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THE EFFICIENT FRONTIER OF OIL PROJECTS PORTFOLIO AS A TOOL FOR DECISION-MAKING

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Abstract
The selection of portfolios of oil projects is an important concern for managers of large oil companies because of the huge amount of investment, requirements of production of oil and gas, limitation of money, staff, rigs, etc. The traditional analytical tool for selection of portfolios is the Markowitz's Mean-Variance model where the focus is purely on financial return. The final product of the Markowitz's model is the efficient frontier, which is a geometric curve composed by infinite number of viable portfolios. The *choice of the optimal portfolio among infinite possibilities is the final problem*, but the *Mean-Variance model does not recommend which one is the best portfolio.* We extend the Mean-Variance model in order to consider some goals of the corporation such as yearly production, constraint on investment, etc. Similarly, we find the efficient frontier of portfolios of projects. Again, we have the problem of which portfolio to select, that is, *the one with high return and risk or the other with lower return and risk*? In this paper we argue that if investors are diversified, managers should select projects with highest return, regardless of risk. However, in practice, if bonuses of managers are tied to their performance, the choice for portfolio with lower return and risk is possible, what is a classic agency problem.

Key Words: Portfolio selection, efficient frontier, oil projects, diversified investor, risk, and return.

1. Introduction

Despite high oil prices, decision-makers in the oil industry suffer an increasing pressure for higher returns for oil projects. However, there is a ubiquitous tradeoff between risk and return. Managers must be able to determine how much risk a firm can support, in order to avoid financial distress or low performance, and how much risk the firm is willing to accept. In this context, portfolio selection and management of projects has gained increasing role in the search for opportunities to generate value for investors.

The valuation and portfolio selection of financial assets has been widely discussed in many classic textbooks as Markowitz (1952), Fama (1972) and Luenberger (1998). In these books, the classical model consists of three mains steps:

i) Estimation of expected value and risk of the future rate of return of each financial assets (common stock, bonds, etc) using past data as a proxy;
ii) Selection of assets to compose the best portfolio under investor's perspective;
iii) Allocation of financial resources (investment) of investors among different selected financial assets.

The solution of this model is a typical problem of mathematical programming, where the objective is usually the maximization of expected return and the main constraint is the amount of investment.

The portfolio selection of projects is of different kind, especially for some industries such as petroleum, where projects demand high investments and have a long-term operational life. Apart from these, stocks differ from projects in: i) Standardization; ii) Life cycle; iii) High liquidity in competitive markets; iv) Existence of historical time series to estimate return and risk.

This paper introduces some concepts and techniques that can be employed as tools for managers in this hard task of choosing the optimal portfolio of projects. We make use of well known financial concepts, such as the efficient frontier of financial assets as well as other classical evaluation techniques.

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This remainder of this paper is structured in four sections. The first section presents the main procedures to estimate the risk and return of projects, while the section two shows the construction of the efficient frontier of portfolio of projects using a mathematical programming and an objective function to satisfy all restrictions. Section three presents how to choose the optimal portfolio of projects using four hypothetical oil projects and final section show the main conclusions.

2. How to estimate the return and risk of projects

The return of a project (R) depends on the evolution of variables such as price, cost, production, interest rate, inflation, etc. But, since we don't know how these variables will behave in the future, the return is a random variable and its true value will come from probability distribution.

Here we will make the assumptions that probability distribution of future values of return is Gaussian. Since the mean and variance are the input parameters of Gaussian distribution[1], we will be interested in these two variables.

The expected value of the one-period rate of return (R) commonly used in investment analysis and decision-making in financial assets is (eq.(1)):

$$\text{E[R]} = \frac{E[P(2)] - P(1) + E[D]}{P(1)}, \qquad (1)$$

where E[P(2)] is the expected price of asset in time 2, P(1) is the price of asset in time 1 and E[D] is the expected dividend cash paid at time 2, where the time interval may be a year, semester, month, etc.

Differently, the return of projects is not estimated according to Eq.(1) because it depends on cash flows over different years. In literature of economic analysis of projects and capital budgeting, Stermole and Stermole (2000), Ross et al. (2004), and Brealey et al.(2005) and suggest that net present value (NPV) and internal rate of return (IRR) are the mean indicators of return of projects[2].

The expected value of the random variable NPV (E[NPV]) of a project is defines as:

$$\text{E[NPV]} = \sum_{t=1}^{T} \frac{E[NCF(t)]}{(1+k)^t}, \qquad (2)$$

where E[NCF (t)] is the net cash in year t and *k* is the opportunity cost of capital or discount rate.

The NPV as stated in equation 2 is defined as the difference between cash in and cash out, that is, it refers to the added value to investors when projects are selected. In this way it is a measure of absolute return, different from the normalized return of equation 1.

The variance of the random variable NPV of a project is defined as:

$$\text{Var[NPV]} = \sum_{t=1}^{N} \left(\frac{1}{(1+k)^t} \right)^2 Var\left[NCF(t)\right] + 2\left(\frac{1}{(1+k)^t}\right)\left(\frac{1}{(1+k)^{t+1}}\right) \sum_{t=1}^{N} \sum_{t=2}^{N} Cov\left[NCF(t), NCF(t+1)\right]. \qquad (3)$$

The variance is the *square* of the spread of values of the variable around its expected value and is a measure of dispersion of data. Since the unit of variance is different from that of the variable, in practice we use the standard deviation because it has the same unit as the random variable.

Another popular measure of return of project commonly used in capital budgeting is a multi-period rate that is defined as:

[1] The Gaussian probability density function is:

$$\text{f(R)} = \frac{1}{\sigma\sqrt{2\Pi}} e^{-\frac{1}{2}\left(\frac{R-\mu}{\sigma}\right)^2}$$, where R is the random variable. It can be easily proved that:

$E[R] = \int_{-\infty}^{+\infty} RF(R)dR = \mu$, that is, the mean or expected value of R is one parameter of Gaussian distribution.

$Var[R] = \int_{-\infty}^{+\infty} (R - E[R])^2 F(R)dR = \sigma^2$, again, this means that the variance of R is the square of parameter σ.

[2] An empirical work of Campbell e Harvey (2001) shows that NPV is indeed the main indicator used by financial executives to make their decisions.

$$\sum_{t=1}^{T} \frac{E[NCF(t)]}{(1+IRR)^t} = 0. \qquad (4)$$

It is out of the scope of this paper the discussion between properties and comparisons involving NPV and TIR, but it is sufficient to say that NPV is the economic measure that must be preferred[3].

The estimation of the risk using equation 3 depends on the prior knowledge of the probability distribution of cash flows in time t, but, in practice, usually we don't have probability distribution of cash flow at time t. Alternatively, we estimate the risk of NPV according to:

- Modeling the dynamics in price, production, costs, etc using probability distributions[4];
- Run simulations of NPV using the Monte Carlo method;

Assuming that we have a thousand of values of NPV, we can carry out an exploratory data analysis and estimate the expected value and risk of NPV. This procedure will be used in this paper and will be delineate in the next sections.

3. The construction of the efficient frontier of portfolios of projects

Before presenting formally what is the meaning of efficient frontier, we consider a problem of Gamma Oil Corp, which is common to many corporations and has the following characteristics:

- *The company has the opportunity to invest in N projects;*
- *The yearly corporate budget is not enough to fund all projects;*
- *The corporate managers have the flexibility to make farm-in and farm-out in the projects;*
- *The company has requirements of production and cash flows each year.*

The problem is to find *the best combination of projects so that the NPV is the largest and risk is the minimum, considering restrictions of investment, goals of production and cash flows.*

The mathematical model to solve the problem has one objective function that is the maximization of return and restrictions. We will see that the *efficient frontier will appear as a geometric solution of this problem.*

The objective function is the maximization of NPV of portfolio:

$$\mathrm{E}\,[\mathrm{NPV_P}] = \sum_{i=1}^{N} x_i NPV_i \qquad (5)$$

The first restriction is the minimization of variance of the return of portfolio:

$$\sigma^2\,[\mathrm{NPV_P}] = \sum_{i=1}^{N} (x_i)^2 \sigma^2{}_i + 2\sum_{i=1}^{N} \sum_{j=1}^{N} x_i x_j \sigma_{i,j} \qquad (6)$$

The yearly investment in all these projects in each year is limited:

$$\sum_{i=1}^{N} x_i I_i(t) \le I^*(t) \qquad (7)$$

The yearly minimum requirement of cash flow is:

$$\sum_{i=1}^{N} x_i NCF_i(t) \ge NCF^*(t) \qquad (8)$$

The yearly requirement of production is:

$$\sum_{i=1}^{N} x_i Q(t) \ge Q(t)^* \qquad (9)$$

Equations 5 up to 9 represent the mathematical model whose solution gives the optimal working interest (x_i) in each project considering restriction of capital, goals of production and cash flows so that the *NPV of portfolio is maximized*.

Before presenting the complete model, consider that Gamma Oil Corp has the opportunity to invest in projects BC-01 and BC-02, whose expected value and standard deviation of NPV are in Table 1.

Table 1 – Expected value and standard deviation of NPV of two oil projects

Projects	E [NPV]	σ[NPV]
BC-01	US$ 100 million	US$ 50 million
BC-02	US$ 120 million	US$ 90 million

[3] Classical textbooks presents the main issues involving properties of main economic measures from cash flow (Stermole and Stermole, 2000 and Brealey and Myers , 2005).

[4] In order to estimate parameters of the probability distribution of price, cost, etc we can use past data.

The E[NPV] of projects BC-01 and BC-02 is dependent of variables that are common to both projects such as the oil price, interest rate, inflation, etc. Then, we have to consider that since E[NPV] of the two projects are dependent on oil price, they may move together up and down and may be correlated. In this case, we assume that the correlation coefficient between NPV of these projects is 50%.

In addition, we assume that the company *has the flexibility to allocate its budget between these two projects* and choose the best combination of risk and return of the portfolio.

Now, we can use equations 5 and 6 to estimate the expected value and standard deviation of NPV of the portfolio composed by projects BC-01 and BC-02. Results are in Table 2.

Table 2 – Expected value and standard deviation of NPV of projects

Working interest in BC-01	Working interest in BC-02	Standard deviation of NPV (Risk)	Expected value of NPV (Return)
100%	0	**90.00**	**120.00**
95%	5%	86.78	119.00
90%	10%	83.61	118.00
85%	15%	80.51	117.00
80%	20%	77.49	116.00
75%	25%	74.54	115.00
70%	30%	71.69	114.00
65%	35%	68.94	113.00
60%	40%	66.30	112.00
55%	45%	63.80	111.00
50%	50%	61.44	110.00
45%	55%	59.25	109.00
40%	60%	57.24	108.00
35%	65%	55.43	107.00
30%	70%	53.84	106.00
25%	75%	52.50	105.00
20%	80%	51.42	104.00
15%	85%	50.62	103.00
10%	90%	50.11	102.00
5%	95%	49.90	101.00
0%	100%	**50.00**	**100.00**

In Table 2, we see two extreme cases. First, if the corporation invests all his money in project BC-01 its return and risk is exactly those of the project. Second, if the company invests its entire budget in project BC-02, its risk and return will be equal to those of this project. Between these two extremes cases, there are infinite combinations involving participations of these two projects. In Figure 1 we present 21 combinations out of million that are possible.

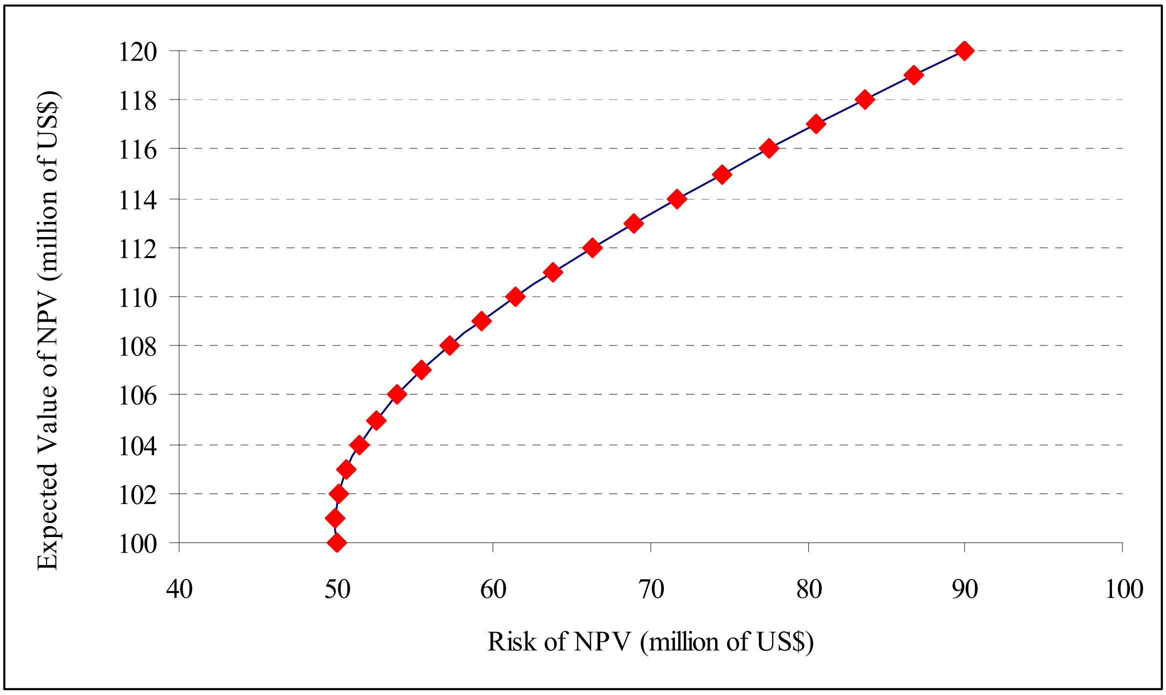

Figure 1 – Efficient frontier of projects BC-01 and BC-02

Figure 1 show the efficient frontier as the geometric place where E[NPV] is highest for a given risk. The efficient frontier also provides financial and strategic information about the return of the investment opportunity:

- As the risk increases, the expected value also increases and this is an indication that the decision-maker that takes decision according to Figure 1 is risk-averse[5];
- The efficient frontier provides to managers how much value can be added to investors for the company stock of productive assets and risk tolerance.

After obtaining the efficient frontier, the next step consists *in choosing the optimal portfolio* from those ones of the efficient frontier. We will discuss this point in the next section.

4. The choice of the optimal portfolio of oil projects

We consider that Gamma Oil Corp has the opportunity to compose a portfolio from four oil production projects, whose simplified cash flows are in the annex. The discount rate ranges from 8% up to 12% whereas mostly of the corporate tax is around 40%, except the project BC-04 located in an area of poor infrastructure that has a corporate tax equal to 20%.

The traditional economic analysis of future cash flows from each project indicates that their expected value and risk[6] of NPV varies widely, as shown in Figure 2.

[5] This seems to be a trick point. Since the distribution is normal, the probability the true return is above or below the expected value is 50%. Then, an increase in risk will not modify the probability of true return above or below its mean, but will indeed alter the quotient μ/σ.

[6] The estimation of risk of each project involves the probabilistic modeling of future values of cash flows using Monte Carlo simulation, but we will not go into the details of this methodology. Interested readers may consult, for example, Mian (2001).

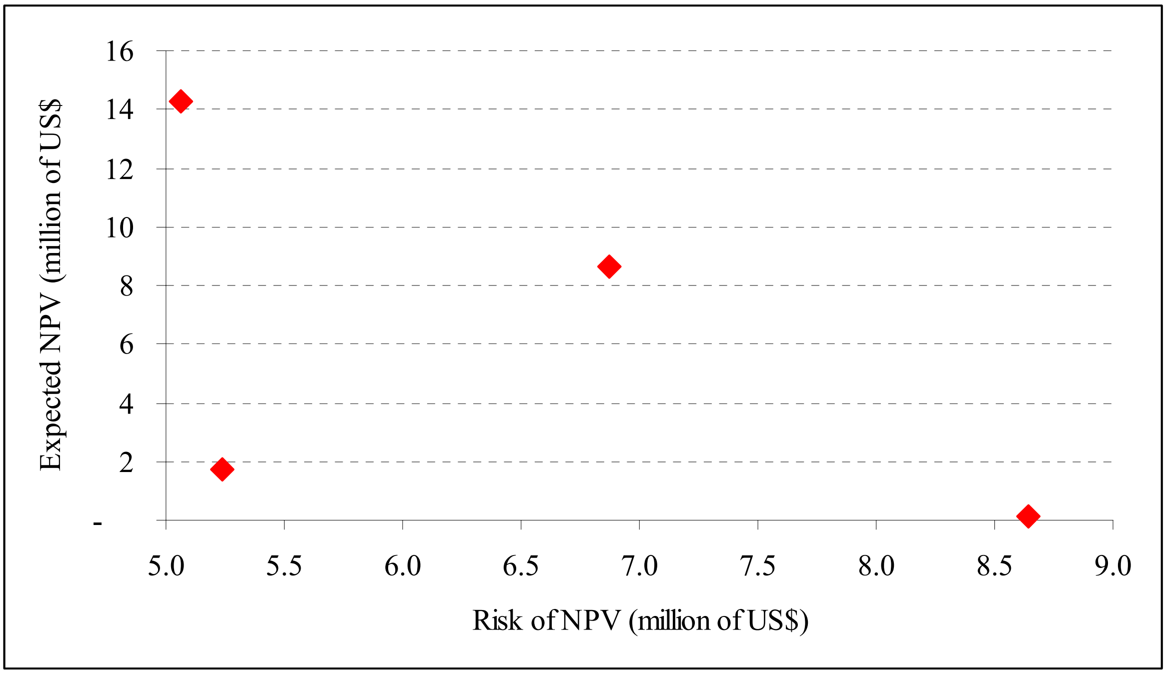

Figure 2 – Expected value and risk of NPV for all four projects

For example, project BC-01 has an expected NPV of around US$ 14 million and a risk of nearly US$ 5.0 million. On the other extreme, project BC-04 has an expected NPV of only US$ 96.3 thousand, but a risk equal to US$ 8.6 million. The choice of BC-01 or BC-04 may be inefficient, whereas a combination involving different projects may give better results.

Then, in spite of simply analyzing expected value and risk of NPV, the corporate objective is the maximization of its NPV derived from these projects taking into account yearly restrictions and goals shown in Table 3.

Table 3 – Yearly restrictions and goals of Gamma Oil Corp.

Years	**Restrictions on investment**	**Goals on production**	**Goals on cash flow**
2006	45,000,000.00	-	-
2007	50,000,000.00	-	-
2008	15,000,000.00	300,000.00	-
2009	3,000,000.00	700,000.00	-
2010	-	700,000.00	8,000,000.00
2011	-	700,000.00	8,000,000.00
2012	-	700,000.00	8,000,000.00
2013	-	700,000.00	8,000,000.00
2014	-	700,000.00	8,000,000.00
2015	-	500,000.00	8,000,000.00
2016	-	500,000.00	6,000,000.00
2017	-	500,000.00	3,000,000.00
2018	-	100,000.00	2,000,000.00
2019	-	-	-

From Table 3, the company has limitation of investment from year 2006 until the year 2009. From this period up, there is no more investment to be allocated in these projects. In terms of oil production, the company has many goals, especially the one to meet its market share that demands the production stated in column 3 of Table 3. Finally, there is requirement in terms of cash flows from the year 2010 until 2018. In year 2019, there is no requirement of both oil production and cash flows, but in reality, production and cash flows will be above this value.

If the corporation had a infinite budget, it would invest in all projects[7] and get a expected NPV equal to US$ 24.7 million and a risk of NPV of US$ 24.14 million[8]. Since the corporation has constraints of investment and requirements of production and cash flows, we have to find the efficient frontier of portfolios compounded of these four projects using the model described by the set of equations from 5 to 9. Results of this model are in Figure 3.

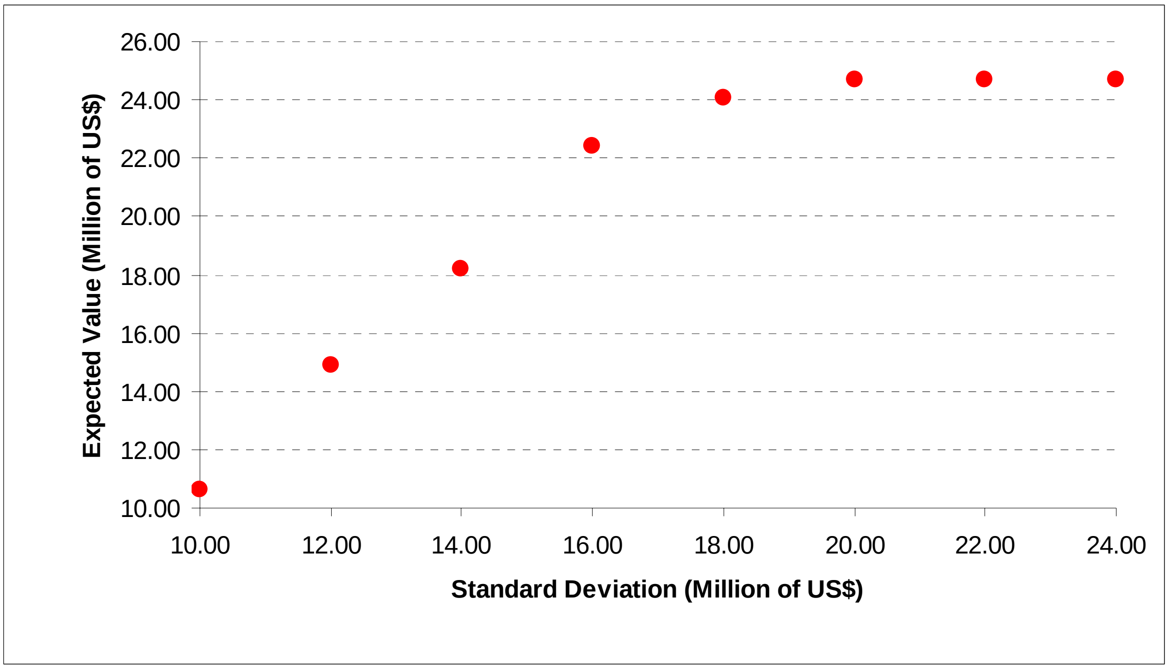

Figure 3 – Efficient frontier of portfolio of projects

The efficient frontier of portfolios displayed in Figure 3 presents 8 portfolios with different values of expected value and risk of NPV. The managerial problem here is the choice of the optimal portfolio.

The choice of portfolio depends on what kind of risk we are talking about. There are three ways to see the risk of a project:

- The risk of project in a isolated way, that is, if the corporation has only the project;
- The risk of project internally for the portfolio of projects of the company;
- The risk of project from the viewpoint of diversified investors.

After the choice of the type of risk, should we choose a portfolio with low risk, but also low return? Should we have a risk-prone behavior and choose a portfolio with higher risk? Here we will consider two approaches: 1) the non-diversified investor; 2) diversified investor.

4.1. The choice of diversified investor

Financial theory states that, if there are no market imperfections, the task of diversification and risk reduction belongs to shareholders, not to corporations. Under this assumption, managers should choose those portfolios located in the ***west side of the efficient frontier***, where there is a higher potential of return. Each investor decides his optimal risk-return relation, aiming to maximize his utility, by choosing between the amounts of risky and risk-less assets in his own portfolio.

In the real world, there are market imperfections, however, that causes internal diversification (i.e., risk reduction within the firm) to be optimal for shareholders. Stulz (1984) and Smith and Stulz (1985) show that in a world with taxes, informational asymmetry or bankruptcy costs, managers may increase firm value by internally managing the risk-return relation of the firm's projects.

If investors are not able to invest in as many stocks as it is necessary to fully diversify their risks, it may also be optimal to internally manage the company risk-return relation. This is the case of many emerging markets (e.g Brazil and China), for which there is only one major oil company that has liquid stocks being traded. For example, domestic small investors in Brazil are not able to diversify the risks normally associated to oil companies (such as geological and

[7] Actually, in order to invest in all projects, the corporation should invest around US$ 128.5 million to finance all these projects.

[8] Since we assume that the values of the NPV of portfolios are distributed as Gaussian model, there is 68% chance that the interval between US$ 575 thousands and US$ 48.8 million will comprise the true value of NPV.

operational risks) by investing in more than one oil company, since Petrobras is the only oil company that has liquid stocks being traded at the São Paulo stock exchange (BOVESPA). We address this issue in the next section.

4.2. The choice of the undiversified investor

Here we discuss the choice of the optimal portfolio for non-diversified investors. If we have two portfolios with the same expected NPV, but one has a lower risk, the choice of a risk-averse investor is straight: *choose the portfolio with lowest risk*. But, if we have tow portfolios where one has lower expected value and risk of NPV where the other has higher expected value and return of NPV, the choice is not obvious: it depends on the *preference of risk/expected value of investor*.

The microeconomic theory of choices under uncertainty can be used to help managers decide which portfolios to select. According Raiffa (1968), if the NPV is distributed as a Gaussian model, the certainty-equivalent (CE) can be approximated as:

$$CE = \mu - \frac{1}{2T}\sigma^2 , \qquad (9)$$

where T is the risk tolerance of the decision-maker (managers). We will use equation 9 to find the certainty-equivalent of each portfolio and choose the one with the highest CE.

The estimation of T is a complex task, since it depends on economic conditions, psychological characteristics, among others, and is out of the scope of this paper. We assume that risk tolerance of managers is US$ 20 million. In Figure 4 we present the CE of the 8 portfolios of oil producing projects.

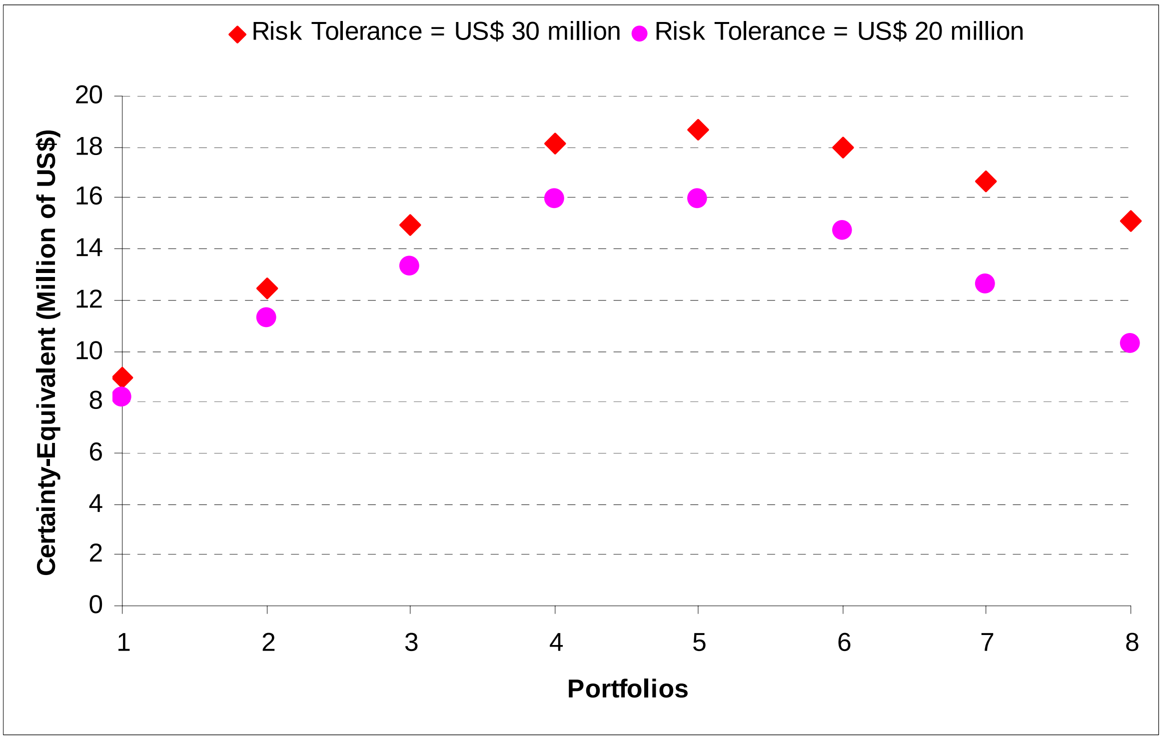

Figure 4 – Certainty-Equivalent of portfolios of projects.

The CE depends on intrinsic characteristics of the project as well as risk attitudes of decision-maker through the risk tolerance. If T is US$ 20 million, the CE of projects with low or high risk is low. This has an important interpretation. Since managers are rational, but also risk-averse, we have:

- **Low expected value and low risk of NPV of portfolio**. In this case, the CE is low because the return is low, not because of the risk. The decision-maker is prone to accept more risk, as long as the return increases.
- **Medium expected value and risk of NPV of portfolio**. An increase in expected return with an acceptable raise in risk will enlarge the CE. This is what has happened with portfolio 4, which has a CE equal to US$ 15.99 million.
- **High expected value and risk of NPV of portfolio**. In this situation, the expected value is high, which might increases the utility of decision-maker, but the risk is excessive and this gives rise to low certainty equivalent.

The certainty-equivalent depends strongly on the risk tolerance of decision-maker. An increase in risk tolerance may turn the certainty-equivalent curve to become linear with risk. As we can see in the preference theory, the risk tolerance T, has a considerable impact on the valuation of a risky project. So, preference analysis is appealing because it enables the company's decision makers to utilize a relatively consistent measure of valuation across a broad range of portfolios.

5. Conclusions

This paper has discussed some concerns about the choice of the optimal portfolio from the efficient frontier. The choice must be according to a number of considerations, but the most important findings are:

- If the investor is diversified, the manager should select the portfolio with the highest return, regardless of its risk;
- Because the manager's bonus depends on the success of his decisions, portfolios with lower risk may be selected, giving rise to a agency problem in which the manager cares more about his carrier than the wealth of investors;
- The most sound risk indicator of projects is not the standard deviation of NPV or NPV/I because it makes no difference between upside and downside, but the probability of negative NPV;

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Appendix

Project BC-01 - [Discount rate = 10%; Corporate tax = 40%]

Year	Invest.	Prod.	Price	Cost	NCF
2006	8,000,000.00				-8,000,000.00
2007	2,500,000.00				-2,500,000.00
2008	2,000,000.00	150,000.00	35.00	15.00	-200,000.00
2009		350,000.00	35.00	15.00	4,200,000.00
2010		500,000.00	35.00	15.00	6,000,000.00
2011		600,000.00	35.00	15.00	7,200,000.00
2012		600,000.00	35.00	15.00	7,200,000.00
2013		500,000.00	35.00	15.00	6,000,000.00
2014		400,000.00	35.00	15.00	4,800,000.00
2015		300,000.00	35.00	15.00	3,600,000.00
2016		200,000.00	35.00	15.00	2,400,000.00
2017		100,000.00	35.00	15.00	1,200,000.00
2018		100,000.00	35.00	15.00	1,200,000.00
2019		100,000.00	35.00	15.00	1,200,000.00
Results					
NPV BC-01	14,271,218.56				
Risk	5,066,839.00				

Project BC-02 - [Discount rate = 8% and Corporate tax = 40%]

Year	Invest.	Prod.	Price	Cost	NCF
2006	10,000,000.00				-10,000,000.00
2007	7,000,000.00				-7,000,000.00
2008	5,000,000.00	0.00	35.00	15.00	-5,000,000.00
2009	3,000,000.00	0.00	35.00	15.00	-3,000,000.00
2010		400,000.00	35.00	15.00	4,800,000.00
2011		600,000.00	35.00	15.00	7,200,000.00
2012		600,000.00	35.00	15.00	7,200,000.00
2013		500,000.00	35.00	15.00	6,000,000.00
2014		400,000.00	35.00	15.00	4,800,000.00
2015		400,000.00	35.00	15.00	4,800,000.00
2016		400,000.00	35.00	15.00	4,800,000.00
2017		100,000.00	35.00	15.00	1,200,000.00
2018		100,000.00	35.00	15.00	1,200,000.00
2019		50,000.00	35.00	15.00	600,000.00
Results					
NPV BC-02	1,746,462.82				
Risk	5,240,435.00				

Project BC – 03 - [Discount rate = 10%; Corporate tax = 40%]

Year	Invest.	Prod.	Price	Cost	NCF
2006	13,000,000.00				-13,000,000.00
2007	18,000,000.00				-18,000,000.00
2008		300,000.00	35.00	15.00	3,600,000.00
2009		600,000.00	35.00	15.00	7,200,000.00
2010		600,000.00	35.00	15.00	7,200,000.00
2011		600,000.00	35.00	15.00	7,200,000.00
2012		600,000.00	35.00	15.00	7,200,000.00
2013		600,000.00	35.00	15.00	7,200,000.00
2014		600,000.00	35.00	15.00	7,200,000.00
2015		600,000.00	35.00	15.00	7,200,000.00

2016		600,000.00	35.00	15.00	7,200,000.00
2017		600,000.00	35.00	15.00	7,200,000.00
2018		100,000.00	35.00	15.00	1,200,000.00
2019		100,000.00	35.00	15.00	1,200,000.00
Results					
NPV- BC-03	8,610,095.95				
Risk	6,874,516.00				

Project BC-04 - [Discount rate = 12%; Corporate tax = 20%]

Year	Invest.	Prod.	Price	Cost	NCF
2006	20,000,000.00				-20,000,000.00
2007	30,000,000.00				-30,000,000.00
2008	10,000,000.00	400,000.00	38.00	15.00	-2,640,000.00
2009		500,000.00	38.00	15.00	9,200,000.00
2010		600,000.00	38.00	15.00	11,040,000.00
2011		700,000.00	38.00	15.00	12,880,000.00
2012		700,000.00	38.00	15.00	12,880,000.00
2013		700,000.00	38.00	15.00	12,880,000.00
2014		700,000.00	38.00	15.00	12,880,000.00
2015		700,000.00	38.00	15.00	12,880,000.00
2016		500,000.00	38.00	15.00	9,200,000.00
2017		300,000.00	38.00	15.00	5,520,000.00
2018		200,000.00	38.00	15.00	3,680,000.00
2019		100,000.00	38.00	15.00	1,840,000.00
Results					
NPV BC-04	96,256.20				
Risk	8,646,812.00				