters should be better equipped to produce accurate estimates. A wealth of production data, such as production rate (oil, gas, water), pressure (wellhead, wellbore), and temperature, is gathered and stored in structured time series during operation (Xiao & Sun, 2017). Further, chemical and radioactive tracers can be injected to map inter-well permeable paths, thus improve understanding of fluid communication within the reservoir, and 4D seismic can be acquired to track the fluid movements and saturation changes within the reservoir over time (Kelamis *et al.*, 1997). Ultimately, all data gathered during the operations should contribute to reduce the technical uncertainty in the input parameters of a reservoir model. The production data also allows for different forecasting techniques like the classic decline curve analysis and the water cut versus cumulative oil production methodology.

2.3.3 Quantifying uncertainty

As previously mentioned, the licensees must quantitatively describe the uncertainties related to the reserve estimates and the production forecast in the PDO. The language of uncertainty is probability, thus, to quantify the uncertainties in the estimates, probabilities must be assigned to the possible outcomes. Since the reserves and production rates are continuous variables, i.e. they can take any value between their minimum and maximum, a meaningful probability can only be specified for outcomes defined over an interval (Bratvold & Begg, 2010). The uncertainty in the forecasts are therefore quantified in the PDO by providing three separate estimates, namely the P10, mean, and P90. In this thesis, the P10 is defined as the low estimate, meaning that the forecaster believes that there is a 10 percent chance that production will be less than this estimate. P90 is the high estimate such that the P10 – P90 estimates bind an 80 percent confidence interval for the actual production, and by definition, the forecaster is then 80 percent certain that the actual production will be somewhere between these two estimates. To determine the P10 – mean – P90 estimates, a probability distribution that identifies all possible outcomes and their respective likelihood of occurrence must be generated. An example of a probabilistic forecast of the reserves in a reservoir is given in figure 10, where the "Statistical (Capen)" denotation set is identical to the one used herein.

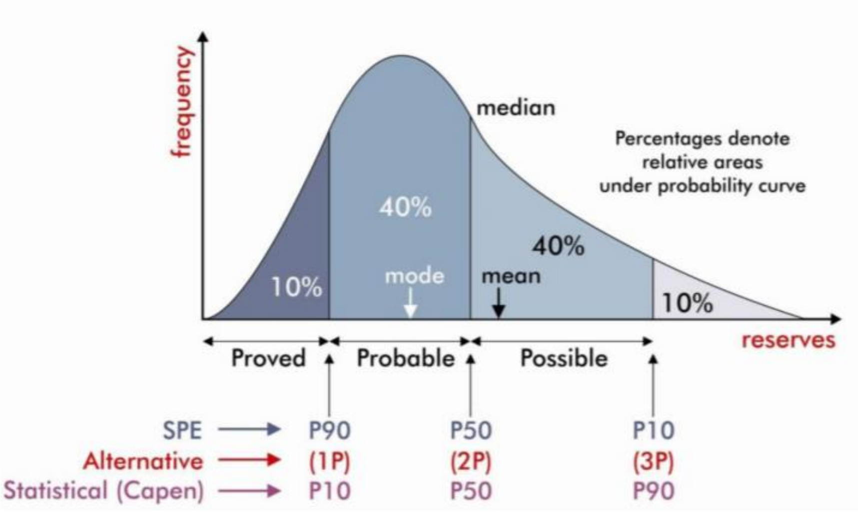


Figure 10: Definition of probabilistic estimation (Tugan & Onur, 2015).

2.4 The economics of a petroleum development

While a petroleum development is a complex venture, the fundamental objective is trivial. The development must be profitable both for the companies and the society for it to be a viable project. The profitability of a petroleum project is, as with all projects, determined by the ratio of revenues to costs. In this industry, both costs and revenues are massive, meaning that even small deviations from forecasts in terms of percentage have great effect on actual earnings.

2.4.1 Net present value

The net present value (NPV) method is one of the most common profitability metrics used to evaluate investment opportunities[5]. In the analytical section of this thesis, it will be used to calculate the present value of production shortfalls from redevelopments on the NCS. Using this method, all expected revenues and costs associated with a project are discounted back to the value at the time of the final investment decision. The NPV can be calculated for an investment using equation 2.1.

$$NPV = \sum_{t=0}^{n} \frac{E[X]_t}{(1+d)^t} \tag{2.1}$$

Where:

E[X] = The expected cash flow
d = Discount rate
t = Time (years)

A positive NPV indicates that the project is expected to contribute value to the companies and the society, and from a risk neutral perspective the project should therefore receive funding.

An important choice that greatly affects the outcome of the NPV calculation is the discount rate. This discount rate is usually set to reflect the companies' cost of capital, which can be calculated from the weighted average cost of capital method (WACC) and will indicate the return that both shareholders and lenders demand on investments.

---

[5] Under assumptions of efficient markets and no arbitrage, the NPV measures the present value of the future cash flows that a project will produce. A positive NPV means that the investment should increase the value of the firm and lead to maximizing shareholder wealth. A positive NPV project provides a return that is more than enough to compensate for the required return on the investment. Thus, using NPV as a guideline for capital investment decisions is consistent with the goal of creating wealth.

2.4.2 Project costs

There are huge costs associated with petroleum production worldwide. The costs can be sorted according to the main project phases during which they are experienced, namely exploration, development, operation, and decommissioning. The expenses of the petroleum industry in Norway are publicly available figures, and the NPD has provided an overview of the costs on the shelf corresponding to the aforementioned project phases. Figure 11 shows historical cost data and future projections, where the "investment" category can be equated to development.

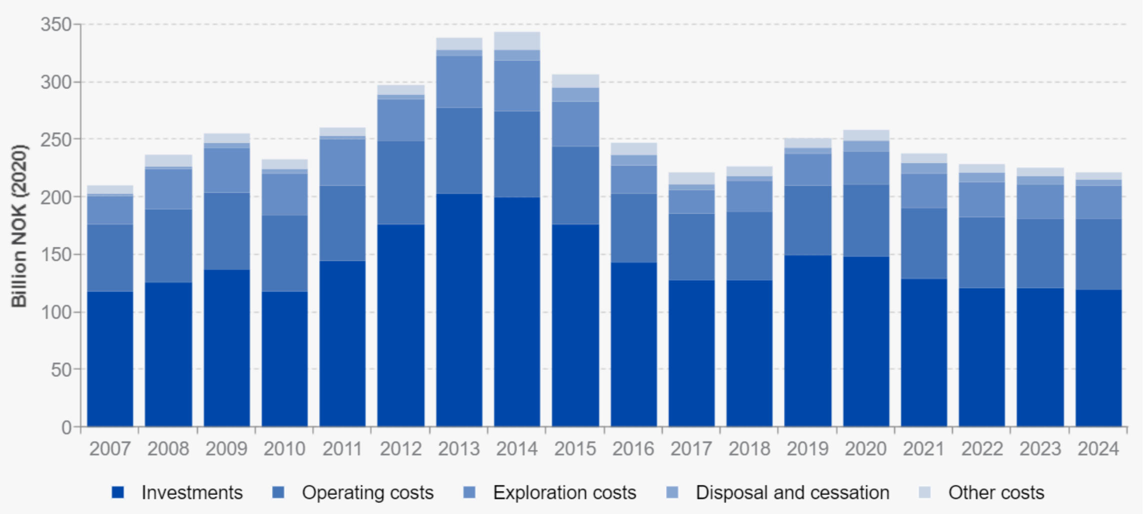


Figure 11: Historical and projected costs on the NCS (Norwegian Petroleum, n.d).

Naturally, for offshore developments, the investments are significant early in the project life cycle. They are related to engineering, procurement, construction, and infrastructure (EPCI). Investments are also occurring later in field life, often associated with a redevelopment. As seen from figure 11, the "investments" category contains the bulk of the expenditure made on the NCS in any given year. The fraction of the total cost it entails for each year varies according to the changing status of the field population on the shelf, but across the years with historical data, approximately 60 percent of the costs are due to development.

Figure 11 also illustrates that "disposal and cessation" costs, i.e. decommissioning, is a marginal factor in the total costs on the shelf. However, since there are few fields that have been decommissioned compared with fields in development or production, figure 11 does not reflect the contribution of decommissioning to the total costs of a project. Historically, for fields that have been decommissioned on the NCS, this phase has demanded 3-15 percent of the total project costs, eight percent on average, illustrated in figure 12. Note that all costs are discounted to 2016-NOK, meaning that the nominal costs of decommissioning are substantially higher in reference to the total costs.

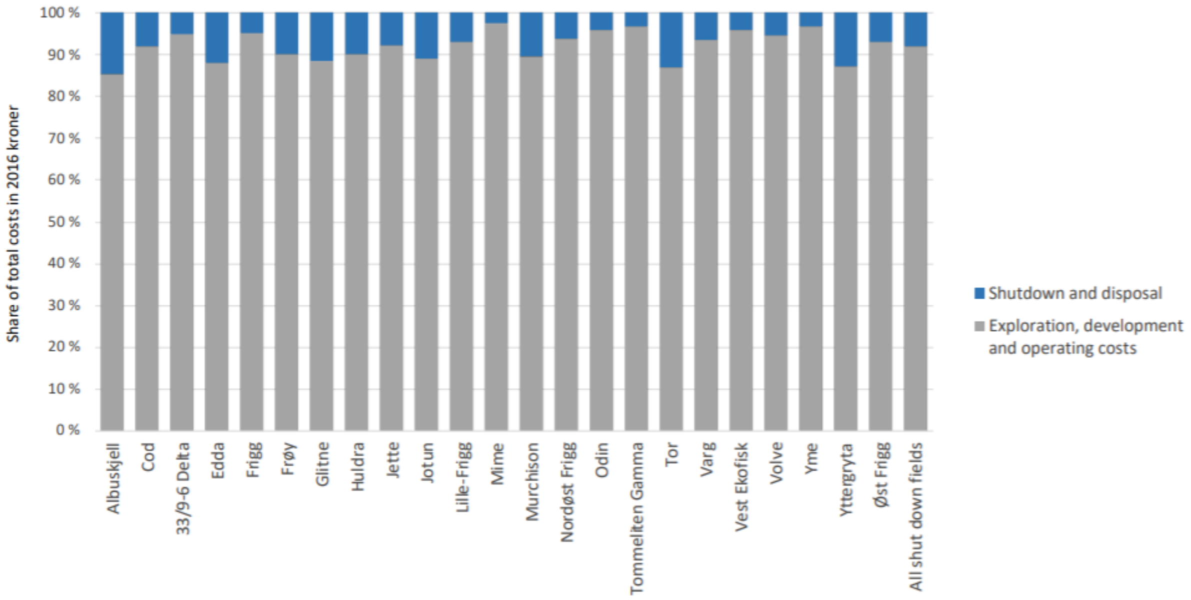


Figure 12: Shutdown and disposal costs in relation to total costs on fields which have ceased operation (NPD, 2017).

2.4.3 Revenue

Petroleum fields generate revenues through the sale of hydrocarbons. The produced hydrocarbons are separated and treated such that we, in addition to oil and gas, have condensate and liquid natural gas (LNG) as marketable products. The oil produced is brought to market and sold at the spot price or a predetermined forward price. However, the produced gas is often used as pressure support and drive mechanism in the reservoirs, such that the marketable volumes of gas may be significantly less than what is produced.

For offshore field developments to be profitable, the hydrocarbon reserves must be substantiable due to the large capital investments necessary to extract them from the reservoir, resulting in fields on the shelf producing for multiple years. In fact, the first major discovery on the shelf, Ekofisk[6], are still in production at present time. However, regardless of size, the production profile for any field will follow a similar trend, illustrated in figure 13. Initially, the production increases quite rapidly until the plateau phase is reached. At the plateau, the field is producing at its highest rate for a limited time. Eventually, the production will decrease and continue to do so until the economic limit is reached.

---

[6] First oil produced in 1971

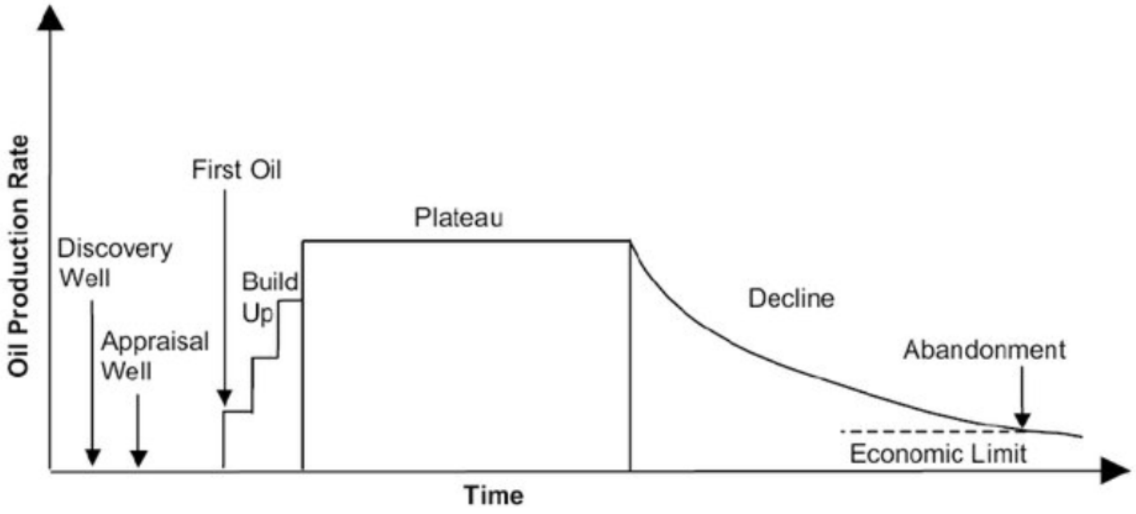


Figure 13: Standard production profile for a petroleum field (Höök et al., 2009).

As pointed out earlier, fields on the NCS often receive additional funding not described in the original Plan for Development and Operation, and a secondary build up phase and plateau will often occur as a result. The actual production profile for the Ekofisk field, given in figure 14, illustrates an extreme secondary build up resulting from the decision to implement water injection at the field.

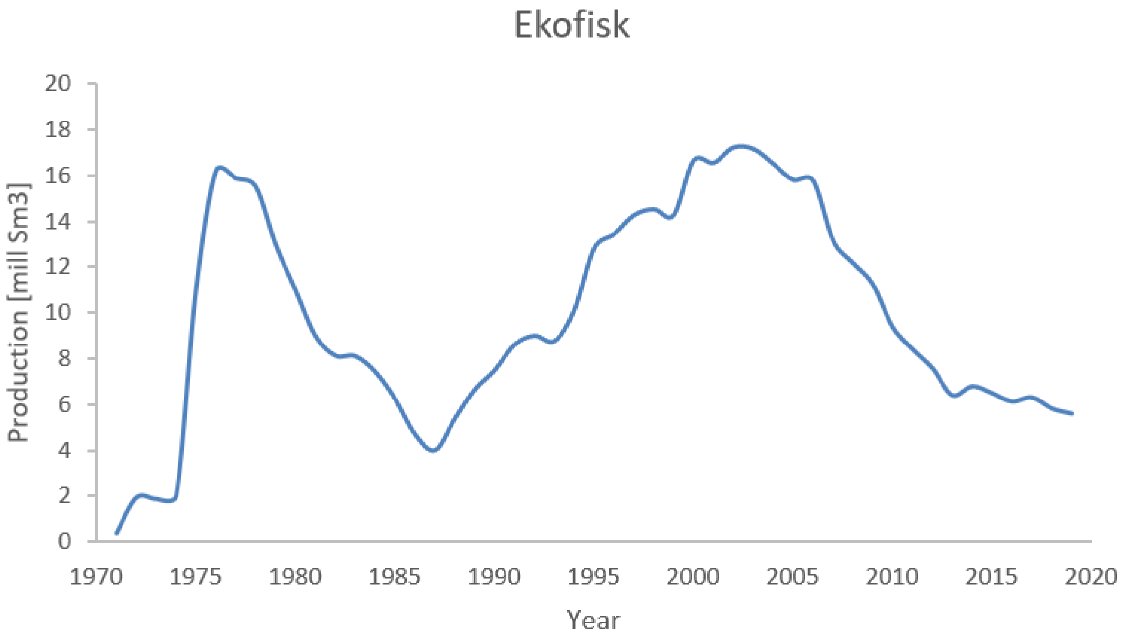


Figure 14: Actual production profile for the Ekofisk field.

The plateau phase of the production, both the initial and possible secondary plateaus, are most significant for the financial success of the project. It is not arbitrary for project profitability at which time expenses are undertaken and revenues are generated. Money is less valuable in the future than at the present, a fact known as “the time value of money”. With the plateau being reached relatively shortly after production start, the produced volumes at this stage has the greater impact on the NPV calculation compared to volumes produced later in field life.

Figure 15 shows the effect of time on the value of 10 dollars, calculated with equation 2.1 using a 10 percent discount rate. From the figure, it is evident that the 10 dollars are worth significantly less in the future than in the present. The same holds true for the revenues generated by hydrocarbon sales from petroleum fields, meaning that the timing of the production volumes is significant in determining profits.

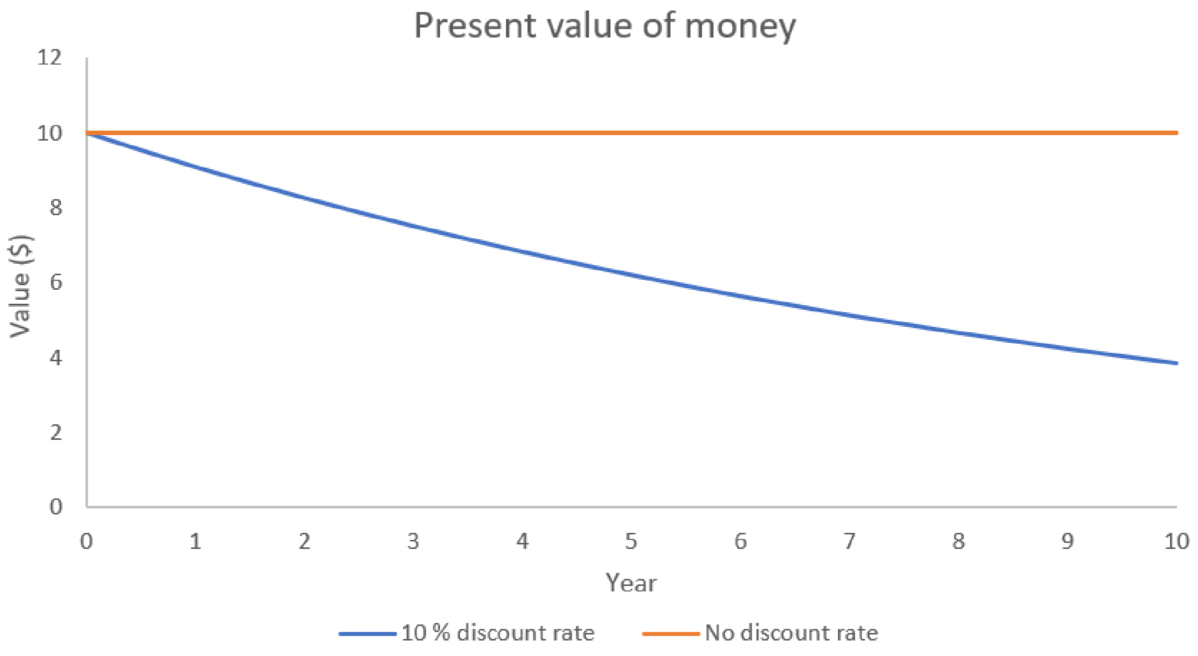


Figure 15: Representation of the impact of discounting on future revenues.

2.5 Megaprojects

Petroleum field developments on the NCS have high capital requirements and virtually all can be categorized as megaprojects. According to Flyvbjerg (2017, p. 3), “megaprojects are large-scale, complex ventures that typically cost a billion dollars or more, take many years to develop and build, [and] involve multiple public and private stakeholders […].” The use of megaprojects is ever increasing across a range of industries, such as infrastructure, information technology, military and defence, and energy. Also, the size of the projects is constantly growing, with the largest equivalent to the size of entire national economies measured by gross domestic product (GDP). Globally, the market value for these megaprojects has been estimated to around six to nine trillion US dollars, corresponding approximately to eight percent of the global GDP (Flyvbjerg, 2014). The management of megaprojects is therefore extremely important for effective use of resources for both public and private entities. However, megaprojects consistently struggle with significant overruns in both costs and schedule, as well as delivering the expected benefits. These findings have lead Flyvbjerg to coin the term “Iron law of megaprojects”, saying that the performance of megaprojects tend to be “Over budget, over time, under benefits, over and over again” (Flyvbjerg, 2011, cited in Flyvbjerg, 2017, p. 11) In the following subsections, historical performance of megaprojects will be presented. The discussion will be primarily focused on research concerning petroleum projects, but insights from other industries will also be drawn upon.

2.5.1 Infrastructure projects

Early research on the performance of megaprojects were conducted on public projects in the infrastructure sector. Flyvbjerg *et al.* (2002) presented one of the first studies that contained a sample size of projects large enough to infer statistically significant conclusions. The cost deviation from the FID estimate were analysed for 258 infrastructure projects across different geographical locations and infrastructure sectors. It was seen that in nine out of ten projects, the cost was underestimated, with an average actual cost 28 percent higher than the estimate. In fact, the probability of a project being delivered to budget was only 14 percent across the 258 projects. The results were statistically significant, and it was found no evidence suggesting that underestimation of costs has reduced over the 70 years’ worth of projects in the dataset despite the major technical advances over the period.

2.5.2 Petroleum projects

Merrow (2011, p. 38) classified a petroleum development project as a success if it fulfilled the following requirements:

1. Actual cost of the development is not exceeding estimated cost by more than 25 percent.
2. Actual development time is not exceeding schedule by more than 25 percent.
3. The production attainment from the field in early years is close to estimated production

In 2012, Merrow published results from an analysis conducted on a robust sample of oil and gas projects drawn from the Independent Project Analysis (IPA) database. The set of projects followed the iron law of megaprojects to the extent that Merrow claimed that only 22 percent of the projects in the study could reasonably be called a success. The success rate for upstream petroleum projects was also worse than in other industries where Merrow observed a 50 percent success rate for megaprojects. Moreover, when comparing the results with an earlier study conducted by the same author, the petroleum industry had regressed from 2003, where a success rate of approximately 50 percent was observed (Merrow, 2012).

Further research is available analysing cost – and schedule estimates in the oil and gas industry. In 2014, the consultancy firm Ernst & Young (EY) conducted a study evaluating the performance of megaprojects in different segments of the industry across the globe. Again, it is found that a substantial fraction of the projects, 64 percent, are experiencing cost[7] overruns and that it evidently is a global phenomenon as the average budget overrun exceeded 50 percent in every geographical region. The industry also struggled with completing the megaprojects within schedule[8], as 73 percent of the projects reported schedule delays. Granted, the dataset included projects that had yet to reach the FID, but even when considering only the 20 largest post-FID projects, 65 percent were facing cost overruns and the FID budget were exceeded by 23 percent on average (EY, 2014).

2.5.3 Cost – and schedule overruns on the Norwegian Continental Shelf

The previously cited research considered megaprojects in a global context. Considering projects on the Norwegian Continental Shelf specifically, Oglend *et al.* (2016) did a study on budget performance using a sample of 80 field developments. The results are presented in figure 16.

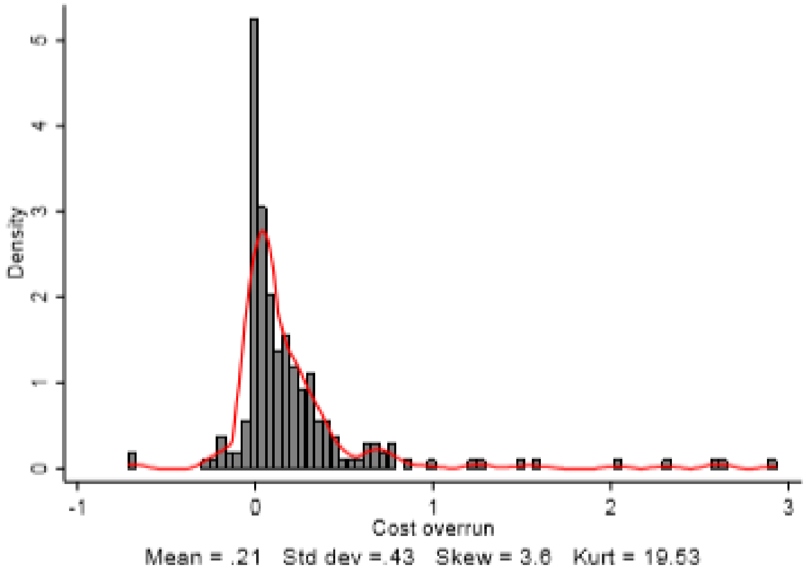


Figure 16: Distribution of cost overruns for petroleum development projects on the NCS (Oglend et al., 2016).

---

[7] Sample of 205 projects.
[8] Sample of 242 projects.

The statistical distribution of the budget outcomes exhibits a positive mean, corresponding to an average cost overrun of 21 percent, and the distribution is positively skewed, meaning that the likelihood for cost overruns are greater than for cost underruns. The authors report that 64 of the projects were completed with overruns relative to the FID estimate (Oglend *et al.*, 2016). Observing the cost overrun distribution, its statistical properties strongly suggest that technical uncertainty in the forecasts is not the root cause of the cost overruns. Had that been the case, one would expect the distribution of outcomes to be symmetrical and centred around a zero mean, which it is clearly not. One would also expect to observe an improvement in forecast accuracy over time, as the inadequacies in the forecasting procedures would be addressed, thus the procedure would be further refined for later projects (Flyvbjerg *et al.*, 2002). However, it was not found any indication of improvement in the cost estimates over the course of the 14 years covered in the study (Oglend *et al.*, 2016).

For another subset of 68 development projects on the NCS, Mohus (2018) confirmed the observations presented in Oglend *et al.* (2016). 82 percent of the development projects failed to meet their budget, which resulted in an accumulated overrun of 213 billion 2017-NOK for the fields in the analysis. This corresponded to an average cost overrun of 26 percent. The field developments also struggled meeting schedule, with an average delay of 25 percent further eroding value from the projects.

2.5.4 Production attainment

As discussed, the production performance in the first few years of operation are especially important to the profitability of petroleum projects due to high production volumes and lower effect of discounting. These early production years were the focus of two separate studies into production attainment.

Nandurdikar & Wallace (2011) found that the average field in their global sample of projects only delivered four out of five barrels forecasted at project sanction. The average production attainment for each of the first four production years are illustrated in figure 17. Again, it is revealed that the forecast quality in the industry is regressing, as projects with start-up in 1995 delivered 94 percent of the estimated production on average. This indicates a failure to address the underlying issues causing unwarranted optimism in the estimates. In fact, only 30 percent of the projects experiencing production shortfalls conducted a root cause analysis to understand the reasons behind the unfavourable results.

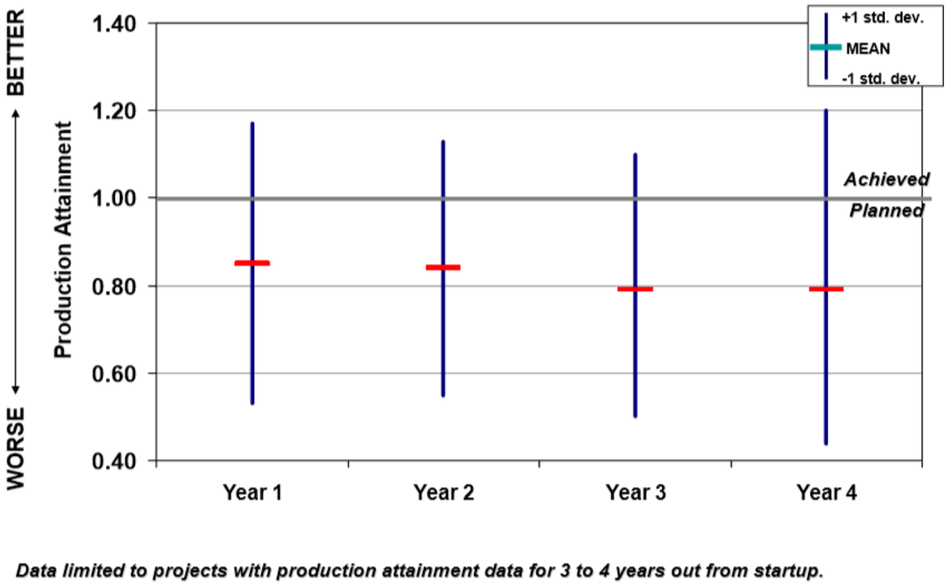


Figure 17: Average production attainment for each of the first four years of operation (Nandurdikar & Wallace, 2011)

Isolating the NCS, Bratvold *et al.* (2019) observed equally poor early production performance for Norwegian field developments. Of 56 fields approved for development during the last two decades, only 28 percent managed to meet their mean accumulated production forecast over the F4Y and, as seen in figure 18, the average field underproduced the mean forecast in each of the first six[9] operational years. Still, the production performance from the fields seem to improve in later years and the average field manage to produce slightly more than the total mean forecasted volumes over the entire period. However, the overproduction in later years is mainly due to additional investments into redevelopment projects and when this occurs, the FID estimate is incomparable with the actual production. After eliminating the effect of additional investments, it was calculated that the poor production attainment accumulated to approximately 200 billion 2017-NOK in reduced revenue for the 56 fields. This corresponds to a 17 percent value loss relative to the mean estimate (Mohus, 2018).

---

[9] The slope of the mean forecasted production is steeper than the actual production from year 0-5

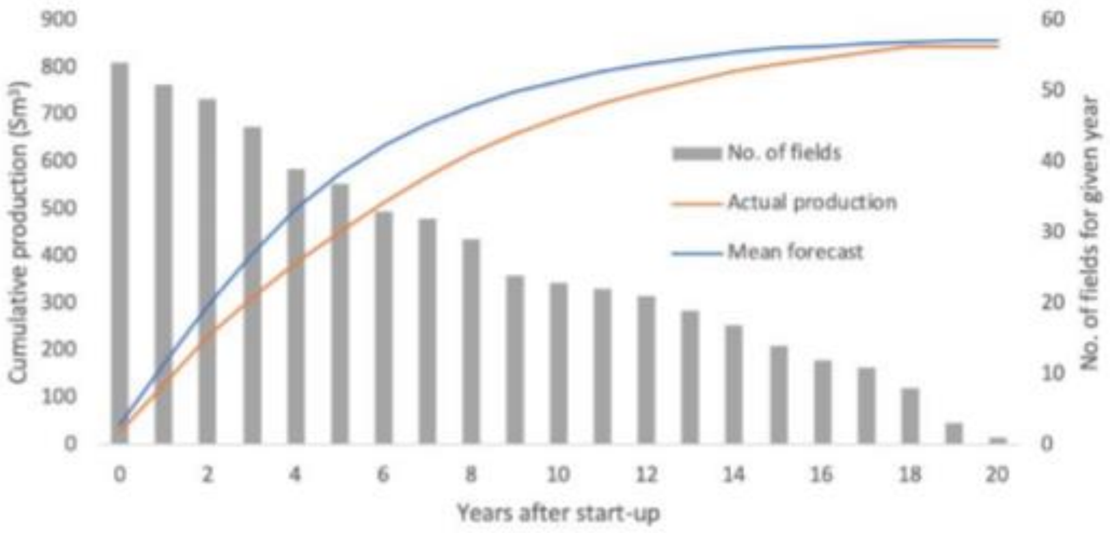


Figure 18: Cumulative actual production vs cumulative mean forecasted production (Bratvold et al., 2019)..

2.6 Decision analysis

Value is created through decisions and to maximize profits and thrive in business, organisations must constantly make good decisions. Bratvold & Begg (2009, p. 21) define a good decision as one that is “Logically consistent with the decision maker’s belief, alternatives, and preferences.” Few decisions, in life or in business, are made without uncertainties affecting the outcome. Therefore, good decisions may lead to bad outcomes and the other way around, which can make it difficult to separate the quality of the decision from the outcome.

In the petroleum industry, the outcome of investment decisions is affected by several outside factors over which the decision maker has no real control. For example, the oil price is an essential profit determining factor that the petroleum companies cannot influence. Prior to 2015, the oil price was exceptionally high for the good part of a decade. However, previously presented research showed that few development projects could be classified as successes based on Merrow’s criteria. The high oil price effectively masked the consequences of many of the issues in the industry like cost escalation and reduced production attainment (EY, 2014). Oil prices higher than those forecasted kept the profits up, providing “good outcomes” for projects that were arguably bad investment decisions.

In *Making Good Decisions*, Bratvold & Begg (2010, p. 7) highlight five challenges that commonly affect decision making in the upstream petroleum industry:

- *Uncertainty*: In the petroleum industry, decisions are made based on inherently uncertain information. The industry continuously develops more sophisticated models to aid decision making, yet uncertainty in the model design and input variables will always remain.

- *Complexity*: Not only are the decision basis uncertain. During a project, there are many decisions to be made. The decision maker must consider several factors, many of which interacts with one another and are affected differently by the decisions.
- *Multiple objectives*: A petroleum development often has multiple objectives that the decision is evaluated upon. The objectives might be in conflict, for instance reducing costs and reducing risks, and they are often measured by different metrics making direct comparisons between the objectives challenging.
- *Ambiguity*: Another consequence of multiple objectives in decision making is the problem of establishing consensus on the relative importance of each objective. Stakeholders might have different views on which objectives are more important.
- *Anxiety about consequences*: Decision makers in the petroleum industry are of critical importance. The outcome of their decisions impacts the organization, the society, the environment, stakeholders, as well as themselves.

3 Analytical procedure

This chapter presents how data is gathered for this project and the procedure implemented to analyse the data statistically. The limitations of the data and the analysis will also be discussed.

3.1 Data

3.1.1 Obtaining datasets

This thesis considers the quality of the oil production forecasts for petroleum fields on the Norwegian Continental Shelf, focusing on redevelopment projects. In order to draw conclusions related to the thesis objective, actual – and forecasted production must be compared. Operators are required to annually submit production forecasts to the authorities that describe the forecasted production schedule for the remaining projected field lifetime. These forecasts are reported to the NPD and used in forming the annual national budget, but they are not made public. To write this thesis, access was granted to production forecast data covering the years 1996 through 2019 under a non-disclosure agreement. Historical production data is publicly available information and has been downloaded from the NPD's fact pages (NPD, n.d).

The fields where additional funding resulted in a redevelopment had to be recognized, which was done by identifying fields where one or multiple secondary PDO's had been approved by the MPE. Also, the dates at which the PDO's were approved had to be collected such that the appropriate forecast was used in the analysis. The website "norskpetroleum.no" include descriptions of every petroleum field on the shelf and was initially used for this purpose. However, it was unclear whether all qualified fields could be identified from the website and the NPD was therefore contacted. From NPD, a complete dataset with all PDO approval dates on the shelf was received, including PDO amendments and exemptions. No such dataset is yet publicly available, but it will soon be accessible through the NPD website according to information received in mail from an NPD employee (Bygdevoll, E-mail to author, March 26, 2020).

3.1.2 Fields and PDO's included in the analysis

During the Norwegian petroleum age, there has to date been 242 separate fields that have had their PDO approved. Of these 242 fields, 122 have submitted production forecasts to the authorities between 1996 and 2019 and are included in the dataset received from the NPD. In that subset, there are a total of 38 fields that have received a secondary PDO approval. Since the analysis is conducted solely on oil production forecasts, the fields that have no, or very limited oil production have been removed. Also, some fields have submitted multiple PDO's ahead of first oil. These PDO's are rejected in this analysis as they are more reflective of the state of knowledge in an original development as studied by Bratvold *et al.* (2019). This delimitation reduces the sample size to 29 fields, but several of the fields remaining in the sample have been granted multiple PDO's during their lifecycle. In fact, across the 29 fields, 71 PDO's have been approved. Note that the fields could have their original PDO approved and come onstream prior to 1996.

In the analysis, however, it was not possible to include all these fields nor all the redevelopments. The reasons for exclusions are threefold. First, some fields had several PDO's approved within a close timeframe. In that case, the earlier redevelopments did not have actual production prior to initiating another investment. Taking the Troll field as an example, the authorities approved PDO's in 1996, 1997, 1999, and 2000, making it impossible to include the first three in the analysis. Second, there exists numerous fields where information regarding approved PDO's are lacking such that it is challenging to determine the time of completion for the project. For reasons discussed later, in section 4.4, the scheduled – and actual time of first oil associated with the redevelopment is essential to the outcome of the analysis, meaning that PDO's where this could not be obtained must be excluded. Finally, for fields producing both marketable volumes of oil and gas, PDO's related to the production of gas often has marginal effect on the oil production and are excluded from the analysis for that reason. After making the mentioned exclusions, the remaining sample contains 20 fields and 32 redevelopments. The process of obtaining the sample used in the analysis are summarized in table 3.

Table 3: The process of constructing the sample used in the statistical analysis.

Bulk data	•242 fields have recieved PDO approval on the NCS. •NPD has collected production forecasts from 122 fields in the 1996-2019 period. •38 fields have recieved a secondary PDO approval between 1996 and 2019.
First deliminaton	•Fields with no or very limited production of oil are excluded. •Secondary PDO's approved before first oil are excluded. •After first delimination, sample contains 29 fields and 71 PDO's.
Second delimination	•PDO's without actual production prior to the implementation of another PDO are excluded. •PDO's with lacking information about scheduled - and actual completion are excluded. •PDO's related to gas production are excluded.
Final sample	•The final sample contains 20 fields and 32 PDO's.

3.2 Method

When generating a production forecast, there are different methods to handle uncertainty which is broadly categorized as deterministic and probabilistic. A deterministic model typically considers the best estimates of the inputs to produce the “expected value” as a single point estimate (Bratvold & Begg, 2010). However, this method is not suited to properly describe uncertainty for continuous variables, hence the forecasts should be probabilistic. Probabilistic forecasting quantifies the uncertainty of a prediction using stochastic probability theory to generate probabilistic distributions to describe the likelihood of the outcomes over an interval. (Gneiting & Katzfuss, 2014). A probabilistic view on uncertainty in production forecasting is increasingly adapted across the industry, which the growth in published papers concerning the topic is clearly indicating, see figure 19.

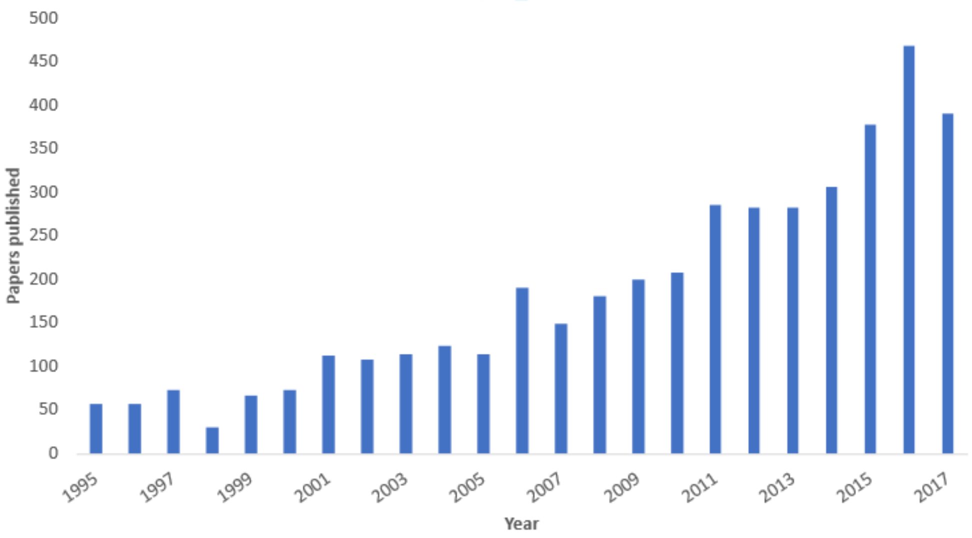


Figure 19: Growth in the number of papers concerning probabilistic forecasting (Bratvold et al., 2019).

In the PDO guidelines provided by the Norwegian authorities, the following is stated: “Expected production profiles for oil, gas, condensate , NGL and water for the entire field […] must be stated along with the associated uncertainty” (MPE, 2018, p. 37). The authorities request that the uncertainty in the production forecast is expressed in terms of P10 – mean – P90 estimates, which are in line with a probabilistic forecasting methodology. In this subchapter, the procedure for generating the probability distributions used to compare the given forecasts with the actual production will be outlined.

3.2.1 Statistical distributions

The volume of oil produced can take any positive value imaginable between zero and the original oil in place (OOIP), hence it can be treated as a continuous random variable, although the actual value is controlled by deterministic, physical processes. To quantify uncertainty in the production forecasts, a probability density function is used to generate a probability distribution that describe the likelihood of different outcomes for the variable. There exist numerous probability density functions that can be applied to generate a probability distribution, and it is the nature of the random variable that determines the appropriate distribution to describe the possible outcomes (Pachamanova & Fabozzi, 2010). In this thesis, the log-normal distribution, which is related to the normal distribution, is used to describe the oil production.

The normal distribution is arguably the most common probability distribution. It is symmetric about the mean, resulting in the familiar bell shape, and entirely defined by its mean and standard deviation. Its popularity in scientific applications is partly due to the central limit theorem, which explains why this distribution is often appropriate. The central limit theorem states that the distribution of sample means approximates a normal distribution as the sample size becomes larger, regardless of the underlying distribution of the sample (McCune, 2010).

The log-normal distribution can only be generated from a set of normally distributed variables. It is the statistical distribution of logarithmic values from the related normal distribution and using logarithmic equations, the distributions can be translated between one another. Compared with the normal distribution, the log-normal distribution holds attractiveness by only existing for positive real values. The log-normal distribution is bounded by zero, but unconstrained on the upside, thus exhibiting positive skew. Similarly, the oil production cannot be less than zero and is theoretically only constrained on the upside by the OOIP, although the capacity of the installed facilities may impose limitations on the production rate in some instances. Figure 20 illustrates the normal – and log-normal probability distributions.

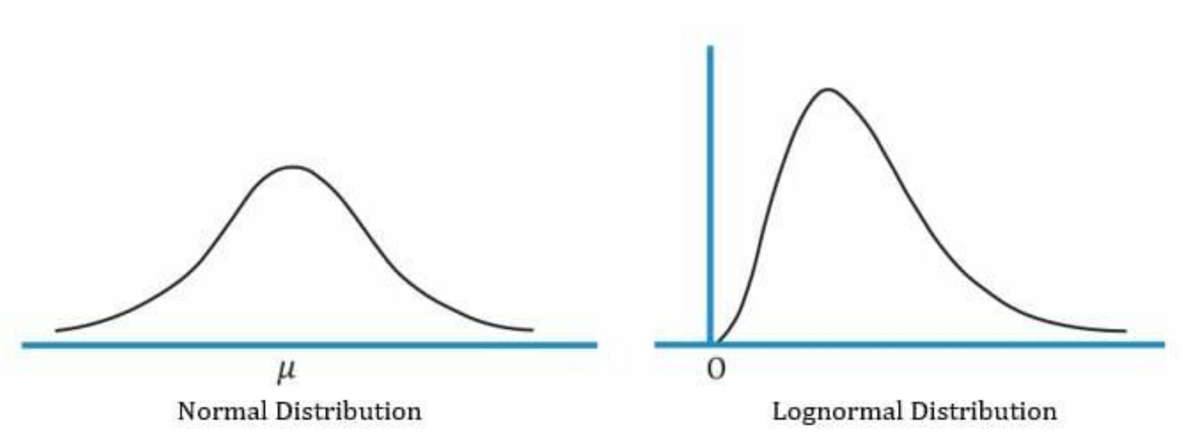


Figure 20: Standard normal – and log-normal distribution (IFT, n.d).

3.2.2 Generating log-normal distribution for single year production forecast

Knowing the mean of the log-normal distribution, along with a point value corresponding to a percentile in the distribution is enough to generate the complete log-normal distribution. Alternatively, two percentile point values can be used to obtain the result. The production forecast dataset provided by NPD includes P10 – mean – P90 estimates for each field and these were used as inputs to generate the log-normal probability distribution. From the logarithmic mean – and P10 values, the standard deviation, σ_N, of the related normal distribution is found using the quadratic formula in equation 3.1. The equation provides two solutions, where the highest value is used in the further calculations.

$$\sigma_N = \frac{-B \pm \sqrt{B^2 - 4AC}}{2A} \tag{3.1}$$

Where:

$$A = 1$$
$$B = -2\theta^{-1}(\alpha)$$
$$C = 2 * [\ln(z) - \ln(m)]$$

σ_N = The standard deviation of the normal distribution

θ = The standard normal distribution function that has a mean of zero and standard deviation of one

α = The percentile from which the z value is found

z = The point value corresponding to a percentile in the lognormal distribution (P10 value)

m = Mean value of the lognormal distribution

After obtaining the standard deviation, the mean of the normal distribution, μ_N, is calculated with equation 3.2.

$$\mu_N = \ln(m) - \frac{\sigma_N^2}{2} \tag{3.2}$$

The mean and standard deviation of the normal distribution are the inputs in the log-normal probability density function. The log-normal probability distribution resulting from this procedure for a single forecasting year is graphed in figure 21, where the inputs used are from an arbitrarily chosen field in the sample.

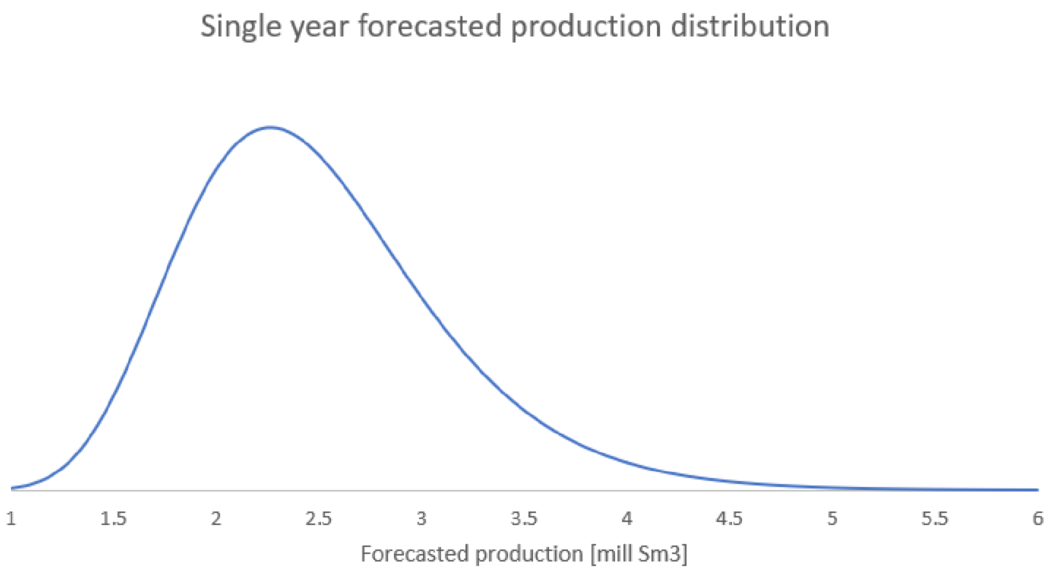


Figure 21: Forecasted production for one year for a random field in the sample.

3.2.3 Generating log-normal distribution for aggregated production forecasts

To observe the production attainment relative to plan over a longer period, production forecast for three years was aggregated to compare with the cumulative production from the same years. The method of aggerating production forecasts is similar to the one described in the previous subsection, but the mathematical rules governing the statistical properties involved requires a few additional steps to the procedure.

The mean and standard deviation of the normal distribution are identically found for each year in the aggregation using equation 3.1 and 3.2. The log-normal mean values for each year can simply be summed to find the total mean of the aggregation. However, such a summation is mathematically invalid for the P10 and P90 values. Instead, the variance of the log-normal distribution, σ^2_{LN}, must be found from equation 3.3 for each year in the aggregation.

$$\sigma_{LN}^2 = e^{2\mu_N+\sigma_N^2} * (e^{\sigma_N^2} - 1) \tag{3.3}$$

Where:

σ^2_{LN} = Variance of the log-normal distribution
μ_N = Mean of the normal distribution
σ^2_N = Variance of the normal distribution

The variances for each forecast year are then added to find the total variance of the aggregation. This being the variance for the log-normal distribution, it must be converted to the variance of the related normal distribution using equation 3.4. Taking the square root of the result from equation 3.4 yields the standard deviation of the normal distribution which is an input parameter in the log-normal probability density function.

$$\sigma_N^2 = -2\ln(\mu_{LN}) + \ln(\sigma_{LN}^2 + \mu_{LN}^2) \tag{3.4}$$

Next, the mean of the normal distribution, which is the other input in the log-normal probability density function, may be found with equation 3.5. Note that the means and variance in equation 3.5 are reflective of the aggregated probability distribution.

$$\mu_N = 2\ln(\mu_{LN}) - \frac{1}{2}\ln(\sigma_{LN}^2 + \mu_{LN}^2) \tag{3.5}$$

Figure 22 illustrates the aggregated production forecast resulting from the described procedure for a field in the sample using the first three years (F3Y) of forecasted production after a redevelopment. Generating this probability distribution allows for the identification of any percentile value in the forecast, such as the P10 and P90, by taking the inverse of the log-normal probability density function.

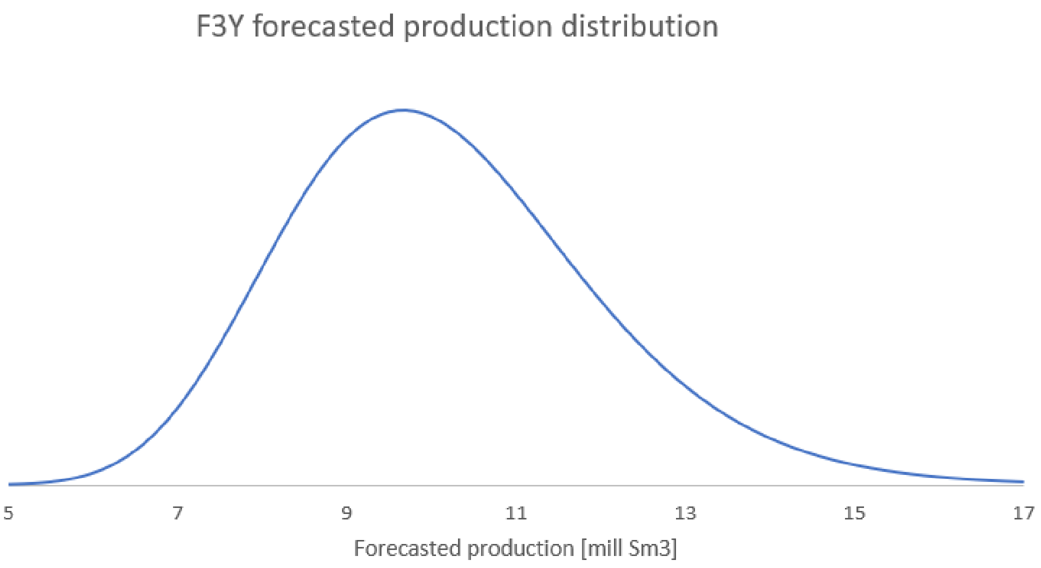


Figure 22: Forecasted production aggregated over three years for a random field in the sample.

3.2.4 Pearson's second skewness coefficient

The base case in the forecasts are reflecting the estimated mean production. Later, in chapter 4, an analysis will be presented where the base case is also referred to as the P50. In statistics, the P50 in a probability distribution is equal to the median, interpreted as 50 percent of the actual outcomes are expected to exceed the P50. The median is therefore not equal to the mean in general. This is only true for a strictly symmetric probability distribution, such as the normal distribution. The input parameters used to generate the probability distributions in this thesis are exhibiting positive skew, characterized by the ratio of equation 3.6 being greater than one. Positive skew results in the mean being greater than the P50.

$$\frac{P90 - P10}{P50 - P10} > 1 \leftrightarrow P50 < \mu \tag{3.6}$$

Since the input parameters are positively skewed, the same will be the case for the fitted log-normal distribution. The severity of the skewness was calculated for the generated log-normal distributions using Pearson's second skewness coefficient, given in equation 3.7.

$$SK_2 = 3 * \frac{\mu - P50}{\sigma} \tag{3.7}$$

3.3 Uncertainties in the analytical procedure

As stated, in the annual production forecasts, three values are reported to describe the projected oil production. In the dataset received from the NPD, these three values are denoted as the low, base and – high estimate, respectively. Currently, it is clearly formulated in the PDO guidelines that the low – and high estimates should reflect the P10 – and P90 percentiles (MPE, 2018, p. 37). Although previous revisions of the PDO guidelines also stipulates that high – and low estimates should be presented along with the base case, the high – and low estimates was not required to be the P10 and P90 percentile values (MPE, 1990, MPE, 2010). Therefore, it is possible that estimates prior to the most recent revision of the PDO guidelines are reflective of other percentiles. Nevertheless, for it to be possible to conduct this analysis, it is assumed that all forecasts are reported in the P10 – mean – P90 format.

The log-normal probability distribution for the production estimates could be generated with three different inputs sets, namely P10 – mean, P90 – mean, and P10 – P90. The resulting probability distributions are slightly different from one another, such that the choice of input sets may have a marginal impact on the results. The main issue of the industry being production shortfall, the P10 – mean input set was chosen such that the probability distribution is optimally fitted to the low estimate. Figure 23 illustrates the log-normal probability distribution of a single forecasting year for a field in the sample using the three different fitting sets.

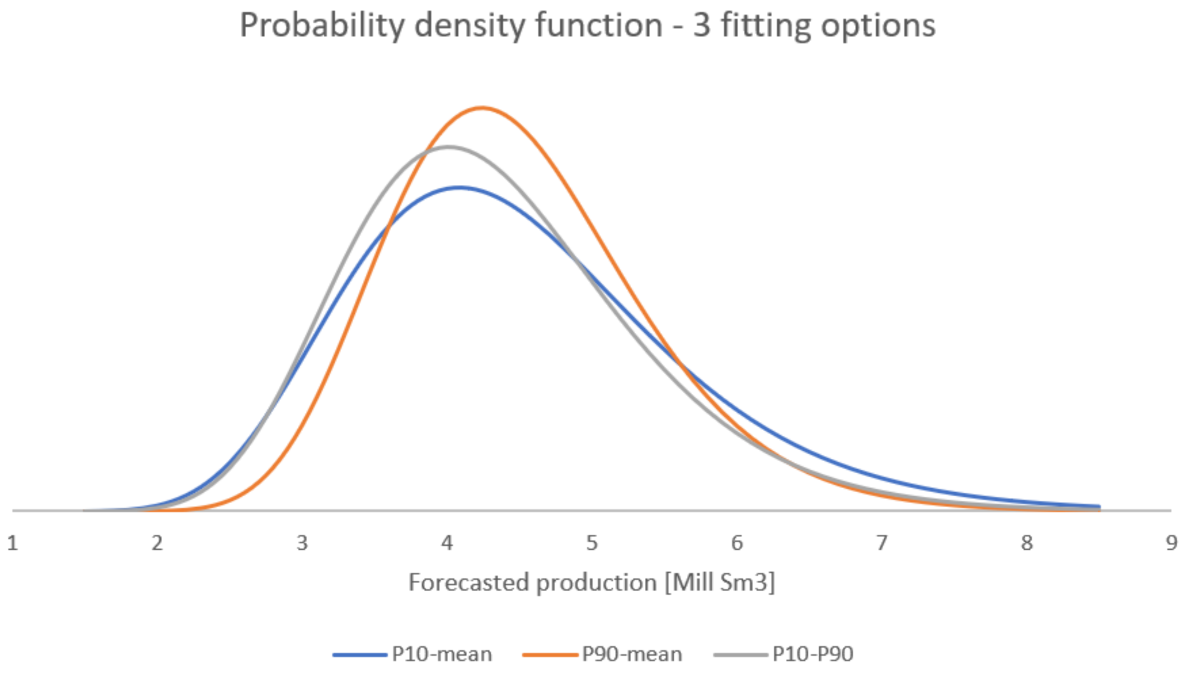


Figure 23: Forecasted production when using each of the three possible fitting sets.

3.4 Limitations

The factors that impose limitations on the analysis presented in this thesis are mainly due to unavailable information and data. It is frequently observed that investments are made on fields to increase production, yet there is no record of a PDO approval. This is likely due to activities such as infill drilling and developing additional volumes close to existing infrastructure and could therefore be PDO exemption projects. However, they are not registered in the NPD dataset that supposedly also should include all PDO exemptions and amendments. The lack of information from these investments have major drawbacks. Most importantly, it eliminates the opportunity of assessing the production attainment related to the investment, which would strengthen the basis of a statistical analysis. Also, in some instances, it directly affects the present analysis by limiting the number of production years that can be assessed for a preceding redevelopment. The reason being that the comparison of the forecasted and actual volumes must be ended if an unexplained increase in production occurs in the decline phase. Figure 24 illustrates the issue, showing the production – and investment profile of the Grane field. A consistent increase in production is observed from 2014 through 2017, although no PDO is approved. As a production increase at this point is not reflected in the forecasts made at project sanction, this is certainly a result of a redevelopment. Hypothetically, an analysis of an earlier redevelopment on this field must be stopped in 2014 as the production profile from that point would be incomparable with the estimate given in the PDO.

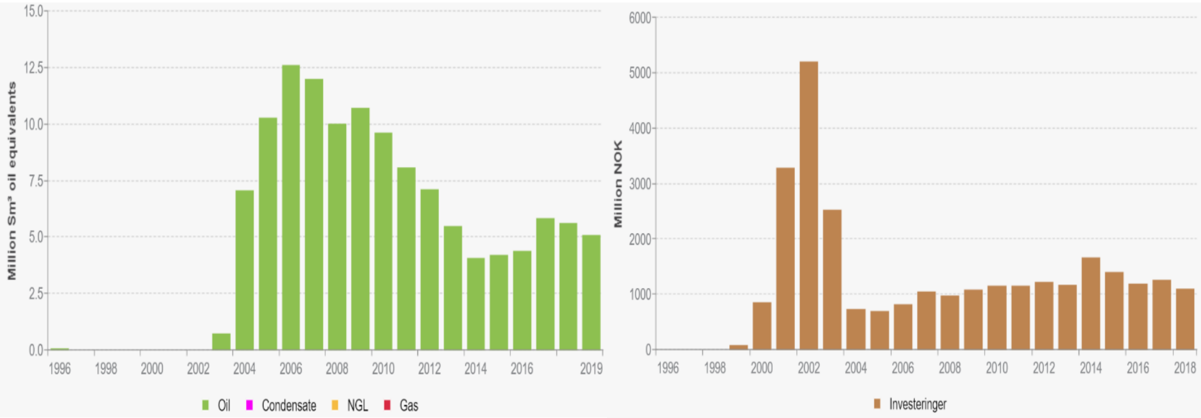


Figure 24: Production profile and annual investments for the Grane field (Norwegian Petroleum, n.d).

This author also encourages the operators to provide low – and high production estimates for the entire projected field lifetime, as indeed they should in order to meet the requirements from the MPE. Currently, it is experienced that the P10 – and P90 estimates for several fields are discontinued years before the mean estimate. This prohibits probabilistic comparison of actual and estimated production for these years as a probability distribution cannot be generated without the percentile values.

It was also necessary to eliminate multiple confirmed PDO's due to limited information regarding the objective of the redevelopment, as well as the scheduled – and actual completion of the project. A public database containing all approved PDO applications would be a great asset to have available when researching any aspect of the petroleum activities on the NCS. Access to such a database may have led to the inclusion of more redevelopment projects in the analysis.

The scope of this paper is limited to fields on the NCS. Gaining access to forecast data for other geographical areas would both expand the current analysis and facilitate research into possible differences between regions, nations, and development solutions.

4 Analysis of production forecasts

To analyse the quality of the production forecasts for redevelopments on the NCS, the actual production must be compared with the estimates given at the time of the final investment decision. For Norwegian petroleum projects, the FID can be defined as the time of PDO approval. The following analysis will therefore be based on the forecasts submitted to the authorities the year of PDO approval. Since the production forecast data received from NPD is confidential, the analysis will not include field – or operator names, nor will the figures contain values at the axis' if this could allow for the identification of a field. The exception is when publicly available information is cited. The dataset used herein comprises of 32 redevelopment projects from 20 fields.

4.1 Estimated production

The 20 fields included in the analysis have contributed significantly to the total production on the shelf. The total annual mean estimated production from the 20 fields are shown in figure 25. The annual mean values are generated from the forecasts submitted the previous year.

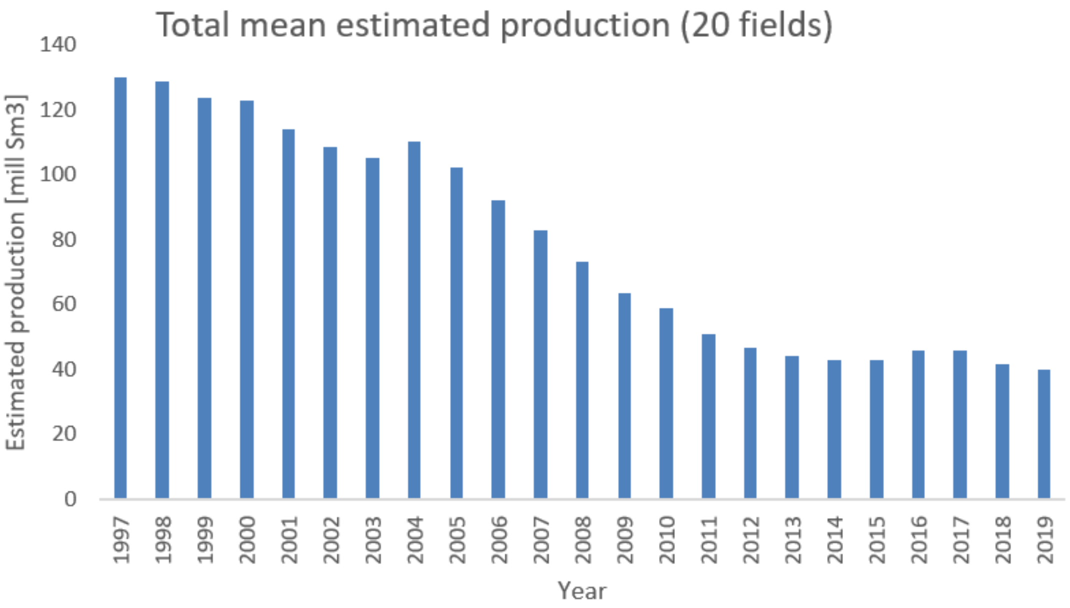


Figure 25: Total annual estimated production for the fields in the analysis in the 1997 – 2017 period.

It is seen that the estimated production for the period is highest in 1997 and diminishes significantly toward the end of the period. This is a good reflection of the current state of the NCS. Although new fields are being discovered and producing fields receive funds for redevelopment, their contribution to production cannot fully compensate for the diminishing returns from the major fields on the shelf.

4.2 Confidence interval

The uncertainty in the production forecasts is quantified by the P10 and P90 estimates. Together they bound an 80 percent confidence interval for the actual production that can be visualized by plotting the P10 – and P90 production profiles. For a field on the NCS, the production forecast submitted the year of PDO approval is illustrated in figure 26.

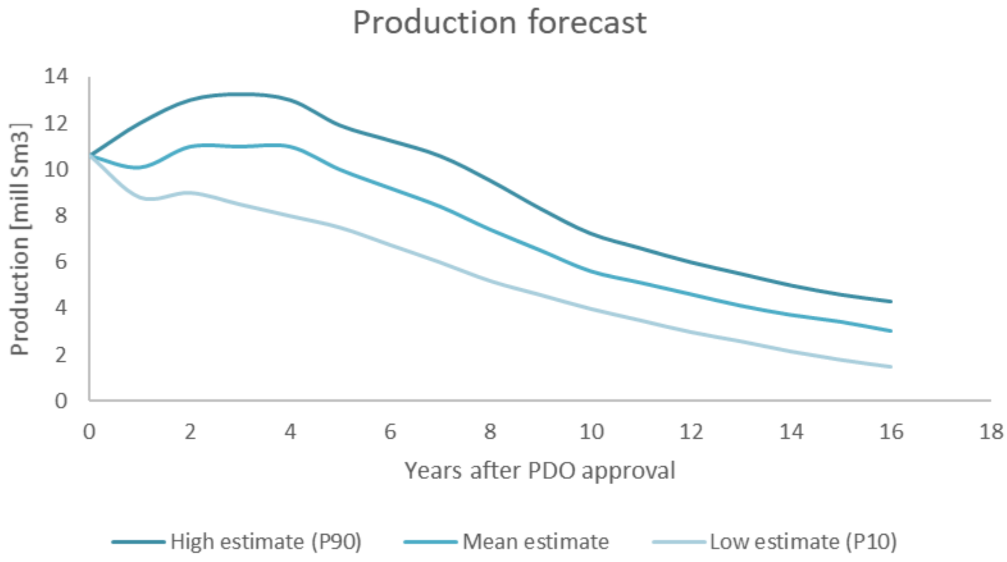


Figure 26: Illustration of the P10, mean, - and P90 estimates for a field on the NCS.

The difference between the estimates reflects the uncertainty in the forecasts. If the range bounded by the P10 – P90 estimates is small, the forecasters express confidence in their ability to predict the production, and conversely, if the range is large, the forecasters are more uncertain about the field production.

4.3 Actual production

The actual production data used to control the forecasts are downloaded from the website of the NPD (NPD, n.d). The actual annual production from the 20 fields in the analysis is given in figure 27. Compared to the mean forecast in figure 25, it is observed that the estimate is slightly higher than the corresponding production until 2012. At this point, the total mean estimate is aligning well with the outcome.

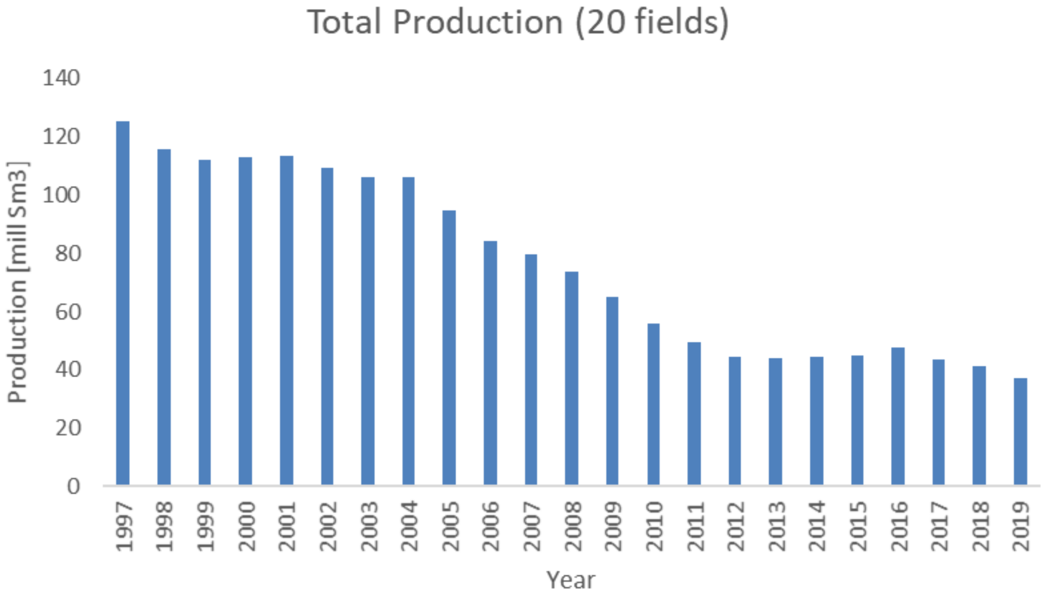


Figure 27: Total production for the fields in the analysis in the 1997 – 2017 period.

4.4 Comparing forecasted production with actual production

Previous studies on the quality of production forecasts have focused on the original development (Nandurdikar & Wallace, 2011, Bratvold *et al.*, 2019). There are two possible methods to conduct such an analysis, which will be described in the following subsections.

4.4.1 Normalized to estimated production start

Using this method, the scheduled production start is taken as the first year in the comparison. This methods' effect on the analysis is easily illustrated by an example. Field A is a discovered prospect on the NCS and has had its PDO approved. In the PDO, a development schedule is given, and production is forecasted to begin as scheduled. However, delays push back the production start by one year. In this situation, normalizing to estimated production start leads to the production forecasts in the first year being compared to production which has not yet commenced. Also, the forecasts for the subsequent years will not be aligned with the intended production year for the remainder of the analysis. As a consequence, when analysing production shortfalls, the effect of schedule delays will be included in the results.

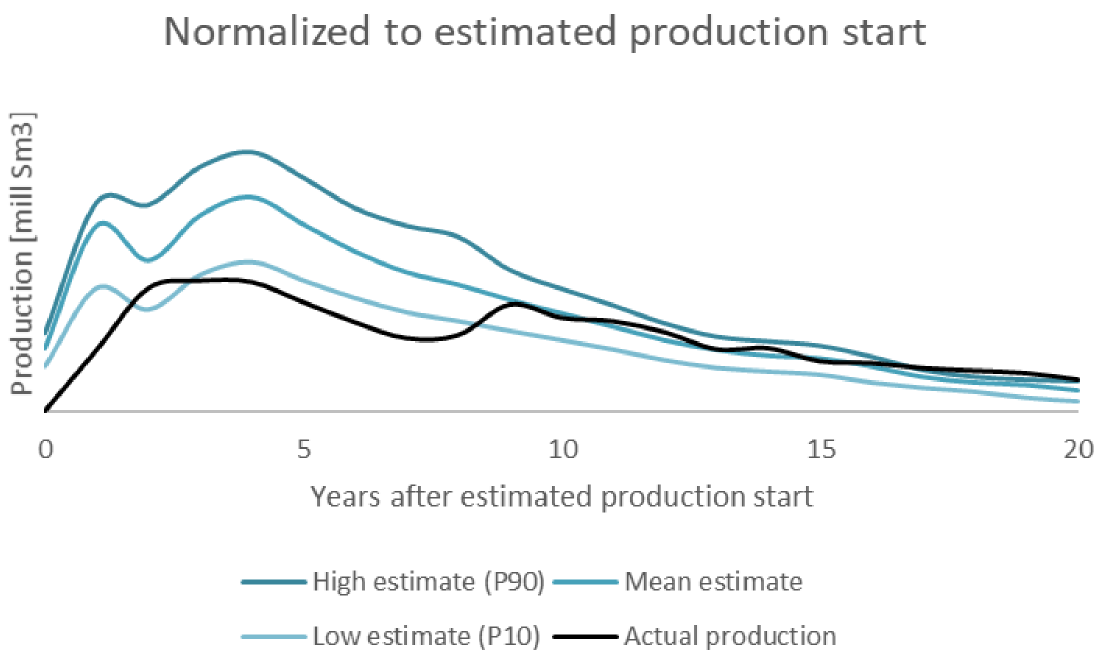


Figure 28: Actual production profile vs forecasted production profile for a field on the NCS when normalizing to estimated production start.

4.4.2 Normalized to actual production start

Consider the same example as in the previous subsection. To minimize the effect of schedule overruns on the production attainment analysis, time can be shifted such that the estimated first production year is set equal to actual first production year, illustrated in figure 29. Still, as annual data is utilized, schedule overruns occurring within the same calendar year as scheduled production start will influence the results, e.g. a 3 month delay from August to November. Compared to figure 28, for the same field A, observe that the actual production now is transferred one year to the left, thus accounting for the schedule overrun outside of the calendar year. The total production is not affected when using either of the methods, but when normalizing to production start the discount factor will be less, leading to greater profits.

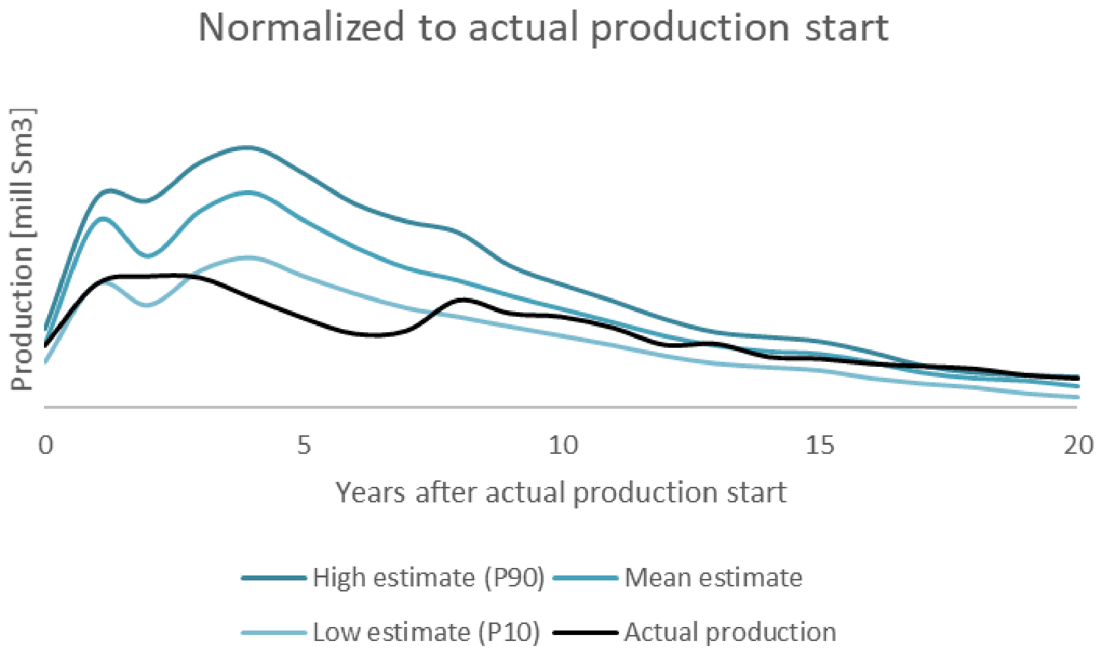


Figure 29: Actual production profile vs forecasted production profile for a field on the NCS when normalizing to actual production start.

4.4.3 Method to analyse redevelopments

In the two previous subsections, the examples were given for the analysis of an original PDO, i.e. forecasts submitted prior to first oil. Because the second method described reduces the influence of schedule overruns on the results, this is the preferred method of forecast evaluation. When analysing the original investment decision, this method is easily adopted, as both the time of PDO approval and time of first oil is known. However, when considering redevelopment projects, as is the focus of this thesis, the situation is more muddled. Although the time of PDO approval is known, it is challenging to establish when the project has been completed and if it has been completed according to schedule due to the field production being ongoing whilst the project is developed. Still, efforts have been made to identify these parameters for all redevelopment projects included in the analysis, such that the actual production is compared to the corresponding estimate.

It is clearly observed from the actual production profile of field A that it was subject to a redevelopment around the year seven of its life. Again using field A as an example, figure 30 illustrates the standard situation sought after when conducting the analysis on redevelopment projects. Figure 30 is also a good representation of a previously discussed issue, that the P10 – and P90 estimates are not reported for the full projected lifetime of the field.

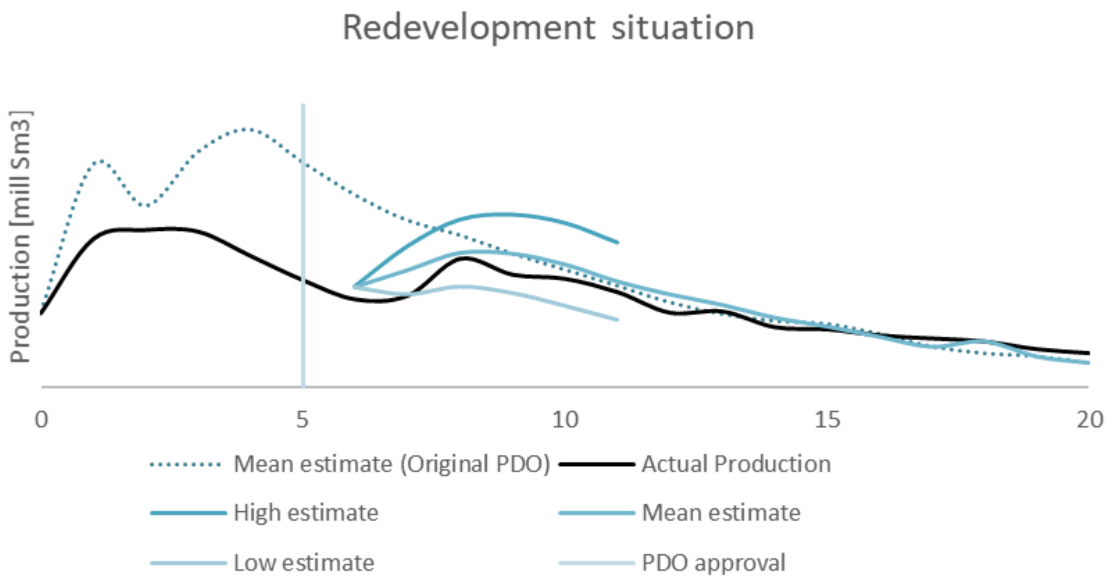


Figure 30: Actual production profile vs forecasted production profile for a redevelopment project on the NCS when normalizing to actual production start.

Contrary to the original development, when analysing redevelopment projects, it is not possible to incorporate projects that has experienced major schedule delays in the analysis. This is a consequence of the ongoing production during the development period. The Vallhall redevelopment project will be presented as an example to illustrate the issue. The operator of the field received approval for the redevelopment of Vallhall in June 2007, with scheduled production start in November 2010. The project owner experienced major problems and actual production start did not commence before January 2013 (NPD, 2013). If this were prior to first oil, the forecasts could be normalized to actual production start, such that the forecasted production in 2011 would be compared with actual production in 2013 without notably affecting the results of the analysis. However, the ongoing production from the field during the redevelopment period has certainly reduced the remaining reserves, which results in reduced reservoir pressure and unfavourable flow characteristics in the reservoir in 2013 compared to 2011. Consequently, the production rate in 2013 would be lower than in 2011 assuming identical effect of the redevelopment. For this reason, the fields with major schedule delays must be excluded when analysing redevelopments.

4.5 Statistical distribution of outcomes

This section is dedicated to describing the results from the probabilistic analysis of the production forecasts. Throughout, figures and tables will be presented to evaluate the quality of the production forecast for redevelopment projects on the NCS. The first three years of production is the primary focus in the analysis, considering the low – and high production estimates as well as the mean. It is the initial years of production that carries the greatest impact on the revenue and profitability of the project due to the discount factor being at its smallest. It is also during the plateau phase, which typically occurs within this timeframe, that the field produces at its highest rate before entering the decline phase. The volumes produced in this period is therefore a substantial fraction of the total volume produced from the field, using the time of redevelopment as the reference point. Before the results is presented, some attributes of probabilistic forecasting will be discussed.

4.5.1 Evaluating probabilistic forecasts

Ideally, the operators would consistently generate well-calibrated production forecasts. According to Bratvold *et al.* (2019, p. 2), " A well-calibrated production forecast is unbiased and consistent with the forecasters' knowledge." Conversely, a forecaster is well-calibrated when he or she deliver forecasts that meet the following two requirements:

1. For a set of forecasts, the fraction of the actual outcomes that falls within the given confidence interval is equal to the assigned confidence interval. On the other hand, if a greater number of the actual outcomes than anticipated falls outside of the range of predicted outcomes, the forecaster is considered overconfident (Fischhoff, 2012). In the context of this thesis, the forecasters on the NCS provide an 80 percent confidence interval, meaning that forecasters are well calibrated if no more than 20 percent of the actual outcomes are outside the confidence interval bounded by the P10 and P90 estimates.
2. The average of the actual production is close to the average estimated production. Otherwise, the forecaster is either optimistic or pessimistic (Bratvold *et al.*, 2019).

That megaproject forecasts across industries are plagued with overconfidence – and optimism bias is a known phenomenon in literature. The effect of both biases is readily illustrated by figure 31, where synthetic data is used to generate the distribution of forecasted – and actual outcomes for OOIP.

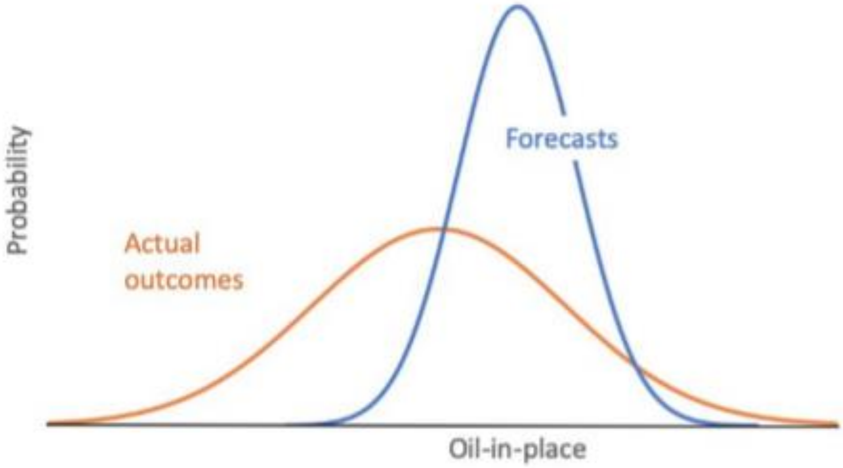


Figure 31: Synthetic data used to generate the actual – and forecasted distribution of outcomes for OOIP (Bratvold et al., 2019).

In figure 31, the overconfidence bias results in the forecasted distribution of outcomes being too narrow compared to the distribution of actual outcomes, whilst the optimism bias is responsible for the forecasted mean being greater than the actual mean. The combination of the two biases result in misrepresentation of both the mean and standard deviation of the distribution of potential outcomes (Briel *et al.*, 2013).

To evaluate whether the forecasters on the NCS are able to deliver unbiased production estimates for redevelopment projects, the following scatterplot can be generated for the first three years of production.

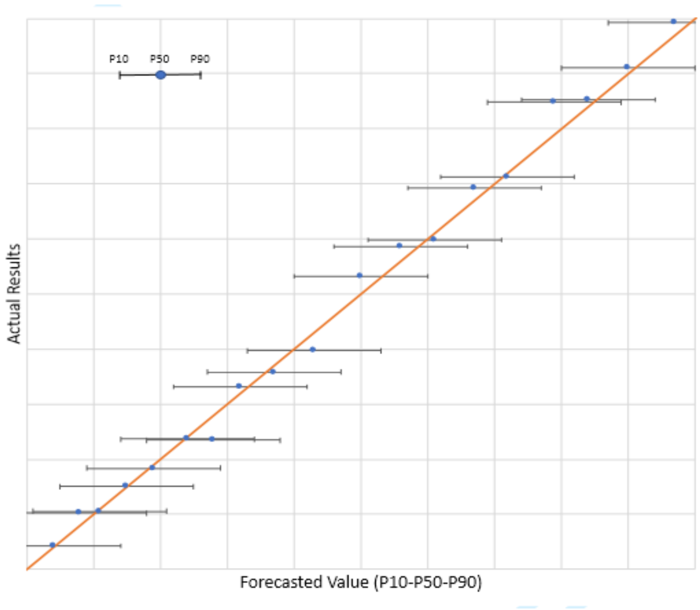


Figure 32: synthetic data used to plot actual production against the P50 forecast. The "error" bars represent the 80 % confidence interval (Bratvold et al., 2019).

Figure 32 is constructed using synthetic data. In the scatter diagram, the forecasted production is plotted against the actual production. The central blue circles represent the P50 estimate, while the left – and right caps on the error bars represent the low – and high estimate, respectively. If the P50 estimate was completely descriptive of the actual outcome, the blue circles would perfectly align with the orange diagonal, given a symmetric probability distribution. However, in reality, such results will never be observed. Instead, unbiased forecasts are distinguished by the fulfilment of two requirements:

1. Roughly half the P50 markers are located at either side of the diagonal.
2. In approximately 80 percent of the forecast, the diagonal is encompassed by the error bars, corresponding to the actual production falling between the P10/P90 estimate 80 percent of the time.

4.5.2 Sample size

The first three years of production after redevelopment was analysed using a subset of 21 projects drawn from the complete dataset containing the 32 redevelopments. Some factors leading to the reduced number of re-developments included in this section have been touched upon previously. To briefly reiterate and expand, some redevelopments are affected by subsequent investments, thus limiting the number of valid production years for that re-development to less than three. Also, the complete sample includes redevelopments that have been too recently approved to have three years of production. Finally, the issue of operators not reporting P10/P90 values for the entire projected field lifetime or stetting them equal to the mean estimate has caused the exclusion of eight redevelopments in this analysis. If the analysis were to be conducted for a greater number of aggregation years, this wrongful reporting would be even more of a constraint. Revisit figure 30 for a graphical presentation of this issue.

4.5.3 Mean estimate vs P50 estimate

The scatterplots generated for the F3Y denotes the central estimate as the P50 instead of the mean as this is more natural to evaluate the presence of optimism bias. However, because of positive skew in the input variables, the mean is not equal to the P50. Therefore, Pearson's second skewness coefficient was calculated for each forecast year for the redevelopments included in the F3Y analysis as described in section 3.2.4. According to Bulmer (1979), a distribution with skewness less than 0.5 is approximately symmetrical, while a distribution with a score between 0.5 and 1 is characterized as moderately skewed. The maximum – and minimum skewness of the distributions in the sample was 0.57 and 0.05 respectively, with 97 percent being less than 0.5. Once the single-year distributions were aggregated to create the probability distribution for the first three production years, the skewness was reduced for all redevelopments in accordance with the central limit theorem. For the F3Y distributions, the average skewness was 0.19 with 0.32 as the maximum. The average relative difference between the mean and P50 estimate is 0.9 percent, the maximum difference being 2.3 percent. The results from the calculations shows that it is fair to use the forecasters mean estimate as an approximation of their P50 when analysing their tendency towards optimism bias. Furthermore, since the actual P50 values can be extracted from the generated probability distributions, the validity of the approximation can be confirmed by doing the analysis using both the mean – and the P50 as the central estimate. When doing so, the results of the analysis remained unaffected, meaning that the number of projects with production less than the mean estimate is identical to the number of projects with production less than the P50 estimate.

4.5.4 Analysis of the first three production years

The results of the analysis of the first three years of production for the 21 redevelopments are given in figure 33. It is the same data in both renditions, but the scatterplot on the right-hand side has been scaled down to provide a clearer picture of the fields producing less than 18 million Sm^3 over the period.

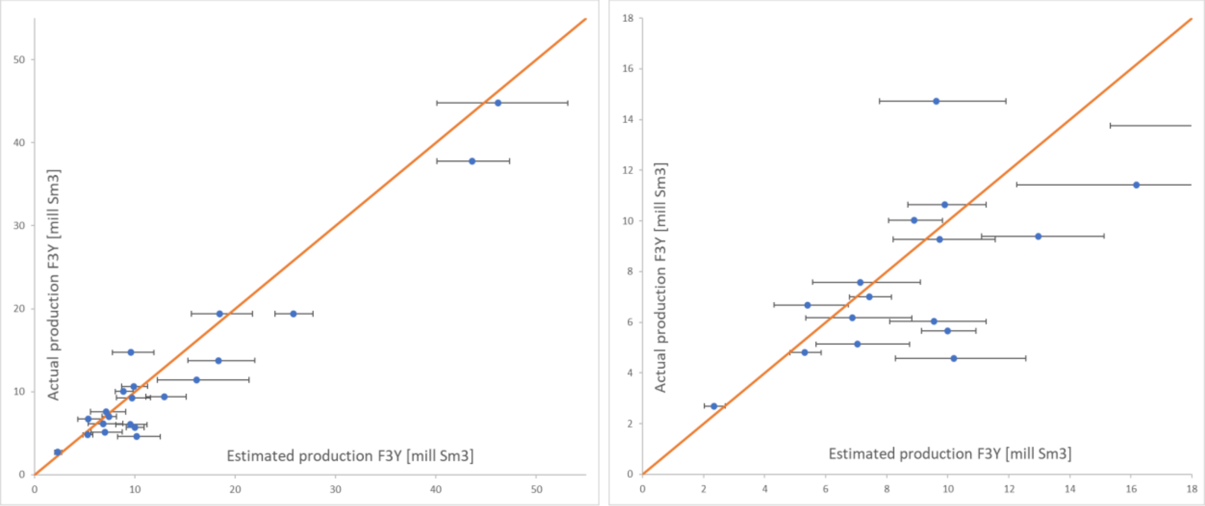


Figure 33: The results of the statistical analysis of production attainment over the F3Y. Left: Showing all redevelopments in the analysis. Right: Showing redevelopments with P50 forecast less than 18 mill Sm^3 for the F3Y.

The graphical representation of the analysis clearly illustrates that the redevelopment forecasts for the F3Y are affected by both overconfidence and optimism. Less than half of the projects have actual production that are within the 80 percent confidence interval reported to the authorities. Of the projects with production outside the confidence interval, 83 percent was underperforming the P10. Considering the P50 only, two thirds of the blue circles are to the right of the diagonal in contrast to the 50 percent expected with unbiased forecasts. In figure 34, the optimism demonstrated in the redevelopment forecasts is assessed by comparing the cumulative aggregated actual production with the forecasted mean and P10. The actual – and forecasted production have been normalized such that the mean forecast is 1.0.

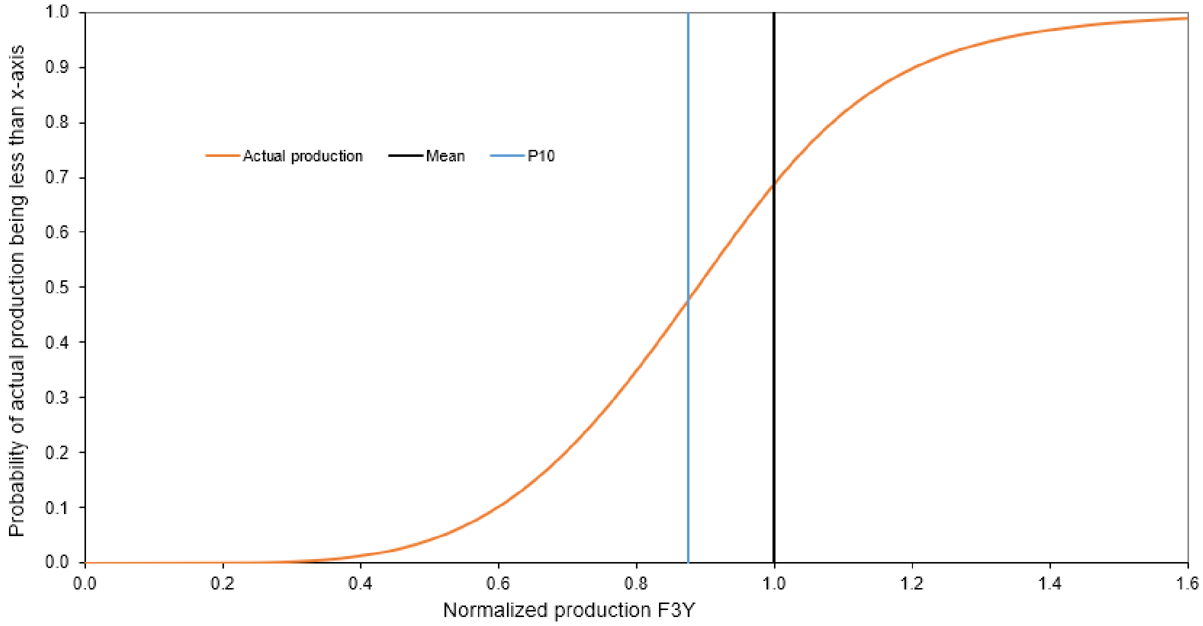


Figure 34: Cumulative distribution of the normalized actual production for all 21 redevelopments over the F3Y. The normalized mean – and P10 forecasts are shown as vertical lines.

Since the ratio of actual production to mean forecast is unique to each redevelopment, a metalog distribution were tailored to the normalized production data to generate the aggregated cumulative production curve for all redevelopments. The metalog distribution was used because its shape flexibility makes it easy to fit the cumulative density function to the data (Keelin, 2016). On the vertical axis, the point of intersection between the actual cumulative production and the mean forecast provide the probability of the production being less than the mean estimate, which was the case for 67 percent of the redevelopments. Similarly, it is observed that 48 percent of the redevelopments had production less than the aggregated P10 estimate. The table below summarizes the findings compared with the perfectly calibrated forecaster.

Table 4: Percentage of redevelopments with actual production less than the P10, P50 – and P90 forecast over the F3Y.

	Under P10	**Under P50**	**Under P90**	**Inside P10-P90**
Redevelopment forecasts	48 %	67 %	90 %	43 %
Unbiased forecasts	10 %	50 %	90 %	80 %

4.5.5 Sensitivity analysis on the number of aggregation years

Readers could be asking whether the results presented in this thesis would differ with a different number of aggregation years used in the analysis. Figure 35 display a sensitivity analysis of the analytical results with respect to the number of years in the aggregation.

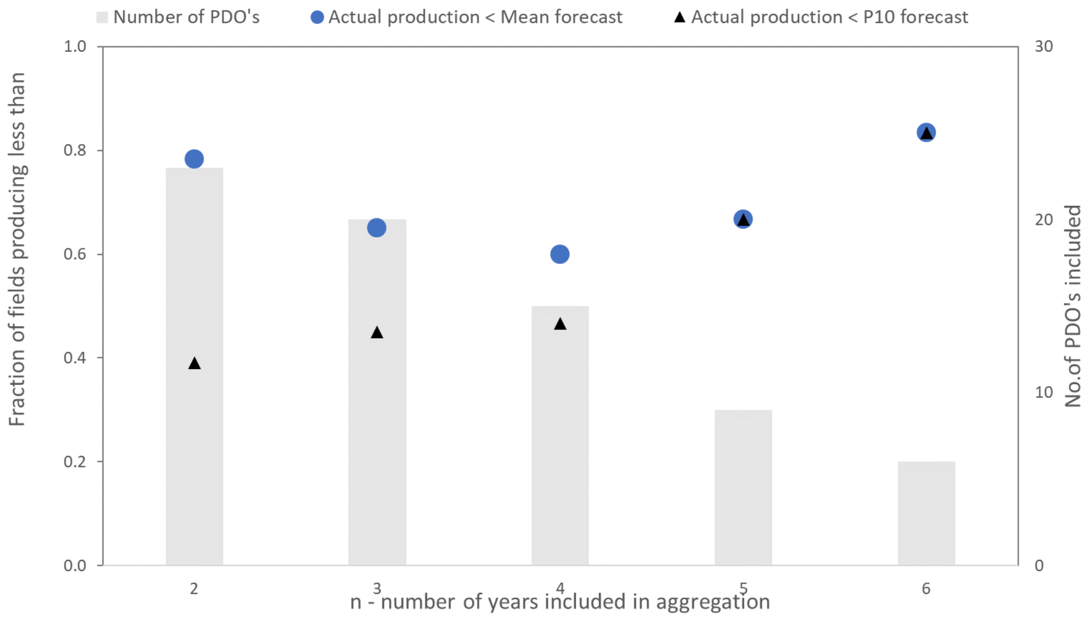


Figure 35: Sensitivity analysis showing the impact of the number of aggregated production years on the analytical results.

The blue circles show the fraction of fields producing less than the mean forecast, while the black triangles represent the fraction of fields producing less than the P10 forecast. The grey bars are the number of redevelopments in the analysis. The number of projects with valid mean and P10 estimates are reducing as n is increasing due to factors previously discussed. It can be observed from the figure that the fraction of projects meeting the P10 forecast is relatively insensitive to years in aggregation from year two through four. Due to limited numbers of redevelopments included in the analysis for years five and six, one should be careful to draw conclusion from the results from these years. However, for the fields that are included, the fraction failing to meet the forecasted production, both the mean estimate and the P10 estimate, is increasing. In fact, all the fields failing to meet the mean forecast are also failing the P10 forecast, such that the two data series are coinciding at that point.

4.5.6 Improvement in forecasts

The dataset in this analysis comprises of fields with large differences in operating lifetime. The redevelopments were therefore sorted according to the time from first oil to ministry approval of the projects, with the purpose of investigating whether the number of years of production prior to redevelopment influences forecast quality. The forecasters for the redevelopment projects have access to a wealth of reservoir – and production data, and as greater amount of data should aid understanding of the reservoir mechanics it is reasonable to expect a positive correlation of forecast accuracy with years of historical production on a field. The mean forecast for the F3Y was compared with the actual production for each of the 32 redevelopments. For the redevelopments that had less than three years of production, either two or one production years was used. Only three fields in the sample had less than three years of production. The results are presented in figure 36.

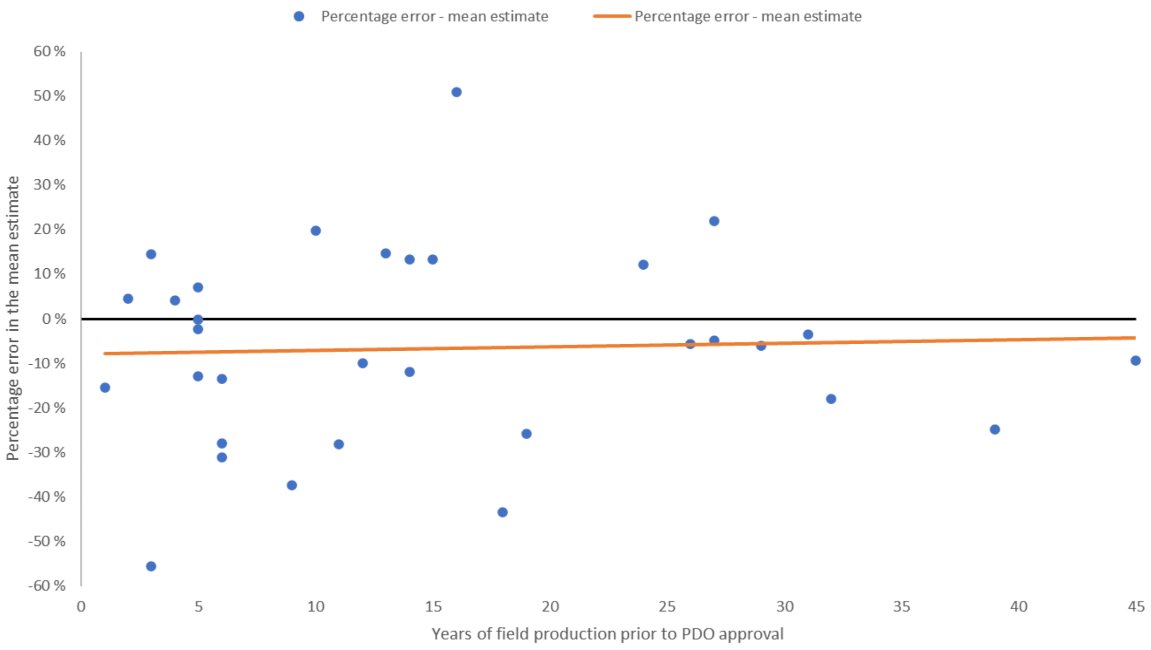


Figure 36: Production excess or shortfall relative to the mean estimate for each of the 32 re-developments sorted according to years of field production prior to FID.

The position of the blue circles on the vertical axis represent the error in the mean estimate when compared with the actual production. The error values are calculated according to international convention, by taking the actual production minus the estimated production in percent of estimated production (Flyvbjerg *et al.*, 2002). Negative values are production shortfalls, while positive values express that the redevelopment had excess production relative to the mean estimate. If the average of the blue circles converges towards the horizontal axis as years of historical field production increases, then forecast accuracy for redevelopments is positively correlated with years of historical production. By looking at the trendline, a minor positive relationship does exist between these parameters, indicating that increased knowledge about the reservoir slightly improves the quality of the redevelopment production forecasts by reducing optimism in the mean estimate. However, it is also clear that access to more production data does not in and of itself significantly improve forecast performance.

Previously, figure 19 was presented to illustrate the increased emphasis on probabilistic forecasting in the industry over time. To see if this translates to improved forecast quality, the data presented in figure 36 was rearranged and sorted according to the year of PDO approval.

Again, if the average of the blue circles is approaching the horizontal axis when moving along that axis, this indicates an improvement in forecast quality for more recent redevelopments. In figure 37 below, it is clearly a positive slope in the trendline indicating forecast improvement over time. It is also registered that the slope of the trendline is significantly steeper than the one in figure 36. This result might seem somewhat counterintuitive as recently approved redevelopments also should be expected to have the most years of production prior to PDO approval, hence figure 36 and 37 should be almost perfectly correlated. However, due to the severe differences in age of the fields included in the analysis, some redevelopments can have 20 years of production prior to PDO approval and still have earlier approval date than redevelopments with five years of production history.

Figure 37: Production excess or shortfall relative to the mean estimate for each of the 32 redevelopments sorted according to the FID year.

The dataset for this thesis consists of 32 redevelopments from 20 fields. Consequently, some of the fields in the dataset have had multiple redevelopments approved between 1996 and 2018. A relevant question then, is whether the precision in the forecasts is improved for the later redevelopments. The circumstances to facilitate this improvement is readily in place. There is more historical data available, along with technical advances in the industry over time and previous experience in executing projects at the same field. The relevant fields were isolated, and their redevelopments was grouped according to the order in which they were developed. The results are presented in figure 38, where the fields that had three redevelopments in the period are marked with orange circles.

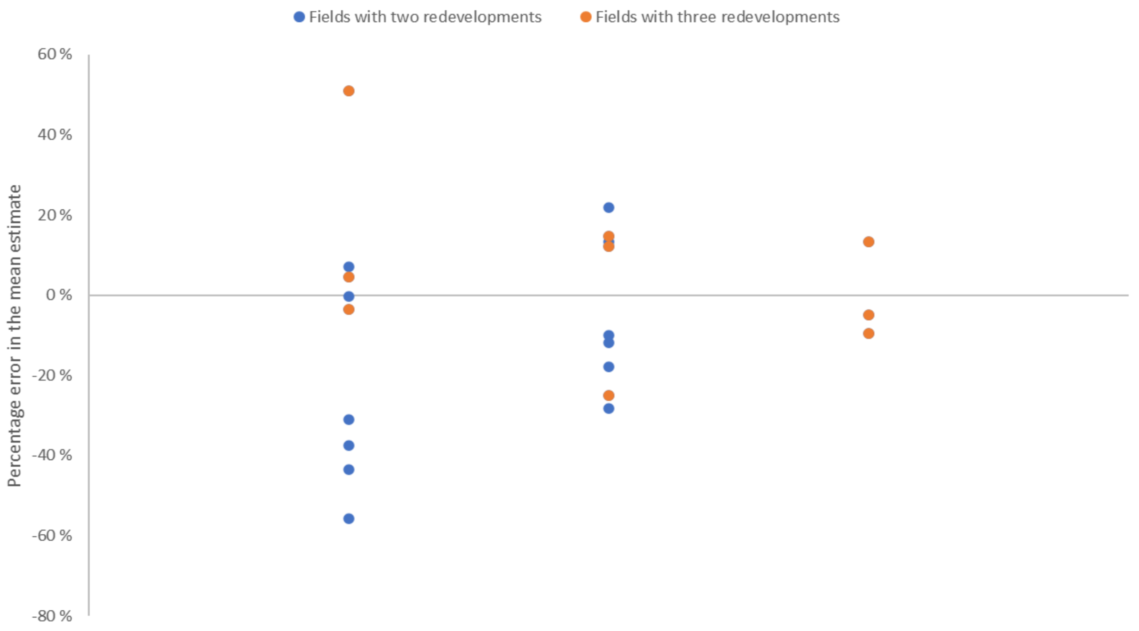


Figure 38: Production excess or shortfall relative to the mean estimate for redevelopments whose fields had more than one redevelopment included in the analysis.

A few fields display greater deviation from the mean in the later redevelopments, but these had very precise estimates for the first redevelopment, which is difficult to improve upon. Instead the key insight is the reduced variability in the estimates for the later redevelopments, indicating that the average forecasts is more precise for these projects. Also, the correlation between figure 37 and 38 should be acknowledged. Since forecasts for later redevelopments on the same fields tend to be more precise than their predecessors, the observed improvement in forecast quality over time will be boosted by the panel data dimension of the sample.

For the fields that had their original development approved after 1995, the same analysis was conducted to compare their original forecasts with the forecasts from their first redevelopments. Following the same logic as previously outlined, one should, from a purely technical standpoint, expect an improvement in forecast quality. Nine fields qualified for the analysis, and the average redevelopment forecast did indicate a lesser degree of optimism compared with the original, as seen in figure 39. To check whether this is merely a spurious relationship, the non-parametric Mann-Whitney[10] test was used to check for significance. Although unable to confirm the alternative hypothesis that the mean error in the forecasts is stochastically different

---

[10] The Mann-Whitney test is used instead of the classic t-test because the usual OLS t-statistics do not have t-distributions in the presence of heteroskedasticity (Wooldridge, 2014).

for the original development and the redevelopment, the test approached significance with a p-value of 0.063[11].

Figure 39: Production excess or shortfall relative to the mean estimate for original developments and redevelopments.

---

[11] The null hypothesis is typically rejected if $p < 0.05$

5 Economic impact of underproduction

Initiation of redevelopment projects to increase the production lifetime of petroleum fields are essential to the Norwegian authorities' resource management strategy, and the redevelopments projects have been important for both the industry and society as value generators. However, in chapter four, it was established that the forecasts presented at the time of FID for the redevelopment projects in this thesis suffers from optimism – and overconfidence bias. This leads to reduced production attainment for the average field in the sample compared to the expected volumes at project sanction. The economic impact of the production shortfalls for the 32 redevelopments will be outlined in this chapter.

5.1 Production profile

The data received from the Norwegian petroleum directorate allowed for the inclusion of 20 separate fields and 32 redevelopment projects in the analysis. For these redevelopments, an aggregated production profile is created and presented along with the actual production profile in figure 40. Only the mean estimates are included, the reason being that P10/P90 estimates are not additive and therefore not as easily aggregated to create a single production profile for the redevelopments in the analysis. Again, it is emphasized that the effect of schedule delays is limited by setting the actual production start equal to the forecasted production start and that the effect of later investments on the fields is removed.

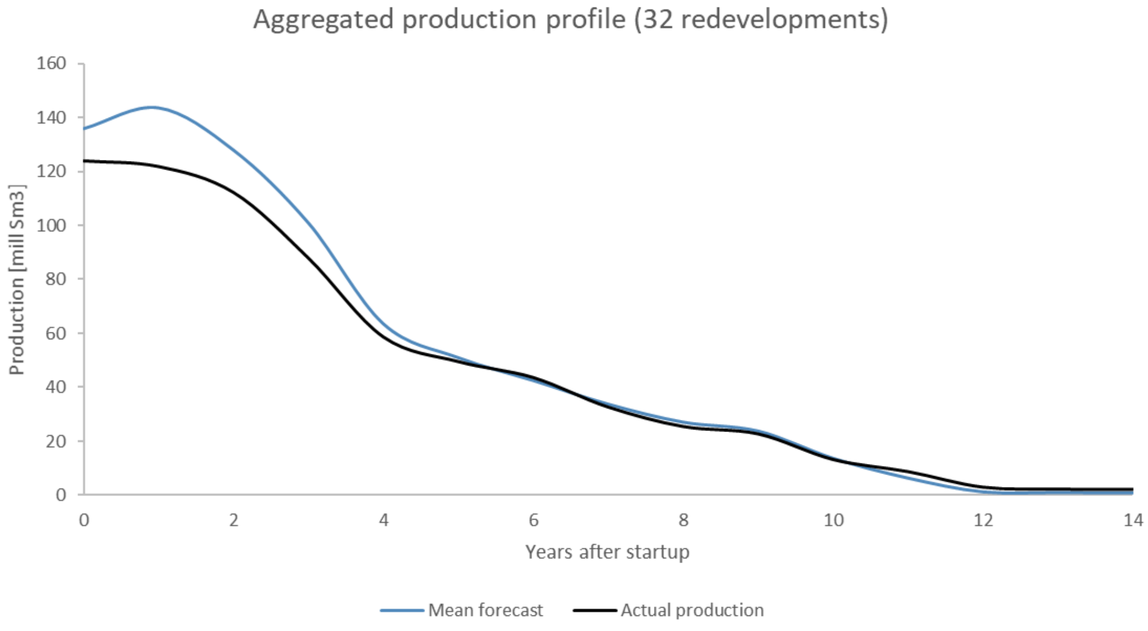


Figure 40: Actual production profile and mean estimated production profile for all redevelopments in the analysis.

Figure 40 shows that the average redevelopment in the analysis fails to meet the mean forecasted production for each of the first five years of production. This is not unexpected, as 67 percent of the subset of 21 redevelopments presented in chapter 4 delivered less than their P50 estimate over the first three years. From year six, the mean estimate and the actual production is close to identical. However, the production shortfalls from the first five years results in the average redevelopment not delivering the ultimate recovery expected from the investment. This is illustrated in figure 41, where the same dataset is used to generate the cumulative estimated production and the cumulative actual production. The importance of the initial three production years is evident as 50 percent of the volumes are produced during this period. The combined production shortfall for all projects in the analysis is approximately 64.5 million Sm^3, corresponding to an underproduction of 8.3 percent, most of which was accrued in the F3Y.

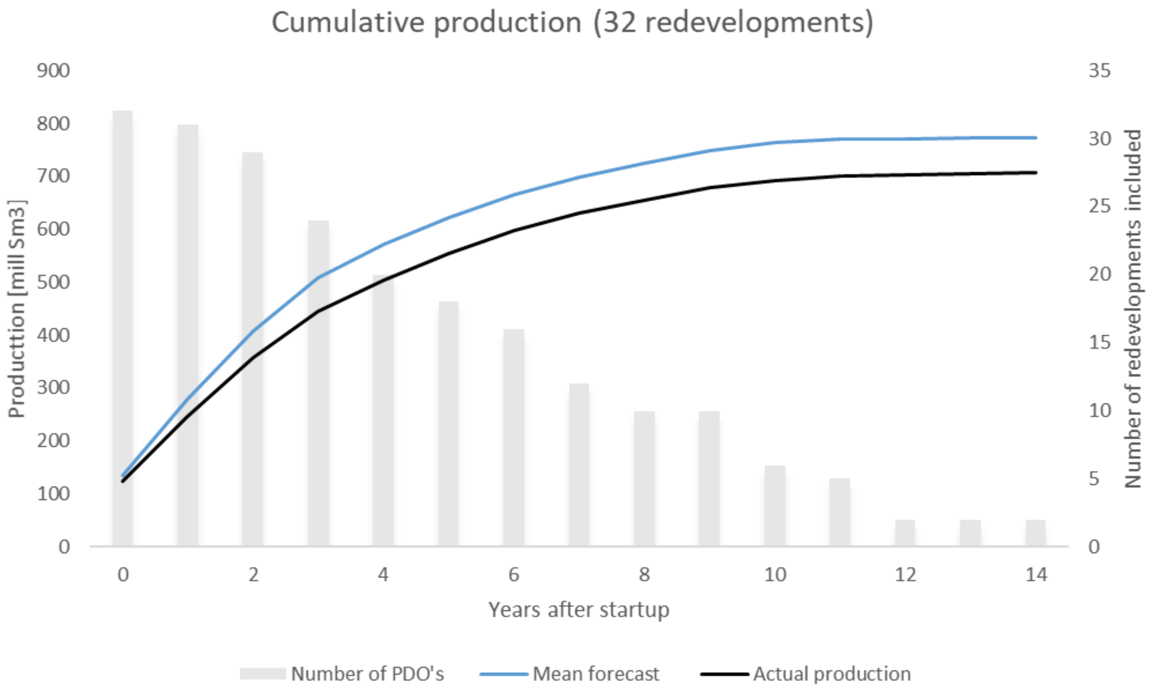


Figure 41: Actual cumulative production and mean estimated cumulative production for all redevelopments in the analysis.

5.2 Present value of production shortfalls

To assess the total value erosion from not meeting forecasted production, the difference between the expected revenue and the actual revenue must be obtained for all redevelopments in the sample. The revenues from the redevelopments are discounted back to the time of PDO approval and then adjusted for inflation such that all revenues reported reflect 2019-NOK.

5.2.1 Determining input values

The volumes produced in a given year is assumed sold for the average oil price in that same year. The Brent spot price is very volatile, and its status greatly affect the revenue from the projects. The exchange rate between USD and NOK, applied to convert the sales price from USD, are also fluctuating and affecting revenue from the respective years. The historical annual exchange rates are tracked by the Central Bank of Norway (Norges Bank, n.d), while the Brent price is retrieved from the U.S. Energy Information Administration (2020). Figure 42 show the annual average Brent price and exchange rate for the time period considered in this thesis.

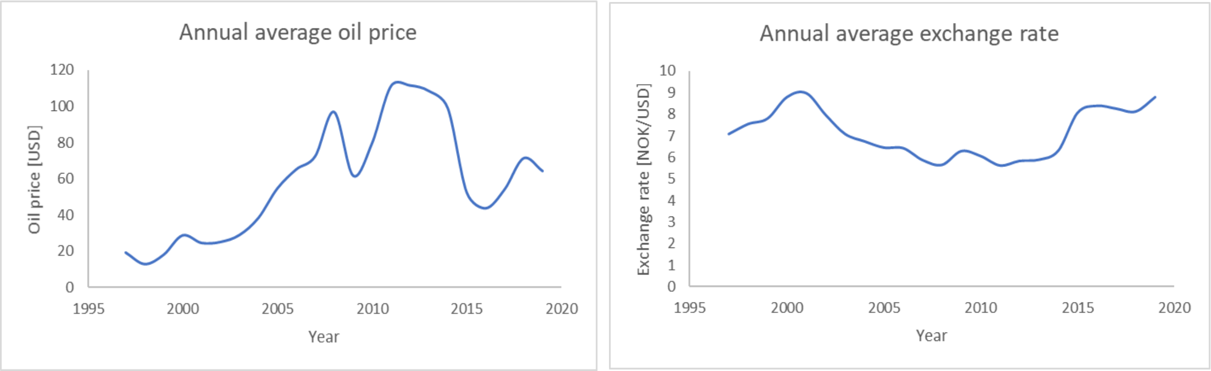


Figure 42: Annual average oil price and exchange rate in the 1997 – 2019 period

The Norwegian consume price index, maintained by Statistics Norway (n.d) was used to adjust for inflation. The inflation factors for each year is found by taking the ratio of the 2019 value of the index to the value of the index at the year of PDO approval. Finally, the discount rate must be set. The discount rate used for a project is unique to a company based on their cost of capital, hence there is no "wrong" discount rate. In these calculations, ten percent were adopted as the discount rate for all redevelopments as this is a commonly accepted value in the petroleum industry (Harden, 2014). After determining the input values for all redevelopments, the estimated – and actual revenues was calculated with equation 5.1, where the conversion factor is 6.29 barrels/Sm^3.

$$PV = \frac{Production\ [mill\ Sm^3] * Oil\ price\ [USD] * Exchange\ rate\ \left[\frac{NOK}{USD}\right] * Conversion\ factor\ [\frac{bbl}{Sm^3}]}{(1+d)^t} \tag{5.1}$$

5.2.2 Example calculation

In this section, an example will be presented to clarify the calculations performed to determine the difference between the expected – and actual revenue from production for each redevelopment in the sample. Consider a redevelopment that received PDO approval in 1998 and started production three years later, presented in table 5. The redevelopment has severely underperformed compared to the mean estimate the first nine years causing revenue to be significantly less than expected. Although the production relative to the mean estimate improved towards the tail end of production, the power of compounding reduces the positive effect from the excess production such that it is almost insignificant to the result. In total, production shortfalls relative to the mean forecast caused the redevelopment to have an economic loss of 18.6 billion 1998 NOK, which is equivalent to 28.8 billion NOK in 2019.

Table 5: Example of how the present value of production shortfalls is calculated.

Field	NCS7-1
PDO approved	1998
Discount factor	10 %

Years after PDO approval	**0**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**
Mean estimate [mill Sm3]				11.77	15.85	16.08	15.24	13.98	12.10	9.58	7.66	6.61	5.64	4.93	4.45
Actual production [mill Sm3]				11.55	12.64	13.60	11.54	8.96	8.32	8.38	8.47	6.01	5.83	5.52	4.45
Oil price [USD]				24.46	24.99	28.85	38.26	54.57	65.16	72.44	96.94	61.74	79.61	111.26	111.63
Exchange rate [NOK/USD]				8.99	7.97	7.08	6.74	6.45	6.42	5.86	5.64	6.28	6.05	5.61	5.82
Conversion factor [bbl/Sm3]				6.29	6.29	6.29	6.29	6.29	6.29	6.29	6.29	6.29	6.29	6.29	6.29
Annual economic value of underproduction [mill NOK]				308	4016	3192	5999	11108	9956	3192	-2807	1474	-564	-2305	-13
Discounted value [mill 1998 NOK]				232	2743	1982	3386	5700	4644	1354	-1082	517	-180	-668	-3

Total revenue lost [mill 1998 NOK]	18625
Inflation adjustment factor	1.55
Total revenue lost [mill 2019 NOK]	28862

5.3 Results

The calculations performed in table 5 was done for all redevelopments in the sample and summarized to obtain the total value erosion from the reduced production attainment. The total revenue lost relative to the mean estimate for the 32 redevelopments accumulated to 102.7 billion NOK expressed in 2019 values, corresponding to a loss of six percent of forecasted revenues. This revenue loss is separate from possible losses due to cost – and schedule overruns from the projects. The results are summarized in table 6.

Table 6: Total value lost by underproduction relative to the mean forecast.

Present value of production shortfalls	
Total revenue mean estimate [mill 2019 NOK]	kr 1,702,454
Total actual revenue [mill 2019 NOK]	kr 1,599,730
Total loss from underproduction [mill 2019 NOK]	kr 102,724

6 Two models for explaining forecasting inaccuracies

Chapter four illustrated that forecasters on the NCS have a tendency of overestimating production from redevelopment projects. In chapter five, it was calculated that the loss from the production shortfalls accumulated to approximately 102 billion 2019-NOK. This chapter will discuss the reasons for forecasting inaccuracies using two different explanatory models that focus on the root causes of biases in the estimates.

6.1 Sources of forecasting inaccuracies

In section 2.5, the suboptimal performance of megaprojects in the oil and gas industry was discussed. As described, the forecasts presented at project sanction generally fail to correctly represent the developments and the projects tend to be over budget, over time, and under benefits, in line with Flyvbjerg's "Iron law of megaprojects". The question now becomes, what are the underlying factors contributing to the unfavourable results?

First, there is no denying that the competence of the project manager and the project organisation is key to the outcome of a development. The complexity and potential consequences of megaprojects are on a completely different scale compared with conventional projects, making them a different beast to manage. In Flyvbjerg (2014, p. 6), an analogy was made saying "If managers of conventional projects need the equivalent of a driver's licence to do what they do, then managers of megaprojects need the equivalent of a pilot's jumbo jet licence." The point being that only talented, experienced projects managers are qualified to manage megaprojects. While basic principles of project management are applicable to megaprojects and conforming with best practices from literature is important to foster success, megaprojects exhibit attributes uncommon to conventional projects that require managerial attention. For a further discussion on specific methods for megaproject management, the reader is referred to part 2 and 3 of the book *Industrial Megaprojects* (Merrow, 2011). This thesis does not attempt to address potential shortcomings in project execution, although it is impactful. Instead, human decision making is presented as the root cause for the industry's failure to meet their estimates.

Scholars often refer to two different approaches to decision making, normative and intuitive. Normative decision making refers to a logical, methodical, and structured approach to reach the best decision, whilst intuitive decision making is quick, often subconscious, based on the infamous "gut feeling". A normative process is known to produce the better results when faced with complex decisions (Bratvold & Begg, 2010). However, empirical studies have established that people often diverge from normative decision processing, relying on heuristic[12] rules instead (Stanovich & West, 2000). Heuristics may be functional in an environment where continuous feedback is available through repeated exposure to the same decision problem and access to the outcomes, but this condition is rarely satisfied in the petroleum industry. Instead, reliance on heuristics often leads to specific systemic biases in judgement, and although this has been known since the pioneer work of Tversky & Kahneman (1973), it continuous to affect project performance today.

The remainder of this chapter will focus on the underlying mechanisms contributing to forecasting errors and in turn causing subpar performance of megaprojects in the oil and gas industry. The reasons for forecasting errors will be divided into three main groups (Flyvbjerg *et al.*, 2009, p. 172):

- Bad luck
- Delusion
- Deception

Bad luck is the typical reasons for failure given by project managers and project champions, while delusion and deception are the root causes for underperformance. Delusion explains inaccuracies in forecasts with people being affected by cognitive illusions, resulting in unwarranted optimism and confidence in their projects. Deception, on the other hand, is a more ominous explanation, calling out strategic manipulation and misrepresentation of a project as a reason for forecasting errors.

6.2 Bad luck

There are many potential complications that can affect any given petroleum development project. Reservoir complexity, change of scope after FID, technical uncertainties, and bad weather were all cited as contributory factors for cost escalation in a case study of five field developments on the NCS (NPD, 2013). For the much-maligned developments of Martin Linge and Goliat, insufficient quality from foreign contractors has been cited as the main causes of significant cost – and schedule overruns. An argument can be made that the realisation of any one of these complications is an exogenous event over which the project organization and

---

[12] Heuristics: “The way people reduce the complex tasks of assessing likelihoods and predicting values to simpler judgemental operations” (Tversky & Kahneman, 1973).

management have limited control, and therefore they should not be held accountable for the consequences.

In case studies, that argument may seem plausible. However, when a larger set of projects are subject to statistical analysis, these excuses for poor performance do not hold up. Had the deviation from the mean forecast been mainly due to bad luck and technical uncertainty, one should expect the error distribution to be approximately symmetric around the median. The analysis in chapter 4 provides evidence against a symmetric error distribution, which is consistent with findings from previous studies into production attainment and cost – and schedule overruns.

Although it is admittedly difficult to predict exactly which complications will affect a particular development, that a project will face adversity is probable. Consequently, this should be accounted for in the forecasts, which ought to be possible based on previous project experience, but the empirical data suggest that it is typically not (Bratvold *et al.*, 2019). The project owners therefore expose themselves to risks they may not be prepared to take, including the risks of so called "black swans", introduced by Taleb (2007), understood as unlikely events carrying extreme impact.

The consistent forecasting errors on the NCS is indicative of an industry wide failure to properly assess the risks related to a development. However, bad luck is no longer a compelling explanation, especially not in redevelopment projects where reservoirs and technology are reasonably well-understood, thus limiting exposure to black swans. As a result, the forecast errors must be explained in terms of delusion and deception.

6.3 Delusion

While bad luck is an attractive explanation for management and forecasters as it may liberate them for liability, delusion attribute the underperformance of megaprojects to flawed decision making from the same individuals. However, explanations in terms of delusion has one redeeming trait; the incorrect forecasts and sub-optimal decisions are not intentional. Kahneman & Tversky (1977) argues that biases in estimates are a consequence of a phenomenon named "The planning fallacy", which is when forecasters and decision makers adopt an inside view to a project. When caught in the planning fallacy people neglect historical experiences from similar projects, thus overemphasizing the specifics of the project in question when generating the forecasts. The result is a tendency to believe that one's own project will proceed as planned, even while knowing that most similar projects have experienced overruns or benefit shortfalls

(Buehler *et al.*, 1994). This belief will manifest itself in the forecasts by a delusional optimism and confidence in a positive project outcome, making the project unlikely to deliver its expected returns.

6.3.1 Optimism

An inclination for optimism seems to prevail among humans. Individuals often have a positive outlook on their ability, and in the face of uncertainty people maintain overly positive expectations. For instance, most people believe that they are both safer and more skilful drivers than the average person (Svenson, 1981), and the average person exhibit optimism about their susceptibility to health problems (Weinstein, 1982). Optimistic outlooks hold true for experts as well as lay people. Medical doctors overestimate treatment effectiveness, financial analyst overestimates the expected profits, and forecasters in the petroleum industry overestimate production. People are susceptible to maintain an optimism bias even when faced with disconfirming information, as it has been discovered that people selectively update their probability judgements after receiving new information. When the new information is positive, the probability judgment is updated to match that of reality. However, if negative information is received, for instance that the likelihood of suffering from cancer are higher than first anticipated, people do not update their probability assessment to the same degree. This provides the basis for a robust optimism bias (Sharot, 2011).

6.3.2 Overconfidence

"The illusion of control" refer to people's tendency to believe they have greater control over uncertain events than justified. Consequently, overconfidence materializes since the full range of possible outcomes have not been accounted for. In a study concerning biases in the petroleum industry, 123 industry professionals were asked to construct 80 percent confidence intervals around ten variables relevant for their profession. Figure 43 display the results where a clear discrepancy is seen between the observed number of correct answers and the expected results of well-calibrated forecasters, indicating severe overconfidence among the participants (Welsh *et al.*, 2005).

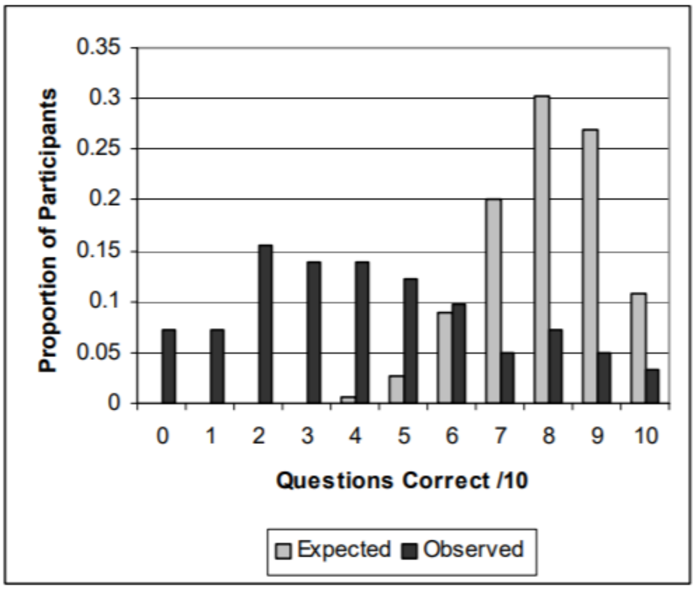


Figure 43: Observed correct responses vs expected correct responses for well-calibrated forecasters (Welsh et al., 2005).

The findings are in correspondence to real-world observations, where overconfidence in megaproject estimates are well-documented. Overconfidence is also a dominant presence in the current study into production attainment.

Overconfidence in forecasts used in the final investment decision can have a significant material impact on decision making. This was shown by Welsh *et al.* (2007), who calculated the net present value of an offshore petroleum development by using a probabilistic model to determine the OOIP, recovery factor, and oil price. The NPV of the development was calculated for different degrees of overconfidence in the input values, ranging from zero to 30 percent, as shown in figure 44.

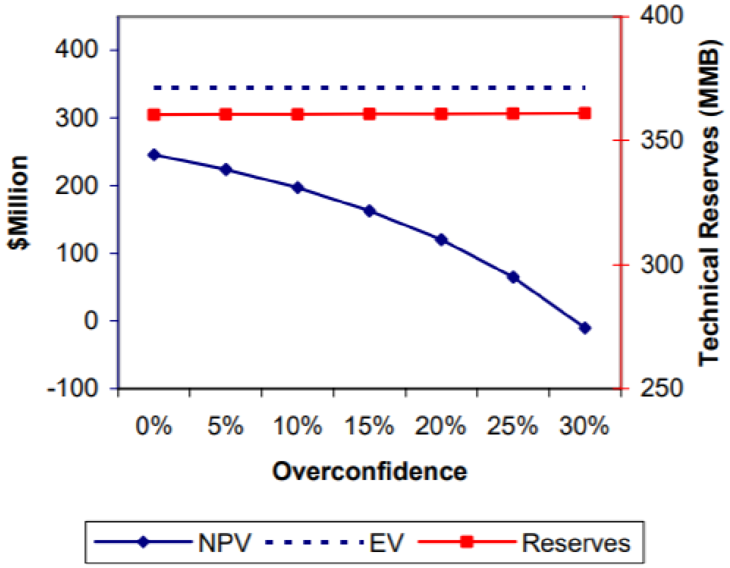


Figure 44: The impact of overconfidence on NPV (Welsh et al., 2007).

The mean NPV of the project using unbiased estimates was $246 million. However, if the estimates of the input values were five percent overconfident, the real NPV would be $224 million, which is $22 million less than a hypothetical company would presume when making an investment decision. At 30 percent overconfidence the real project value would be negative, thus the company might approve an investment that likely will yield negative returns while they expect a profit of $246 million. This model clearly illustrates why overconfidence must be reduced in the forecasts.

Although optimism and overconfidence can be biases on itself, separate biases may also exacerbate their presence in forecasts. These are heuristics which affect judgement, but their effect cannot be isolated in the forecasts as they are rather impacting the degree of optimism and overconfidence observed. The heuristics especially relevant in the petroleum industry will be discussed next.

6.3.3 Information availability and representativeness

The perceived likelihood of an event is subjective and dependent on the knowledge of the individual assessing the probability. However, the current state of knowledge may be distorted by the availability, recency, and vividness of events in memory. The availability bias is introduced when an individual fails to consider the complete range of possible outcomes due to focusing on the outcomes more easily recalled (Welsh *et al.*, 2005, Bratvold & Begg, 2010). For instance, Lichtenstein *et al.* (1978) found that the judged frequency of death from highly reported catastrophic events were overestimated, while less covered, typically unspectacular, causes such as diseases are underestimated. Similarly, a manager who recently oversaw a successful development project will have this experience fresh in mind. Thus, it is likely to affect his or her assessment of a new project, possibly making the manager prone to overconfidence and optimism.

Representativeness is another bias that easily can manipulate a forecasters probability assessment. People tend to mistake the representativeness of an event with the likelihood of that event occurring. Imagine that you as a manager of a petroleum development project are shown a reservoir model built by your experts. The model includes a myriad of variables allowing for detailed visualization of fluid flow through the reservoir and the impact of production well placement. The level of detail in the model makes it seem like a credible representation of how fluid is expected to behave in the reservoir, and therefore also a probable scenario. However, although the model may be globally correct, it is unlikely to be locally accurate. This is because the model incorporates probabilistic variables and adding more such features to the model, while making it more descriptive, makes the model less likely to be true (Welsh *et al.*, 2005, Bratvold & Begg, 2010). If you as a manager, like many people, confuse probability with representativeness, the detail of the model might cause you to overestimate its likelihood.

6.3.4 Anchoring

Forecasts in the oil and gas industry is often generated using historical projects as analogues. The analogues serve as anchors that the forecasters base the estimates of the new projects upon. Analogues may be reliable when the circumstances of the new projects and the analogues closely resemble one another. However, if the projects differ from the analogues, and it need not be by much, one must be watchful of the bias in judgement often accompanying the use of anchors.

To produce unbiased estimates when using an anchor, the forecasters must adjust the estimates away from the anchor according to the different specifications of the projects. However, people tend to struggle with adjusting the estimates enough to counteract the effect of the anchor. This has been shown through numerous studies, where arbitrary anchors have proved to significantly impact peoples estimates when asked general knowledge questions (Chapman & Johnson, 2002). Still, critics have maintained that these findings are not translatable to a business context. It is rather hypothesized that familiarity with the subject matter will counteract the anchoring effect, as a professional does not have to rely solely on the anchor to support their estimates. This critique was addressed in Heywood-Smith *et al.* (2008), where petroleum engineers were tasked with constructing 80 percent confidence intervals for industry relevant parameters, such as porosity, GOR, and recovery factor, given specific scenarios. An anchoring effect were observed, illustrated in figure 45. The groups presented with anchors had slightly lower/higher mean estimates than the group that did not see an anchor prior to submitting their estimates. Furthermore, it is also witnessed that the presence of both anchors causes a tighter confidence interval.

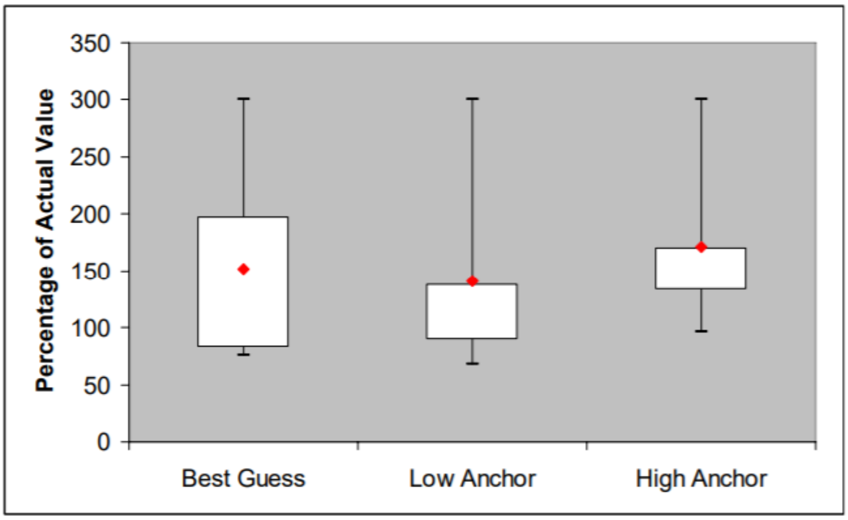


Figure 45: The effect of anchoring on estimates. The red circles are the normalized mean estimates, the boxes are 25th to 75th percentiles, and the bars are min and max estimates (Heywood-Smith et al., 2008).

The results suggest that anchoring may very well cause biases in estimates regardless of subject familiarity. However, although not able to fully compensate for the anchoring effect, knowledge may reduce its impact as the authors noted that the strength of the effect was lower than expected. Yet, if an analogue is relied upon to construct the production forecasts, the forecasts are more susceptible to overconfidence.

Note that this discussion does not suggest that one should refrain from using analogues in a forecasting process. The present section merely describes how analogues act as anchors, and the effect a single anchor can have on estimates. Research have shown that the use of analogues can be beneficial for forecast accuracy if applied correctly (Flyvbjerg, 2008, Welsh & Begg, 2010), which will be discussed more in detail in section 7.4.3.

6.3.5 Group dynamics

Many decisions in the petroleum industry are made by groups or based on the information provided by a group. A group of experts collaborating optimally encourage individuals to express their view and appraise alternative solutions, ultimately finding the best decision.

Unfortunately, group dynamics may limit the effectiveness of collaboration. The term “groupthink” was used by Janis (1982) to describe the phenomenon of group conformity, where the desire for unanimity amongst the members reduce the quality of the decision process. “Groupthink” is facilitated by directive leadership and members valuing their affiliation with the group, which in turn may lead to close-mindedness and overestimation of the quality of work (Janis, 2008). For instance, if a leader of a cohesive group takes a directive approach by early stating his/her opinion on a decision problem, the other members are inclined to concur, thus limiting discussion of alternative solutions. Although few alternatives have been assessed, the group may have a false confidence of the quality of the decision, as this is implied by the consensus amongst the members.

When Nandurdikar & Wallace (2011) studied production attainment in the petroleum industry, they provided the project teams responsible for the forecasts with a questionnaire to assess the quality of their work. In the survey, 85 to 90 percent of the teams responded that their forecast was of high quality, which is staggering when 75 percent of the projects failed to meet their forecasted production. They also highlight two responses where teams rated their forecasts as excellent/good, while the actual production attainment were only 68 and 36 percent. In fact, there was no significant difference in production attainment between those teams that rated their forecasts highly and those who rated their forecast fair/poor (Nandurdikar & Wallace, 2011). Although one cannot explicitly determine that “groupthink” is a factor here, the project teams responding to the survey seem to clearly overestimate the quality of their work, as predicted by the theory.

Another mechanism that might reduce the effectiveness of a group is known as the “trust heuristic”. The trust heuristic describe managers’ tendency to rely on the judgement of the individuals they trust the most in a group rather than factoring in all opinions (Mackie, 2007). However, the benefit of having a group working together on a problem is the opportunity to draw upon “the wisdom of the crowd”. For instance, by incorporating multiple opinions in forecasts, the risk of overconfidence and optimism should be reduced as the forecast should better represent the true distribution of outcomes, resulting in better decision making. The link between overconfidence in forecasts and the trust heuristic were made clear in Welsh *et al.* (2007), where reduction in forecast overconfidence were modelled as a function of individuals providing input to the forecast, shown in figure 46.

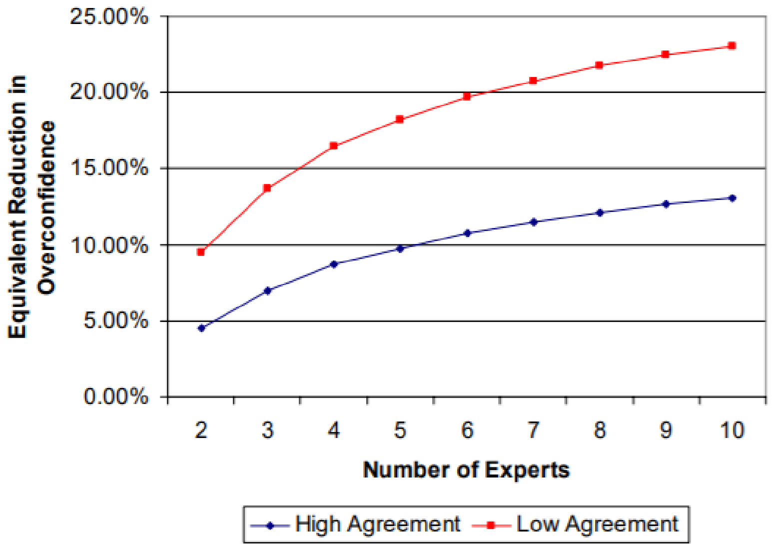


Figure 46: Reduction in overconfidence as a function of experts providing input and degree of agreement among the experts (Welsh et al., 2007).

6.4 Deception

Contrary to the mechanisms behind delusion, deception represents a conscious choice from decision makers to misrepresent the merits of their projects. Deception can be explained in terms of the relationship between the stakeholders in a project and the agency issues this presents.

6.4.1 Principal – Agent problem

The principal – agent problem (P-A) is a thoroughly documented economic theory. It occurs when an agent acting on behalf of the principal has incentives which are misaligned with that of the principal. Typical P-A relationships discussed in literature are CEO's appointed by a board to act on behalf of shareholders and government agencies acting on behalf of the public.

On the NCS, there are complex, multi-tier P-A relationships in existence. Considering a single development, approval is granted by the government for the socioeconomic benefit of the public. The project is managed by the licensee group, but carried out by the operator, who in turn employs contractors to work on the project. Several sub-contractors will be used by the contractors, ultimately generating a large supply chain network. In Flyvbjerg *et al.* (2009), a sketch of the P-A relationships existing in a large capital project is presented.

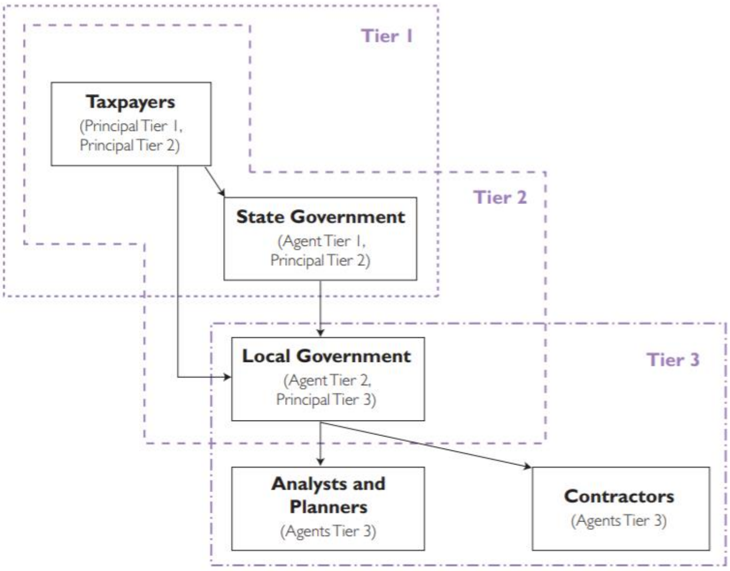


Figure 47: Illustration of multi-tier P-A relationships (Flyvbjerg et al., 2009).

The first tier considers the relationship between the taxpayer, i.e. the public, and the state government. Being the agent, the state government is instructed to act in the best interest of the principal, which is the public. The public expect the state to maximize the socioeconomic benefit of the resources on the NCS, and the previously outlined PDO process was constructed for this purpose. However, with the Norwegian parliament being up for re-election every fourth year, it is conceivable that decision making might be affected by a “political sublime”. The political sublime recognizes politicians’ incentive to approve large developments as this typically generate positive publicity and stimulate the economy, which is advantageous for re-election into parliament (Flyvbjerg, 2017). In a recent report made by Acona on behalf of the Petroleum Safety Authority Norway, the effect of political interests and industry lobbying on the development of the Goliat field was acknowledged (Hatlestad, 2019, pp. 32-33). Hatlestad also addressed the issue in an interview[13]: Both Eni and StatoilHydro compromised on their own internal requirements for project maturity, which appear to be politically motivated to get the project approved before the general election of 2009 (Tollaksen, 2019). At the time, the Goliat project was highlighted as a milestone for the industry and for the development of the northern region of Norway. A recent profitability analysis estimates an NPV loss of ca. 12 billion 2009-NOK for the project due to major overruns and production shortfalls (Rosendahl, 2017).

---

[13] Translated from Norwegian

The second tier P-A relationship has the licensee group acting as agents for both the state government and the shareholders of the companies. Although both principals inherently seek economically profitable projects, hence the incentives of the state and the licensees are seemingly aligned, there are scenarios where the occurrence of strategic deception are imaginable. For instance, due to differences in risk preferences, the licensees have incentives to present favourable forecasts to the state to secure approval for marginally profitable developments.

The contractors acting as agents for the licensee group is in the third tier of P-A relationships. In this tier, potential P-A conflicts are easily identifiable. Given the opportunity, contractors might choose to increase their own benefits on the expense of the principal. As an example, if the licences are relaxed in their contract follow up, suppliers may be inclined to reduce quality to increase profits. This occurred on the Gjøa development, where a supplier simplified its manufacturing procedure, resulting in insufficient quality of delivery. The contracted manufacturing quality was breached when the supplier overextended by accepting too many deliveries, which led to capacity constraints (NPD, 2013).

The third P-A tier also includes the forecasters and managers that are employed by the companies to act as their agents. They are responsible for generating unbiased forecasts and making economically rational decisions that benefit the shareholders of the companies. However, as demonstrated throughout this thesis, they are consistently biased in their forecasts, which is detrimental to financial efficiency. While delusion serves as an explanation for this failure, the employees do have personal incentives to produce optimistic forecasts. Since receiving approval of a project is typically associated with positive outcomes for the individuals involved in terms of potential promotions, bonuses, etc, they have incentives to present information that is compatible with having the project approved. As projects typically competes for funding with other projects, generating optimistic forecasts may be appealing to project teams almost regardless of the true profitability of the developments.

Still, it is possible to advocate against the validity of this incentive. After all, if forecasters/mangers misrepresent the merits of their projects, the projects will necessarily be less likely to deliver the expected profitability, and a negative outcome should reflect negatively on the persons involved. However, a negative outcome is not guaranteed, and certain people may not be opposed to take this gamble. More important though, especially in production forecasting, is the lack of a single point of accountability for forecast performance, which

Nandurdikar & Wallace (2011) cited as one of four main reasons for the production shortfalls observed in their study. Due to the significant time lag between when the FID forecast is made and the outcome is realised, the engineers responsible for creating the production forecasts have often moved on to new projects. When Nandurdikar and Wallace intervieved people associated with a devlopment project one year after production startup the responses were often along the lines of; "I can't speak to what's happening now, but I didn't put the forecast together so I can't say why the estimates were so optimistic" (Nandurdikar & Wallace, 2011, p. 9). Generating production forecasts are also a team effort, while the main responsibility of the overall project manager is usually to deliver the project on budget and on schedule. Ultimately, if no one is really accountable for poor performance, then the negative aspects of generating optimistic forecasts falls away for the individuals. This is further exacerbated by the projects being evaluated in isolation such that "bad luck" are a credible explanation for unfavourable results, as well as a "lack of corporate interest and willingness to keep track of past forecasts" that the outcome can be evaluated against (Bratvold *et al.*, 2020).

6.4.2 Drivers of strategic deception

P – A relationships exists everywhere in business. For every two levels of a supply chain, not to mention every two levels of an organization, there is a principal and an agent. The fundamental condition that must be present for a P-A conflict to arise is self-interest on the part of the agent. Still, for the P-A problem to result in deception, the agent must deliberately act selfishly while fully aware that it is in violation with his ethical obligation to the principal, which is why it is also called the moral hazard problem.

In a development project on the NCS there are many stakeholders (politicians, licensees, contractors, managers, forecasters, engineers, etc) that have divergent incentives. If they do choose to act deceivingly to influence the forecasting of costs and benefits at the approval stage, this is liable to bias the entire project. However, the risk of strategic deception within each P-A relationship is not constant. It is fuelled by the realisation of conditions such as asymmetric information, and differences in risk preferences and time horizons (Flyvbjerg *et al.*, 2009).

Asymmetrical information refers to a situation where the agent who champions a project possess information about the project that the principal does not. The risk of deception increases with the degree of information asymmetry, as the principal will be progressively easier to deceive. There is necessarily asymmetrical information in play when the state government grant approval to development projects. The estimates for cost, schedule, reserves, and production given in the PDO are provided by the licensee group. They have expertise and knowledge about the project superior to that of the state, who must rely on their estimates in the decision making. Coupled with the state's limited influence on the development after PDO approval, there is ample opportunity to focus on the benefits and downplay the risks of a project on the side of the licensees. This fact is also conceded by the NPD, who states in a report on project execution on the shelf: "Players in the industry have the greatest knowledge, expertise and information about opportunities and challenges in their business […]. Full responsibility for operations, including project planning and execution, lies with the companies" (NPD, 2020, p. 10).

Differences in risk preferences are another driving mechanism of strategic deception. Consider a hypothetical project where the principal is risk neutral while the agent is risk seeking. To obtain project approval, the agent has an incentive to tone down the risk of the venture in order to convince the principal of the benefits (Flyvbjerg *et al.*, 2009). A similar dynamic is in place on the NCS through the petroleum tax system. Companies operating on the shelf are subject to a special tax rate of 56 % in addition to the ordinary rate of 22 %, giving a marginal tax rate of 78 %. However, only a company's net profit is taxable, while deductions are allowed for all relevant costs, such as exploration, development, operation, etc. An additional uplift[14] granted on capital expenditure is also deductible from the taxable income (Aker BP, 2020). Ultimately, the companies are reimbursed by the state for approximately 88 % of their investments on the shelf (Tveter, 2017). The incentive for the players on the shelf to pursue projects where the risk of overruns is high is thus readily in place. Presenting a favourable production forecast in the PDO to receive project approval may therefore be in their self-interest, and opportunity exist with the presence of asymmetrical information

It is common for principals and agents to consider different time horizons when evaluating investment decisions. This is especially true in public/private projects, where the taxpayers typically have a much longer time horizons than their agents. Consequently, the decision making may be affected, usually to the disfavour of the taxpayer. The Goliat development is an intuitive example, where politicians' focus on personal short-term benefits negatively influenced financial performance. Similarly, the desire for benefits in the shorter term might persuade the companies on the shelf to adopt a schedule driven strategy on projects, emphasizing speed to first oil. A schedule driven approach typically leads to an aggressive reservoir appraisal process. With these developments far more likely to suffer poor production

---

[14] 5.2 % in 2020

attainment compared to projects with a conservative appraisal strategy, the public benefit is negatively affected (Nandurdikar & Wallace, 2011).

7 Discussion

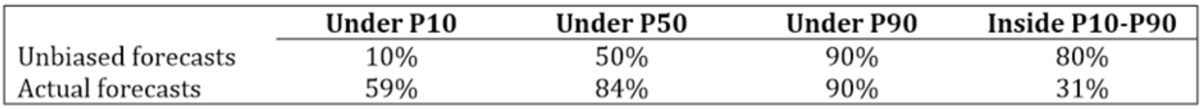
The forecasts presented in the PDO must be unbiased to support unbiased decision making. Yet, as demonstrated by the current work, this is not a trait exhibited by the production forecasts for redevelopments. The forecasts tend to be optimistic, resulting in a value loss for the average project, and overconfident, meaning that the total risk is not accounted for. Still, one should at least expect to see favourable results relative to the those for original developments. To address this hypothesis, chapter seven opens with a comparison of the production forecast quality for redevelopments and original developments. Further, the implications of biased forecasts will be assessed. Does it affect the companies' decisions and capital allocation? Finally, this chapter discuss different approaches to overcome delusion and deception in forecasting.

7.1 Quality of production forecasts - redevelopments vs original developments

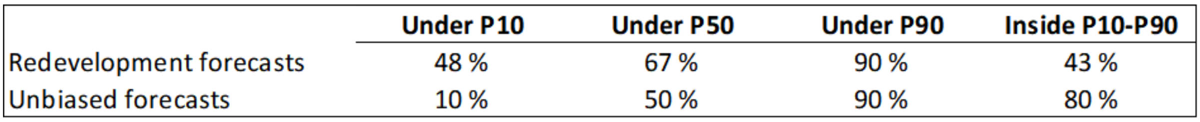
How the results presented in this thesis compares with those of Bratvold *et al.* (2019), who studied the production attainment from original field developments on the NCS, is of major interest. Similar analytical procedures and analyses were applied for this work particularly to facilitate comparisons between the studies. Since redevelopments have the benefit of a solid data foundation when generating forecasts, an improvement in forecast quality should, from a technical standpoint, be expected when compared with the original development.

The results from Bratvold *et al.* (2019) were previously shown in section 1.2.2, but are also presented in table 7 alongside the redevelopment results to ease the comparison for the reader. The topmost set is from the original developments, while the lower set is the results from the analysis in this thesis.

Table 7: Synopsis of the results from statistical analysis of production attainment on the NCS. Above: Original developments (Bratvold et al., 2019). Below: Redevelopments.



	Under P10	Under P50	Under P90	Inside P10-P90
Unbiased forecasts	10%	50%	90%	80%
Actual forecasts	59%	84%	90%	31%



	Under P10	Under P50	Under P90	Inside P10-P90
Redevelopment forecasts	48 %	67 %	90 %	43 %
Unbiased forecasts	10 %	50 %	90 %	80 %

As seen from table 7, the forecasts made for the redevelopment projects are less biased than the forecasts made for the original developments. The fraction of projects failing to meet the P10 – and P50 forecast have been reduced by 11 and 17 percentage points, respectively.

However, if only the mean forecasts of the different sets of projects are compared, see figure 2 (p. 4) against figure 37 (p. 53), the error in the mean estimates are far greater for the original developments than for the redevelopments. In fact, the sets of projects are dissimilar to the extent that one would expect the difference in the fraction of developments with realised production within the confidence interval to be greater than observed. The difference in financial losses from underproduction between the original field developments and redevelopments tell the same story. As noted in section 2.5.4, 200 billion 2017 NOK were left on the table by the original developments, corresponding to a 17 percent PV reduction relative to mean (Mohus, 2018). For the redevelopments, the equivalent PV loss was 6 percent.

The apparent reason that the smaller errors in the mean estimates do not completely translate to increased forecast accuracy is quite intuitive. First study the graph of the cumulative distribution of the normalised actual production from Bratvold *et al.* (2019) in figure 48.

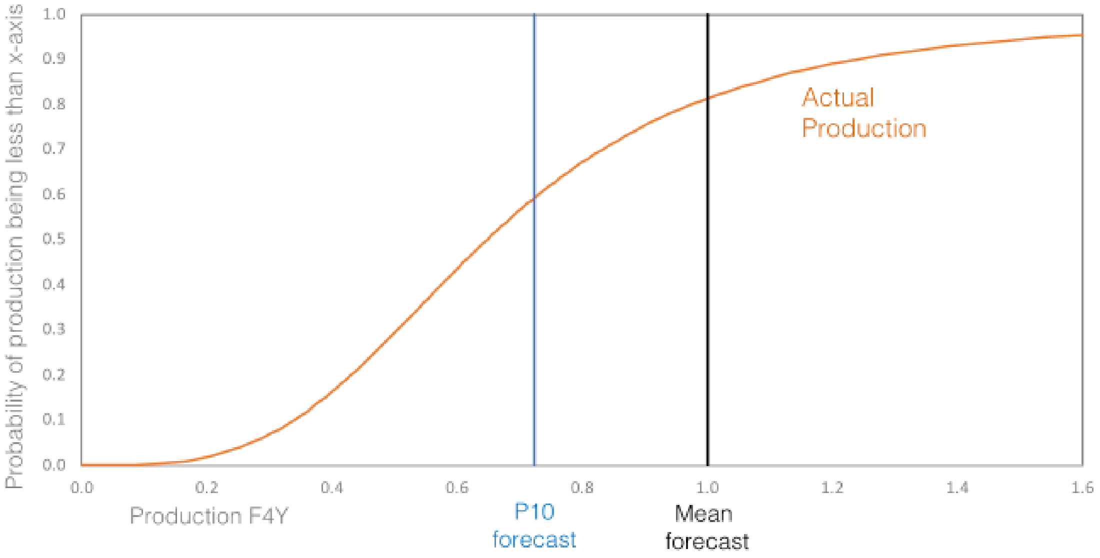


Figure 48: Cumulative distribution of the normalized actual production for 32 original developments on the NCS (Bratvold et al., 2019).

By comparing figure 48 with the equivalent graph made for the redevelopments in figure 34 (p. 50, or see next page), one immediately observes that the slope of the cumulative actual production curve is steeper for the redevelopments. The steeper slope visualizes the improved production attainment relative to the mean forecast. Equally noticeable is the difference in point of intersection of the P10 vertical with the horizontal axis in the graphs. For the redevelopments, the average normalized P10 estimate, i.e. the ratio of the P10 estimate to the mean estimate, are significantly higher than the corresponding estimate for the original developments. In effect, this means that the range of outcomes bounded by the 80 percent confidence interval is smaller, such that the actual production for the average redevelopment project must be closer to the mean estimate to fall within the predicted range of outcomes. For example, a hypothetical new field development that produced 80 percent of the mean forecasted volumes over the first few production years would typically meet its P10 forecast, whereas for a redevelopment, the average project would not meet its P10 forecast even if it produced 85 percent of its mean forecasted volumes.

Of course, it is not unnatural for the forecasters to assign a smaller range of possible outcomes to the same confidence interval for redevelopments. Rather, it is expected. The historical production from the fields reduce the uncertainty in parameters important to production forecasting, and the size of the range assigned to the confidence interval is a reflection of the degree of uncertainty. However, as the forecasters initially are severely overconfident in their estimates, the trend is carried on to the redevelopment projects although the production attainment relative to mean estimate have improved. Had the forecasters instead refrained from reducing the range of outcomes covered by the confidence interval for redevelopment projects, overconfidence would be a much less prominent trait in the forecasts. This is shown in figure 49, where the normalized aggregated P10 estimate from the set of original field developments in figure 48 is superimposed onto the graph for the redevelopments.

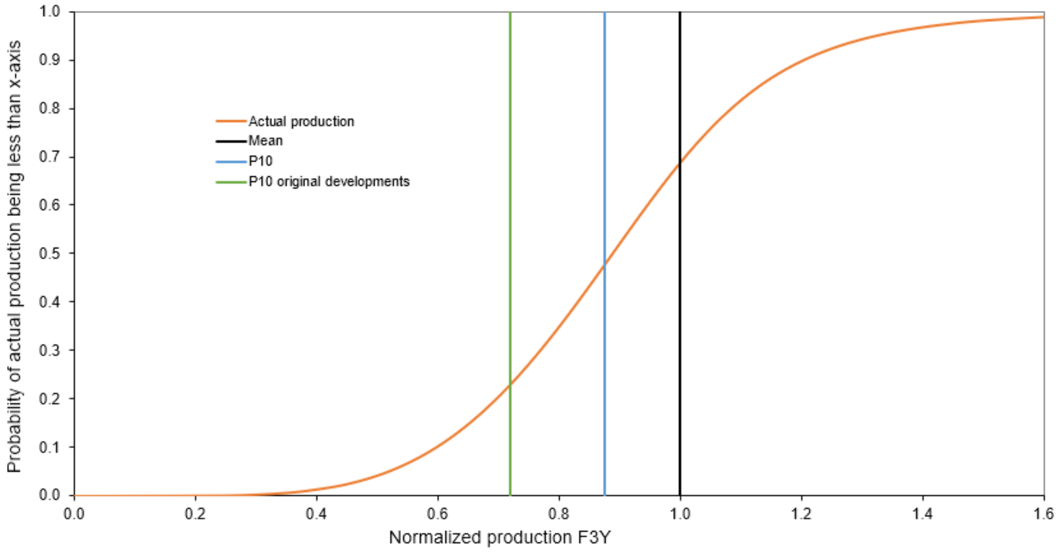


Figure 49: Cumulative distribution of the normalized actual production for redevelopments with the aggregated P10 forecast from original developments superimposed onto the graph.

7.2 Relative impact of delusion and deception on production forecasts on the NCS

Clearly, the production estimates made at the time of FID is systematically biased. This can be explained by delusion or deception on the part of the forecasters/decision makers according to the two models presented in chapter 6. However, delusion and deception are not mutually exclusive. The forecasting process might be affected by both sources of bias simultaneously, or either one separately. In practice, identifying which model that holds the most explanatory power is difficult, especially as virtually no individual or organization will freely admit to deceiving the principal. Still, by examining the circumstances surrounding a group of projects, the relative impact of delusion and deception on the forecasts may be inferred. The matrix presented in figure 50 illustrates some scenarios where delusion and deception can be expected to influence forecasts and decision making in varying degree (Flyvbjerg *et al.*, 2009).

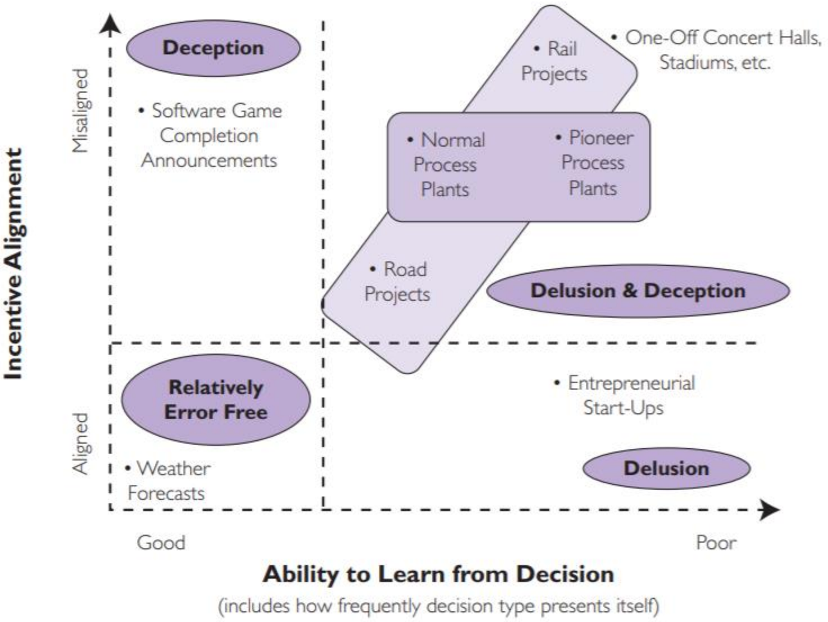


Figure 50: Situations where delusion and deception is expected to operate (Flyvbjerg et al., 2009).

Forecasters that operate in professions where the incentives are well-aligned and there is ample opportunity to learn from experience are scarcely affected by delusion or deception and are therefore often able to deliver unbiased forecasts. The typical example is meteorologists. They are frequently exposed to similar decision problems and receive instant feedback on their predictions. Nor is there any incentive for them to produce biased weather forecasts. As such, the accuracy in the weather forecasts has steadily improved over time in response to technical advancements, with 7 – day weather forecasts in 2016 being equally as accurate as 4 – day forecasts in 1981 (Haiden *et al.*, 2016).

Entrepreneurs tend to perceive their chances of success favourably. Cooper *et al.* (1988) discovered that 81 percent of entrepreneurs assessed their chances of success as 70 percent or better, while the true success rate is closer to one third. Deception holds little explanatory power over the optimism expressed by the entrepreneurs as they are typically owners of the businesses, hence there is limited scope for incentive misalignment. With entrepreneurs likely to take an inside view on their business ventures and the innovative nature of the businesses providing modest opportunity to learn from historical experience, delusion is better suited to explain the entrepreneurs' overoptimism.

A situation where strategic deception is more likely is in the announcement of video game completion times. The producers usually make several games annually, providing a good learning environment to reduce the influence of delusion, but they continue to announce release dates that are not overheld. Therefore, the optimistic schedule forecasts are rather attributed to a strategy designed to damage competitors' sale of similar products (Flyvbjerg *et al.*, 2009).

In the top-right of the matrix in figure 50, projects that are likely to be affected by both delusion and deception simultaneously are found and, perhaps unsurprisingly, it is when both biases operate together the largest forecast errors arise. It is in this section petroleum development projects on the NCS are sorted. However, projects can be ranked according to their susceptibility to delusion and deception within this section of the matrix. This is illustrated by the infrastructure examples given in figure 50. For example, standard process plant projects are situated to the left of pioneer process plants since they are relatively more frequent, so the opportunity for learning is greater. Consequently, a standard process plant project should be less susceptible to delusion.

Now consider development projects on the NCS. While it is still true that it is difficult to identify which model holds the most explanatory power for each individual project, looking at redevelopments and original developments as two separate groups of projects can help illustrate why redevelopment forecasts are less biased. When the players on the NCS submit PDO's to the authorities, stakeholders have incentives to present projects in a favourable light, as discussed at length in chapter 6.4. Since the actors involved in both project groups remains the same, and so does the presence of the drivers of the P-A problem, it could be argued that the relative impact of deception on the production forecasts are not likely to change drastically between the original developments and redevelopments. However, this argument fails to consider the effect of external pressures on human decision making. When political and organizational pressures are high, so is the explanatory power of deception, as illustrated in figure 51.

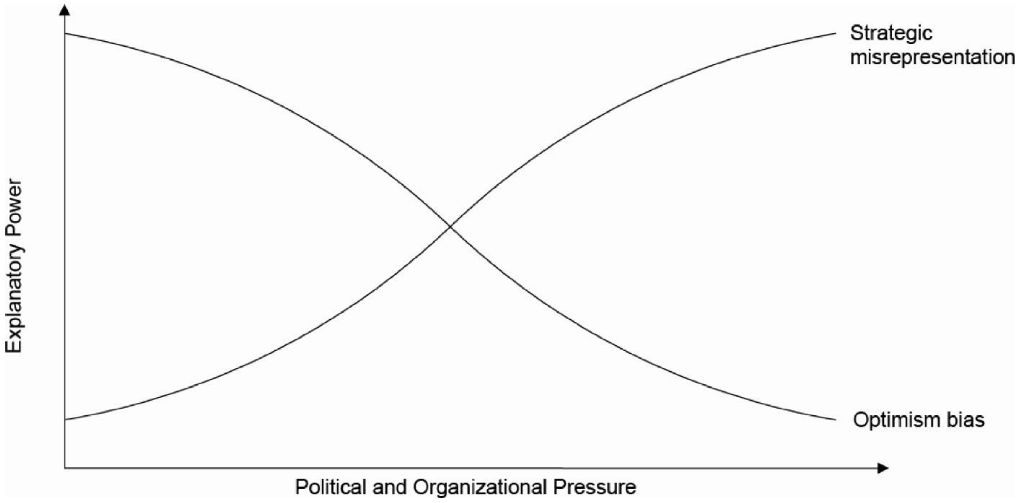


Figure 51: Explanatory power of delusion and deception as a function of political and organizational pressure (Flyvbjerg, 2008)

Political and organizational pressure is much more prominent for original developments. The political debates in the parliament typically concern which areas on the shelf to open for the petroleum industry, and which new developments that should be approved, not redevelopments. For instance, it has for a long time been discussions in the parliament on petroleum operations in the artic. The right wing of the Norwegian political landscape, along with the industry themselves, push for opening of new acreage, while the environmental parties and organizations argue against. Currently, the debate concerns the placement of the "ice border" that defines how far north petroleum activities can be allowed. This debate is so important in the parliament that one of the parties in government called it the "climate question of the decade" (Rommetveit & Topdahl, 2020), while another party threatened to withdraw their support of the government if the ice border is moved further south (Fremstad & Løset, 2020). As discussed, the Goliat development was affected by the different interests surrounding the artic, which contributed to the unrealistic forecasts. However, when the operator of Goliat later discovered additional resources that could be connected to the field there was no debate to whether these resources should be developed. The new resources improve the profitability of the field while complying with the authorities' strategy of maximizing the resources in a reservoir, and there is no additional effect on wildlife and other industries. Therefore, the interests of the stakeholders are very much aligned for the Goliat redevelopment, and the political and organizational pressure is low. Of course, this logic does not apply solely to the artic region. There is much more external pressure influencing forecasts for original developments across the shelf. When the fields first have been developed, there are few that oppose to projects that increase the recovery factor from the reservoirs. Consequently, the scope of deception is greater for original developments compared to redevelopments and it holds more explanatory power over the forecasting inaccuracies.

With respect to delusion, consider a hypothetical development where there is no uncertainty at all. In this case, delusion could not affect the forecasts, which demonstrates that delusion is correlated with uncertainty. As pointed out previously, the fact that redevelopments have access to years of production – and reservoir data when generating forecasts should reduce the technical uncertainty in the forecasts. In addition, the forecasters can draw on insight from previous development projects on the same field. The impact of learning through multiple projects on the same field was illustrated in figure 38 and 39, where it was observed that the average deviation in actual production from the mean estimate was reduced with the number of developments on the field. It is therefore safe to conclude that the scope for delusion is much reduced for redevelopments compared to the original developments.

To summarize this discussion, it is argued that the improvements in forecast quality observed for redevelopments originate from reduced susceptibility to both delusion and deception relative to the original development. Also, deception holds less explanatory power over forecast inaccuracies for redevelopment. If one were to visualize this in the framework of figure 50, the two groups of development projects may have a relationship similar to that of the rail and road projects given as an example in the figure.

7.3 The importance of generating unbiased forecasts

All forecasts presented in the PDO are made to support the final investment decision, but as demonstrated, the forecasts tend to be biased towards positive outcomes which allegedly causes sub-optimal capital allocation. However, improving forecast accuracy do not create value by itself. As explained by Bratvold & Begg (2010, p. 14): "[Quantifying uncertainty] has value only to the extent that it holds the potential to change a decision. […] Thus, the goal is not to reduce uncertainty, or even to define it precisely, but to make good decisions." Take the most recent giant discovery on the NCS, Johan Sverdrup, as an example. In the impact assessment, which is a part of the PDO, Statoil wrote[15]: Based on the calculations, the Johan Sverdrup development is easily the most profitable investment project granted the Norwegian society in the coming decades (Statoil, 2014, p. 131). Thus, one may argue, it is to some extent trivial whether or not the profitability calculations were based on biased estimates[16], as Johan Sverdrup

---

[15] Translated from Norwegian

[16] Johan Sverdrup was in fact delivered under budget and ahead of schedule.

is so profitable that the decision to develop the field would stand also when based on unbiased estimates.

Going even further, Hirschman (1967) introduced the idea that underestimating the complexity and potential difficulties of projects is desirable. This was based on an assumption that people also underestimate their creativity and capability to handle difficulties, which offset the optimistic outlook on cost/complexity. Therefore, he argued, misjudging projects is the only way peoples creativity can fully blossom and allow for the initiation of projects that we are able to handle, but would otherwise not pursue had the full extent of the project complexity been known beforehand. Hirschman named his theory "The Hiding Hand", to reference an invisible force that "beneficially hides difficulties from us" (Hirschman, 1967, p. 13). Hirschman was inspired by Sawyer (1952) who observed that a number of projects with massive miscalculations of costs were made successful by a corresponding underestimation of benefits. Referring to the projects in his study Sawyer went on to say that these were cases "in which miscalculation or shear ignorance apparently was crucial to getting an enterprise launched at all", and that this "appears to have been a condition of [the] successful enterprise" (Sawyer, 1952, p. 199).

It turns out that Hiding Hand is an entirely flawed premise. Both Hirschman and Sawyer's research was based on a limited number of projects, and their observation of underestimation of benefits is not supported when considering a larger sample size of projects. Instead, as seen in this study and others (Nandurdikar & Wallace, 2011, Flyvbjerg, 2016, Bratvold *et al.*, 2019), project benefits tend to be overestimated, thus compounding on, not outweighing, the problem of cost – and schedule underestimation. Still, Hirschman's principle is appealing to forecasters and decision makers as it encourage them to proceed with projects and not be overly worried about encountering difficulties and overruns as the Hiding Hand will resolve the problems. This endorsement of optimism in forecasts help explain why the Hiding Hand principle has been popular since its inception, and still is today (Flyvbjerg, 2016). Another unfortunate aspect of the Hiding Hand is that it can be used as an internal justification for decision makers, forecasters, project champions, etc to engage in strategic deception to get a project selected. While this must be discouraged from an economical point of view, it is worth mentioning that deception is highly unethical, especially when managing the resources of the society as is the case for the players on the NCS.

Knowing that no Hiding Hand exist to bail out projects that are approved based on optimistic forecasts, there are good reasons for organizations to focus on improving their forecast accuracy. For a petroleum development, if costs – and schedule are underestimated while production is overestimated this will result in an inflated profitability index for the project, which in turn causes two issues. First, the project may be approved despite being economically unviable. A theoretical example of how biased forecasts may fool decision makers in such a way was given in section 6.3.2. Second, the project may receive approval over an objectively superior project whose merits have been realistically represented. This point is an especially interesting one. Since projects are primarily selected based on their profitability, which is derived from the forecasts of cost, schedule – and production, biased forecasts causes a form of inverted Darwinism in the selection process, i.e. “survival of the unfittest”. The projects whose investment appraisal are most boosted by biased forecasts are, other things equal, the ones that are selected for implementation. However, these are the same projects that are the most likely to experience overruns and production shortfalls. The projects are set up to fail, so we should not be surprised when that is precisely what they do. (Flyvbjerg, 2014).

Both cases described above contribute to pareto inefficiency, i.e. sub-optimal capital allocation, and clearly demonstrate why generating unbiased forecasts is essential to consistently make good, economically efficient, decisions. Furthermore, generating unbiased forecasts will arguably become even more important in the future. As the NCS continue to mature, projects, both redevelopments and new field developments, will likely become increasingly economically marginal, making their financial success very sensitive to deviations in cost, schedule – and production. Consequently, if forecasts continue to be equally as biased as today, the likelihood of decision makers misallocating resources by selecting sub-optimal projects will increase.

Returning to the case of Johan Sverdrup, the discussion at this point may seem to support a notion that improving forecast accuracy is unimportant for extremely profitable development projects. As mentioned, the decision to implement such projects are likely optimal even with a high percentage of bias in the forecasts and improving forecast accuracy holds value only when it has the potential to change decisions. Despite this, generating unbiased forecast remain important also for these projects as the forecasts influence decisions regarding the development plans. For example, the capacity of facilities and infrastructure are decided based on the forecasted production, and realised production outside of the estimates will impose economic losses both in the case of underestimation and overestimation. Offshore fields are always constrained on the upside by the installed facilities. Hence, if the production is underestimated, the facilities and infrastructure on the field may require additional investments to debottleneck the production system and deliver higher production rates. Given overestimation of the production, the project wastes capital due to the unused capacity of the installations (Demirmen, 2007). The latter was an issue on the Valhall redevelopment, where the production potential proved to be worse than expected, resulting in facilities with more capacity and longer design life than necessary (NPD, 2013).

Furthermore, the information contained in the total value erosion calculated in chapter five must be addressed. The total value erosion for the 32 redevelopments was estimated to 102.7 billion 2019-NOK, but this number is arrived at by taking the difference between the estimated mean forecasted revenues and the estimated actual revenues. Since improving the quality of forecasts only holds value if it changes decisions, the actual value erosion caused by biased forecasts is different from the calculated total value erosion from not meeting forecasted production. However, to calculate the actual value erosion, the realised value of the best alternative project/development solution must be compared with the realised value of the project selected for implementation. Of course, this cannot be done, and the best approximation requires access to the companies' estimated value of alternative projects, which forecasts also is likely to be biased. The method used in chapter five is therefore the best available for this research to quantify the value loss caused by inaccurate forecasts, but it is acknowledged that the estimated total value erosion is probably higher than the actual value erosion resulting from biased forecasts.

7.4 How can the industry improve?

Although the analysis presented in figure 37 did indicate that the industry has improved production forecasts for redevelopments over the past one and a half decade, this does not mean that biased forecasts is a thing of the past. As shown in figure 2, Bratvold *et al.* (2019) observed a similar improvement in forecast quality for original developments between 1996 and 2008, before the quality then regressed to approximately the same state in 2018 as it was in 1996. Consequently, the "Iron law of megaprojects" cannot be repealed for the petroleum industry until unbiased forecasts for cost, schedule – and production have been produced over an extended period of time. Knowing that generating unbiased forecasts is essential in securing efficient capital allocation, the industry should strive to make this a trait of their forecasts. As argued in chapter 6, the root cause of the forecasting errors is not poor project execution, bad luck, or technical complexity, but rather flawed human decision making in the form of delusion and deception. Therefore, to improve forecast performance, the industry should focus on minimizing the influence of delusion and deception.

7.4.1 Overcoming delusion

A first crucial step for petroleum companies is to raise awareness within the organization of the cognitive biases that affect human decision making. Since these biases are subconscious, simply recognizing their presence and understanding their effect on estimates is the first line of defence in producing unbiased forecasts. When forecasters are familiar with the biases, then individuals can personally take precautions in their decision-making process to minimize the impact of delusion. For example, being aware of the availability heuristic will allow forecasters to assess whether the assumptions governing their estimates are excessively influenced by recent or memorable events. Similarly, knowing the effect an analogue can have on estimates may inspire forecasters to appraise additional scenarios to ensure the analogue is not causing optimism or overconfidence in the forecasts. In Bratvold & Begg (2010, pp. 161-182), the authors suggest specific approaches individuals can take to minimize the influence of cognitive biases on forecasts. However, these suggestions, or others, will never be abided to in a forecasting process unless organizations educate their employees on the cognitive biases and potential remedial actions.

Further, it is essential that companies have systems in place to record all forecasts and compare them with the actual outcomes, such that both the organization as a whole and the individual forecasters can receive feedback on forecast performance. As discussed, feedback is reducing the scope of delusion by providing an environment for learning, and without it, people will likely continue to commit the same mistakes over again. Unfortunately, compared to the rapid feedback available to well-calibrated meteorologists, most feedback processes in the petroleum industry will be slow, thus more ineffective, due to long time horizons between when the forecasts are made, and the outcome is realised. To remedy this, historical data could be used to train employees by giving them the opportunity to more frequently encounter decision problems where immediate and precise feedback is available. Russo & Schoemaker (1992) gave an example of how Shell used historical data in such a capacity. Shell observed that new hires in the geology department were significantly overconfident in their estimates despite being well-educated individuals. Given that overconfidence is detrimental to value creation, Shell initiated a training program for the geologists. The geologists received technical information from previously drilled exploration wells before being asked to assess the probability of finding oil, as well as a numerical range for the reserves, given that the well was successful. Then, they were presented with the actual outcome of each well. According to Shell, this training proved very effective in reducing overconfidence in the geologist's estimates. The fact that being well-calibrated in estimates is a teachable skill should encourage companies that truly values unbiased forecasts to provide debiasing training for their employees.

The way uncertainty is approached is another fundamental issue that must be addressed in order for the industry produce unbiased forecasts. Uncertainty is typically considered an enemy in decision making, and much time and resources are therefore allocated to develop and use sophisticated models to reduce the uncertainty in the decision outcome, i.e. the estimates. Reducing uncertainty is of course profitable if the cost of the process is less than the value this contributes, and it is an important part of the planning phase of a petroleum development project. However, when operating in a complex environment such as the upstream petroleum industry, uncertainty cannot be eliminated, it is inherent to any investment decision. In fact, this uncertainty is an important part of what allows companies to create competitive advantage. A problem then arises when the quest for certainty persuades people to ignore uncertainties that they do not know how to deal with, or to bend the reality to fit the desired outcome (Bratvold & Begg, 2010). The results are biased forecasts. Managers carry responsibility for how uncertainty is approached within their organization as their standards are essential in creating the culture the lower level employees adhere to. However, it is often the managers that are most negative to uncertainties in the decision outcome, as they are the ones that must make decisions and therefore, somewhat understandably, they crave precise estimates. Imagine your conventional manager in the petroleum industry that receives a probabilistic estimate from an employee. Bratvold *et al.* (2020) explains that a typical response might be along the lines of the following: *It is too much uncertainty in the estimate for me to make a decision. Rework the analysis and do not return it until the uncertainty has been significantly reduced.* This approach to uncertainty is harmful to forecast quality and will work against any measures to improve the forecasts. Instead, managers, and others, should embrace uncertainty by being unbiased in their assessment of it. Doing so will allow them to prepare for all decision outcomes, both positive and negative. A manager who embraces uncertainty and is aware of people's tendency for positive bias in their estimates should rather take the following approach to the situation above: *The uncertainty range in the estimate is to narrow, and I believe it is optimistic as well. Rework the analysis to be a more realistic representation of the uncertainty, given your state of knowledge. The uncertainty range must likely be significantly increased* (Bratvold et al., 2020*)*.

7.4.2 Overcoming deception

The suggestions for improvement up until this point have been focusing on reducing the scope for delusion. To reduce risk of deception, incentive schemes should be used to align the incentives of the agents with those of the principles.

In the second P-A tier, the licensees are the agents of the state government and the public. Following the logic outlined in Flyvbjerg *et al.* (2009) for public infrastructure projects, both financial – and non-financial incentives should be given to the companies to encourage unbiased forecasting, and with respect to financial incentives, they state the following: “Institutions proposing and approving large infrastructure projects should *share financial responsibility* for covering cost overruns and benefit shortfalls resulting from misrepresentation and bias in forecasting, which helps align incentives” (Flyvbjerg *et al.*, 2009, p. 183).

Considering the cost sharing formula between the state and the companies, clearly the structure of the Norwegian petroleum tax system invites companies to be risk seeking by having the state cover 88 percent of their investments on the shelf. This massive reimbursement from the state is a consequence of a deliberate political choice to implement a neutral tax system that aim to ensure that a profitable investment before tax is still profitable after tax. The current system serves Norway well, but the state accepts high risk under this tax structure (Lund, 2014). Since the companies are only accountable for approximately 12 percent of the costs, most of the risk related to cost overruns are assigned to the public. Hence, the companies have weak financial incentives to provide precise cost estimates in the PDO. In the wake of the major cost overruns on the shelf, arguments have been made to transfer more of the risk of overruns to the companies by reducing tax deduction for costs exceeding the budget presented in the PDO (Topdahl, 2012, Bellona, 2018). Excluding all other consequences of this suggestion, doing so will provide a stronger incentive for the companies to present unbiased budget forecasts in the PDO.

Moving focus back on production forecasts, nor for production do the state provide any significant outside incentives to deliver unbiased forecasts. While financial incentives can easily be given for development costs, an equally direct financial incentive might not be available for production. However, the state could promote the significance of unbiased production forecast by creating alternative incentive schemes, for instance by including historical quality of production forecasts as a selection criterium when awarding production licences.

The companies themselves can also benefit from creating incentive schemes for their employees that aim to secure unbiased forecasting within the organization. There are numerous ways to structure incentive schemes. For instance, forecast quality can be emphasized in performance reviews, as well as being tied to financial rewards. Also, the forecasts can be placed under increased scrutiny by having the licence group more thoroughly review the forecasts, or alternatively use an independent body to assess the forecast quality. Regardless of the specific methods used to incentivize unbiased forecasting, the companies should award well-calibrated forecasts and ensure transparency in the forecasting process.

7.4.3 Bypassing delusion and deception

There exists one method, called reference class forecasting (RCF), that tries to bypass the effects of delusion and deception on forecasts by making the forecasts conditional on the outcomes of a larger set of comparable projects. Essentially, this is using multiple analogues as anchors in the forecasting process.

The theoretical foundation for RCF was originally developed by Kahneman & Tversky (1977) as a way to take the outside view on a project, rather than the inside view that causes biased forecasts through “the planning fallacy”. However, the authors never developed their idea for practical application. The first to do so was Bent Flyvbjerg in association with COWI in 2004 (Flyvbjerg, 2004). They used a comprehensive dataset of 252 projects from Europe and North America to create reference classes for different types of infrastructure projects, such as roads and rails, considering the cost performance relative to budget. The reference class is then used to create a probability distribution for cost overruns, similar to the metalog distribution generated for production attainment in this thesis (for a refresher, revisit figure 34, p. 50). From the probability distribution of cost overruns, the uplift needed to adjust for optimism and overconfidence in the budget can be found, illustrated in figure 52 for road projects. For a hypothetical road project, the uplift distribution show that the P50 estimate should be increased by 15[17] percent.

---

[17] From the 50% mark on the horizontal axis, find the intersection with the red curve, and then locate the corresponding point on the vertical axis, which is 15%.

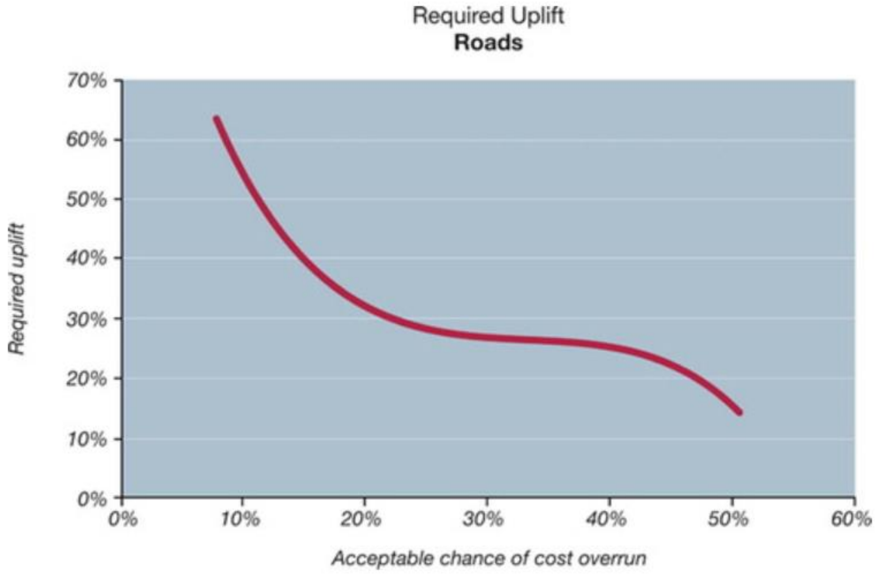
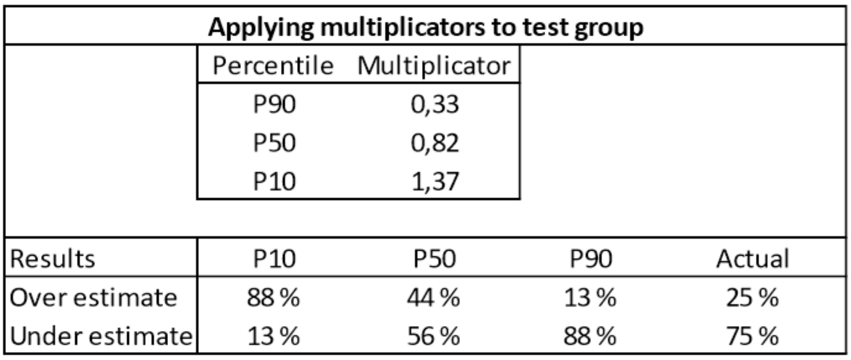


Figure 52: Required uplift to account optimism in the cost forecast for road projects (Flyvbjerg, 2008)

Clearly, the RCF method does not eliminate the need to do a thorough budgeting job in the first place. It is rather a way to calculate a correction factor that can be applied to the forecasts to adjust for people's tendency to underestimate the cost of a project, thus bypassing delusion and deception by focusing on the historical outcomes of comparable projects. The RCF method developed by Flyvbjerg and COWI were later systematically used to adjust FID forecasts for UK infrastructure projects (Flyvbjerg, 2008).

Recently, Mohus (2018) attempted to adopt the procedure outlined above to test the effectiveness of RCF on costs, schedule – and production forecasts for original field developments on the NCS. The reference class were built with the fields that had PDO approval from 1995-2010 and then tested on the fields that had a later approval date. For production forecasts aggregated over the F4Y, the reference class contained 39 fields while the test group contained 17 fields. The reference class was used to find the required uplift for the P10, mean – and P90 estimate respectively, and then the forecasts for the fields in the test group were adjusted by these uplifts and compared with the actual production. The results are given in table 8.

Table 8: Results from applying RCF to production forecasts for original field developments on the NCS (Mohus, 2018).



Applying multiplicators to test group

Percentile	Multiplicator
P90	0,33
P50	0,82
P10	1,37

Results	P10	P50	P90	Actual
Over estimate	88 %	44 %	13 %	25 %
Under estimate	13 %	56 %	88 %	75 %

Comparing the RCF results in table 8 with the actual outcomes presented in table 1 (page 3), though it is not the identical sample, the results indicates that adjusting the production forecasts in the tests group based on the outcomes of the reference class has reduced the bias in the forecasts. After applying the uplift, 75 percent of the fields have actual production within the confidence interval, and only 13 percent underperform the P10.

If future research on RCF on the shelf proves equally positive, the state should consider making RCF mandatory in the PDO process[18]. However, this is contingent on the state being able to construct appropriate reference classes for different project groups. According to Flyvbjerg (2008) “The [reference] class must be broad enough to be statistically meaningful but narrow enough to be truly comparable with the specific project”. For instance, it would not be correct to use both original developments and redevelopments in the same reference class for production as these groups of projects are likely statistically different from one another, thus a separate reference class must be constructed for redevelopments. However, when constructing a reference class for redevelopments, it must also be considered whether there are significant differences within this group such that it should be further subdivided. The results presented in chapter 4, for example, indicated that it may be a significant difference in forecast quality for newer and older redevelopments on the same field. To make such conclusions and create a reference class for redevelopments, more research on these projects with a larger dataset is required.

---

[18] Current, unpublished, research at the University of Stavanger indicate that a refined RCF process improves forecasts on the NCS by 70-90 percent as measured by root mean square error (Bratvold, E-mail to author, June 23, 2020).

8 Conclusion

To maximize the value of the petroleum resources on the NCS, the public are relying upon the national government and the petroleum companies operating on the shelf to make good, economically efficient decisions. However, high quality decisions requires unbiased assessments of uncertainties related to the development projects, and yet the analysis presented in this thesis shows that redevelopment decisions made for fields on the NCS are based on production forecasts that tend to be severely biased.

The cumulative actual production over the first three operational years was compared with the FID forecasts for 32 redevelopments approved between 1996 and 2019. A thorough statistical analysis was conducted on a subset of 21 projects, where the results showed that 67 percent produced less than the expected volumes. Moreover, only 43 percent of the projects had actual production fall within their estimated 80 percent confidence interval, which is mostly due to significant underproduction, seeing as 48 percent of the projects produced less than the P10 forecast.

Since the forecasts are biased, conventional explanations of poor performance in the form of "bad luck" cannot account for the reduced production attainment. Rather, it is argued that the inaccurate forecasts can be explained in terms of delusion and deception. Delusion stems from forecasters taking an "inside view" to their project, focusing on its unique specifics rather than the historical outcomes of similar projects. The "inside view" leads to unrealistic forecasts through optimism and overconfidence biases. These are robust biases in human judgement which are enhanced by people's reliance on heuristic rules such as anchoring, information availability, and representativeness. However, delusions are honest mistakes and companies can take mitigating action by raising awareness of cognitive illusions and provide debiasing training for their employees. Contrary to delusion, deception is a deliberate choice from one or more stakeholders to misrepresent the merits of a project to increase the likelihood of the project receiving approval. Deception occurs because of diverging incentives between the stakeholders in a principal – agent relationship and its explanatory power over forecasting inaccuracies is greater for projects where the political and organizational pressure is high. The risk of deceptive forecasts is increasing with the presence of asymmetric information, and difference in risk preference and time horizons between principle and agent. To overcome deception, incentive schemes should be designed to align the interests of all involved parties.

This study is the first of its kind that focus on redevelopment projects, thus the analysis provides fresh insight on the industry's ability to transform the knowledge gained from historical production data into precise forecasts. When evaluating the production attainment relative to the mean forecast, a minor positive correlation exists within the sample between years of historical production prior to initiation of a redevelopment and forecast accuracy. The results also indicate that the forecast accuracy improves with the number of redevelopments on the same field. Hence, reduced uncertainty in the parameters important for production forecasting seem to improve the quality of the forecasts. This conclusion is supported by the observed improvement in forecast quality for redevelopments relative to the original developments considered in Bratvold *et al.* (2019). The fraction of projects producing less than the P50 forecast has been reduced by 17 percentage points, while it is seen a 12 percentage points increase in projects with actual production inside the estimated confidence interval. The improvement in redevelopment forecast quality is reflected in the reduced scope of both delusion and deception for this group of projects compared to the original developments.

Biased forecasts cause value erosion. The 32 redevelopments produced an average of 8.3 percent less than the mean forecasted volumes, which translates to a total estimated revenue loss of approximately 102 billion 2019-NOK, equal to a six percent loss of expected revenues. However, as improving the quality of forecasts only holds value if it has the potential to change decisions, it is recognized that the actual value erosion caused by biased forecasts will be different to the estimated value erosion from not meeting forecasted production. Still, the estimate gives an indication of the revenues lost by inaccurate forecasts, 78 percent of which would have accrued to the public through taxes. It is positive that the results from this analysis indicate an improvement in redevelopment production forecast quality since 1996, but it remains a long way to go for the industry to overcome delusion and deception in their forecasts. Debiasing of forecasts holds great value for the companies and the society, and hopefully the players on the NCS will focus on improving forecast quality such that in the future, unrealistic forecasts are the exception rather than the norm.

> "In fact, in light of what we know about how bias affects decision making and the economic impacts of this, it could reasonably be claimed that debiasing of industry decisions has greater potential to improve economic outcomes than time and money put into honing technological and modelling processes" (Welsh & Begg, 2015).

Bibliography

Aker BP (2020). Tax manual.

Alvik, I. (2016). "Main elements of the Norwegian license system." Retrieved 10.04, 2020, from https://www.uio.no/studier/emner/jus/jus/JUS5411/v16/presentasjoner/petroleum-law---license-system-[lecture-3].pdf.

Bellona. (2018). "Leterefusjonsordningen - alt du trenger å vite." Retrieved 06.02, 2020, from https://bellona.no/nyheter/olje-og-gass/2018-02-leterefusjonsordningen-alt-du-trenger-a-vite.

Bratvold, R. B. & S. Begg (2009). "Would You Know a Good Decision if You Saw One?" The Way Ahead **05**(02): 21-23.

Bratvold, R. B. & S. H. Begg (2010). Making good decisions. Richardson, Tex, Society of Petroleum Engineers.

Bratvold, R. B., E. Mohus, D. Petutschnig & E. Bickel (2019). Production Forecasting: Optimistic and Overconfident–Over and Over Again. SPE Annual Technical Conference and Exhibition, Society of Petroleum Engineers.

Bratvold, R. B., E. Mohus, D. Petutschnig, E. Bickel, E. F. Berget & S. Bekkedal (2020). Production Forecasting: Optimistic and Overconfident - Over and Over Agian

Briel, E., P. Luan & R. Westney (2013). "Built-In Bias Jeopardizes Project Success." Oil and Gas Facilities **2**(02): 19-24.

Buehler, R., D. Griffin & M. Ross (1994). "Exploring the" planning fallacy": Why people underestimate their task completion times." Journal of personality and social psychology **67**(3): 366.

Bulmer, M. G. (1979). Principles of statistics, Courier Corporation.

Chapman, G. B. & E. J. Johnson (2002). "Incorporating the irrelevant: Anchors in judgments of belief and value." Heuristics and biases: The psychology of intuitive judgment: 120-138.

Cooper, A. C., C. Y. Woo & W. C. Dunkelberg (1988). "Entrepreneurs' perceived chances for success." Journal of Business Venturing **3**(2): 97-108.

Demirmen, F. (2007). "Reserves estimation: the challenge for the industry." Journal of Petroleum Technology **59**(05): 80-89.

Ellis, E. S., D. Kosynkin & M. N. Askar (2016). Transforming Oil Tracer Studies. SPE Kingdom of Saudi Arabia Annual Technical Symposium and Exhibition. Dammam, Saudi Arabia, Society of Petroleum Engineers**:** 14.

EY (2014). "Sustainability Reporting the time is now." EYGM limited. Preuzeto sa sajta dana **31**(08): 2016.

Fischhoff, B. (2012). Judgment and Decision Making. Florence, UNITED STATES, Taylor & Francis Group.

Flyvbjerg, B. (2004). "Procedures for Dealing with Optimism Bias in Transport Planning."

Flyvbjerg, B. (2008). "Curbing optimism bias and strategic misrepresentation in planning: Reference class forecasting in practice." European planning studies **16**(1): 3-21.

Flyvbjerg, B. (2014). "What you should know about megaprojects and why: An overview." Project management journal **45**(2): 6-19.

Flyvbjerg, B. (2016). "The Fallacy of Beneficial Ignorance: A Test of Hirschman's Hiding Hand." World Development **84**: 176-189.

Flyvbjerg, B. (2017). "Introduction: The iron law of megaproject management." Bent Flyvbjerg: 1-18.

Flyvbjerg, B., M. Garbuio & D. Lovallo (2009). "Delusion and deception in large infrastructure projects: two models for explaining and preventing executive disaster." California management review **51**(2): 170-194.

Flyvbjerg, B., M. S. Holm & S. Buhl (2002). "Underestimating costs in public works projects: Error or lie?" Journal of the American planning association **68**(3): 279-295.

Fremstad, M. & K. Løset. (2020). "Jensen advarer Solberg: - Da lever regjeringen svært farlig "   Retrieved 08.06, 2020, from https://www.tv2.no/a/11389799/.

Gneiting, T. & M. Katzfuss (2014). "Probabilistic forecasting." Annual Review of Statistics and Its Application **1**: 125-151.

Haiden, T., M. Janousek, J. Bidlot, L. Ferranti, F. Prates, F. Vitart, P. Bauer & D. Richardson (2016). Evaluation of ECMWF forecasts, including the 2016 resolution upgrade, European Centre for Medium Range Weather Forecasts.

Harden, C. (2014). Discount Rate Development in Oil and Gas Valuation. SPE Hydrocarbon Economics and Evaluation Symposium. Houston, Texas, Society of Petroleum Engineers**:** 10.

Hatlestad, H. (2019). Utredning av feltutbyggningsprosjekter på norsk sokkel - Hovedrapport.

Heywood-Smith, A. B., M. B. Welsh & S. H. Begg (2008). Cognitive Errors in Estimation: Does Anchoring Cause Overconfidence? SPE Annual Technical Conference and Exhibition. Denver, Colorado, USA, Society of Petroleum Engineers**:** 10.

Hirschman, A. O. (1967). "The principle of the hiding hand." The public interest **6**: 10.

Höök, M., B. Söderbergh, K. Jakobsson & K. Aleklett (2009). "The Evolution of Giant Oil Field Production Behavior." Natural Resources Research **18**: 39-56.

IFT. (n.d). "Common Probability Distributions "   Retrieved 02.23, 2020, from https://ift.world/booklets/quant-common-probability-distributions-part4/.

Janis, I. L. (1982). "Groupthink: Psychological studies of policy decisions and fiascoes."

Janis, I. L. (2008). "Groupthink." IEEE Engineering Management Review **36**(1): 36.

Kahneman, D. & A. Tversky (1977). Intuitive Prediction: Biases and Corrective Procedures.

Keelin, T. W. (2016). "The metalog distributions." Decision Analysis **13**(4): 243-277.

Kelamis, P. G., R. C. Uden & I. Dunderdale (1997). 4D Seismic Aspects of Reservoir Management. Offshore Technology Conference. Houston, Texas, Offshore Technology Conference**:** 13.

Leana, C. R. (1985). "A Partial Test of Janis' Groupthink Model: Effects of Group Cohesiveness and Leader Behavior on Defective Decision Making." Journal of Management **11**(1): 5-18.

Lichtenstein, S., P. Slovic, B. Fischhoff, M. Layman & B. Combs (1978). "Judged frequency of lethal events." Journal of Experimental Psychology: Human Learning and Memory **4**(6): 551-578.

Lund, D. (2014). "State participation and taxation in Norwegian petroleum: Lessons for others?" Energy Strategy Reviews **3**: 49-54.

Mackie, S. (2007). Human decision-making under uncertainty in the upstream oil and gas industry.

McCune, S. K. (2010). Practice Makes Perfect Statistics, McGraw-Hill USA.

Merrow, E. W. (2011). Industrial mega-projects : concepts, strategies, and practices for success. Hoboken, N.J., Wiley.

Merrow, E. W. (2012). "Oil and gas industry megaprojects: Our recent track record." Oil and Gas Facilities **1**(02): 38-42.

Mohus, E. (2018). Over Budget, Over Time, and Reduced Revenue, Over and Over Again-An Analysis of the Norwegian Petroleum Industry's Inability to Forecast Production, University of Stavanger, Norway.

MPE (1990). Guidlines on arrangement and contents of plan for development and operation of petroleum deposits

MPE (2010). Veiledning til plan for utbygging og drift av en petroleumsforekomst (PUD) og plan for anlegg og drift av innretninger for transport og for utnyttelse av petroleum (PAD).

MPE (2018). Guidlines for plan for development and operation of a petroleum deposit (PDO) and plan for installation and operation of facilities for transport and utilisation of petroleum (PIO).

Nandurdikar, N. S. & L. Wallace (2011). Failure to produce: An investigation of deficiencies in production attainment. SPE Annual Technical Conference and Exhibition, Society of Petroleum Engineers.

Norges Bank. (n.d, 05.22, 2020). "Exchange rates."   Retrieved 04.24, 2020, from https://www.norges-bank.no/en/topics/Statistics/exchange_rates/?tab=currency&id=USD.

Norwegian Petroleum. (n.d). "Grane."   Retrieved 03.20, 2020, from https://www.norskpetroleum.no/en/facts/field/grane/.

Norwegian Petroleum. (n.d, 05.12, 2020). "Investments and operating costs "   Retrieved 03.10, 2020, from https://www.norskpetroleum.no/en/economy/investments-operating-costs/#overall-costs).

Norwegian Petroleum. (n.d, 09.01, 2020). "The Petroleum Act and the licensing system." Retrieved 01.20, 2020, from https://www.norskpetroleum.no/en/framework/the-petroleum-act-and-the-licensing-system/.

NPD (2012). Facts 2012 The Norwegian petroleum sector.

NPD (2013). Vurdering av gjennomførte prosjekter på norsk sokkel 45.

NPD (2016). The Norwegian Petroleum Directorate's resource classification system 2016.

NPD (2017). Resource report 2017

NPD (2019). Resource report discoveries and fields 2019

NPD (2020). Project execution on the Norwegian continental shelf.

NPD. (n.d, 03.22, 2019). "Act 29 November 1996 No. 72 relating to petroleum activities " Retrieved 05.04, 2020, from https://www.npd.no/en/regulations/acts/act-29-november-1996-no2.-72-relating-to-petroleum-activities/#Section-1-2.

NPD. (n.d, 05.25, 2020). "Production saleable yearly." Retrieved 01.20, 2020, from https://factpages.npd.no/nb-no/field/tableview/production/saleable/yearly.

Oglend, A., P. Osmundsen & S. Lorentzen (2016). Cost Overruns in Norwegian Oil and Gas Projects: A Long-tailed Tale. IAEE Energy Forum, Bergen Special.

Pachamanova, D. A. & F. J. Fabozzi (2010). Simulation and Optimization in Finance: Modeling with MATLAB, @RISK, or VBA. Hoboken, NJ, USA, Hoboken, NJ, USA: John Wiley & Sons, Inc.,10.1002/9781118267752.

Ringrose, P. & M. Bentley (2015). Reservoir Model Design: A Practitioner's Guide. Dordrecht, Dordrecht: Springer Netherlands,10.1007/978-94-007-5497-3.

Rommetveit, A. & R. C. Topdahl. (2020). "Derfor er iskanten politisk sprengstoff " Retrieved 06.08, 2020, from https://www.nrk.no/klima/xl/derfor-er-iskanten-politisk-sprengstoff-1.14985643.

Rosendahl, K. E. (2017). Lønnsomhet ved Goliatfeltet.

Russo, J. & P. Schoemaker (1992). "Managing Overconfidence." Sloan Management Review **33**: 7-17.

Saasen, A. & M. Khalifeh (2020). Introduction to Permanent Plug and Abandonment of Wells, Springer.

Sawyer, J. E. (1952). "Entrepreneurial error and economic growth." Explorations in Economic History **4**(4): 199.

Sharot, T. (2011). "The optimism bias." Current Biology **21**(23): R941-R945.

SPE (2001). Guidelines for the Evaluation of Petroleum Reserves and Resources. A supplement to the SPE/WPC Petroleum Reserves Definitions and the

SPE/WPC/AAPG Petroleum Resources Definitions.

Stanovich, K. E. & R. F. West (2000). "Individual differences in reasoning: Implications for the rationality debate?" Behavioral and Brain Sciences **23**(5): 645-665.

Statistics Norway. (n.d, 05.11, 2020). "Consumer Price Index."   Retrieved 05.25, 2020, from https://www.ssb.no/en/kpi.

Statoil (2014). Johan Sverdrup-feltet, PL 265, PL 501, PL 501B og PL 502, PUD del II - Konsekvensutredning, November 2014

Svenson, O. (1981). "Are we all less risky and more skillful than our fellow drivers?" Acta psychologica **47**(2): 143-148.

Taleb, N. N. (2007). The black swan: The impact of the highly improbable, Random house.

Tollaksen, T. G. (2019). "Goliat burde kommet i mål for under 40 milliarder kroner " Retrieved 05.08, 2020, from https://www.aftenbladet.no/aenergi/i/WbapaG/goliat-burde-kommet-i-mal-for-under-40-milliarder-kroner.

Topdahl, R. C. (2012). "Oljeselskapene bør ta regningen "   Retrieved 06.02, 2020, from https://www.aftenposten.no/okonomi/i/BRvyl/oljeselskapene-boer-ta-regningen.

Tugan, M. F. & M. Onur (2015). Selection of Best Reserves Estimation Methodology to Quantify and Reduce the Uncertainty – Accompanied by Çayirdere Gas Field Case Study. SPE Middle East Oil & Gas Show and Conference. Manama, Bahrain, Society of Petroleum Engineers**:** 18.

Tversky, A. & D. Kahneman (1973). Judgment under Uncertainty: Heuristics and Biases. E. Oregon Research Inst.

Tveter, H. (2017). Statens kostnader knyttet til særordingene i oljeskatten

U.S. Energy Information Administration. (2020). "Spot Prices for Crude Oil and Petroleum Products." Retrieved 05.25, 2020, from https://www.eia.gov/dnav/pet/hist/LeafHandler.ashx?n=PET&s=RBRTE&f=A.

Weinstein, N. D. (1982). "Unrealistic optimism about susceptibility to health problems." Journal of behavioral medicine **5**(4): 441-460.

Welsh, M. B. & S. H. Begg (2010). Don't Let it Weigh You Down: How to Benefit From Anchoring. SPE Annual Technical Conference and Exhibition. Florence, Italy, Society of Petroleum Engineers**:** 8.

Welsh, M. B. & S. H. Begg (2015). "WHAT HAVE WE LEARNT? INSIGHTS FROM A DECADE OF BIAS RESEARCH."

Welsh, M. B., S. H. Begg & R. B. Bratvold (2007). Modelling the Economic Impact of Common Biases on Oil and Gas Decisions. SPE Annual Technical Conference and Exhibition. Anaheim, California, U.S.A., Society of Petroleum Engineers**:** 7.

Welsh, M. B., R. B. Bratvold & S. H. Begg (2005). Cognitive Biases in the Petroleum Industry: Impact and Remediation. SPE Annual Technical Conference and Exhibition. Dallas, Texas, Society of Petroleum Engineers**:** 10.

Wooldridge, J. M. (2014). Introduction to econometrics. Andover, Cengage Learning.

Xiao, J. & X. Sun (2017). Big Data Analytics Drive EOR Projects. SPE Offshore Europe Conference & Exhibition. Aberdeen, United Kingdom, Society of Petroleum Engineers**:** 9.