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Katerina Shaton

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Investments in upstream gas transport pipelines are characterized by significant economy of scale: there is a low additional cost to establish capacity in excess of the committed volumes. The excess capacity provides flexibility for cost-efficient expansions of the transportation system if there are new discoveries in the future. Therefore, investments in excess pipeline capacity may have a significant value for the gas sector in general, which is disregarded by the private decision-makers. The flexibility to expand the transportation network can be regarded as an option, which can be exercised if there are new discoveries and market conditions are favorable. The objective of this paper is to consider how Real Options thinking can be applied to estimate the monetary value of the flexibility provided by excess capacity in gas transport pipeline investments. The proposed method is based on the binomial lattices and allows including both market and project-specific risks. An example demonstrates how this value can be used by a public decision-maker in the evaluation of infrastructure projects in the Norwegian gas transport sector.

Keywords: Gas pipeline Investments, Excess Capacity, Value of Flexibility, Real Options

1 Introduction

Relatively low coal prices and low prices on carbon currently challenge the competitive position of natural gas in the European power market. However, it remains one of the main energy sources in the European energy mix: 23.2% of the total energy consumed was covered by natural gas in 2013 (Eurostat, 2014). In the longer run, with a higher carbon price, natural gas is expected to gain more importance in the energy mix due to its abundance, cost competitiveness, and a low carbon footprint. Well-functioning of the gas market depends on the availability of transport infrastructure and its efficient operations. Norway, which is the second largest supplier of natural gas to the EU after Russia, supplied about 21% of its total demand in 2013 (EIA, 2014). The natural gas infrastructure on the Norwegian Continental Shelf (NCS) is represented by a system of platforms, processing plants, receiving terminals and an extensive network of pipelines, with the total length of about 8000 km and transport capacity of 120 billion Sm³ per year. This transportation network connects gas producers on the shelf of Norway with the end-users markets in Germany, Belgium, the United Kingdom and France. Historically, investments in gas transport infrastructure have been made on the basis of financial analysis performed by investing companies and political considerations of the government (see e.g. Holden (2013) for a comprehensive overview of the Norwegian policy in the petroleum sector). The choice of a transport solution is a matter of negotiations between petroleum companies and authorities. Companies base their decisions on a least cost planning method, and due to high required rates of return, their planning horizon is rather short. The authorities consider in-

infrastructure development from the perspective of the long-term management of petroleum resources on the Norwegian continental shelf (NCS). In cases of major infrastructure developments, this means that not only the fields that trigger a gas transport need are included in the analysis, but also contingent resources and undiscovered resources are taken into account. A relevant example of an infrastructure development is the ongoing discussion of a transport solution in the Barents Sea. Exploration interests of petroleum companies move further to the North. According to the estimates provided by the Norwegian Petroleum Directorate, on average, about 43% of all undiscovered petroleum resources on the NCS are attributed to the Barents Sea (NPD, 2014). The only gas transport infrastructure in the region available at the moment is the LNG (Liquefied Natural Gas) facility at Melkøya, which processes the gas from Snøhvit, the only gas field operating in that region. The operator of the field considers the expansion of the production and, accordingly, the expansion of the LNG facility. The main advantage of this solution is the market flexibility: a producer is not locked into the European market; the gas can be shipped by vessels to the highest value markets, implying higher profit (according to some estimates (e.g. Gassco, 2014), the LNG flexibility may be up to 10% of the market price of the pipeline gas).

On the other hand, there is an option of a pipeline solution, connecting the Barents Sea with the existing transport network. The pipeline solution requires higher initial investments, lacks destination flexibility, but implies considerably lower than the LNG operating costs. Another benefit of the pipeline solution is the utilization of the transport capacity in the existing pipeline network, which may become spare in the near future. Maintenance

costs for these transport facilities will be shared between larger volumes of transported gas, reducing the total unit costs. The most important advantage of the pipeline solution is a significant economy of scale in investments, which enables over-dimensioning. There is a low additional cost to establish a capacity above the committed volumes, with regard to future discoveries and corresponding tie-ins. Available spare pipeline capacity in the transport system provides incentives for exploration in the region and reduces the cost threshold for development of deposits along the pipeline. There are two perspectives of evaluation of infrastructure projects. The first perspective represents interests of a commercial company, which is willing to establish a transport solution for a certain field, and focuses on short-term cost minimization. The second perspective evaluates the solution from the point of view of a public decision-maker, which aims to maximize value creation on the NCS in the long run. The first perspective emphasizes market flexibility of LNG solutions and the related benefits, the second perspective emphasizes the benefits created by the economy of scale in investment of pipeline solutions and opportunities provided by that.

According to the study conducted by the operator of the gas infrastructure network on the NCS in 2014, existing fields and discoveries are not sufficient to justify an investment in new gas infrastructure from the Barents Sea (Gassco, 2014). While the pre-tax NPV (at 7 percent real discount rate) is similar for a new 32" pipeline and the LNG solution, the expansion of the LNG train is better when measured by the real IRR on investments. When the potential outcome of near-term (3 years) exploration activities in the Barents Sea are taken into consideration, a 42" pipeline gives a higher NPV in four out of five exploration scenarios, and a marginally lower NPV in one

scenario. An analysis of the long-term resource scenarios also proves robustness of the pipeline solution with excess capacity.

From the NCS perspective, the excess pipeline capacity has a certain value, because it creates a possibility to connect new fields in the future at a low cost if there are new discoveries. From the project-economic perspective, investments in the excess pipeline capacity represent a capital tied-up in unprofitable investments. Therefore, the costs of excess capacity should be justified analytically. However, the currently used evaluation approach does not directly quantify the benefits of the flexibility provided by the excess capacity (e.g. Barents Sea Gas Infrastructure (BSGI), 2014, NCS2020-study, 2012). The Real Options Analysis (ROA) provides a means to estimate the monetary value of flexibility in investments, which is the ability to alter the course of the project so that expected returns are maximized or expected losses are minimized (Brandão et al., 2005). Copeland and Antikarov (2003) define a real option as the right, but not the obligation, to take an action (e.g., deferring, expanding, contracting or abandoning) at a predetermined cost, called exercise price, for a predetermined period of time – the life of the option. Real option valuation techniques are conceptually different from traditional discounted cash flow tools, as they directly value managerial flexibility. Examples of project flexibilities include deferring investment until new information arrives, expanding operations if market conditions are favorable, abandoning a project, suspending operations temporarily, switching inputs or outputs. According to Sarkar (2009), excess capacity can be regarded as an option to expand the production. The

objective of this paper is to consider how real options thinking can be applied to estimate the monetary value of the flexibility provided by excess capacity in gas transport pipeline investments.

The paper is organized as follows. A review of the relevant research is presented in Section 2. Section 3 describes the chosen approach for a real options valuation. The application of this approach to the valuation of the flexibility provided by excess pipeline capacity is demonstrated in Section 4. The implications of such valuations on the investment appraisal and decision system in the Norwegian gas transport sector is discussed in Section 5. Section 6 concludes.

2 Literature Review

Petroleum investments have been among the earliest applications of the real options valuations. A license for petroleum reserve exploration and operation, obtained by a petroleum firm, can be considered as an option to invest into development of oil fields if the market conditions are favorable. Examples of ROA of investment in petroleum reserves can be found in the classical books by Dixit and Pindyck (1994) and Trigeorgis (1996), and in number of research articles. Smith and McCardle (1999) consider the application of the options approach to oil and gas investment valuation and discuss the benefits of real options analysis over the traditional decision analysis techniques. Lund (2000) considers the value of flexibility in offshore oil fields development on the coast of Norway, using stochastic dynamic programming to model market risk and reservoir uncertainty. Miltersen (2000) allows for a stochastic interest rate and convenience yields in real option

valuation of petroleum deposit investment. Chorn and Shokhor (2006) combine Bellman's equation with a real options valuation algorithm to represent sequential investment decisions in petroleum field development. Johnson et al. (2006) examine the application of system dynamics to real options analysis in the oil and gas industry. Enders et al. (2010) apply stochastic dynamic programming to analyze the interaction between two types of real options arising in natural gas production: the option to scale the production level and to scale the extraction rate by pausing production. These studies are related to investment decisions in the upstream, or production, segment of the gas value chain.

A more recent stream of research is applications of ROA dealing with distribution, or the downstream, part of natural gas value chain (e.g., investments into natural gas power plants or LNG plants). Näsäkkälä and Fleten (2005) value the flexibility in the choice of technology regarding investments in gas-fired power plants, modelling the spark spread, and estimate investment thresholds for optimal decisions. Abadie and Chamorro (2009) present a valuation of investment options into a NGCC power plant and an LNG facility following a least squares Monte Carlo approach. Another application of RO analysis in the distribution segment is storage valuation: Arvesen et al. (2012) study the value of using the pipeline linepack as a short-term gas storage.

What is common for these two fields of research is that in the investment analysis of a field development or a power plant construction, the gas transport capacity is treated as an exogenous constraint. A common approach to dealing with gas transport infrastructure investments, both in

the research and practice, is to apply optimization techniques, where existing infrastructure and potential projects are included in the model and the optimal design is defined with the focus on the properties of the network (e.g. Rømo et al., 2009, Hellemo et al. 2012). When the optimal design of transport network is defined, the investment analysis focuses on the activities “on the nodes” of transport infrastructure: gas production and distribution. This paper represents an attempt to expand the scope of ROA applications to the investment valuations of gas transport infrastructure projects.

3 Methodology

3.1 Real Options Valuation Approaches

Since the term “real option” was introduced by Myers in 1977, the ROA attracted the attention of researchers and practitioners, and various approaches of real options valuations have been proposed (for a critical review see e.g. Borison, 2005). The so-called “classic approach” (e.g. Amram and Kutilaka, 1999) is based on the theory of financial option pricing introduced by Black and Scholes (1973). This theory presumes that markets are complete, all risks are liquidly traded on the financial market, and can be hedged through constructing a portfolio of financial instruments which provide the exact same payoff as the project itself in any state and at any point in time. This assumption rarely holds for real world projects, since there are many non-tradable, or private, risks, which cannot be hedged away. In response, researchers (e.g. Dixit and Pindyck, 1994) suggested to use finance-based real options approach to valuations of project where

market risks are dominating, and to apply decision analysis techniques (as decision trees) to projects with primarily private risks. However, there are approaches which allow evaluating of projects where both types of risks are present and significant. Smith and Nau (1995) proposed an integrated approach, where both market and private risks are identified explicitly. According to this approach, market risks can be modelled using the traditional financial option pricing techniques (the replicating portfolio approach), while private risks are modelled through subjective beliefs and preferences of stakeholders expressed as utility functions. Another approach to dealing with incomplete markets in real options valuations has been proposed by Copeland and Antikarov (2001). This approach does not explicitly rely on the existence of a traded replicating portfolio that can serve as a basis for valuation of the project market value. Instead, it is assumed that the present value of the project without options (evaluated with traditional discounted cash flow technique) is the best unbiased estimator of the market value of the project (the Market Asser Disclaimer (MAD) assumption). The market value of the project is then assumed to vary over time according to a random walk stochastic process (Geometric Brownian Motion, GBM), and the options can be valued with traditional option pricing methods. The assumption that the project value follows the GBM is based on the Samuelson's proof (1965) that properly anticipated prices fluctuate randomly, meaning that multiple uncertainties affecting project's cash flows, which can follow different stochastic processes (e.g. mean-reverting), can be reduced to a single uncertainty, which follows a GMB. There are numerous sources of uncertainty affecting the volatility of project returns in the gas transport sector. The main two are the rate of exploration

success and the dynamics of gas prices. Certainly, these two factors are not sole, there is also uncertainty over the investment costs, which may change significantly during the planning and construction period. The long-term valuations may also be affected by the development of new technologies that influence investment and operating costs. The dynamics of gas prices and investment costs are the market uncertainties, the rate of exploration success and technological developments are the project-specific, or private, uncertainties. The approach to real options valuations in the gas transport projects needs to be able to incorporate both types of uncertainties. Therefore, the relevant methodologies are the integrated approach of Smith and Nau and the approach proposed by Copeland and Antikarov (henceforth the CA approach). The latter one is adopted to the purpose of this paper, as this approach can be relatively easily applied in practice of project evaluations by a public decision-maker.

There are two main ways for option pricing: a continuous model developed by Black and Scholes (1973) and a discrete approach of the binomial model, see Cox, Ross, and Rubinstein, 1979. The binomial model is adopted in the CA approach. Besides being mathematically less demanding, the binomial model has advantages over the continuous model for real option valuations (c.f. Copeland and Antikarov, 2003).

In the binomial model, the price of the underlying asset follows a multiplicative binomial process: the price can either move up by a fixed value u or down by a fixed value d . If the value of the project follows the Geometric Brownian Motion, this value at any point in time has a lognormal distribution. By equating the first and second moments of a binomial and lognor-

mal distribution, we derive that $u = e^{\sigma\sqrt{t}}$ (t is a length of the binomial period, σ is volatility), under the assumption that $u = 1/d$. This procedure ensures that the discrete distribution approximates the continuous distribution in the limit. Applying this technique, we get a recombining (event) tree representing the development of the asset value S_{ij} (i is index for time, j is index for state at time i).

In order to derive the value of the American call option, a decision tree is built. The tree is solved recursively. At the expiration date, the option value is equal to (zero value if not exercised):

$$C_{ij} = \max(S_{ij} - E, 0) \quad (1)$$

where E is the exercise price of the option. Before the expiration, the values on the nodes of the decision tree is defined using the risk-neutral probability approach (maximum between the value of the exercised option and the "alive" option):

$$C_{ij} = \max\left(S_{ij} - E, \frac{(pC_{i+1,j} + (1-p)C_{i+1,j+1})}{1+r}\right) \quad (2)$$

where r is a risk-free rate. The risk-neutral probability $p = (e^{rt} - d)/(u - d)$ is constant and is applied throughout the tree. Solving the tree backwards, we obtain the value of the project at time 0.

3.2 Valuation of an Option to Expand

The option to expand can be valued as follows. The underlying risky asset is the value of the project V , which follows a binomial stochastic process. The values of the up and down movements, u and d , are estimated based

on the volatility of the project value. The expiration time is limited by the life-time of the project. Additional investment needed to expand the project is the exercise price E . If the option to expand is exercised, the scale of the project is increased to a factor k . To find the values on the nodes of the decision tree, we start at the end node. If the increase of the project value due to the expansion exceeds the cost of expansion ($kV_{ij} - E > 0$), the option is exercised. At the expiration date t , the payoff is defined as:

$$C_{ij} = \max(V_{ij}, (1 + k)V_{ij} - E) \quad (3)$$

Before the expiration, if the option is exercised, the payoff is $(1 + k)V_{ij} - E$; if the option is kept "alive", the payoff is defined using the risk-neutral probability approach. The decision rule is:

$$C_{ij} = \max\left(\frac{(pC_{i+1,j} + (1 - p)C_{i+1,j+1})}{1 + r}, (1 + k)V_{ij} - E\right) \quad (4)$$

The value of the flexibility is the difference between the value of the project with the option to expand (C_0) and the value without the option (V_0).

The described approach of the option to expand valuation can be adapted to gas infrastructure investments in the following way. The investment cost for excess pipeline capacity is the price that the investors pay to get the option to expand the system by tying-in new transport facilities and connecting new fields at a later point in time. The value of this option depends on the uncertainty over the project value. The project valuation includes all parts of the value chain, from the subsurface to the market, incorporating cost estimates from field developments, offshore and onshore processing facilities, and transport of gas to the relevant market.

To approximate the stochastic process followed by the project value, three parameters are needed: the estimate of the current value of the project, the volatility of returns, and the risk-free rate. The risk-free rate over the life of the option is constant; the one determined by the Government bonds can be used. The initial project value V_0 can be estimated as a traditional net present value (NPV), calculated based on the risk-free discount rate. The volatility of project the value σ is to be approximated by Monte Carlo simulation, which includes different price and resource scenarios. The upscaling potential k is limited by the available excess capacity. The exercise price of the option is the additional investments, required for upgrading the pipeline with new compressors, and for the development of new fields, that come on-stream if the market conditions are favorable. The option to expand may be exercised at any time in the future, limited by the lifetime of the pipeline in question (30-40 years).

4 Example of Option Valuation

In order to demonstrate how the described technique can be applied for a valuation of value of flexibility provided by excess capacity, a simulated example, similar to the Barents Sea Gas Infrastructure project, is considered. There is a transport solution, which assumes a pipeline of 32", suggested based on a medium resource scenario. The expected pre-tax NPV of the whole project is 50 billion NOK, estimated by the traditional technique, using a risk-free rate 2%. It is assumed, the option to expand can be exercised during the first 20 years of the pipeline operation.

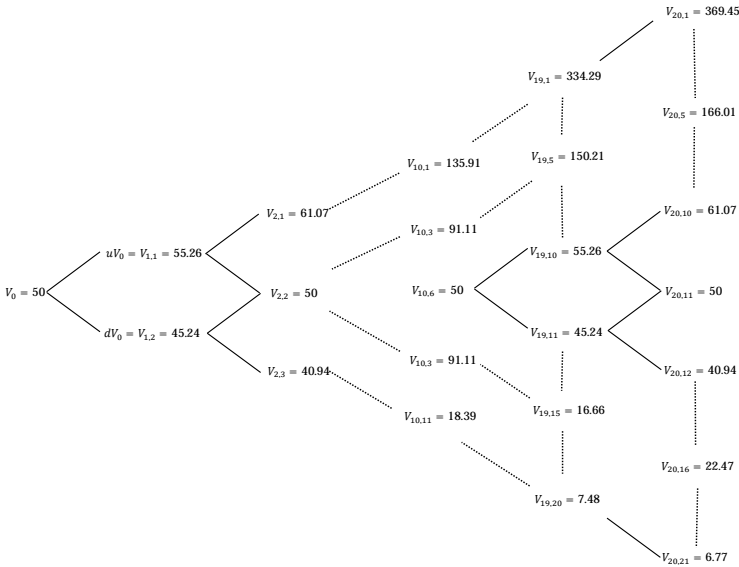


Figure 1 Event tree: value of the underlying asset

Assuming volatility equal to 10% a year ($u = e^{\sigma\sqrt{t}} = 1.105$, $d = 1/u = 0.905$), an event tree representing the dynamics of the project value over the 20 year period (21 different outcomes) is generated (see Figure 1).

For an additional 5 billion NOK, the initial pipeline dimension can be increased to 42". It gives the option to expand the gas production by 50%, if rate of exploration success is high and market conditions are favorable. This option can be exercised for 25 billion NOK investment in the pipeline and processing facilities upgrading and associated fields development. The decision tree (see Figure 2) is solved backwards to find the value of the project with flexibility.

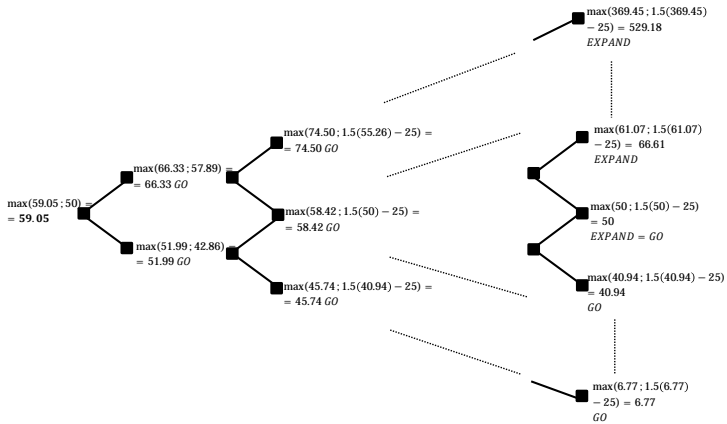


Figure 2 Decision tree for the option to expand

The calculated risk-neutral probability is

$$p = \frac{e^{rt} - d}{u - d} = 0.575.$$

The value of the flexibility provided by the excess pipeline capacity is the difference between the initially estimated NPV and the value of the project obtained after solving the decision tree. In the example, the value of the flexibility provided by pre-investment of 5 billion NOK is 9.05 billion NOK, meaning that the investments in excess pipeline capacity are reasonable.

The value of flexibility gets higher if the volatility increases. In the example, with σ equal to 0.2, the value of flexibility is 12.85 billion NOK. The size of a potential expansion also positively affects the value of flexibility: it increases up to 13.61 billion NOK, if the project can be scaled up to 60%. With a higher exercise price, the expansion gets less attractive and the value of

flexibility reduces: cost of expansion of 30 billion, gives the value of flexibility equal to 6.77 billion NOK.

5 Value of Flexibility in Project Appraisal

There is a growing number of studies showing the importance of the use of ROA in the public decision-making. Livermore (2013) discusses the issue of the real options theory use for public decision-making in petroleum industry. He argues that consideration of real options is necessary to maximize economic returns from non-renewable natural resource extraction, using the example of offshore oil drilling in the USA as a case study. The author claims that the cost-benefit analysis of economic consequences of leasing of offshore lands performed by the responsible authority and the existing bidding system fail to account for real option value, therefore, failing to maximize the net benefits generated by this public resource. He states: "Ultimately, planning and leasing decisions are being made without estimations of option value, and private market actors do not have incentives to adequately consider several of the central uncertainties that are relevant to society in general (Livermore, 2013, p.637)".

The flexibility provided by excess pipeline capacity has a high value for the NCS in the long run and, hence, for the Norwegian society. The private companies do not have incentives to consider such long-term development in their project appraisal. Consideration of the prospects for the further development of the transportation network is the task of the independent system operator and public authorities, which approve the infrastructure development plans. While the project economic perspective comprises

only the costs and revenues that occur to the parties directly involved in the project: the producer from the existing fields (or shippers) and investors (which are often the same companies); a public decision-maker should also consider the effects on shippers and owners of the existing infrastructure. These differences between the project-economic perspective and the perspective of the NCS is demonstrated on the simulated example that follows. The example considered in Table 1 represents a case similar to the Barents Sea Infrastructure Project: there is an LNG facility of a capacity exactly needed to transport the gas from the existing discoveries (there is no economy of scale in investments, hence, no reason for pre-investments), and a pipeline solution with a capacity 50% higher with regard to possible future tie-ins. At the initial stage of the analysis, only the existing fields and discoveries are included, giving the expected revenue from selling the pipeline gas 70 billion NOK (9 NOK is approximately 1 €), excluding the production costs. The expected revenue for the LNG alternative is 5% higher due to the destination flexibility (the option premium). The LNG solution requires 14 billion NOK of initial investments (CAPEX), the costs of the sea shipping counts for additions 14 billion NOK (OPEX). The pipeline solution requires a higher initial investments, 25 billion NOK. The tariffs in the new facility and in the downstream network include the capital element and the operating cost (the Tariff Regulations, 2002). The operating element is calculated annually, and covers the operating cost of running a facility. The capital element should cover the investment cost with a 'reasonable' return on the capital invested during the lifetime of a license (historically, 7% before tax). The capital element represents the revenue for the investors/owners of the infrastructure. The total tariff paid by the shippers for the transportation in

the new pipeline is 27 billion NOK (25 billion as the capital element and 2 billion as the operating element). The shipper will as well use the existing network downstream, the total tariff paid is 4 billion NOK. Comparing the NPV (7% discount rate) of the alternatives from the project-economic perspective, the LNG solution is better: 45.5 billion NOK vs. 39 billion NOK.

Expanding the evaluation framework, the planner should include the effects on the rest of the transportation network. The inflow of gas from the new pipeline into the existing downstream network brings additional income to its owners (the capital element of the tariff paid by shippers, 3 billion NOK) and reduces operating element of the tariff for the shippers (1 billion NOK of savings). The prospects for future tie-ins are included in the analysis as option value of flexibility provided by excess capacity (9 billion NOK). From the perspective of the Shelf, the NPV of the pipeline solution is higher than of the LNG solution: 45.5 billion NOK vs. 52 billion NOK.

Table 1 Example of a project valuation with simulated numbers (Million NOK, 7% discount rate)

Cash Flows	LNG solution	Pipeline solution
Shippers in the new infrastructure		
Revenue (excl. production costs)	70000	70000
Value of destination flexibility	3500	0
Tariff in the new infrastructure	0	- 27000

Cash Flows	LNG solution	Pipeline solution
Tariff in the downstream network	0	- 4000
Cost of shipping	- 14000	0
Investors in the new infrastructure		
Investment costs	- 14000	- 25000
Tariff revenue	0	25000
TOTAL FOR THE PROJECT	45500	39000
Shippers in the existing infrastructure		
	0	1000
Owners of the existing infrastructure		
	0	3000
Option value of flexibility	0	9000
TOTAL FOR THE SHELF	45500	52000

Though this aspect is not covered in this paper, it should be noted that infrastructure projects in the gas sector may have significant externalities, such as environmental impacts, impacts on fisheries and shipping, which should be as well taken into consideration in the socioeconomic evaluations of a project (for a relevant discussion, see e.g. Shaton, 2015).

This example shows that the evaluations of a project from the project-economic and NCS perspective may lead to opposite decisions. The participation of the independent system operator in the infrastructure planning on the NCS ensures that the effects on the existing network are taken into account, however, the value of flexibility in the pipeline investments has not been directly quantified and included in the analyses so far. The presented example shows that this value can be estimated and used in the project appraisal.

6 Conclusion

Real options theory is a means to structure and value flexible strategies to address uncertainty. Real options is particularly appealing concept when capital intensive investments must be undertaken under great uncertainty. In the case of gas transport infrastructure projects, multi-billion investment decisions should be made under the uncertainty over gas prices and highly inexact knowledge of the long-term resource base. Infrastructure developments on the NCS are financed by petroleum companies, which need transport solutions for their gas fields. However, the development of the transportation network is coordinated by an independent system operator, in order to ensure that effects of the new infrastructure development on the existing transportation system and overall value creation on the Shelf are taken into account. According to its architect role, the system operator can give recommendations regarding the landing points, connections, and the capacity of pipelines. Investments in excess pipeline capacity gives possibilities for efficient connections in the future. When an LNG and a pipeline

solutions are considered, there arises a trade-off between the destination flexibility of LNG and strategic flexibility provided by excess pipeline capacity. The destination flexibility of LNG can be easily included in the project evaluation as a price premium for the unit of sold gas. The task of estimation of the monetary value of flexibility provided by excess capacity is not straightforward. This paper discusses how the real options analysis can be applied to estimate the value of flexibility in gas pipeline investments, and how this value can be used in the project evaluations by the system operator.

The infrastructure development decisions taken so far on the shelf of Norway prove to be very efficient. However, the decision system in the sector still has a room for improvement. In the study of possible infrastructure solutions in the Barents Sea, the system operator Gassco states the following: "Identification of possible measures to bridge the gap between socio-economic and project economic perspectives should be a focus area in near-term" (Gassco, 2014, p.36). Real options analysis applied to the valuations of the flexibility provided by excess capacity can be one of the analytical tools to bridge the gap between the two evaluation perspectives. The main implication of such valuations is a more robust and transparent analytical platform for the decision-making in the gas transport infrastructure development.

The approach presented in this paper can be extended to incorporate multiple options. In the preformed calculations, only the option to expand the system up to the full capacity of the pipeline in question is considered. While in practice, there are possibilities to expand the system step-wise by

new tie-ins of different size. It can be modelled as a compound option, using the proposed framework.

The consideration of the investments in excess pipeline capacity through the lenses of the ROA has some limitations, as it cannot incorporate such effects as increased value creation onshore due to expansion of petroleum activities. However, the real option value can serve as a good proxy of the value of the excess pipeline capacity and play an important role in project evaluations.

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