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A portfolio optimization model for a large number of hydrocarbon exploration projects

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Abstract. *Over the past few years the global oil and gas industry has been going through a severe market downturn. Despite recent signs of stabilization, oil prices have a long history marked by volatility. In this context, it is imperative for oil companies to optimize their capital allocation, as this might support risk mitigation. The purpose of this paper is to offer a tool that might support the strategic decision-making process for companies operating in the oil industry. Our model uses Markowitz' portfolio selection theory to construct the efficient frontier for currently producing fields and a set of investment projects. These relate to oil and gas exploration projects and projects aimed at enhancing current production. The net present value is obtained for each project under a set of user-supplied scenarios. For the base-case scenario we also model oil prices through Monte Carlo simulation. We run the model for a combination of portfolio items which include both currently producing assets and new exploration projects, using data characteristics of a mature region with a high number of low-production fields. Our objective is to find the vector of weights (equity stake in each project) which minimizes portfolio risk, given a set of expected portfolio returns. The model is of particular interest for companies operating in Eastern Europe, or in any other mature region. It can also support divestment and acquisition decisions since these may place the company's portfolio closer or farther away from the efficient frontier. The model is highly versatile and can be implemented on any software with an optimization package such as Microsoft Excel.*

Keywords: portfolio management, optimization, petroleum industry, efficient frontier, Monte Carlo simulation.

Introduction

The performance of every company is affected by the dynamics of its environment. For companies operating in commodity industries, external factors can be highly volatile. For example, the oil market has been experiencing a severe downturn over the past few years. Despite currently displaying some signs of stabilization, in recent years the volatility on this market has been extreme, with oil prices coming down from highs above 100 dollars per barrel in September 2014 to lows under 30 dollars per barrel in January 2016. This is not a new development as significant price swings have also been seen during the 2008 financial crisis. An event such as a major financial meltdown affects the entire global economy, but the oil market is also particularly susceptible to geopolitical events, especially those occurring in major producing countries. This makes the oil price impossible to forecast with any degree of accuracy. For capital allocation decisions, the uncertainty problem is further compounded by the fact that projects aiming to explore for or exploit new resources are typically highly capital intensive and can span over many years. Therefore, an investment

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decision for such projects requires planning over a long period of time, typically ten years or more. In this context it is imperative for companies to optimize their capital allocation across a wide range of potential scenarios, as this might represent a needed support for better risk management.

One of the methods used to optimize a company's portfolio is the application of the mean-variance model or efficient frontier concept. This originated in capital markets, where it was used to optimize an investor's portfolio allocation decision by taking into account both the expected return (the mean) and the risk (variance) associated with a particular financial asset. It was later applied at a corporate level by replacing financial assets with different investment projects where expected returns and risks are calculated based on discounted cash flows. Still, there are a number of particularities to consider when applying this methodology at the corporate level. We outline these in the literature review section.

We investigate the particular case of a fictional oil and gas company operating in a mature region, such as Eastern Europe. For this company we construct a realistic portfolio comprised of producing fields and new projects. The latter category is split into exploration projects and projects designed to enhance current production. We apply the efficient frontier methodology to the portfolio under five scenarios in which we vary a number of external parameters. We also conduct Monte Carlo simulations on the oil price and apply the same methodology for the 1000 oil price series obtained. These processes are detailed in the methodology section.

The main contribution of this paper comes from the implementation of the portfolio optimization model in the case of a company operating in the oil industry. Such a model can theoretically be implemented using any standard software containing an optimization package, such as Microsoft Excel Solver. However, the large number of items in the portfolio (100 in our case) can make the process of trying to find a global optimum a very lengthy one, especially when applying Monte Carlo simulations. On the other hand, specialized software designed specifically for the oil and gas industry may be difficult for a small company to implement. Our Matlab implementation has the advantage of being flexible and relatively cheap. Flexibility is essential when considering the inclusion of other types of assets in the model, such as refineries, petrochemical plants and power plants. Limitations of the model and future development opportunities are discussed at length in the last two sections of the paper.

Literature review

The portfolio optimization methodology used in this paper has its origins in the seminal work of Markowitz (1952). His portfolio selection theory showed that instead of simply aiming to maximize expected return, an investor must also take into account the risk associated with the investment. This is measured by the variance or standard deviation of the expected returns. For a higher level of risk, an investor would demand a higher level of return. As such, there exist portfolios which have the maximum expected return for a given level of risk, or the minimum level of risk for a particular expected return. These portfolios form the efficient frontier. Furthermore, if the expected returns of the individual assets in the portfolio are less than perfectly positively correlated, the portfolio standard deviation will be lower than the sum of standard deviations of the individual assets. Moreover, any rational investor would choose a portfolio located only on the efficient frontier and disregard the others, as the former would provide him/her with the best risk-return trade-off.

Markowitz' theory was first applied to capital markets, but was later adapted to aid companies in their investment decision-making process. However, application to investment projects is not straightforward since these differ in certain crucial respects from financial market investments. The most important difference comes from the relationships between projects (Devinney & Stewart, 1988). These can be very subtle and hard to quantify. For example, a hydrocarbon exploration project can add, even in the case of failure, knowledge regarding the region's geology. This knowledge can lead to improvements in other projects (Lopes & Almeida, 2013). Another important difference comes from the lower level of investment flexibility, as investing in small shares of a large number of projects may not be possible (Ball & Savage, 1999).

Portfolio optimization in the oil and gas industry has to deal with the additional complexity of multiple objectives and constraints. Apart from budget constraints and return targets, an oil and gas company may also have a certain level of hydrocarbon reserves as an additional goal. Multiple performance goals can lead to the absence of a feasible solution to the optimization problem (Howell III & Tyler, 2001). Even when an efficient frontier is successfully created, the question of which efficient portfolio to choose remains. Walls (2004) used decision analysis to augment portfolio optimization by applying the company's financial risk tolerance to help select an efficient portfolio. Furthermore, non-financial metrics relating to the company's strategic preferences must also be considered when selecting a portfolio on the efficient frontier. These can refer to, among others, project type (onshore, deep-water etc.) or geographical location (Willigers & Majou, 2010).

The basis for the portfolio optimization process is the discounted cash flow valuation of projects. The expected NPV (net present value) of each project is obtained under a set of predefined scenarios or through Monte Carlo simulation. The two approaches can be considered complementary (Allan, 2010; Tyler & McVean, 2001). Another method of project valuation used in the oil and gas industry, and not based on discounted cash flows, is real option valuation. The advantage of this method is that it accounts for managerial flexibility (Armstrong & Jehl, 1999; Fleten et al., 2011).

Tonnsen (2008) finds limitations to the efficient frontier portfolio optimization method when both expected return and uncertainty are seen as a function of budget (more drilling reduces uncertainty regarding oil and gas reserves). The author also points out that the level of granularity used in the analysis can influence results.

Data and methodology

We construct a portfolio which combines an E&P (exploration and production) company's existing fields with a set of projects aimed at increasing production from those fields, and a number of exploration projects. The portfolio is split as follows: 40 currently producing fields, 40 production enhancement projects, and 20 exploration projects. The data used are fictional, but realistic for a small company operating in a mature region. This is the reason why we use a large portfolio where most of the production can be attributed to a small number of fields or projects. For example, in the company's portfolio of producing fields, the top ten fields are responsible for 79% of total production. Furthermore, we apply a decline rate of 10% per year for the entire portfolio to reflect the maturity of the region. Sample production profiles for the three types of portfolio items are shown in figure 1. The currently producing fields decline during the entire period. For simplicity, we assumed that all production generated by the production enhancement projects comes on stream in 2021 and then declines, while production from the exploration projects increases during the first three years, and then declines. Realistically, oil and gas projects may exhibit different production patterns, with some plateauing for several years. Nevertheless, this does not affect the validity of our model.

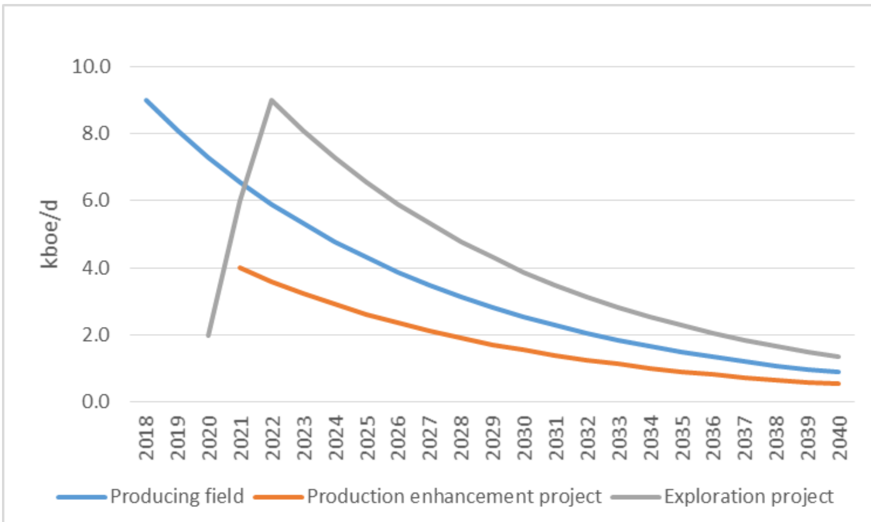

Figure 1. Production profile examples for the three types of portfolio items

Source: Authors' own calculations.

The expected NPV is calculated for each item in the portfolio under a set of internal and external parameters. The internal parameters are the probabilities of three production outcomes (base, high and low volumes) for the production enhancement projects, where high and low volumes are defined as a ±50% deviation from base volumes. For the exploration projects, a fourth outcome of geological exploration failure is added. The probabilities used are shown in figure 2. The external parameters considered are oil and gas prices, as well as the level of royalties, the latter defined as the share of production which goes to the government. For the purposes of this exercise we assume that this rate remains constant for the entire period and is independent of the type of project (onshore, offshore), production volumes or any other characteristics. In reality, fiscal regimes can be highly complex and vary considerably across countries or regions. The oil price used in valuing the entire oil production is assumed to be the Brent price. This is the main global benchmark oil price, but other benchmark prices more relevant to the geographical location of the company's operations can also be used, such as the Urals price for Eastern Europe.

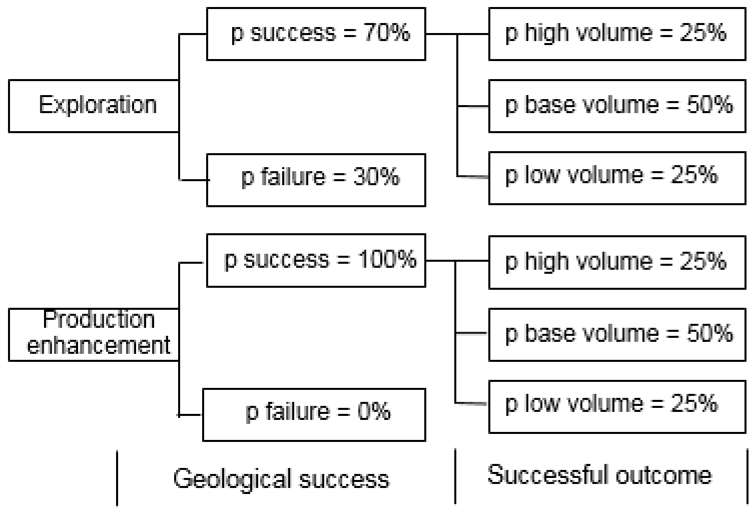

Figure 2. Probabilities applied to exploration and production enhancement projects

Source: Authors' own research.

These three parameters are varied across five scenarios. Other variables used in the expected NPV calculation are capital expenditure (CAPEX), operating costs per barrel of oil equivalent (OPEX), the oil/gas production split, abandonment costs, and the corporate tax rate. Both oil and gas production are measured in thousand barrels of oil equivalent per day (kboe/d); financial variables are measured in millions of US dollars. Cash flows are discounted over a period of 23 years (2018 – 2040). For the production enhancement projects, capital expenditures occur in 2021, while the CAPEX for exploration projects occurs in two phases: an exploration phase in 2018 and a development phase in 2019 if the exploration phase is successful. Currently producing fields have no CAPEX. OPEX varies for each field, but is assumed constant over the entire period. Abandonment costs are assumed to be incurred for each item in the portfolio during the final year. The corporate tax rate is set at 16% for each year. Cash flows are discounted at a rate of 10% per year. This is just a fixed rate typically used in the industry to compare NPVs across multiple projects. Investment decisions are generally made by considering the NPV in conjunction with other project metrics such as the internal rate of return.

We calculate the expected NPV for each portfolio item under each of the five scenarios considered, resulting in a 100×5 matrix on which we apply the Markowitz portfolio optimization theory as follows:

Minimize:

$$f(X) = X^T(cov(NPV^T)X) \quad (1)$$

Subject to:

$$\sum_{i=1}^{n} x_i E(npv_i) = r \quad (2)$$

(3)

$$\sum_{i=1}^{n} x_i capex_i = c \quad (4)$$

$$x_i \in [0,1]$$

Where X is a vector, the elements of which are bound to the interval [0,1] (4); NPV is the expected NPV matrix obtained previously; npv_i and $capex_i$ are elements of the NPV and CAPEX matrices, respectively, corresponding to the expected NPV and CAPEX of each item across the scenarios in the case of the former and the entire period in the case of the latter; r and c are the expected return and capex constraints, respectively; n is the number of items in the portfolio.

Our objective is to find the vector of weights (equity interest) for each portfolio item which minimizes the portfolio variance (1) subject to a portfolio expected return (2) and CAPEX (3) constraint. The CAPEX constraint is set at 2 billion US dollars for all runs (including the Monte Carlo simulation described below). Furthermore, each element in the vector of weights is bound to the closed interval [0,1]. This last restriction can be relaxed if a company aims to see which types of projects or assets are most attractive for its portfolio when considering a return target above that which can be achieved with full participation in all portfolio items.

Optimization is carried out using Matlab's global search algorithm. Any software with a solver package can theoretically be used. In order to ensure maximum portability, we first attempted to implement the model on Microsoft Excel's built-in solver package, but this proved unfeasible due to the long time (several hours) required to reach a solution. Furthermore, we are interested in obtaining a global solution, which the algorithm used is designed for.

On the base-case scenario, we apply Monte Carlo simulation for the oil price. This is done by sampling 1000 oil price series from a normal distribution with a mean of 35 dollars per barrel and a standard deviation of 26 dollars per barrel. The mean and standard deviation are based on historical oil price data (1861-2016) obtained from the BP Statistical Review of World Energy (BP, 2017). In order to avoid impossible or highly unlikely situations, we place an upper bound of 200 dollars per barrel and a lower bound of 20 dollars per barrel on the values returned. For practical purposes, a company may wish to use a mean and standard deviation corresponding to oil price data spanning the past several years, and not the entire series available, as done here. We obtain a 100×1000 matrix on which we apply the same process as before.

Results and discussions

We obtain the efficient frontier for both the five scenarios and the Monte Carlo simulation cases. These are shown in figures 3 and 4. The portfolio standard deviations corresponding to the different expected return values are smaller in the latter case. This is because here we only varied the oil price, while the other parameters (gas price and royalty level) remained constant, corresponding to the base-case scenario. As expected and shown in tables 1 and 2, the progressive increase in the expected return constraint results in more portfolio items being selected (equity interest higher than zero). Some remain unattractive even at a high level of expected return. As noted in the literature review section, the Monte Carlo and scenario approaches are complementary. The stochastic simulation of the first approach may seem particularly useful given the unpredictability of the oil price, but unlike this method which takes random numbers from the normal distribution, any scenarios used will not be random. Instead these would represent management's expectations regarding the future evolution of a set of variables. For this model we applied Monte Carlo simulation only to the oil price, but it can also be applied to other variables, including internal parameters such as the probabilities of exploration success. It may not make sense to apply it to certain variables, like those concerning fiscal conditions. In this case the presence of a random element is unlikely since a company may be in a position to influence, or at least better anticipate future fiscal measures through its dialog with the government. The gas price can be modelled in a similar fashion, but linking it with the oil price should also be considered. This is due to the similar cost structures of oil and natural gas operations, as both require exploration activities and the construction of specific infrastructure. Moreover, many natural gas supply contracts are linked to the oil price, at least in Europe.

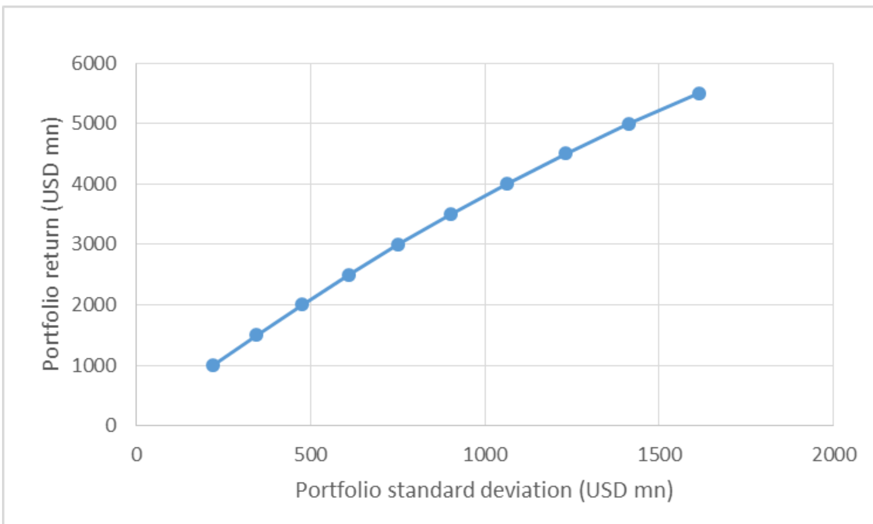

Figure 3. Efficient frontier based on five scenarios

Source: Authors' own research.

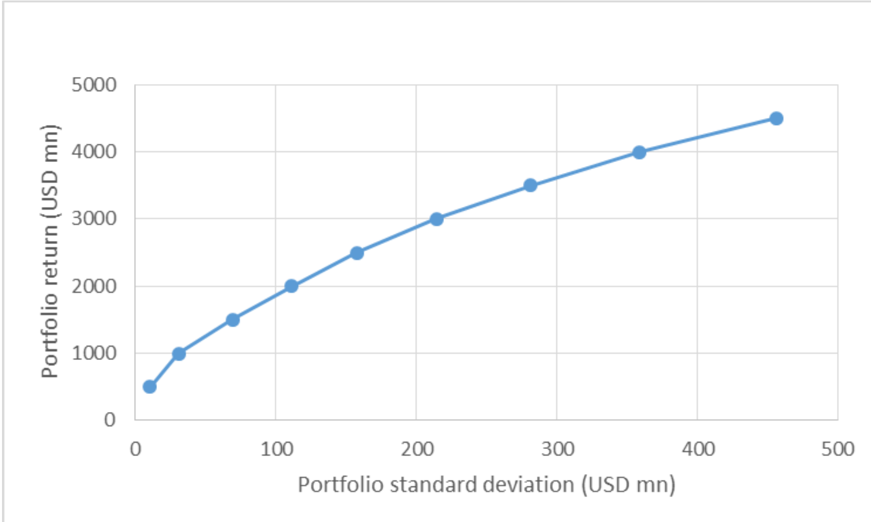

Figure 4. Efficient frontier based on Monte Carlo simulation for the oil price

Source: Authors' own research.

Table 1. Sum of portfolio weights for the three types of items corresponding to the efficient frontier points: five scenarios case

Portfolio return (USD mn)	1000	1500	2000	2500	3000	3500	4000	4500	5000	5500
Portfolio standard deviation (USD mn)	219	345	475	610	752	902	1062	1232	1414	1617
Currently producing	4.00	6.87	8.07	10.00	16.89	21.00	25.00	28.34	34.88	37.00
Production enhancement	1.55	5.00	7.00	9.90	12.00	18.92	26.00	27.00	30.00	34.00
Exploration	0.00	0.00	1.00	1.00	1.00	1.00	1.97	2.00	4.00	5.86

Source: Authors' own research.

Table 2. Sum of portfolio weights for the three types of items corresponding to the efficient frontier points: Monte Carlo simulation case

Portfolio return (USD mn)	500	1000	1500	2000	2500	3000	3500	4000	4500
Portfolio standard deviation (USD mn)	10	31	69	111	157	214	281	359	456
Currently producing	4.00	12.00	12.54	15.57	20.00	24.00	28.60	32.00	37.00
Production enhancement	5.00	11.77	14.00	17.00	19.92	22.97	29.30	34.00	38.00
Exploration	0.66	2.00	2.89	3.00	4.00	5.00	5.00	5.86	8.10

Source: Authors' own research.

The portfolio variance in the model presented here comes from the different proportions of oil and gas production applied to each item, and the variation in oil and gas prices. As such, we can see a strong positive correlation between the expected NPVs of each item in the portfolio. Most correlation coefficients are above 0.9, with the lowest at 0.8. This is to be expected since our fictional portfolio is bound to a limited geographical region with a single royalty regime and no foreign exchange rate fluctuations. A company operating in a single country may experience the same strong correlations. This does not invalidate our analysis since as long as all items are not perfectly positively correlated (i.e. the correlation coefficient is not equal to 1), there will still be room for optimization. Nevertheless, this methodology may prove more valuable for a company with operations in different parts of the world, subject to diverse market conditions.

This model can be useful in supporting management decisions, not just regarding new projects, but also for the company's current portfolio. The assignment of a zero weight for a currently producing field could indicate the need for divestment. A further advantage comes from considering a wider range of options for investment or divestment decisions. For our model, the results indicate a weight close to either zero or one for most items, but some have been assigned weights closer to 0.5. This shows that the best option in this case may be a joint venture. However, it is here that we see one of the practical limitations in implementing the efficient frontier concept for an oil and gas company, mentioned in the literature review section. Realistically, a company's portfolio will never be on the efficient frontier. Divesting certain assets may not be possible due to a lack of buyers or certain commitments, while having a stake of say 56.6666% in a project would also be impossible. Nevertheless, this is not the purpose of this model. It is meant to inform management decisions, not replace them. As such, management can quickly and easily see if certain investments or divestments bring the company closer to the frontier.

The efficient frontier methodology is highly scalable. It can be applied at the well, field, or division levels, although a high level of granularity may be unfeasible and unwarranted. In our portfolio, many producing fields have a very low output. These can be aggregated or excluded from the analysis entirely, without significantly altering the results. Furthermore, data at the well level may be inexistent or unreliable.

Conclusion

The model presented here is very basic, meant only to illustrate the application of the efficient frontier concept in a specific context. In order for it to be effectively applied, more variables must be included. In the model we assumed that all the oil produced is valued at the Brent price. In reality this is not the case. A company operating even in a relatively small region, such as a single mid-sized country, would likely produce crude oil of varying qualities. Therefore, a premium or discount to the Brent price (or any other benchmark price) should be considered. The exchange rate must also be taken into account. For a company operating outside the origin country, and outside the US in particular since oil and oil products are typically quoted in US dollars, foreign exchange rate fluctuations might have a tremendous impact on results. Quantifying this impact would require an in-depth analysis of its exposure to different currencies. Furthermore, the model does not consider the relationships between portfolio items. As noted previously, this is one of the main particularities in the application of the efficient frontier concept outside capital markets. This could be modelled as an adjacency bonus for E&P projects located in the same area, as these can benefit from common infrastructure, resulting in a lower CAPEX and/or OPEX. A more general "synergy factor" could be computed separately. This would not be an easy task since, as noted in the literature review section, relationships between projects can be subtle and hard to quantify.

All of the above will be the subject of further research. Specialized software exists on the market which can offer an E&P company these kinds of analyses. However, our Matlab implementation can potentially bring more flexibility. This flexibility is required in addressing an underexplored issue in the literature, namely integration. By integration, we do not understand a company which simply has both upstream and downstream businesses, the assets of which (refineries, power plants etc.) can be located on different continents. In this context, integration refers to a company which processes the raw materials produced into finished or semi-finished products (e.g. turning crude oil into gasoline, or turning natural gas into electric power or chemicals). As an example consider an E&P company which made a significant natural gas discovery and currently has limited opportunities to market this resource. If geography permits, it may decide to build a natural gas liquefaction terminal and ship the natural gas to more distant markets. It may also consider moving along the natural gas value chain. This could mean building power plants which would process the raw material into electric power that can be more easily transported. This would also cut the storage costs for the processed quantities. Another option would be the construction of a petrochemical plant which would process the natural gas into ethylene and polyethylene, with the possibility of moving even further along the chemicals value chain. We can see an example of how the sudden availability of crude oil and natural gas resources can drive integration on a massive scale in ExxonMobil's "Growing the Gulf" expansion program[1]. According to the company, this involves investing 20 billion dollars over ten years in large refineries, petrochemical plants and liquefied natural gas terminals along the American Gulf Coast. These are meant to process the recently unlocked unconventional crude oil and natural gas resources in North America.

There is ample room for increasing the complexity of the model, but too much complexity and a high level of granularity can make it difficult for management to comprehend. For example, results may show that a project with a negative expected NPV would add value to the overall portfolio. Nevertheless, applying the efficient frontier concept to a wider corporate portfolio can be of great benefit to a company's strategic decision-making processes.

References

Allan, P. D. (2010, January). Stochastic analysis of resource plays: maximizing portfolio value and mitigating risks. In SPE Annual Technical Conference and Exhibition. Society of Petroleum Engineers.

Armstrong, M., & Jehl, B. (1999). Comparison of three methods for evaluating oil projects. Journal of petroleum technology, 51(10), 44-49.

Ball, B. C., & Savage, S. L. (1999). Notes on exploration and production portfolio optimization. available for download from http://www. stanford. edu/~ savage or http://www. ziplink. net/~ benball.

[1] Source: company press release available at: http://news.exxonmobil.com/press-release/exxonmobil-plans-investments-20-billion-expand-manufacturing-us-gulf-region. Accessed November 28th, 2017

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BP (2017). BP Statistical Review of World Energy June 2017. Retrieved from https://www.bp.com/en/global/corporate/energy-economics/statistical-review-of-world-energy.html.
Devinney, T. M., & Stewart, D. W. (1988). Rethinking the product portfolio: A generalized investment model. Management Science, 34(9), 1080-1095.
Fleten, S. E., Gunnerud, V., Hem, Ø. D., & Svendsen, A. (2011). Real Option Valuation of Offshore Petroleum Field Tie-ins. Journal of Real Options, 1, 1-17.
Howell III, J. I., & Tyler, P. A. (2001, January). Using portfolio analysis to develop corporate strategy. In SPE Hydrocarbon Economics and Evaluation Symposium. Society of Petroleum Engineers.
Lopes, Y. G., & Almeida, A. T. D. (2013). A multicriteria decision model for selecting a portfolio of oil and gas exploration projects. Pesquisa Operacional, 33(3), 417-441.
Markowitz, H. (1952). Portfolio selection. The journal of finance, 7(1), 77-91.
Tonnsen, R. R. (2008, January). Application of the Efficient Frontier Concept to Resource Play Budget Evaluation and Portfolio Optimization. In SPE Annual Technical Conference and Exhibition. Society of Petroleum Engineers.
Tyler, P. A., & McVean, J. R. (2001, January). Significance of project risking methods on portfolio optimization models. In SPE Latin American and Caribbean Petroleum Engineering Conference. Society of Petroleum Engineers.
Walls, M. R. (2004). Combining decision analysis and portfolio management to improve project selection in the exploration and production firm. Journal of Petroleum Science and Engineering, 44(1), 55-65.
Willigers, B. J., & Majou, F. (2010). Creating efficient portfolios that match competing corporate strategies. SPE Economics & Management, 2(01), 12-18.