Modelling offshore oil and gas decommissioning decision under oil price uncertainty and financial security obligations: a case study of the UKCS

Arturo Regalado[1], National Decommissioning Centre[2], University of Aberdeen, j.regaladoruizdechavez.20@abdn.ac.uk
Prof. Alex Kemp, University of Aberdeen, a.g.kemp@abdn.ac.uk
Dr. Yakubu Abdul-Salam, University of Aberdeen, y.abdul-salam@abdn.ac.uk
Dr. Alisdair MacPherson, University of Aberdeen, alisdair.macpherson@abdn.ac.uk

1. Overview

Decommissioning of offshore oil and gas installations is becoming a central issue for the upstream industry in mature hydrocarbon basins such as the United Kingdom Continental Shelf (UKCS). The decision to begin decommissioning activity is determined by several economic and regulatory factors. One important challenge is the substantial amount of financial resources required. The annual average decommissioning expenditure in the UKCS is expected to be between £1.5 and £2 billion pounds during the next decade (OGUK, 2020). The Oil & Gas Authority (OGA) estimates that the cost to decommission the full inventory of offshore installations could amount to £51 billion (OGA, 2020).

In the United Kingdom (UK), the Petroleum Act 1998, as amended by the Energy Act 2008, introduced provisions to account for financial security of decommissioning liability (BEIS, 2018). Section 29 gives powers to the Secretary of State for Business, Energy, and Industrial Strategy (BEIS) to hold all relevant parties liable for the decommissioning of installations, and Section 36 sets out the duty to carry out the approved abandonment program. Moreover, the Government can require licensees to provide decommissioning security to prevent taxpayers from funding decommissioning liabilities and funds set aside for the purposes of decommissioning are protected in the event of the security provider's insolvency (s 38A).[3] UK legislation expressly accepts the following financial instruments to procure security[4]: a charge over an asset, a cash deposit, a performance bond or guarantee, an insurance policy, and a letter of credit.[5] It should also be noted that trust funds are clearly included as a valid form of security, as the legislative provision states that security may have been provided by way of trust or by another arrangement (s 38A(1)).[6]

Given the number of available financial instruments, one important issue is to determine what economic effects they have on decommissioning decisions. The additional cost of security creates distortions in late-life decision-making. Licensees will choose to cease production and begin decommissioning if revenues are not enough to cover operating costs plus security. Despite its importance, the economic impact of financial security instruments on decommissioning decisions in the UKCS has not received enough attention in the literature. To our knowledge, only Kemp & Stephen (2006) present a comprehensive empirical study that explores the distortions in decommissioning decision making and the direct costs to operators and the Government from different financial security instruments. However, the results were based upon price scenarios and a regulatory environment that do not reflect today's market conditions.

A second challenge affecting the decommissioning decision is oil price uncertainty. The price collapse of 2014-2016 led operators in the UKCS to pay more attention to their levels of decommissioning security and how it is calculated (Holland & Davar, 2016). Notably, the Covid-19 pandemic has put further pressure on operators' cash flows in 2020 and 2021. The likely result is that the share of decommissioning costs will increase with respect to total costs and the industry will delay abandonment as much as possible (Kemp & Stephen, 2020).

[1] Corresponding author.
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[3] See also ss 38 and 38B for related powers held by the Secretary of State.
[4] In the remainder of the paper we use the terms "financial instruments", "security agreement", and "instruments" interchangeably to refer to the instruments to procure financial security for decommissioning (including trust funds).
[5] This is, however, a non-exhaustive list as the term "security" only "includes" these instruments – see Petroleum Act 1998, s 38A(4).
[6] See also the references to trust in s 38A(5) and (6).

Studies of the time series properties of oil price have found that it is best modelled as a stochastic process (Dixit & Pindyck, 1994), although there is no clear consensus as to the best process to use. Hamilton (2009) determines that the real price of oil follows a random walk. On the other hand, Pindyck (1999) finds evidence of mean-reversion in real oil prices. Dixit and Pindyck (1994, p. 78) suggest that geometric Brownian motion is a suitable modelling approach because mean-reversion requires several data points to be statistically confirmed. Despite the controversy, recent studies (Dvir & Rogoff, 2009; Kruse & Wegener, 2020; Rubaszek, 2020) assume mean reversion as the underpinning process and apply it to their models. The literature also considers jump-diffusion models that allow for infrequent but discrete jumps in oil price behaviour, for example, a sudden demand drop like the one from the Covid-19 pandemic or supply-side shocks like the Gulf War of 1991. For evidence of such jump dynamics, see Lee et al. (2010) and Gronwald (2012).

In this paper, we study the effect that oil price uncertainty and financial security instruments have on the decision to decommission. To account for the effect of oil price volatility, we compare uncertainty introduced from three processes: 1) Random Walk with Drift, 2) Geometric Brownian Motion, and 3) Mean Reversion Ohrnstein-Uhlenbeck process. We do not include jump dynamics in the listed models. The reason is that we focus on the differences between processes, not within them. For example, modelling mean reversion with jump will most likely add uncertainty (Al-Harthy, 2007) to the mean reversion process. However, it does not reveal the comparative effect against the Random Walk with Drift or Geometric Brownian Motion.

We study the effect of two financial instruments: the Letter of Credit (LoC) and the Trust Fund. The first is commonly used in the UKCS (Aldersey-Williams, 2018; Kemp & Stephen, 2006; OGUK, 2015). The LoC is part of a category of instruments that requires the licensee to pay a fee to the security issuer in addition to covering decommissioning costs; surety bonds and insurance policy fall in this category. The Trust Fund represents instruments with the underlying mechanism of making advance payments for decommissioning; cash deposits fall into this category. In a Trust Fund, the licensee makes contributions such that the monies deposited plus any interest earned by the Fund accrue to meet decommissioning costs once they take place.

The study contributes to the literature in two important ways. First, we identify the degree of uncertainty introduced by different stochastic processes to model oil price behaviour and how it affects the decision to cease production and decommission. Second, we provide empirical evidence of the effect of financial security instruments on decommissioning decisions in the UKCS.

2. Methods

2.1 Modelling oil price uncertainty

The study was undertaken in two stages. First, we use three stochastic processes to model oil price uncertainty: Random Walk with Drift (RWD), Geometric Brownian Motion (GBM), and a Mean Reversion Ohrnstein-Uhlenbeck process (MR). We then simulate price paths that are incorporated in a Discounted Cash Flow model through revenues. We do not consider jump dynamics because we focus on the differences between processes and not within them.

The RWD is a simple but important model in time series analysis. The model assumes that in each period the variable under study takes a random step away from its past value. If the distribution of random steps has a non-zero mean, we say that the model has a drift. The RWD is a good benchmark because of its simplicity (Rubaszek, 2020). However, there is no theory behind the RWD process that explains the behaviour of oil price. The model can be mathematically expressed as:

$$P_t = \mu + P_{t-1} + \epsilon_t \text{ with } \epsilon_t \sim N(0, \sigma) \tag{1}$$

where:

P is current oil price;
t is the time period;
μ is the drift parameter;
ϵ is a random disturbance;
σ is volatility;
and μ and σ need to be estimated.

The GBM model has been mainly used to model securities, prices, and other economic variables (Dixit & Pindyck, 1994). The Black-Scholes formula for real option valuation is perhaps the most famous example. While appealing and commonly used, it has the issue that the simulated price path tends to drift far away from its starting point; not the case of oil price. The following equation describes the process (Brigo et al., 2011):

$$dP = \mu P dt + \sigma P dW(t) \tag{2}$$

where:

P is oil price;
dt is the change in time;
μ is the drift parameter;
σ is volatility;
$dW(t) = \epsilon\sqrt{dt}$ is a Bronwnian motion $\sim N(0,1)$;
and μ and σ need to be estimated.

As opposed to RWD and GBM, the Mean Reversion model is theoretically suited for oil price behaviour (Pindyck, 1999; Rubaszek, 2020). In a MR process the variable modelled is anchored to a long-term average. The general idea is that even if in the short run crises and shocks affect oil price, in the long run they are drawn back towards equilibrium. This stochastic process is modelled as:

$$dP = \alpha(\bar{P} - P)dt + \sigma P dW_t \tag{3}$$

where:

α is the speed of mean reversion;
$\bar{P}$ is the long-term oil price equilibrium;
σ is volatility;
$\alpha, \bar{P}$ and σ are to be estimated;
and the other variables are defined as in the GBM.

To calibrate the parameters required for the three processes, we use annual Brent spot price data from 1987 to 2020 available from the U.S. Energy Information Administration. We choose annual years because in practice decommissioning decisions are taken based on long-term market conditions, not short-term volatility. Estimation and calibration procedures for the three processes have been discussed extensively in the literature (see Al-Harthy, 2007; Brigo et al., 2011; Dixit & Pindyck, 1994; Ogbogbo, 2018). Table 1 presents the estimates for the parameters.

Table 1. Estimated parameters for the stochastic processes

Parameter	**Value**
μ – drift parameter	1.1%
σ – volatility	7.2%
$\alpha -$ reversion speed	0.1156
$\bar{P} -$ long-term price	\$58.81 per bbl

We now turn to show how oil price uncertainty is incorporated into the estimation of revenues. Revenues are defined as oil price multiplied by quantity produced. We use Monte Carlo methods to simulate 10,000 oil price paths for each process over a 30-year forecast. If we we defined each simulated oil price path as $\hat{P}_{it}^{m}$ where model $m: \{RWD, GBM, MR\}$, simulation $i: \{1,2,3 \ldots 10,000\}$ and time period $t: \{0,1,2 \ldots 30\}$ we can compute the revenues with uncertainty as:

$$\hat{R}_{it}^{m} = \hat{P}_{it}^{m} * Q_t \tag{4}$$

where:

$\hat{R}_{it}^{m}$ is the simulated revenue with uncertainty for model m at time t with simulation i;
$\hat{P}_{it}^{m}$ is the simulated price for model m at time t with simulation i;
Q_t is the total number of oil barrels produced at time t.

2.2 Discounted cash flow model and financial instruments

2.2.1 Assumptions

The second stage consists in building a Discounted Cash Flow model (DCF) that incorporates oil price uncertainty through the simulated revenues from Equation 4 and the cost of financial security obligations. Five oil fields designed to be representative of UKCS assets of recent vintage are assessed. Tables 2 and 3 show the cost and size assumptions used for each field. The information considers cost estimates from different reports by the UK Oil and Gas Authority (OGA, 2019a, 2019b, 2020) and reflects economies of scale.

Production profiles for the five oil fields were also designed to exhibit typical behaviour of UKCS assets of recent vintage. During the initial years production increases until it hits a plateau and then decline begins. Smaller fields show faster decline rates while larger fields will have slower decline rates. We assume that Fields 1-5 have the following decline rates respectively: 32%, 28%, 25%, 20%, and 18%. It is important to highlight that decline rates have an impact on decommissioning decisions. However, we assume fixed decline rates as the focus of the study is on oil price uncertainty and financial security instruments. More research is needed to fully understand the impact of decline rates.

Table 2. Model fields cost assumptions

Variable	**Units**	**Field 1**	**Field 2**	**Field 3**	**Field 4**	**Field 5**
Recoverable reserves	Million barrels (MMbbl)	10	25	50	100	150
Development costs (DEVEX)	USD/bbl	19	16	13	10	7
Annual Operating costs (OPEX)	% of DEVEX	8.75	8.25	7.75	7.25	6.75
Decommissioning costs (DECOMX)	% of DEVEX	10	10	10	10	10
No. of years to complete decommissioning	Years	1	1	1	3	4

Table 3. DEVEX schedule for representative fields

Project year	**Field 1**	**Field 2**	**Field 3**	**Field 4**	**Field 5**
0	50	30	30	20	20
1	50	30	30	30	20
2		40	40	30	20
3				20	30
4					10

Our DCF model incorporates the UK oil and gas tax regime. There are two main elements to the regime: Ring Fence Corporation Tax (RFCT) at a 30% rate and the Supplementary Charge (SC) at a 10% rate. An additional element is the Investment Allowance (IA) which reduces the profits subject to the Supplementary Charge; the amount is a percentage of investment expenditures. With regards to decommissioning, the Government published in 2013 the Decommissioning Relief Deed (DRD) which is a contract between companies and the UK Government that provides certainty on the tax relief that will be obtained when oil and gas assets are decommissioned. Decommissioning costs are allowed as deductions for RFCT, SC, and IA which are available on a 100% first-year basis. The tax rules give way to two general situations: (1) the case where other income is available for which tax refunds can be made immediately; and (2) the case where operators have no other income that can be set against taxes immediately. Because it is not the paper's focus to investigate the comparative merits of tax arrangements in the UKCS, we consider the simple case where the licensee has other sources of income to claim against RFCT and SC. For a more detailed discussion of the UK oil and gas tax regime see Kemp and Stephen (2016). Table 4 sets out the assumed values for the various market and tax regime variables. All assumptions are in money of the day terms.

Table 4. Assumptions for market indicators and tax regime

Variable	Value	Units
Brent oil price	50	USD/bbl
Consumer price index	2	%
Discount rate	10	%
Service producer index	1.7	%
Ring Fence Corporation Tax	30	%
Supplementary Charge	10	%
Investment Allowance	62.5	%

2.2.2 Discounted Cash Flow model

Using the assumptions defined in the preceding Tables, we calculate the post-tax net cash flow (Post-Tax NCF) with oil price uncertainty using the following formula:

$$Post\_\widehat{Tax}\_NCF_t = \hat{R}_{it}^{m} - OPEX_t - DEVEX_t - DECOMX_t - Tax\ paid \quad (5)$$

where:

$\{t \mid t \in Z, t < T\}$;
T is the total lifetime of the project in years;
and Z is the set of integers;

Note that post-tax NCF incorporates uncertainty because we use the simulated revenues from Equation 4. A deterministic case was also considered to compare against the case with uncertainty.

Next, we compute the Cessation of Production (CoP) date. CoP is the relevant metric for the study as it is a proxy variable for the decision to begin decommissioning. We assume that the licensee will choose to end production once operating costs are higher than gross revenues, i.e. the licensee faces an operating loss (Kemp and Stephen, 2006). Another important assumption is that decommissioning takes place on the year immediately following the CoP date. We define CoP date without security using the following Equation that incorporates uncertainty of oil price by using the simulated revenues from Section 2.1:

$$CoP_{ns} = t_{copns} \text{ and it is year } t \text{ where } \hat{R}_{it}^{m} \le OPEX_t \quad (6)$$

where:

CoP_{ns} is the CoP date without financial security;
t_{copns} is the year when CoP without security takes place.

We now include financial obligations in the DCF model. Security cost needs to be accounted for by operators in their project appraisal models because neglecting them provides misleading information and affects decision making. The additional costs create distortions that operators need to be aware of. Consequently, Formula 5 should be adjusted as follows where calculations for security cost will vary depending on the instrument used.

$$Post\_\widehat{Tax}\_NCF_t = \hat{R}_{it}^m - OPEX_t - DEVEX_t - DECOMX_t - Security\ Cost_t - Tax\ paid_t \qquad (7)$$

CoP without security should also be adjusted to incorporate the additional costs from security instruments. Cessation of production will occur once revenues are smaller than OPEX plus security costs. We define CoP with security as:

$$CoP_s = t_{cops} \text{ and it is year } t \text{ where } \hat{R}_{it}^m \leq OPEX_t + Security\ Cost_t \qquad (8)$$

where:

CoP_s is the CoP date with financial security;
t_{cops} is the year when CoP with security takes place.

The effect of security instruments on the decision to decommission is implied from the difference between both types of CoP dates:

$$Financial\ Instruments\ Effect\ on\ CoP = \begin{cases} CoP_s - CoP_{ns} > 0, CoP\ is\ delayed \\ CoP_s - CoP_{ns} = 0, CoP\ is\ unchanged \\ CoP_s - CoP_{ns} < 0, CoP\ is\ accelerated \end{cases} \qquad (9)$$

The next variable that needs to be computed is the cost of financial security. In principle, security can be required by the regulator anytime during the project. It is common, however, to assume a *security trigger date* when the remaining net present value of the field (RNPV) is less than or equal to the present value of the decommissioning cost multiplied by a contingency factor (Aldersey-Williams, 2018; Kemp & Stephen, 2006). The contingency factor is used to incorporate inherent risk in decommissioning cost estimates. In the UK it has traditionally been set at 150%. Security needs to be paid in all years after the trigger date (inclusive) and until the regulator deems that the decommissioning liability has been met. Mathematically:

$$Security\ trigger\ date = t_{sec} \Rightarrow \left\{ t \mid RNPV_t \leq PV\left(\sum_{t=t}^{T} DECOMX_t\right) * \alpha \right\} \qquad (10)$$

where:

α is the contingency factor;
security is paid for all $t \geq t_{sec}$;

The timing of the contributions is not a trivial assumption. Take the case of a Trust Fund. If contributions begin at the outset of the project, it would be expected that there is less pressure on cash flow by late life. If, on the other hand, contributions begin until the project has achieved late-life status, the pressure on cash flow will increase. Consequently, our results are underpinned to the 150% contingency factor assumption and might change if the timing of contributions is modified. This is an issue worth studying in more detail.

The *security cost* term in Equation 7 is calculated in different ways depending on the instrument chosen and its mechanics. In this study we consider the Letter of Credit and the Trust Fund. The instruments are conceptually different. The LoC is an additional expenditure to decommissioning, while contributions to a Trust Fund are advance payment. In a LoC the issuer charges a fee on the present value of the decommissioning costs times the contingency factor; the fee is renewed annually. Because the LoC affects the borrowing capacity of the operator, the company's cost of capital increases during the years paying security. Equation 11 shows the calculations for the LoC cost.

$$LoC\ cost_t = PV\left(\sum_{t=t_{sec}}^{T} DECOMMX_t\right) * \alpha * LoC\ fee \qquad (11)$$

For the Trust Fund, we assume that the operator makes contributions such that the monies deposited plus any interest earned by the Fund accrue to meet the decommissioning costs after CoP takes place. Deposits to the Fund begin with the security trigger date and the monies are withdrawn to pay for decommissioning once the activity begins.

In practice the accrued monies in the Fund may not exactly equal the decommissioning costs, in such cases additional payments or refund might be required. The following procedure is used to calculate the annual contribution to the Trust Fund:

1) Add interest earned by the Trust Fund for the current year. At the security trigger date the interest earned is zero.
2) Add the existing amount in the Trust Fund. At the security trigger date the existing amount is zero.
3) Divide the remaining total decommissioning costs between the remaining number of years paying security. The remaining costs are the total decommissioning costs minus the existing monies in the Fund.
4) Add the amounts in steps 1 through 3.
5) Repeat until CoP is reached and the Fund meets the decommissioning costs.

Current tax rules in the UKCS do not permit Trust Fund contributions to be tax-deductible and interest earned is subject to taxes. The Government's argument against deduction is that tax relief for decommissioning is only given once decommissioning expenditures take place. However, because of the time value of money, this means that tax relief from later periods might not cover for earlier contributions. These rules make the Trust Fund a less attractive instrument because of the direct and indirect costs involved. With respect to the LoC scheme, the investor gets tax relief for the fee paid to the bank and for the decommissioning expenditures when they are incurred. Table 5 presents the assumptions used for the variables relevant to the financial security calculations.

Table 5. Assumptions for financial security instruments

Variable	Value	Units
Security Trigger threshold	150	%
LoC Fee	3	%
LoC Interest Rate	1	%
Trust Fund Interest	5	%

The final step is to pool the simulated CoP dates computed from Equations 6 and 8 by stochastic process and security agreement. Then we calculate the standard deviation of the pooled values as a measure of uncertainty incorporated into the CoP date. A small value of the standard deviation reflects less uncertainty associated with the economic metric as opposed to a large value. The standard deviation is appealing because it allows for comparisons between the different financial security instruments and stochastic processes.

3. Results

3.1 Effects of oil price uncertainty on the decision to decommission

We now consider how oil price uncertainty affects the decision to cease production; a proxy variable for the decision to begin decommissioning. Table 6 presents the standard deviation of CoP by field and uncertainty model. MR has the largest associated uncertainty. For the 10, 25, and 50 MMbbl fields, the average change on CoP is one year; for the 100 and 150 MMbbl ones it is a two-year period. One possible explanation is that RWD and GBM have increasing average oil prices, while mean reversion reflects a dynamic price behaviour around a constant long-term average.

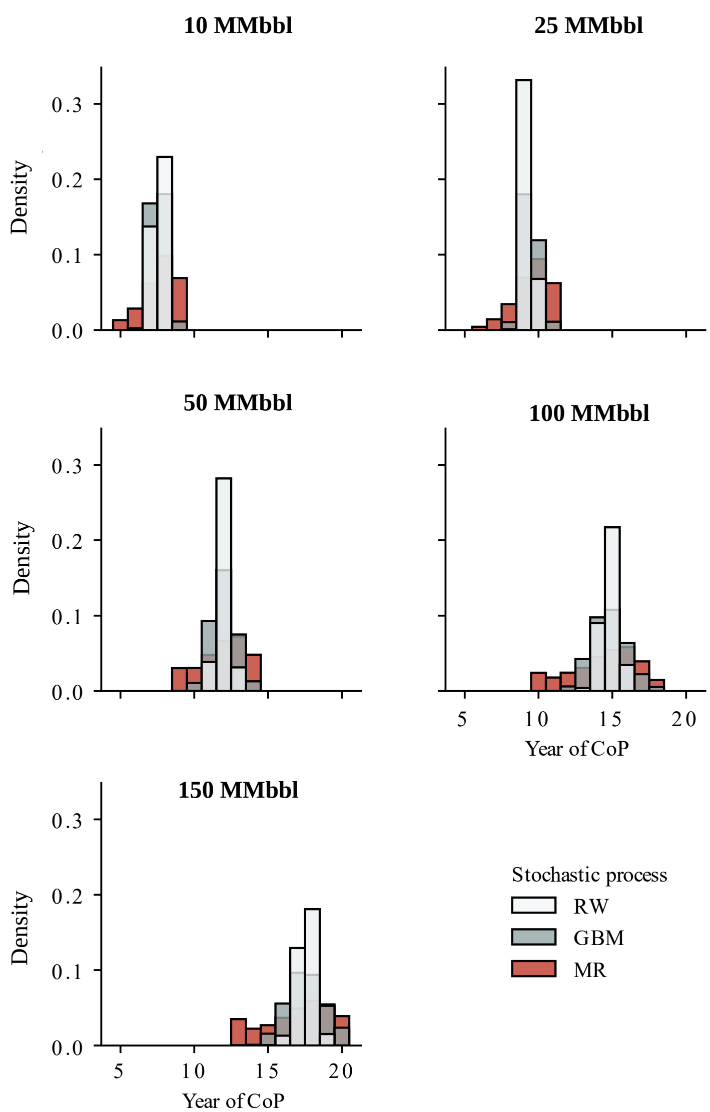
Table 6. Standard deviation of CoP date by stochastic process and Field

Stochastic process	10 MMbbl	25 MMbbl	50 MMbbl	100 MMbbl	150MMbbl
RWD	0.4839	0.3799	0.4471	0.6109	0.6443
GBM	0.5683	0.6134	0.8643	1.2147	1.2750
MR	1.1098	1.1984	1.5433	2.2111	2.1796

To further understand the distribution of CoP dates by uncertainty model we show histograms for all five Fields in Figure 1. The plot clearly shows that the distribution of CoP dates from MR has fatter tails and yields a higher range of possible values compared to RWD and GBM. Two features stand out from the results. First, they show that oil price uncertainty does affect the CoP date. An operator that only uses deterministic assumptions will miss all the possible values that the CoP can take and will incorrectly decide on the optimal decommissioning timing. Uncertainty in oil price brings about a wide range of values for the decision to cease production. Second, and perhaps more important, it underscores how difficult it is to predict the CoP date.

This point is relevant for the Government, supply chain companies, and operators. The Government may approach a company and require them to present decommissioning plans believing there is enough time before the field needs to cease production. However, oil price uncertainty may accelerate CoP date leaving the licensee and Government without the possibility to comfortably prepare for decommissioning. For supply chain companies, uncertainty in CoP makes it difficult to plan and procure the necessary equipment and manpower to conclude contracts and undertake decommissioning work. The shortage of supply chain resources will impact the cost to the operator as post-CoP running costs will need to be paid for longer periods and higher fees will be needed to secure decommissioning equipment.

Figure 1. Distribution of CoP date by stochastic process and field size



3.2 Effects of financial instruments on the decision to decommission

The instruments used to procure financial security for decommissioning liability are expected to affect the decision to decommission. It is informative to analyse the deterministic effect of the financial instruments on the Cessation of Production date before moving to the results with uncertainty. Table 7 shows the effect of the LoC and Trust Fund on CoP date by Field using a deterministic model. The calculation is derived from Equation 9. The most interesting aspect is that the Trust Fund accelerates CoP by one year compared to the CoP without security no matter the field size. On the other hand, the LoC only accelerates CoP for the smallest field.

Table 7. Average effect of financial security instrument on CoP

Instrument	10 MMbbl	25 MMbbl	50 MMbbl	100 MMbbl	150 MMbbl
Letter of Credit	-1	0	0	0	0
Trust Fund	-1	-1	-1	-1	-1

Note: negative values imply CoP acceleration following Equation 9.

The results suggest that the LoC is an instrument that mostly affects small developments. It is worth recalling that in addition to the instrument fee, the loss in borrowing capacity increases the cost of capital of the operator. This might cause a stronger impact on small companies as their borrowing capacity will be limited. Another important highlight is the fact that the Trust Fund accelerates CoP by one year for any project size. A possible explanation for the impact of the Trust Fund in all project sizes is that advance payments for decommissioning that are not tax-deductible carry higher direct costs but also opportunity costs. For example, it is likely that in stringent financial conditions operators will prefer to use the cash to pay debt, meet the payroll or undertake exploration projects instead of paying decommissioning costs or financial security. However, taken together the results do suggest that small developments are at greater risk of having distortions to their decision making because of financial security issues; the CoP decision is affected no matter the instrument chosen.

These findings should be taken with caution because of the assumed timing for the beginning of security payments. If Trust Fund contributions begin earlier in the project's lifetime, the effect will not be so stark. Earlier contributions lead to smaller amounts in the late-life of the field. Further research on the timing of contributions is required to fully understand the magnitude of this effect.

The results are also relevant for the Government. The effect of requiring security instruments is to bring forward the CoP date. If the Government does not act accordingly by accelerating the request for decommissioning plans and engage earlier with licensees, there is an increased risk that resources are not enough to pay for decommissioning activity. On the other hand, the Government should be aware that small projects are at greater risk of distortions in decision making because of financial security. Early engagement with the small projects might be needed to ensure security costs affect the project as little as possible.

While the above results are interesting, the deterministic model lacks robustness in that assumptions are seldom 100% accurate. In reality there is uncertainty in the various assumptions used in the model. The next Section deals with this issue by introducing the effect of oil price uncertainty.

3.3 Combined effects of oil price uncertainty and financial instruments on cessation of production

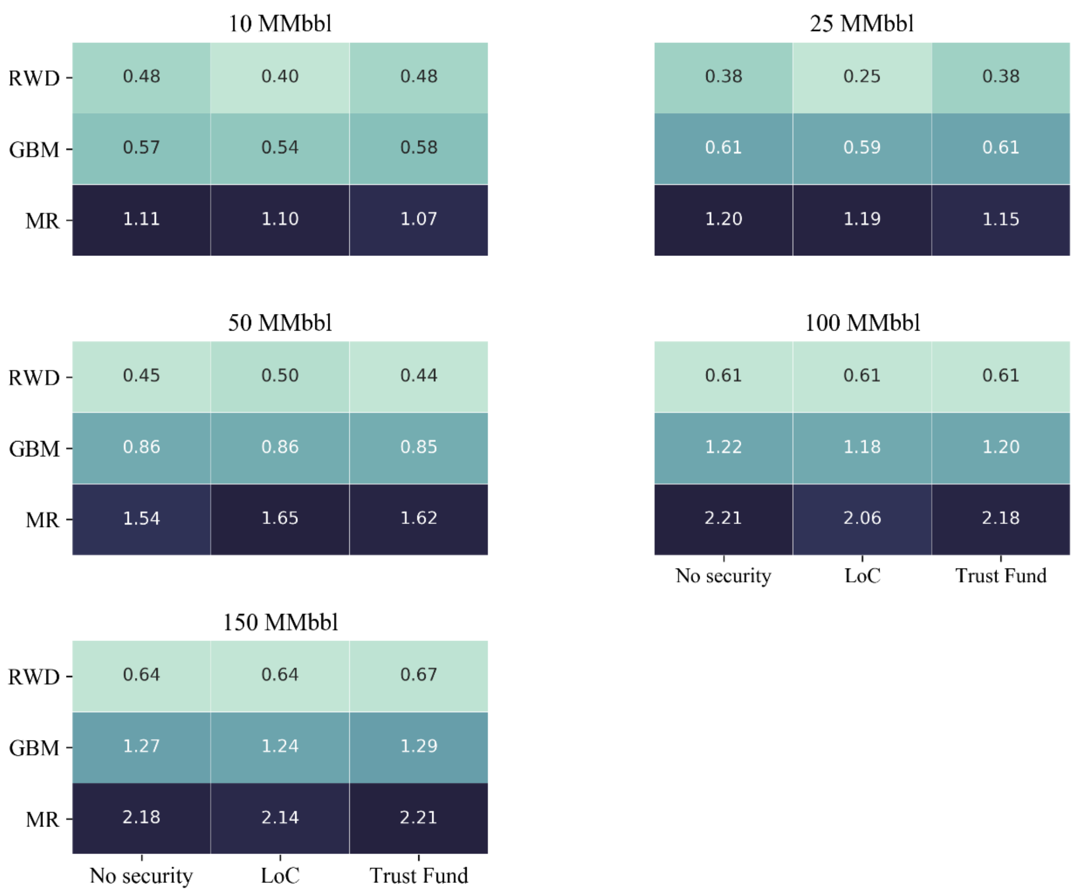
The main objective of this study is to understand the effects that oil price uncertainty and instruments to procure financial security for decommissioning have on the decision to cease production and decommission. Sections 3.1 and 3.2 dealt with the isolated impact; in this section we focus on the combined effect.

Figure 2 shows the standard deviation of CoP date for each field size by uncertainty model and security instrument. Reading from top to bottom in each matrix we can see the effect of each model by security agreement. The mean reversion model introduces a higher degree of uncertainty to the CoP date. This is true for all fields and independent of whether security is procured, and if a LoC or a Trust Fund is used. On the other hand, we can measure uncertainty introduced by security agreement holding oil price model constant by reading across rows of the matrix.

The difference in standard deviation appears to not be as significant as is the case when making comparisons between stochastic processes.

It is not easy to identify the effect of security instruments on the decision to decommission while accounting for uncertainty in oil price looking at the above results. To this end, we present in Figure 3 the average change in CoP compared to the deterministic value for each field size by the oil price model and security agreement. The Figure is revealing in several ways. First, the Trust Fund will most likely accelerate CoP (read across rows of each matrix). Notably, for the largest field, the CoP date is brought forward by two years on average. Second, the model used for oil price uncertainty appears to impact the decision to decommission in the 10, 100 and 150 MMbbl fields. Only the 25 and 50 MMbbl fields do not exhibit changes to CoP between oil price model (read by column). Third, financial security impact on CoP is stronger in certain fields. For example, using a Letter of Credit accelerates CoP by one year in Fields 1, 4 and 5, but shows no impact in Fields 2 and 3.

Figure 2. Uncertainty in CoP date introduced by stochastic process and financial security instrument



Note: Standard deviation of CoP date shown in each cell. Higher values imply higher uncertainty.

What is interesting about the results in Figure 3 is that the size of the field appears to determine the sensitivity of the CoP date to oil price uncertainty and the security agreement. This has important implications for the government and operators. For the government it raises the importance of establishing clear guidelines for the security agreements it promotes based on project size. For example, it might urge a company developing a small project to prefer a LoC rather than a Trust Fund so the impact of CoP is mitigated to a certain degree. Authorities might also wish to consider the possibility of allowing tax deductions for Trust Fund contributions so that the instrument does not generate additional distortions compared to the LoC. Notably, Trust Funds entail a higher risk in that the CoP acceleration might affect decommissioning plans and require engagement between government and operators earlier than expected. In small projects, earlier CoP dates might have a negative impact on maximising economic recovery from the field.

Figure 3. Median effect of financial instrument and stochastic process: CoP acceleration or delay

Note: negative values imply CoP acceleration and positive values imply delay. Cell contains time years.

Operators should be aware of how financial security impacts their decision-making relating to cessation of production, especially if they are developing small projects. Acquiring a LoC appears to be a better alternative than the Trust Fund. However, small companies with no credit record might have difficulties accessing instruments like the LoC at a reasonable cost. In these cases, engagement with the government is necessary to highlight al possible effects of using security instruments like the Trust Fund which involve advance payments. If the LoC is the preferred instrument, the operator should be aware that his borrowing capacity will be adversely affected and the cost of capital will increase.

The Trust Fund carries a high-risk position to the Government. Sudden changes in oil price will affect the timing of contributions affecting the capacity of the Fund to meet the decommissioning expenditures. This might lead to coverage problems of the decommissioning costs and the impossibility of the licensee to meet his liabilities. There is also risk associated to the Government's income. If market conditions change and interest rates fall, the government will receive less income tax from the interest made by the monies in the Fund.

Another important finding from the results is the need to incorporate oil price uncertainty in the discounted cash flow models used to appraise oil field development and decommissioning projects. Notably, the results suggest that the mean reversion process incorporates more uncertainty and would be the recommended model to use. This proposition supports the growing consensus that mean reversion better describes oil price dynamics (Rubaszek, 2020). By accounting for uncertainty, operators will make decisions with robust information that does not depend on 100% accuracy of deterministic assumptions.

Given that mean reversion is the preferred method to model oil price uncertainty, it is valuable to understand how each parameter affects the uncertainty of the CoP date. The three parameters from MR are speed of reversion (α), long term price ($\bar{P}$), and volatility (σ). Figure 4 presents sensitivity analysis of a +/- 10% change in the mean reversion parameters. Unsurprisingly, the volatility parameter σ exhibits the highest changes in the standard deviation of CoP (read across rows of the matrix). We can also see the relationship between each parameter and uncertainty. First, as long-term oil price increases, uncertainty decreases. This is expected because higher prices result in less probability

Figure 4. Sensitivity analysis of Mean Reversion parameters on uncertainty in CoP dates

Note: Standard deviation of CoP date shown in each cell. Higher values imply higher uncertainty and are shown in darker colours.

of having to cease production earlier than expected. Second, as volatility increases, uncertainty in the CoP also increases. High oil price volatility leads to a higher probability of having to cease production earlier than expected. Finally, as the speed of mean reversion increases CoP uncertainty decreases. This is expected because the faster the long-term average is realized, there is less uncertainty in oil price.

Concluding remarks

Decommissioning of offshore oil and gas installations is becoming a main feature of the UKCS given its mature hydrocarbon basin status. In this study we analysed how oil price uncertainty and financial security obligations affect the decision to cease production and begin decommissioning. First, we compared three stochastic processes used to model uncertainty in oil prices. The results suggest that the mean reversion process introduces more uncertainty to the cessation of production date and leads to robust decision-making. Second, the results highlight the comparative merits of two instruments used to procure financial security for decommissioning liability: the Letter of Credit and a Trust Fund. We found that small projects are subject to increased uncertainty because of financial security obligations.

We simplified several assumptions in our modelling strategy to focus on the effect of oil price uncertainty and financial security. Consequently, a number of possible avenues exist for future research. First, a more detailed study of the effect of production decline rates is required. Cash flows are sensitive to changes in quantity produced; decline rates will therefore affect the decision to cease production. Second, the UK has an intricate oil and gas tax regime. We assume the simple setting where operators have other sources of income to claim against RFCT, SC, and IA. However, there are other possible settings and relief on decommissioning expenditures might affect the decision to decommissioning. Finally, the results are underpinned by our assumption relating to the timing of financial security payments. If the timing of the contributions is allowed to change, the merits of each instrument might change.

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