Journal of Petroleum Science and Engineering 157 (2017) 81–93

Contents lists available at ScienceDirect

Journal of Petroleum Science and Engineering

journal homepage: www.elsevier.com/locate/petrol

Expected value, downside risk and upside potential as decision criteria in production strategy selection for petroleum field development

Susana M.G. Santos *, Vinicius E. Botechia, Denis J. Schiozer, Ana T.F.S. Gaspar

Department of Energy, School of Mechanical Engineering, University of Campinas, Brazil

ARTICLE INFO

Keywords:
Decision analysis
Downside risk
Upside potential
Semi-deviation
Production strategy
Reservoir simulation

ABSTRACT

Many factors affect production strategy selection in petroleum field development. Decision makers many times rely on informal procedures and professional experience to base decisions because tools to quantify their expectations are sometimes unclear or incoherent in the petroleum literature. In this work, we improve the decision-making process in field development by providing a set of quantitative criteria that assess production strategies under uncertainty. These criteria incorporate the decision maker's attitude and objectives in the decision. We use lower and upper semi-deviations to effectively quantify downside risk (uncertainty in losses) and upside potential (uncertainty in gains) of production strategies. These metrics assess individual subsets of project variability against reference benchmarks, in line with the decision maker's definition of loss and gain. The general formulation we propose is applicable to production and economic indicators, in a single- or multi-objective framework, and explicitly accounts for the decision maker's attitude: neutrality to downsides and upsides, minimizing exposure to downsides, and exploiting potential upsides. We created this framework using the well-known expected value concept with lower and upper semi-deviation measures. Theoretical examples illustrate problems faced by decision makers when using traditional risk measures, which are overcome by lower and upper semi-deviations. A synthetic benchmark reservoir in the development phase demonstrates the application of the proposed frameworks for production strategy selection.

1. Introduction

The decision to develop a petroleum field is complex. When selecting a production strategy, many factors are taken into account, including the expected return, the level of risk, the decision maker's attitude towards risk, and strategic objectives, such as minimizing exposure to potential downsides or exploiting potential upsides. However, tools to quantify these objectives are sometimes unclear or incoherent in the petroleum literature, leading decision makers to rely on informal procedures and professional experience to make decisions.

In the following sections we overview the most common measures of risk and decision criteria in upstream petroleum investments. We emphasize the advantages and limitations of each, and further refer to finance literature, to choose tools capable of assessing the decision maker's attitude towards production strategy selection.

1.1. Measures of risk in upstream petroleum investments: an overview

Variance (σ^2) and standard deviation (σ) are widely applied risk measures in diverse contexts in upstream oil and gas investments (e.g.: Newendorp and Schuyler, 2000; Lima and Suslick, 2005; Cullick et al., 2007; Hayashi et al., 2007; Capolei et al., 2015a). However, they are many times considered inadequate because they associate risk with volatility around the expected value (EV). Consequently: (1) when the distribution is asymmetric, variance penalizes gains and losses equally; and (2) it is unable to distinguish alternatives with the same variability but different EV (Markowitz, 1959; Harlow, 1991; Sortino and Price, 1994; Rockafellar et al., 2002; Estrada, 2007; Krokhmal et al., 2011). Accordingly, it is more precise to define these as statistical measures of uncertainty rather than measures of risk, as stated, for example, by Walls (2004), and applied by Barros et al. (2016) in petroleum reservoir management.

An alternative metric is the coefficient of variation ($CV = \sigma/EV$), a ratio to distinguish projects with the same variability but different EV. However, it is also a measure of dispersion around the EV and makes no sense if the EV is less than or equal to zero, being useful only for random variables with strictly positive distributions (Curto and Pinto, 2009). Hayashi et al. (2010), Marques et al. (2013), Morosov and Schiozer

* Corresponding author.
E-mail address: sgraca@dep.fem.unicamp.br (S.M.G. Santos).

http://dx.doi.org/10.1016/j.petrol.2017.07.002
Received 20 February 2017; Received in revised form 25 May 2017; Accepted 2 July 2017
Available online 4 July 2017
0920-4105/

(2016), among others, applied this metric to select production strategies in the development phase.

The semi-variance (Eq. (1)), proposed as an alternative to variance (Markowitz, 1959), denotes the downside volatility of returns below a predefined benchmark (B), which depends on the decision maker's definition of loss and is independent of the probability distribution. Far less popular in upstream petroleum investments, it was applied by Orman and Duggan (1999) and Galeno et al. (2009) in portfolio optimization, and by Santos et al. (2017) to select production strategies in the development phase.

$$S_{B-} = \sqrt{S_{B-}^2} = \sqrt{E\{min[(X-B),0]^2\}} \tag{1}$$

where: S_{B-} – lower semi-standard deviation, or lower semi-deviation for short, from a benchmark value B; S_{B-}^2– lower semi-variance from a benchmark value B; E - expectation operator; X – random variable.

Recent advances in decision analysis have formalized two classes of risk measures: coherent measures of risk (Artzner et al., 1999; Delbaen, 2002), and averse measures of risk (Rockafellar and Uryasev, 2002; Rockafellar et al., 2006). Krokhmal et al. (2011) provide simple models to construct averse measures of risk, of which only risk measures of CVaR type and of semi-$\mathscr{L}^{\beta}(\Omega)$ type with $\lambda \in (0,1]$ are coherent-averse measures of risk:

(a) Risk measures of $\mathscr{L}^{\beta}(\Omega)$ type: $\mathscr{R}(X) = \lambda\left\|X - E[X]\right\|_{\beta} - E[X]$, $\beta \in [1, \infty]$, $\lambda > 0$, e.g. $\mathscr{R}(X) = \lambda\sigma(X) - E[X]$ and $\mathscr{R}(X) = \lambda S_{EV}(X) - E[X]$.
(b) Risk measures of semi-$\mathscr{L}^{\beta}(\Omega)$ type: $\mathscr{R}(X) = \lambda\left\|[X - E[X]]_{-}\right\|_{\beta} - E[X]$, $\beta \in [1, \infty]$, $\lambda > 0$, e.g. $\mathscr{R}(X) = \lambda S_{B-}(X) - E[X]$.
(c) Risk measures of CVaR type: (i) $\mathscr{R}(X) = CVaR_a(X)$; (ii) mixed CVaR $\mathscr{R}(X) = \int_0^1 CVaR_a(X)d\lambda(a)$, where $\int_0^1 d\lambda(a) = 1$ and $\lambda(a) \geq 0$; and (iii) worst case mixed CVaR $\mathscr{R}(X) = \sup_{\lambda \in \Lambda} \int_0^1 CVaR_a(X)d\lambda(a)$.

In light of these ideas, Capolei et al. (2015b) assessed the validity of different measures in oil production optimization under the concept of coherent-averse measures of risk. Komlosi (2001), Marques et al. (2014), and Capolei et al. (2015b) applied the financial concepts Value at Risk (VaR) and Conditional Value at Risk (CVaR) in upstream petroleum projects.

In §2.1, we explore the concepts of deviation measures, in particular lower and upper semi-deviations from benchmarks, to quantify the downside risk (uncertainty in losses) and the upside potential (uncertainty in gains) of production strategies.

1.2. Decision criteria in upstream petroleum investments: an overview

Decision makers sometimes assume that the expected value takes risk into account, as it weights each possible outcome by its probability (Walls, 1995a). However, it possesses limitations in incorporating real risk concerns by implying impartiality to the magnitude of potential profits and losses. However, for its simplicity, it is the most frequent decision criterion in upstream petroleum investments (e.g.: Newendorp, 1984; Newendorp and Schuyler, 2000; Koninx, 2001; Begg et al., 2002; Bickel et al., 2008; Nogueira and Schiozer, 2009; van Essen et al., 2009; Schiozer et al., 2015; Shirangi and Durlofsky, 2015).

In an attempt to overcome these limitations, the utility theory was formulated to recognize risk aversion as part of the decision policy. Initially proposed by von Neumann and Morgenstern (1953), utility theory is currently widely documented in the literature (Luce and Raiffa, 1957; Fishburn, 1970; Keeney and Raiffa, 1976; Howard, 1984). However, its real-world application is still controversial because: (1) managers often regard these models as theoretically complex and impractical for day-to-day decision making; and (2) managers are often uncomfortable with the notion of measuring the firm's utility function or risk preference level (Walls, 1995a). Cozzolino (1977), Walls (1995a), Nepomuceno Filho et al. (1999), Newendorp and Schuyler (2000), Suslick and Furtado (2001), among others, applied exponential utility functions to introduce a risk attitude in upstream petroleum investments.

The certainty equivalent (CE) is equal to the expected value minus a risk discount, and is derived from expected utility (EU) through its inverse transform (Keeney and Raiffa, 1976). By providing real monetary units, this formulation is common in upstream petroleum investments (e.g.: Cozzolino, 1977; Rose, 1992; Walls, 1995a; Motta et al., 2000; Newendorp and Schuyler, 2000; Lima and Suslick, 2005; Moore et al., 2005).

Mean-variance frameworks to certainty equivalent are also common. The traditional model in Eq. (2) (Pratt, 1964) was applied by Walls and Dyer (1996), Pinto et al. (2003), Walls (2004, 2005), Galeno et al. (2009), and others, in diverse contexts in upstream petroleum investments. Yeten et al. (2003), Alhuthali et al. (2010), Yasari et al. (2013), Yasari and Pishvaie (2015), Capolei et al. (2015a), and others applied mean-variance frameworks in robust optimization of production strategies.

$$CE(X) = E[X] - c\frac{\sigma^2}{2} = E[X] - \frac{\sigma^2}{2RT} \tag{2}$$

where: CE – certainty equivalent; $E[X]$ – expected value of random variable X; σ^2 – variance; c – risk aversion coefficient; RT – corporate risk tolerance.

Eq. (2) can be modeled using the risk aversion coefficient (c) or the corporate risk tolerance ($RT = 1/c$), which represents “the sum of money such that the executives are indifferent as a company investment to a 50-50 chance of winning that sum and losing half of that sum” (Howard, 1988, p. 689). This value can be estimated through questions answered by the decision maker, but rules of thumb exist in the petroleum literature. Rose (1992), Walls and Dyer (1996), Pinto et al. (2003), and Walls (1995a) provide rules for exploration investments. In petroleum development and production, Lima and Suslick (2005) considered it to be 40% of the corporation budget.

If the decision maker wishes to base decisions on two or more objectives, Multi-Attribute Utility Theory (MAUT) can be applied to handle the tradeoffs between them (Keeney and Raiffa, 1976). Many forms of multi-attribute utility functions are theoretically valid (Keeney and Raiffa, 1976). The linear additive model (Eq. (3)) is frequently preferred because it provides a close approximation for different preferences while remaining easier to apply compared to more accurate but more complex non-linear models (Huber, 1974). In upstream petroleum projects, this model was applied by Walls (1995b), Nepomuceno Filho et al. (1999), Suslick and Furtado (2001), Lopes and Almeida (2013), Santos et al. (2017) and others.

$$u(X) = \sum_{i=1}^{n} k_i u_i(X_i) \tag{3}$$

where: $u_i(x_i)$ – utility function for objective i; X – random variable; k_i – weight (i.e. relative importance) of objective i, such that. $\sum_{i=1}^{n} k_i = 1$.

While common in the petroleum industry, many authors assert that mean-variance models are only valid under strict assumptions, namely that returns must be normally distributed. Consequently, alternative models are common in finance literature, but we noticed that they are rare in petroleum related applications. To enhance our methodology, we referred to this body of literature to find suitable formulations (§1.3).

1.3. Decision criteria in the finance literature: recent developments

Following the original mean-semivariance concept of Markowitz (1959), Fishburn (1977) formulated a generalized mean-risk model (Eq. (4)) to capture the decision maker's attitude below the benchmark. This traditional model uses lower partial moments (LPM) of X of order β at level B (Eq. (5)), of which the semi-variance (Eq. (1)) is a particular case