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The Option to (Re)develop or Abandon a Mature Declining Oil Field

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Abstract

Towards the end of mature fields' life, the production decline leads to diminishing cash flows. At this stage, the operator faces the crucial decision of continuing, abandoning, or reaching for remaining but harder-to-access reserves. The timing of this decision has economic consequences, particularly with uncertain prices and technical challenges.

The optimal decision of redevelopment or abandonment depends on the level of prices and the chance of success in accessing additional reserves. We use an integrated real options framework through an illustrative example to discuss solutions and sensitivities to this multi-dimensional problem.

Keywords: Mature oil fields, Markov decision process, Mean-reverting process, Value of flexibility.

Introduction

Approximately 70% of the world's oil-producible fields are presently categorised as mature fields, and the number of such fields has been steadily increasing (O'Brien et al., 2016). Mature fields are defined as those that have reached the plateau production phase, the decline phase may have started, and the fields are reaching the end of their economic life. In a field development plan, once the initial number of wells applicable to the field is reached, field redevelopment practices such as infill drilling and re-entries are considered to maximise the project value. Infill drilling has been widely adopted as an industry standard for several decades, primarily due to the non-homogeneous characteristics observed in most reservoirs worldwide. In this research, we address the value of flexibility of infill drilling in mature field development, specifically focusing on underbalanced coiled tubing drilling (UBCTD) as a promising technology for re-entry drilling in depleted mature fields.

When the cash flow of a mature field declines, field operators are confronted with a strategic decision—to either persist with the declining value, embark on the redevelopment of the field, or opt for permanent abandonment. The multifaceted uncertainties, including declining production, geological limitations, and oil price fluctuations, contribute to the complexity of the decision-making process. For a development option to be economically viable, its future value must surpass the associated costs. Oil price fluctuations considerably affect these decisions, particularly for marginal fields.

The challenges associated with accessing remaining reserves in a reservoir evolve as the reservoir matures. Geological factors, including depletion, primarily influence this transformation. Underbalanced coiled tubing drilling UBCTD is a technology that has proven well-suited for depleted reservoirs. Additionally, it offers cost savings by replacing the conventional rig with a small, coiled tubing unit (Doremus & Dowell, 1995). The literature demonstrates the successful implementation of this technology for re-entry drilling in depleted mature fields (Krueger & Pridat, 2016). However, this drilling method carries inherent risks, including the potential for formation collapse, representing a worst-case scenario where the target may not be reached and the well cost is lost.

The literature extensively discusses the technical success of this technology and highlights numerous cases where cost savings compared to conventional drilling are indicated, such as Burke et al., (2014), Iadc et al., (2013), and Krueger & Pridat, (2016). It is noted that CTD yields an average cost savings of 34% compared to conventional rigs (Al-Sharea, 2024). The same reference reveals that Underbalanced drilling enhances productivity with a general average productivity index factor (PIF) of 1.84, falling from 1.07 to 3.16. Additionally, it contributes to additional recovery with an average of 17%, within the range of 3% to 50%. However, the literature has a noticeable gap regarding the optimal timing for its implementation to maximise the project's value. Quantifying the probability of success is another knowledge gap.

The field of real options has endeavoured to deal with similar issues, such as Lund, (2000), Smith, (2005), and Jafarizadeh & Bratvold., (2019) and many more. Recently Bakker et al., (2021) discussed the optimal timing for infill drilling in mature fields compared to ren-try or abandonment. While these studies effectively deal with commodity price uncertainty, they tend to oversimplify the technical options and private uncertainties. They usually rely on expert opinion in assigning probabilities subjected to bias. Conversely, some studies rely on decision models sophisticated enough to be understood and implemented by oil and gas operators. Complexities arising from decisions made at the beginning of a field's lifetime or employing complex computational approaches to problem-solving often prove impractical for oil and gas practitioners. We pay more attention to technical and geological uncertainties while consistently managing price uncertainty within a simplified but informative decision framework.

We rely on the literature to calculate a cost-saving factor for this method compared to the traditional drilling method. In the same way, we determine the average barrels that can be added by utilising this technology and the abandonment cost of onshore wells. Then, we employ a flexible Markov chain process, assuming that the optimal decision relies on the stochastic mean-reverting nature of prices, represented using a discrete version of Hahn & Dyer, (2008). We use the concept mentioned to formulate a binomial lattice for a Markov decision chain. A recursive algorithm is implemented using Excel Visual Basic for Applications (VBA), as mentioned by Jafarizadeh and Bratvold (2019). Additionally, we conduct a sensitivity analysis of the critical parameters.

We found that geological and economic factors restrict the application of this drilling method within a limited time frame. Initiating this option during low oil prices diminishes the project's value. Conversely, delaying it for more favourable economic conditions could result in the expiration of this option due to geological constraints. The discounted value of abandonment costs contributes to delaying abandonment by providing added value. However, this value conflicts with the expected rising operating cost. The chance of success, drilling cost, and expected recoverable reserves associated with this drilling technology are decisive factors.

This paper is structured as follows: We briefly review the challenges in developing mature oil fields. Then, we discuss the probability of successfully accessing the remaining reserves in depleted reservoirs. Additionally, we construct a general decision framework. We then outline oil price models and the discrete processes involved in them. After that, we introduce the Markov chain approach and its implementation in our case. Finally, we present the discussion, conclusion, and suggestions for further research.

Challenges in the Development of Mature Oil Fields

Hydrocarbons trapped in depleted, heterogeneous, fractured, and heavily faulted mature reservoirs were commonly regarded as non-commercial or challenging resources, primarily because of the reservoir's complex nature and the difficulties posed by depletion (Johnson et al., 2008). These challenges encompass accessibility and economic viability. When production declines, the field operators decide whether to pursue re-entry drilling if the expected future value of this option surpasses the value of continuing with the current declining production or abandon the field if the future value is less promising. When a re-entry decision is made, the associated abandonment costs are deferred later, generating additional value equal to the discounted value of these costs. In the oil industry, it is common practice to disregard oil price flexibility and solely rely on technical factors when determining the optimal timing for infill drilling. However, oil price fluctuations significantly impact determining the optimal time to take this action, as shown in Figure (1).

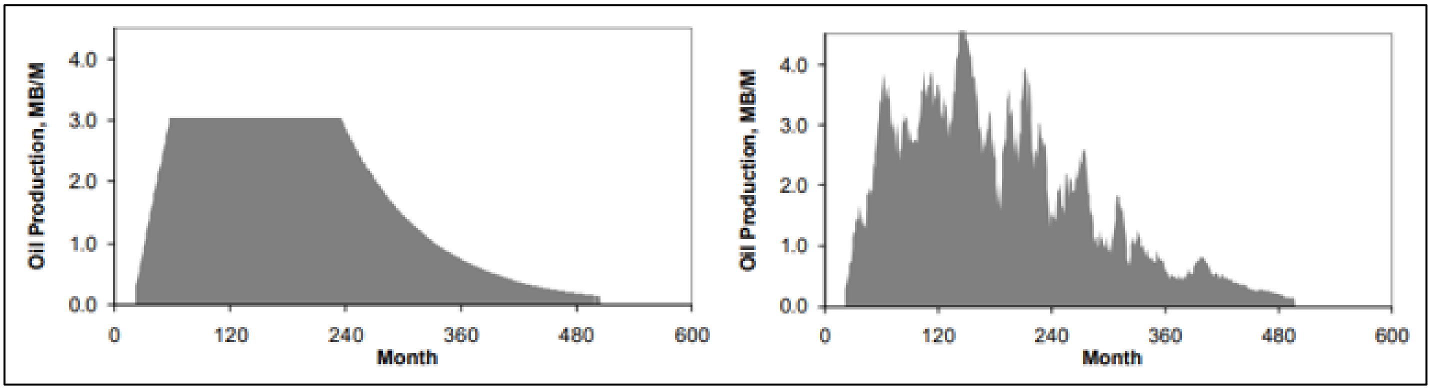


Figure 1: Production profile with no correlation with oil prices (left), production profile correlated with oil prices (right) (Begg et al., 2002).

The window for infill drilling opens once the production decline is confirmed and expires due to economic feasibility or geological difficulties (accessibility), depending on whichever comes first, as shown in Figure (2). From the moment this option becomes valid until its expiration, there is ample time to consider the value of flexibility. We address these inquiries: Does the value of this option surpass the associated costs? When is the optimal time to drill re-entries within the decision window, and what is the value of flexibility?

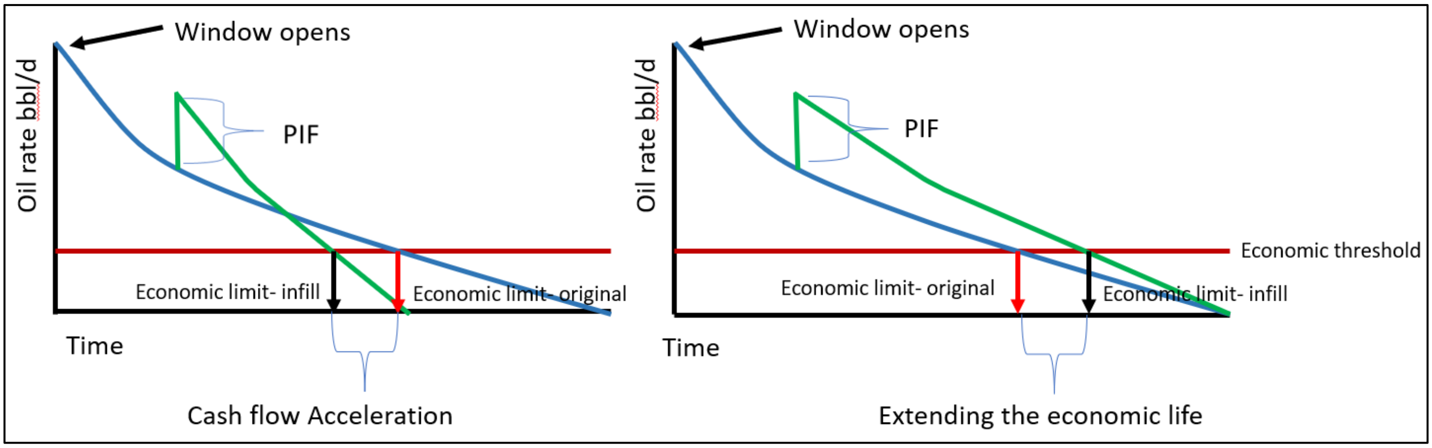


Figure 2: illustrates the economic feasibility of infill wells, indicating the timeframe during which the option for infills opens and closes.

The probability of successfully accessing the remaining reserves in mature fields

In depleted mature fields, accessing the remaining reserves with conventional overbalanced drilling (OBD) becomes challenging due to geological changes (Aadnoy, 1991). Alternatively, underbalanced drilling (UBD) can access the remaining reserves. UBCTD offers the advantage of eliminating formation damage, thereby stimulating productivity and increasing incremental recovery (Cade et al., 2003). However, this drilling technique is associated with the risk of formation collapse, leading to failure to reach the target, representing a worst-case scenario. This inherent problem occurs when the bottom hole pressure exceeds the rock collapse pressure. On the other hand, when the bottom hole pressure exceeds the fracture pressure, additional costs are necessitated to solve this problem. The collapse, bottom hole, and fracture pressure are shown in Figure (3).

The field of geomechanics within the literature on wellbore instability addresses this issue. Uncertainty in wellbore stability arises from inherent uncertainties in input data for computed factors and uncertainties in the measurements of directly measured factors (Bernt S. Aadnoy, 2011). The standard deterministic estimate of these factors offers only single-point values. Instead, assigning probability distributions in inputs allows quantifying cumulative output uncertainties, thereby enhancing decision-making. Previous works have provided valuable insights into understanding uncertainties in wellbore stability, such as Da Fontoura et al., (2002), Bernt S. Aadnoy, (2011), and Udegbunam et al., (2013). However, some studies lack a clear demonstration of the probability of success/failure. In contrast, others may reveal such probabilities without guiding how to integrate them into the decision-making process. Furthermore, the correlation between variables has never been tested in Montecarlo simulations. We contribute to the mentioned literature by providing a transparent framework necessary for consistent operational decisions, as shown in Figure (4). Also, the correlations between variables were considered during Montecarlo simulations, as shown in Figure (3). Furthermore, sensitivity analysis is conducted to show the minimum probability of success and the economic parameters, as shown in the illustrative example.

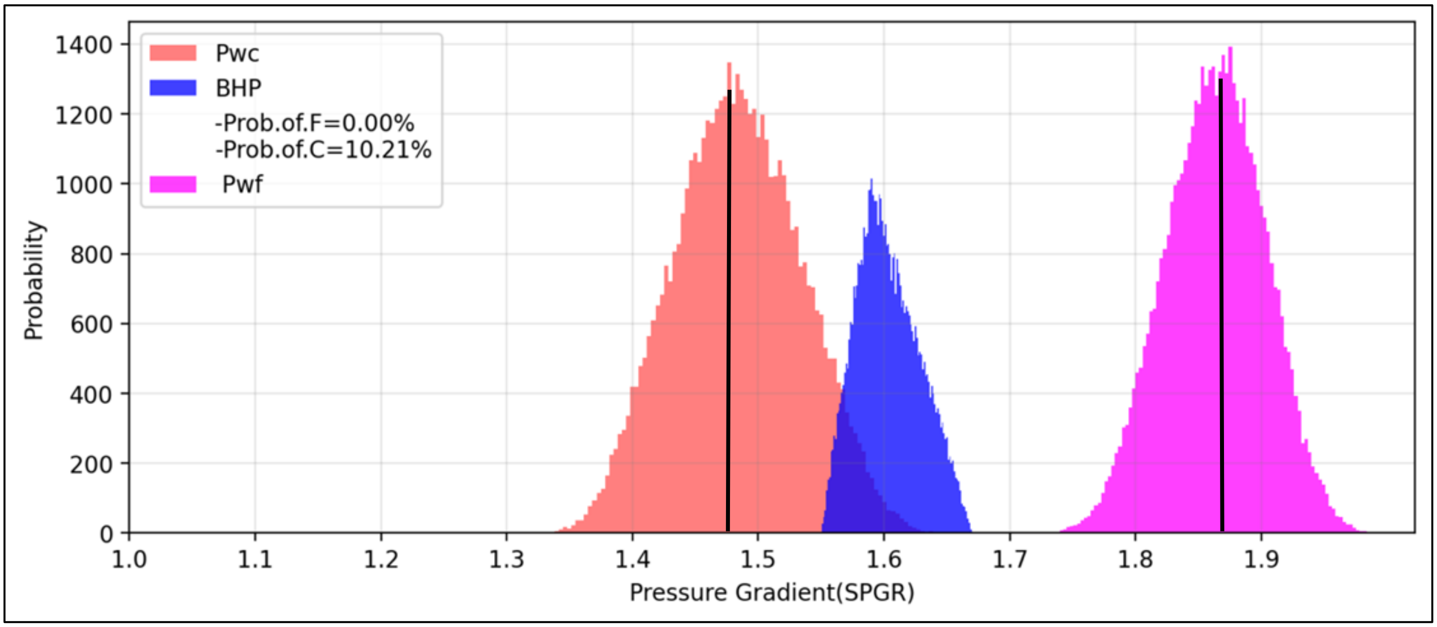


Figure 3: This figure illustrates the deterministic versus probabilistic approach in determining the uncertainty in collapse, bottom hole pressure (BHP), and fracture pressure. It also shows the overlap between collapse and BHP, expressed as the chance of failure (implemented in Python).

Figure (4) shows that we use probability in a consistent decision framework to facilitate decision-making.

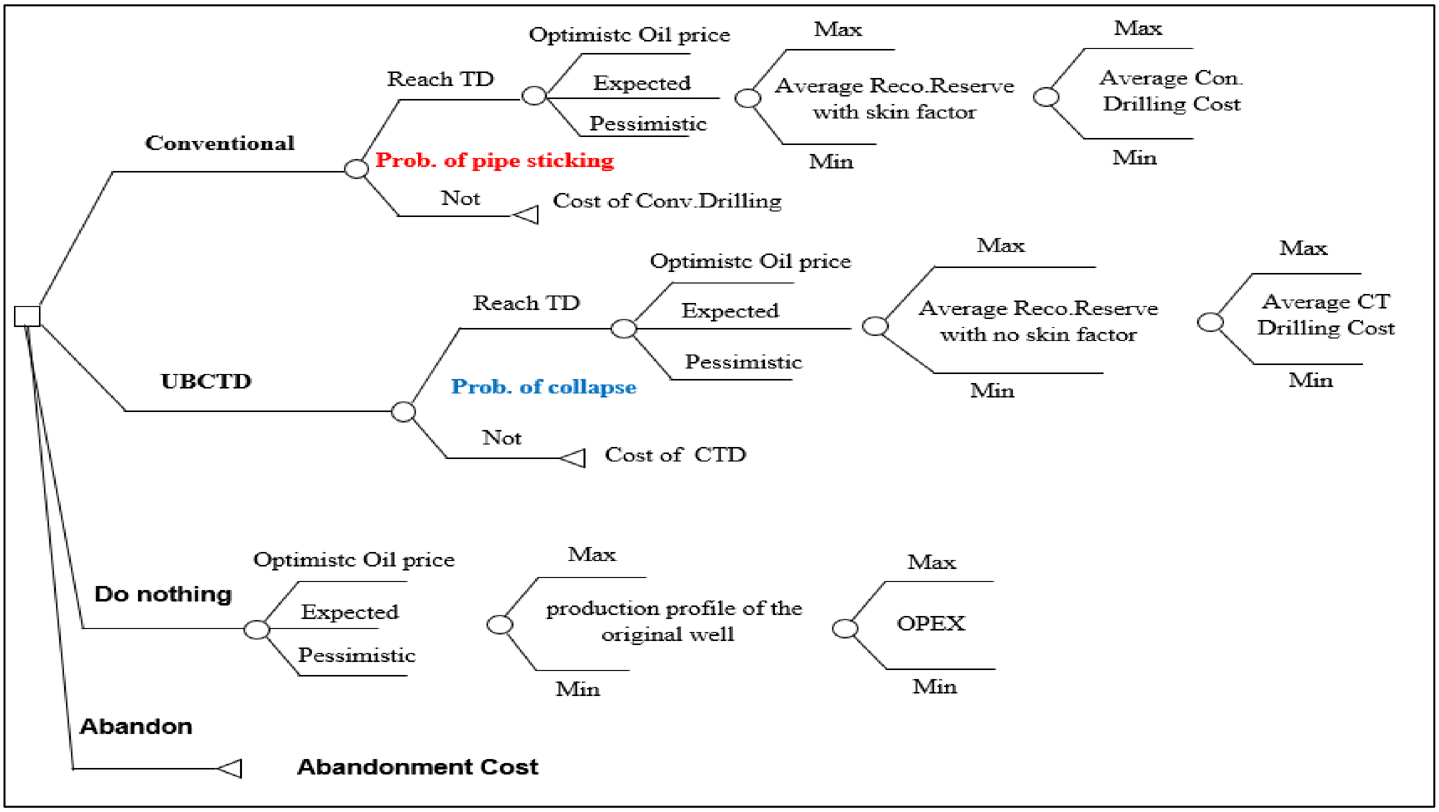


Figure 4: The integrated decision model includes operational options and uncertainties of different natures formulated in economic decision analysis.

Oil Price Uncertainty

Although there are complex models for estimating commodity prices, the mean-reverting price process holds significant theoretical appeal (Jafarizadeh & Bratvold, 2019a). When markets are in equilibrium, higher prices incentivise high-cost oil producers to enter the market, resulting in an increased supply that eventually pushes prices down toward the mean level. Conversely, lower prices prompt expensive oil producers to exit the market, reducing supply and pushing prices upward. This dynamic interplay between price, supply, and demand contributes to the mean reversion behaviour observed in oil prices. This relationship has been thoroughly examined and recognised by Pindyck, (1999) for its role in underlying factors influencing fluctuations in oil prices. By understanding and modelling this mean reversion behaviour, the field operator better understands how oil markets respond to changing conditions and how prices revert to their long-term average over time.

While multifactor models may provide more accurate representations of price dynamics, they come with increased complexity in their formulation and interpretation. On the other hand, single-factor models are easier to work with and understand, making them practical tools for decision-makers, especially in scenarios where a quick and precise assessment of oil price behaviour is needed. Moreover, in the oil and gas industry, operators often prefer using one-factor models to facilitate effective communication (Jafarizadeh & Bratvold, 2019b).

The mean-reverting process consists of an assumed constant average value and a short-term stochastic deviation. These deviations fluctuate randomly around zero, with positive values indicating higher-than-average spot prices and negative values representing lower-than-average prices. Mathematically, the spot price S_t at time t follows the process $\ln(S_t) = \chi_t + \xi_t$, where ξ_t represents the time-independent average level and short-term deviations $\chi_t$follow an Ornstein-Uhlenbeck process, as noted in Equation (1).

$$d\chi_t = -\kappa\chi_t dt + \sigma dz \qquad (1)$$

Here κ represents the mean reversion coefficient, σ Is the standard deviation for the short-term factor, while dzIs the increment of the standard Brownian motion. A higher mean-reversion coefficient implies that short-term deviations dissipate more rapidly. Additionally, increased volatility indicates that we anticipate more significant fluctuations around the average price level.

The value of a forward contract ($F_{t,T}$) For the delivery of a barrel of oil at a time (t), set for delivery at (T), is determined by the spot price and, consequently, influenced by the variable (x_t), as shown in Equation (2).

$$F_{t,T} = \mathrm{e}^{-k(T-t)}x_t + \xi + \left(1 - \mathrm{e}^{-2k(T-t)}\right)\frac{\sigma^2}{4k} \qquad (2)$$

The binomial-lattice representation of a continuous mean-reverting process has been derived and presented by Hahn & Dyer, (2008). The subsequent equations (3 – 6) illustrate the derivation of these expressions.

Within the time interval (Δt), the price represented by the variable (x) can move upwards to the value (x_{t+}) with a probability of price up (p_u), or it can move downwards to the value (x_{t-}) with a probability of the price down (p_d).

$$x_{t+} = x_t + \sqrt{\Delta t\sigma} \qquad (3)$$

$$x_{t-} = x_t - \sqrt{\Delta t\sigma} \qquad (4)$$

$$p_u = max\left(0, min\left(1, {}^1\!/_2 - \sqrt{\Delta}t\left(kx_t + {}^1\!/_2\,\sigma^2\right) / \,2\sigma\right)\right) \qquad (5)$$

$$p_d = 1 - P_u \qquad (6)$$

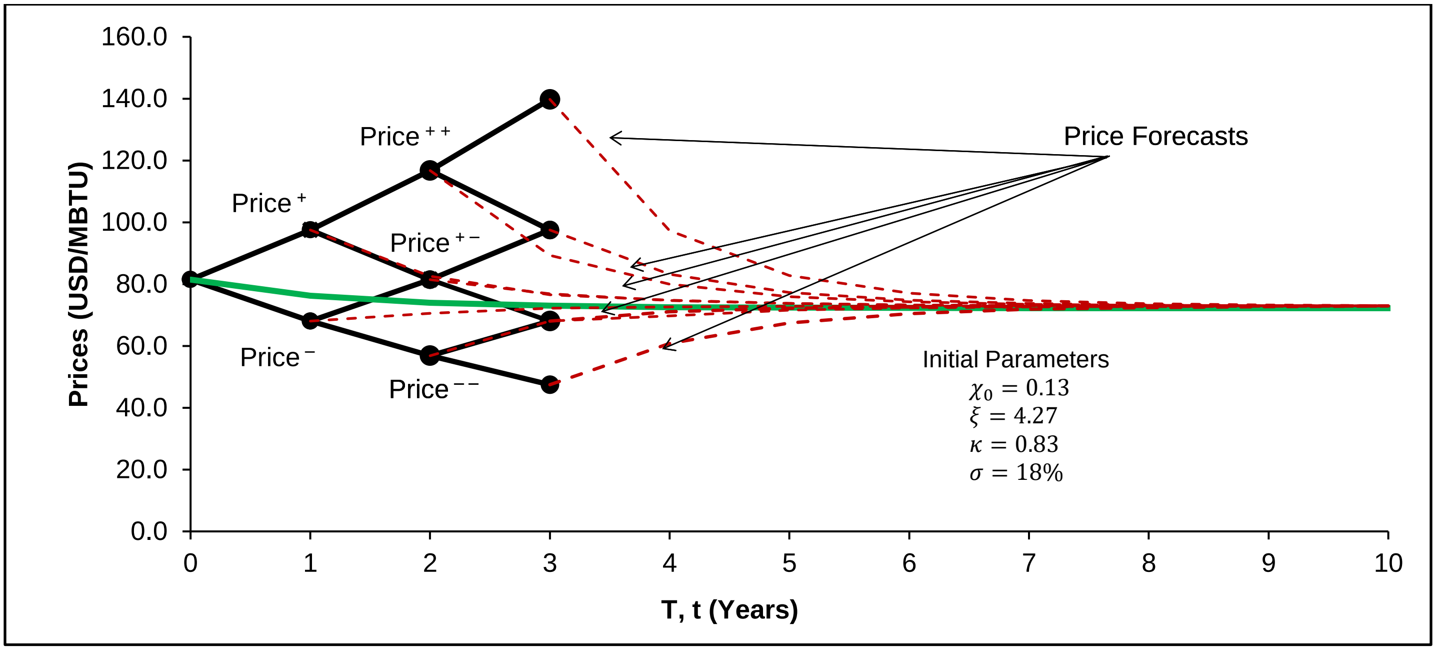


Figure 5: The binomial process of oil price and the forward curves originating from each decision point.

In each period, the probabilities are contingent on (χ_t), which represents the deviation from the mean. Additionally, Equation 5 constrains these probabilities within the range of zero to one.

The decision window opens at the production decline and extends until reaching the economic threshold. Throughout this period, operators reassess the economic viability of decisions, considering the fluctuation in oil prices and value from production cash flows. We use forward price dynamics to assess the value from production. Our binomial lattice begins from the point at which this opportunity window opens.

At the outset of the binomial lattice $t = \tau$, χ_τ is the function of time τ and its initial value is x_0. As the mean value remains constant, future price alterations arise from short-term deviation fluctuations. Consequently, the values of (χ_τ) can be employed as representatives of future prices, where $\chi_\tau - x_0 = ln\, F_{0,0}$, as shown in Equations (7 and 8).

$$\chi_\tau = \mathrm{e}^{-k\tau} x_0 + \xi + (1 - \mathrm{e}^{-k\tau}) \frac{\sigma^2}{4k} - x_0 - \xi + \chi_0 \quad (7)$$

$$\chi_\tau = \mathrm{e}^{-k\tau} x_0 + (1 - \mathrm{e}^{-k\tau}) \frac{\sigma^2}{4k} \quad (8)$$

Markov Decision Approach

During the declining phase in depleted mature fields, the field operator assesses decisions, including drilling re-entries, permanent abandonment, or waiting. Despite the declining production, the field's value is influenced by fluctuations in oil prices. Managers analyse the projected future prices at specific stages and make their decisions. Opting to wait entails monitoring prices for an additional period and confronting the same decisions, as shown in Figure (6). Typically, this process is repeated annually with updated oil prices. The open-ended lines indicate the continuation.

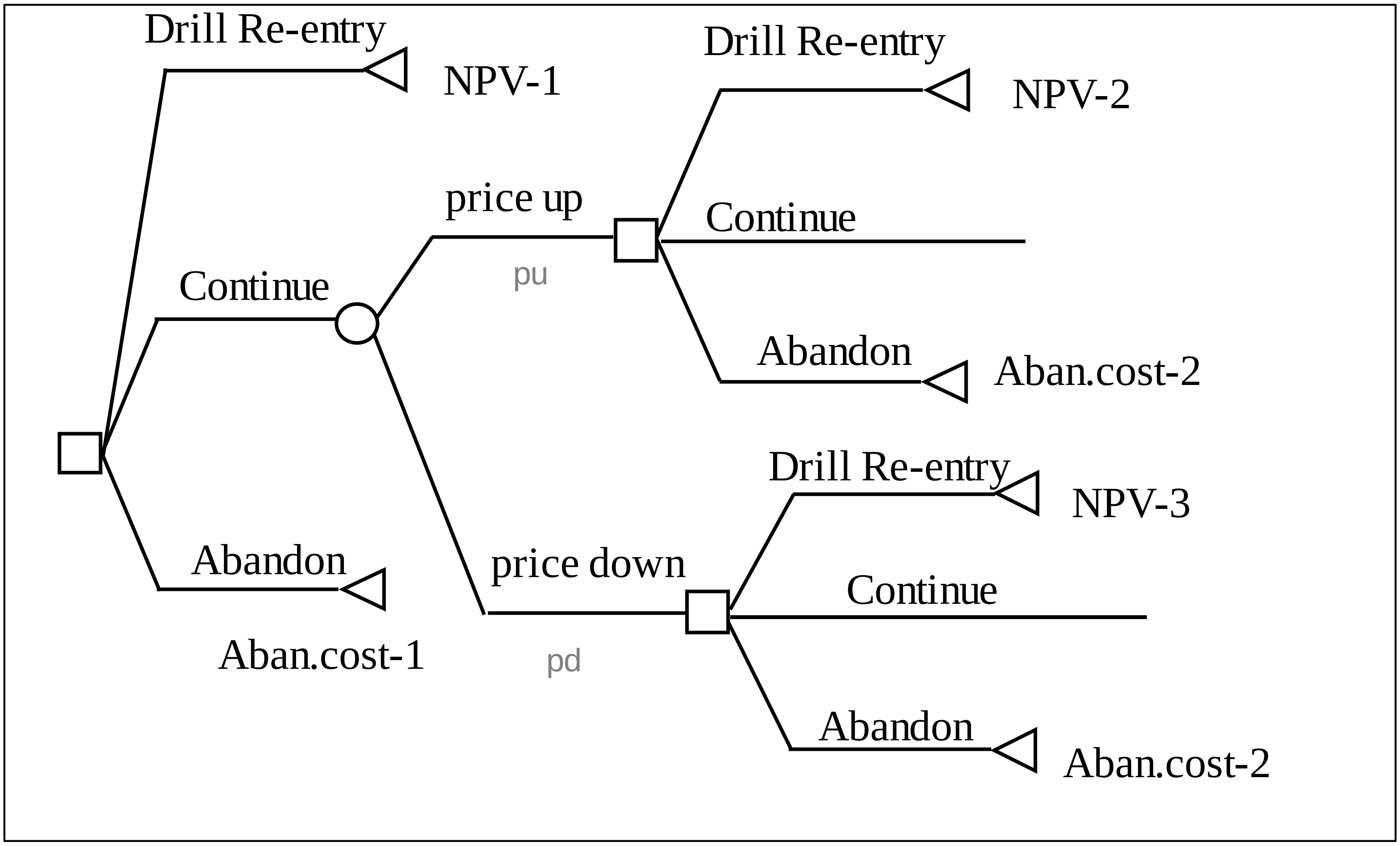


Figure 6: This figure depicts the dynamic decision approach, highlighting the annual decisions and their updated probability of occurrence.

Conducting re-entries in mature fields comes with opening time (T) and closing time (t) for the opportunity window. Early or delayed re-entry may be infeasible. Underbalanced drilling becomes the only method to access the remaining reserve in heavily fractured, faulted, and depleted reservoirs. As the severity of depletion increases, accessing the remaining reserve becomes more challenging. During underbalanced drilling, two distinct challenges arise that could jeopardise the value of this drilling technique: the inherent risk of formation collapse and the operational risk of failure in sustaining the underbalanced condition at the bottom. Nevertheless, UBCTD demonstrates high efficiency in managing unbalanced conditions. Consequently, the sole risk stems from the probability of formation collapse. Extending field life through re-entry drilling delays abandonment costs, yielding additional benefits. Alternatively, immediate field abandonment is an option if the economics are unfavourable. These decisions are based on the economic threshold, determined by future oil price projections. We consider future contracts as a risk-neutral predictor of future price trends and use them to fit the mean reversion process parameters. Additionally, managers are presumed to utilise forward curves to assess the expected discounted payoffs of their decisions.

The forward curve within a mean-reverting process is characterised by its dependence on the parameter (χ_t), allowing us to establish a deterministic payoff function $g(\chi_t)$ at every decision point. As (χ_t) exhibits Markov properties (its present value is independent of its past values), the value of the option at each time point (V_t) will similarly rely on (χ_t), denoted as $v_t(\chi_t)$, therefore $V_t = v_{t(\chi_t),}\ t = \tau, \tau + 1$.

As the opportunity window approaches its closing point at a time ($t = T$), given the diminishing value of the field, managers are tasked with making the optimal decision to either continue, abandon, or undertake re-entry drilling and obtaining $g(\chi_T)$. Within the timeframe of the window ($\tau < t < T$), managers assess the exercise value $(g(\chi_t))$ against the anticipated value of continuing to the following year. Commencing from time T, The valuation procedure follows a recursive algorithm, demonstrated in Equations (9) and (10).

$$V_T(\chi_T) = max(g(\chi_T), NPV^{x_T} Continue) \qquad (9)$$

$$V_t(\chi_t) = max\big(g(\chi_t), 1/(1+r)\big(Pu\, v_{t+1}(\chi_t^{+}) + pd\, v_{t+1}(\chi_t^{-}\,)\big)\big) + CF_t \qquad (10)$$

When $\tau < t < T$, r is the discount rate and $g(\chi_t)$ is the net present value of the option (abandonment or re-entry) at the time (t). τ and T represent the opening and closing times, respectively.

$$g(\chi_t) = max(NPV^{xt} Abandonment, NPV^{xt} Reentry) \qquad (11)$$

When (NPV^{xt}) denotes the net present value (NPV) at time (t) for the total cash flows derived from that specific course of action, subject to the condition of (χ_t). If the managerial decision is to proceed (CF_t) represents the cash flow for the production profile of the original wells. This recursive algorithm in Equations (9 to 11) determines the value of either re-entering or abandoning the oil field at the initiation of the options window $(t = \tau)$.

The overall project value, denoted as (V_0), comprises both the option value $(v_\tau(x_\tau))$ at the opening window and the discounted cash flow before the option within the range of $(0 \leq t < \tau)$ as shown in Equation (12).

$$V_0 = \sum_{t=0}^{\tau} \frac{CF_t}{(1+r)^t} + \frac{v_\tau(\chi_\tau)}{(1+r)^\tau} \qquad (12)$$

The system's progression is driven by prices adhering to a mean-reverting process, and the stopping rule presents two choices: an immediate field abandonment or accessing the remaining reserves now with a delayed abandonment cost. Continuing entails persisting with the ongoing production decline. In our specific scenario, the costs and benefits are not straightforward; instead, they comprise a sequence of cash flows that we evaluate using our dynamic forward curve estimation and subjected to a probability of success/failure.

Illustrative Example

The provided example depicts the valuation procedure for a re-entry well (open hole) that is assumed to be drilled in an onshore reservoir in the USA. The initial oil well is in the declining phase and is projected to be produced for six years, with the choice to either re-enter or abandon it during the decline's second, third, and fourth years. Within our evaluation process, we consider certain technical and economic assumptions as outlined below:

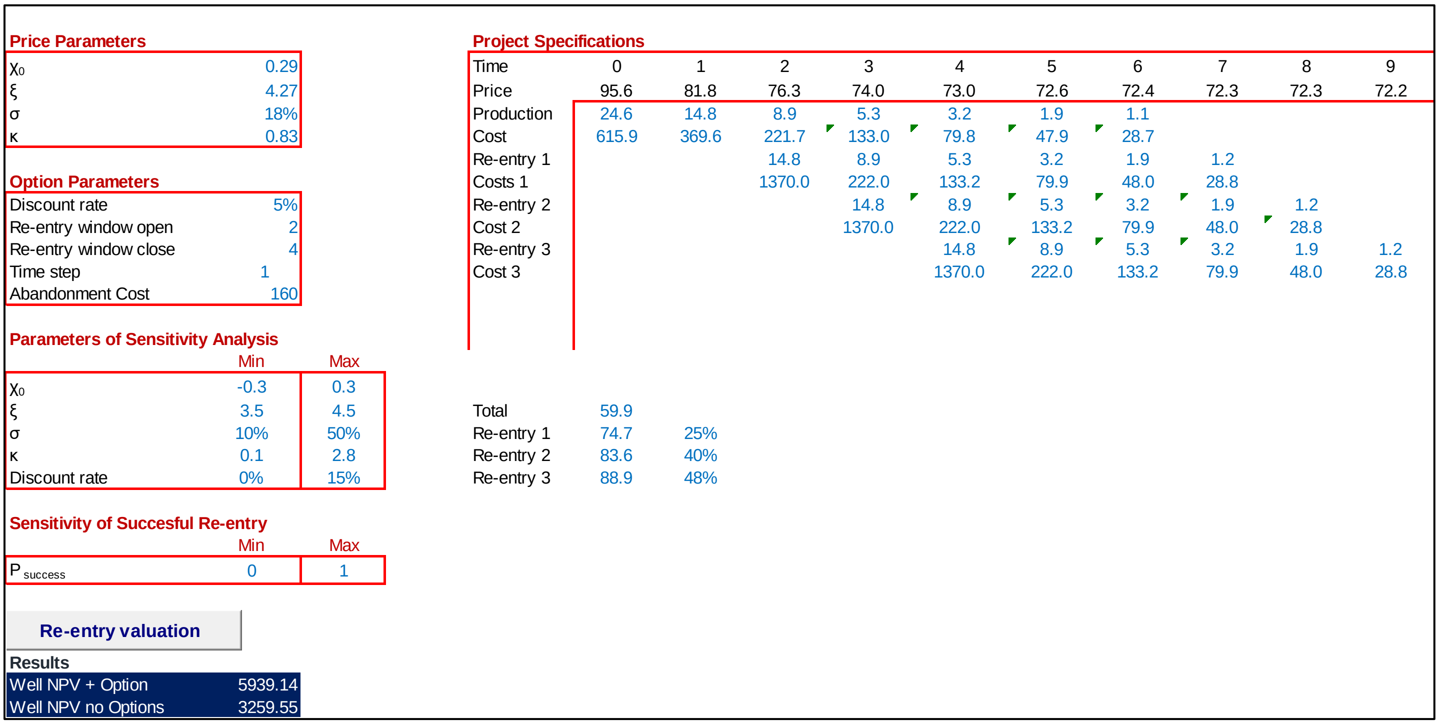
Technical inputs:

- The initial well experiences a decline from 80 barrels per day (15% of annual shutdown for workover), diminishing by 40% each year. The projected economic limit for the original well is expected to occur in the sixth year. The re-entry well targets an isolated pocket in a tight reservoir and experiences an identical decline rate of 40%.
- The drilling cost (CAPEX) for a re-entry well amounts to $1 million, reflecting the average open-hole drilling expenses within a USA-based onshore field. This value is determined by considering the average cost-saving factor of (34%) associated with using Coiled Tubing Drilling (CTD) compared to conventional drilling methods.
- The operational expenditure (Opex) is estimated at $22 per barrel, the average observed in onshore fields across the USA. This data is sourced from the U.S. Energy Information Administration (EIA) report 2016.
- The cost for abandonment is set at $160,000 per well, representing the p90 in onshore USA scenarios (Raimi et al., 2021).
- We assume the probability of experiencing formation collapse in underbalanced drilling is 10.4% using the range of magnitudes mentioned in Udegbunam et al., (2013).

Economic inputs:

- Oil price is forecasted using a geometric mean-reverting process for the long term and a binomial lattice for the short term.
- Model parameters are determined by fitting them with future contracts.
- We use a risk-free discount rate, considering the risk-neutral application in the oil and gas industry (Smith & Mccardle, 1999).
- The algorithm is an updated version based on the approach outlined in (Jafarizadeh & Bratvold, 2019b).

In this scenario, production decreases after the plateau to a point where the managers must consider abandoning, continuing, or re-accessing the reservoir. The decision is influenced by the field's fluctuating value caused by changes in oil prices. The critical question is: When is the optimal time to act, and which option maximises the project value? All these options are evaluated and shown in Figure (7).



Price Parameters

χ_0	0.29
ξ	4.27
σ	18%
κ	0.83

Option Parameters

Discount rate	5%
Re-entry window open	2
Re-entry window close	4
Time step	1
Abandonment Cost	160

Parameters of Sensitivity Analysis

	Min	Max
χ_0	-0.3	0.3
ξ	3.5	4.5
σ	10%	50%
κ	0.1	2.8
Discount rate	0%	15%

Sensitivity of Succesful Re-entry

	Min	Max
P_{success}	0	1

Results

Well NPV + Option	5939.14
Well NPV no Options	3259.55

Project Specifications

Time	0	1	2	3	4	5	6	7	8	9
Price	95.6	81.8	76.3	74.0	73.0	72.6	72.4	72.3	72.3	72.2
Production	24.6	14.8	8.9	5.3	3.2	1.9	1.1			
Cost	615.9	369.6	221.7	133.0	79.8	47.9	28.7			
Re-entry 1			14.8	8.9	5.3	3.2	1.9	1.2		
Costs 1			1370.0	222.0	133.2	79.9	48.0	28.8		
Re-entry 2				14.8	8.9	5.3	3.2	1.9	1.2	
Cost 2				1370.0	222.0	133.2	79.9	48.0	28.8	
Re-entry 3					14.8	8.9	5.3	3.2	1.9	1.2
Cost 3					1370.0	222.0	133.2	79.9	48.0	28.8

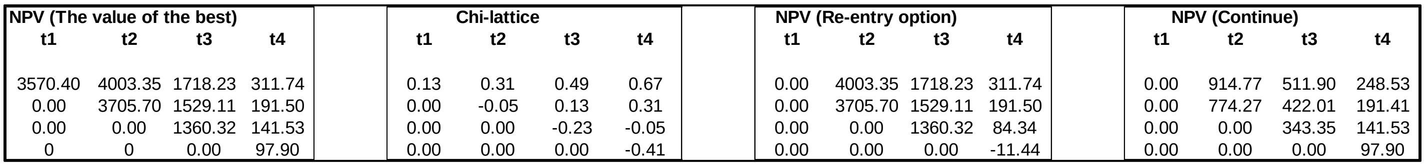
Total	59.9	
Re-entry 1	74.7	25%
Re-entry 2	83.6	40%
Re-entry 3	88.9	48%

Figure 7: The program interface of the valuation model for the re-entry option; all values are multiplied by 1000.

This figure illustrates the program interface, which collectively influences the project's value and integrates projected production profiles, cost considerations, price parameters, operation parameters, abandonment cost, and geological probability of success. The model enables users to enter economic inputs easily.

In this valuation, any option's overall value is the sum resulting from the binomial lattice at (t=2) and the cash flow preceding the option when t < 2. In simpler terms, the project's Net Present Value (NPV) equals the sum of the value derived from the binomial lattice and the value preceding the binomial lattice. Equation 14 is utilised to calculate the NPV of this option, resulting in a value of 5,939,000 USD. For $t \geq 2$, the binomial lattice methodology calculates the remaining portion of the project's value. Equations (9,10 & 11) are used for this process.

Applying the methodology discussed earlier, we compute the value of the re-entry option as follows. At t = 1, as shown in Equation (8), (χ_t) decreased from 0.29 to 0.13. Subsequently, by utilising Equations (3) through (6), we establish a binomial lattice to depict the evolution of (χ_t). By the time t = 4 is reached and after three intervals, (χ_t) could range from a low of (-0.41) to a high of 0.67. Utilising this data, we formulate forward curves for each (χ_t)Moreover, estimate the value of each alternative decision. The recursive algorithm described in Equations (9) through (11) yields an option value of 3,570,000 USD, as shown in Figure (8).



NPV (The value of the best)

t1	t2	t3	t4
3570.40	4003.35	1718.23	311.74
0.00	3705.70	1529.11	191.50
0.00	0.00	1360.32	141.53
0	0	0.00	97.90

Chi-lattice

t1	t2	t3	t4
0.13	0.31	0.49	0.67
0.00	-0.05	0.13	0.31
0.00	0.00	-0.23	-0.05
0.00	0.00	0.00	-0.41

NPV (Re-entry option)

t1	t2	t3	t4
0.00	4003.35	1718.23	311.74
0.00	3705.70	1529.11	191.50
0.00	0.00	1360.32	84.34
0.00	0.00	0.00	-11.44

NPV (Continue)

t1	t2	t3	t4
0.00	914.77	511.90	248.53
0.00	774.27	422.01	191.41
0.00	0.00	343.35	141.53
0.00	0.00	0.00	97.90

Figure 8: The result of the binomial lattice for chi lattice, re-entry option, continuation, and the best option.

This diagram mimics the scenarios analysed by a decision analyst. It initiates at the decision point and illustrates the likelihood of increasing or decreasing oil prices. The forward curves originate from each of these points. Certain time-based restrictions are in place, ensuring that the probabilities of price increases and decreases remain within reasonable bounds. If the probability of a price increase becomes more than three times the original value, it enters an impractical range. Nevertheless, this model considers three time periods.

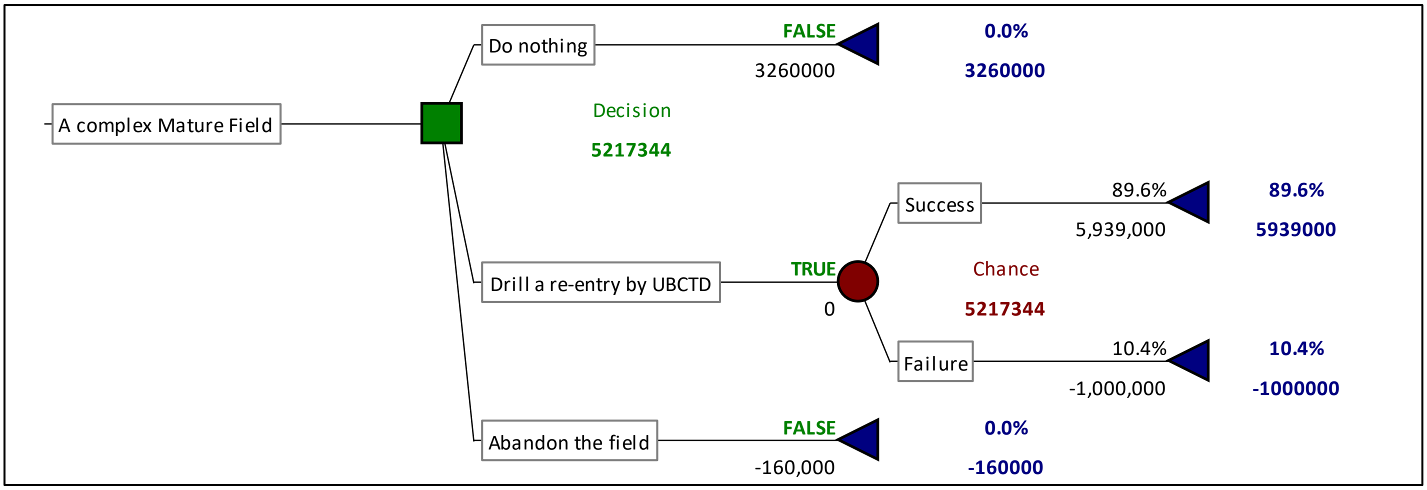


Figure 9: Resolved decision tree incorporating options, probabilities, and outcomes for a single hole.

Discussion

We employ the discrete version of the mean reversion model to generate arrays of forward prices. Each decision point originates from a time step representing the probability of the price rising or falling, along with its initial value. These prices, in turn, are utilised to calculate the NPV for the best decision alternatives, including abandonment or re-entry for the duration of the production period. Our sensitivity analyses demonstrate the effects of price uncertainty and geological parameters on the value of the re-entry option, as depicted in Figures (9) and (10). The long-term mean reversion process determines the economic limit of the project, as shown in Figure (5).

Our model highlights that accessing the remaining reserve through UBCTD before the field reaches its economic limit can yield additional value, mainly when capitalising on favourable oil prices, specifically with low abandonment costs. Based on the mean-reverting behaviour of prices, initiating from a position of high oil prices makes the early re-entry option more favourable, driven by the anticipated decrease in oil prices and the declining pressure of the field. However, when the current spot oil price falls below the average, opting for a later decision would be more advantageous because the upcoming prices are expected to rise. Additionally, the discounted value of the abandonment cost plays a role in delaying abandonment, thereby enhancing the overall value. Other factors are bound to the decision, including the declining production rate of the original wells, the economic limit, geological limitations, and the economic variables (volatility, mean reversion coefficient, and discount factor).

A sensitivity analysis of the probability of success reveals that drilling a re-entry well by UBCTD is viable only when the probability of success exceeds 50%. Otherwise, it is more advantageous to stick with the original production strategy. The breakeven point is the threshold at which the re-entry option yields a higher (NPV) than doing nothing, as shown in Figure (10). Additionally, the discount rate has minimal impact on the total value due to the rapid production decline of the tight reservoir that coincides with the sharp decrease in oil prices. Given that the most significant oil production occurs in the initial stages, the subsequent values are less affected by the discounting impact. Fluctuations in oil prices most significantly influence the project value, as explained by volatility and mean reversion coefficient. As volatility rises, the project value increases. Conversely, a higher mean reversion coefficient decreases the project value, as shown in Figure (10). As the oil price includes short and long-term factors, a three-dimensional sensitivity analysis explained the impact of the mean reverting oil price parameters on the project value, as shown in Figure (11).

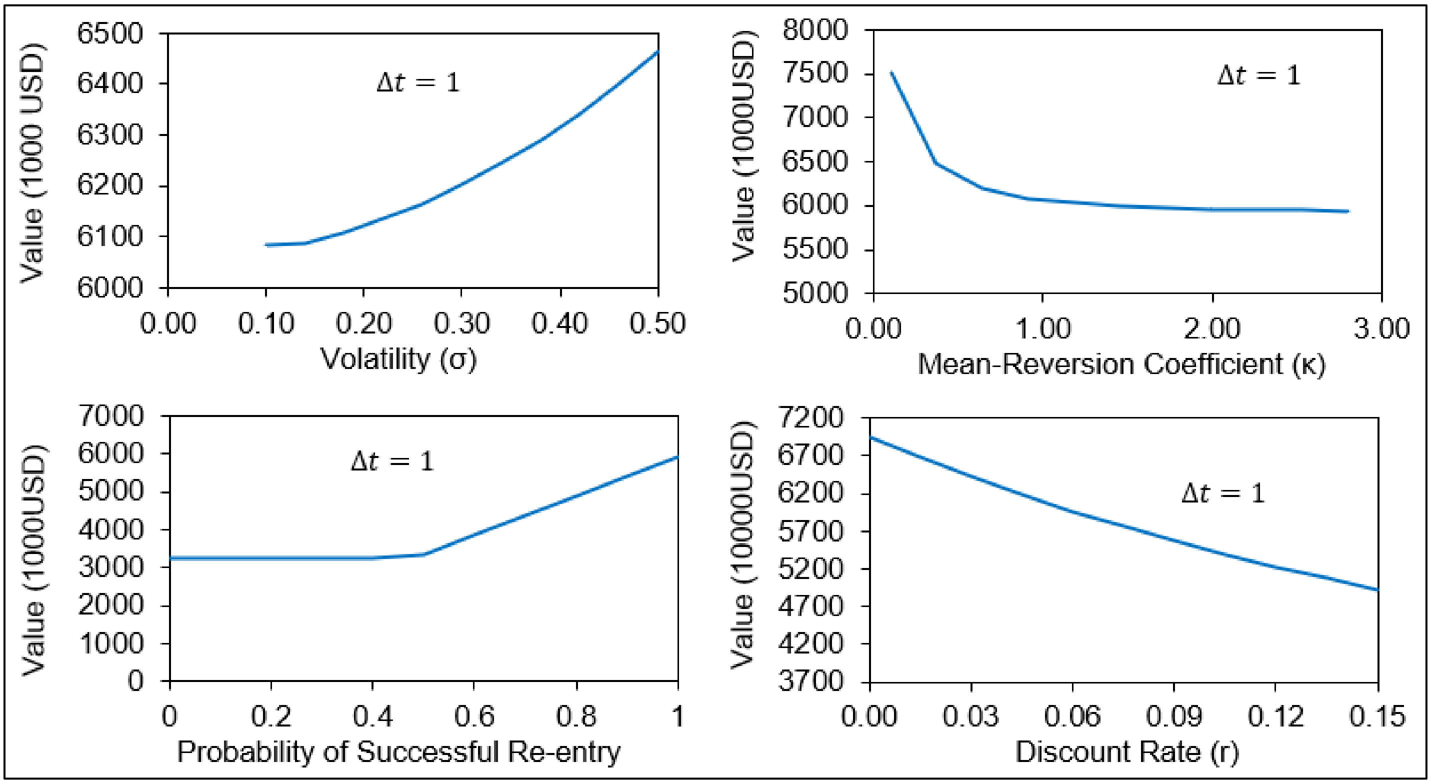


Figure 10: Sensitivity analysis for volatility, mean reversion coefficient, probability of success, and discount rate.

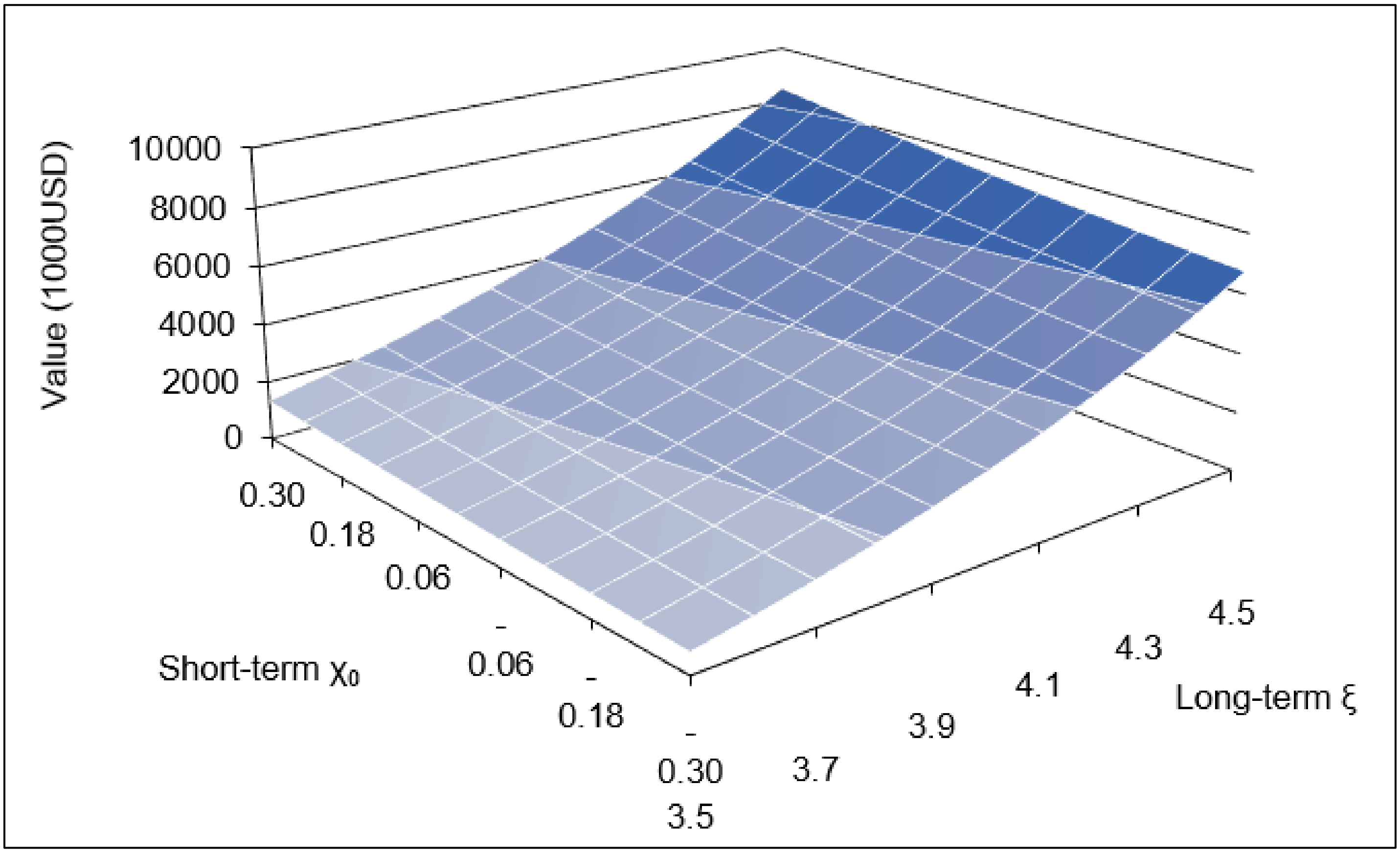


Figure 11 depicts the three-dimensional sensitivity analysis of the short—and long-term variables of the mean reversion process with the project value.

Conclusion

Geological and market uncertainties affect the option to use underbalanced coiled tubing drilling to access the remaining reserves in mature oil fields compared to other options, such as continuing with the declining value or permanently abandoning the field. The assessment is applied in an integrated model, encompassing these options. To optimise the decision, we offer a consistent evaluation model that considers a consistent oil price outlook, geological uncertainties expressed as the probability of success in reaching the target, drilling cost, and the potential recovery of the re-entry. The cost, probability of success, and potential recovery of UBCTD have been derived from the literature.

We model oil price dynamics using a mean-reverting process within a binomial lattice framework. A forward curve is created at every node within this lattice, allowing the approximate value of each potential decision to be approximated. Subsequently, a recursive algorithm is employed to compute the valuation of each option, whether to proceed with the declining value, drilling re-entries, or opting for abandonment. This model provides a consistent tool for making an informed decision for infill drilling in mature fields. It stands out for its simplicity and versatility, accommodating realistic production profiles and delivering outcomes within seconds. Moreover, the model incorporates sensitivity analysis of the critical variables. The analysis highlights that accessing the remaining reserve through UBCTD before the field reaches its economic limit can yield additional value, mainly when capitalising on favourable oil prices, specifically when there are low abandonment costs. Based on the mean-reverting behaviour of prices, initiating from a position of high oil prices makes the early re-entry option more favourable, driven by the anticipated decrease in oil prices and the declining pressure of the field. However, when the current spot oil price falls below the average, opting for a later decision would be more advantageous because the upcoming prices are expected to rise. Additionally, the discounted value of the abandonment cost plays a role in delaying abandonment, thereby enhancing the overall value. Other factors are bound to the decision, including the declining production rate of the original wells, the economic limit, geological limitations, and the economic variables, including volatility, mean reversion coefficient, and discount factor.

Future work

Further effort is needed to consistently elicit the probability of success. Additionally, investigating uncertain recoverable reserves that meet the economic threshold and optimising the sequential drilling strategy is crucial for further research.

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