DETERMINATION OF THE MOST ADEQUATE OIL RIG FLEET USING THE REAL OPTIONS APPROACH

Albino Lopes d'Almeida[1]

Petrobras

E-mail: albinold@petrobras.com.br

ABSTRACT

Oil drilling is a complex activity, involving onshore and offshore drilling and production units, which vary in size and degree of technological complexity. It is a risky business, with high costs and variable remuneration in time, subject to market conditions (e.g. oil price and rig availability). Drilling activity is as an American option, which can be exercised at any time until its expiration, temporarily or totally interrupted at any time, and pays dividends. This work aims to assist an oil drilling rig owner in deciding among different options (operation, temporary suspension, exit from business) and to determine the most adequate drilling rig fleet composition, based on the real options approach Many variables are involved in the process: rig day-rate, new rig acquisition cost, rig temporary suspension cost, rig reactivation cost, rig maintenance cost, rig operational cost, rig abandonment cost, risk-free discount rate, convenience rate and rig day rate volatility. The best composition is obtained by determining optimal switches among the options supposing correspondent day-rate intervals associated with each rig type. The problem is represented by two sets of complex partial differential equations, which are solved by numerical methods. Finally, a sensitivity analysis is performed to present the effect on both the optimal decision rule (abandonment, temporary stopping, continuity, reactivation, business entry) and the rig value, taking into account the embedded options.

Keywords: Real Options, Petroleum, Drilling, Rig, Rig day-rate

1 INTRODUCTION

The oil drilling activity is basically the leasing of a drilling rig from a petroleum company (or its representative) and its operation for petroleum prospect and production. The drilling rig operation is complex, involving onshore and offshore units, for drilling or production, varying in size and degree of technological complexity. The cost per day of a drilling rig (the day-rate) varies enormously over time, as a function of market conditions dictated by oil price, and rig type or category. Other factors include cost variation for raw materials and manpower, regulatory rules (safety, environment, certification) and partnership formation.

A drilling operator company acquires or constructs a unit and receives, in general, day-rate remuneration from the oil company that uses the rig. In some cases it receives an incentive bonus for operational performance or low equipments unavailability. There are also turn-key contracts in which a fixed value is received for a well drilling, independent from the duration. Its application is, however, more restrictive, because it can lead to priority in operation speed and not in well quality.

The remuneration value is affected by economic uncertainty (motion of market influence factors) or by technical uncertainty (new technologies, obsolescence, new contract types and performance of recently-installed equipments). The drilling rig is depreciated by use and by maintenance needing; and the technological development renders it less competitive. Therefore, total return can be reduced by lease day-rate fall or by rig useful life decrease.

The volatility of day-rate overtime is very high, suggesting that economic evaluations based on the net present value (NPV) are inadequate. It is more serious the greater the values involved and the importance of the decision-making. Thus, the companies support periods of negative cash flow in expectation of the situation reversal, as they know that exit – and eventual comeback – has a cost and prevents (or makes difficult) the realization of future profits in case of market recovery. However, it is usual that the nearer the end of rig useful life, the smaller the tendency to support such losses.

In general the rig operating cost presents a nearly constant behavior, since asset depreciation is a very significant part. Even for onshore rigs, where manpower cost has a greater influence, the operating cost does not vary too much in the short or medium terms, since the market is local and less globalized. In Brazil the strongest effect on the exchange rate variation occurred in the beginning of 1999 and in 2002, as Real (the Brazilian currency) had a devaluation in relation to dollar, reducing manpower cost in comparison to international standards.

As rig day-rate is extremely variable, the rig ownership is economically very attractive in periods of high demand; this is decreased when the market cools off and falls of current rates. Thus, decisions about drilling rig acquisition or its sale, operation interruption or reactivation, must be preceded by a detailed and dedicated study, considering managerial options and available time to exercise these options, and avoiding inopportune, frequently irreversible, attitudes (D'Almeida, 2000)..

2 MODEL FOR OPERATION, TEMPORARY STOP AND ABANDONMENT

Real options theory, though recent, presents a large quantity of studies for the petroleum industry (Dias, 2005), mainly for the determination of economic viability of producing fields and for bidding proposals for exploration areas (Paddock & Siegel & Smith, 1988). However, a few works are available in the drilling activity.

In the 1980s a study was conducted in a Chilean copper mine exploitation (Brennan & Schwartz, 1985), considering options of activity, temporary suspension and definitive abandonment. Along with this, Dixit & Pindyck (1994) developed a robust, complete model, which will be adapted for this research study.

It is assumed that the drilling activity is as an American option, which can be exercised at any time until its expiration, temporarily or totally interrupted at any time, and pays dividends. This interruption may be reverted – with reentry or reactivation at any moment, even with such losses as qualification (technical excellence is quickly dissolved when it is not continuously exercised), teams, customer loyalty, image and prestige in the market or inside the community, and equipment scrapping.

In this continuous process model costs are deterministic and return is function of two variables: a stochastic variable represented by the value of the rig freighting charge (P), and the discrete variable, indicating the actual status of the rig. The addition of new stochastic variables would rapidly increase the model complexity without a proportional improvement in the results accuracy.

Variable P is modeled by a Geometric Brownian Motion. The selection of this method is function of the limited useful life of the rigs (ranging from 20 to 30 years) and of continuous technological innovations that cause obsolescence (state-of-the-art floating units are relatively recent). As historical series of more than 30 years would not be available, the use of the Mean-Reverting Process (MRP) would not be appropriate, besides introducing a greater degree of complexity (hyper geometrical functions with infinite series).

The fluctuation of price P is represented by the Contingent Claims Method (CCM), since the rig leasing market is sufficiently complete and this method does not require the calculation of an exogenous risk-adjusted discount rate. The use of dynamic programming would be equivalent to CCM if neutral evaluation of risk is adopted (Dixit & Pindyck, 1994).

A flag defines the actual rig state: 0 (inactivity, the rig was sold, disposed or without conditions for utilization), 1 (rig in activity or available for operation) or m (rig temporarily stopped, waiting for better market conditions).

For each state the associated opportunity values are defined, as follows:

$V_0(P)$ = Value of the option to invest, supposing that the rig is idle;

$V_1(P)$ = Value of the operation profit (or loss) plus the value of option to interrupt or exit the activity; and

$V_M(P)$ = Value of the option to reactivate or abandon, considering the rig temporarily stopped.

Four threshold values are identified, corresponding to boundary regions for the type of attitude to take. They are: P_L, P_M, P_R and P_H, where $0< P_L <P_M <P_R <P_H < \infty$. In some special conditions, consecutive values may be equal.

P_L represents the abandonment value, and when it reaches a low value it seems a complete exit from activity, since the probability of recovery is minimum. It is the point where the exercise of the abandonment option is optimum.

P_M is the threshold for temporary stopping option, and indicates that the activity must be discontinued due to its low value, but interruption must be temporary, waiting for a future comeback.

P_R is the threshold for reactivation option, and drives to an activity recovery, in case the rig is temporarily stopped. However, it is not sufficiently high to justify an entry (or reentry) in business, if the rig is no more available.

P_H is the threshold for the investment option or for reentry, attractive enough to justify a reentry (or comeback to) in the business, or even the expansion for those who are already in the business, since demand conditions and capacity are adequate and justify the sale or the construction of a new rig.

In this way, these four values define five zones of attitudes, as shown in Figure 1. Zone I corresponds to abandon the activity; in zone II the rig is stopped, but ownership is maintained and there are conditions to put it in operation (reactivation).

Zone III is called the “hysteresis zone” in which current state is maintained, as the value of the stochastic variable is not sufficient for an attitude change: it is neither high enough to justify a rig stopping, nor low enough to justify the rig interruption. Zones IV and V show rigs in activity.

While in the latter an entry or an expansion is possible, in the former reactivation is only justified for a temporarily stopped unit.

The cost-related variables of rigs used in the model are:

– P = Rig day-rate;
– I = Acquisition (or construction) cost of a new rig;
– C = Rig operational cost;
– EM = Immediate cost (lump-sum) of the temporary suspension of the rig;
– R = Immediate reactivation cost (lump-sum) of the temporarily stopped rig;
– M = Maintenance or conservation cost of the temporarily stopped rig;
– ES = Immediate abandonment cost (lump-sum), supposing a rig temporary stoppage;
– E = Immediate abandon cost (lump-sum), considering the rig in activity.

These variables present a known, constant cost, in which P, C and M are expressed in millions of dollars per year, and the remaining variables are expressed in millions of dollars.

The following variables are also employed in the model:

– V(P) = Value of the investment project (in millions of dollars);
– r = Risk-free discount rate, real and after taxes (in % per year);
– σ = Volatility or standard deviation of the rate of the stochastic variable P by unit of time (in % per year);
– δ = Convenience rate, which measures the benefit generated by the operating rig. It can be interpreted as a dividend rate; ratio between net cash flow (freight charge minus operation cost and minus taxes) and the rig market value; or, alternatively, the net discount rate, that is function of the attractiveness rate (or the money opportunity cost) required for the investment, calculated by: $\delta = \mu - \alpha$.

Several assumptions must be made about interdependence of variables, as follows:

– Reactivation cost shall be smaller than a new rig acquisition cost ($R < I$), or the temporary stop should not occur; the same reasoning can be extended to the relationship between the maintenance cost and the operational cost ($M < C$);
– The variable P supposes the utilization expectation during a year. Thus, if the day rate is US$ 100,000 and the rig is expected to spend 45 days out of operation – due to repairs, improvements or lack of demand, P will be US$ 32,000,000 per year;

- The passage from an active state to an exit state may be direct (cost E) or by stages (cost EM + ES), where E = EM + ES;
- The variable E can assume negative values, if there is a residual value for the unit sale, which must be superior to exit expenditures. This means that the cost is not sunk, that is, the investment would not be totally irreversible, and present an alternative use;
- In any way, E + I > 0, or we would have a "perpetual machine to make money", it means that we would enter in the business only for the profit to exit, and this process would be indefinitely repeated ("arbitration"). In other words, the acquisition cost of a new rig cannot be smaller than the sale price of a used one, with the same characteristics and in the same instant;
- The variables EM and M are inversely correlated. In order to interrupt the rig activity, costs of labor indemnities, breach of contracts and legal liabilities in relation to environmental and safety conditions are incurred. The higher the immediate cost EM, the smaller the continuous maintenance cost M;
- In general, personnel have a strong impact on a rig suspension. There are three hypotheses for this impact. They include employees´ dismissal with payment of all labor rights (including fine of 40% on the Worker's Guarantee Fund); indemnity due to additional amounts and alteration on administrative work with low remuneration; and maintenance of all rights and payments (in the expectance that would be a short duration stop). These conditions present a decreasing order of values for EM, but an increasing order for M (respectively near-zero cost, partial cost and total cost);
- The values of EM and M depend on the stopping time interval and on the magnitude of the corresponding costs. If reactivation is shortly expected, it should be attractive to keep the team, only reducing costs related to transportation, hotel and eventual services; it is the so-called "mothballed state". In case of a "cold stacked" state, corresponding to a low probability of a soon comeback, minimum maintenance, removal of majority of the team and almost total stoppage of service and supporting contracts are taken into account;

- M and R are related variables. A smaller cost of M (personnel dismissal, little attention to conservation of unit operating conditions, cannibalization and rig deterioration) implies a higher reactivation cost and vice-versa;
- Variable R also depends on necessary requisites for a new actuation stage. If previous conditions are maintained, R assumes a very low value. However, if the new demand requires conversions and additional equipments, R may be significantly higher;
- As the useful life of rigs is superior to 20 years, it can be considered as a perpetual option ($\tau = \infty$);
- Discount rates for revenues and costs are not necessarily equal, since cash flows have different risks;
- Total return from an asset (μ), is the sum of capital gains (valuation/devaluation) plus distributed dividends. In the case of asset "drilling rig", a warm period in the market increases the asset value (capital gains for the rig owner), and this asset also distributes dividends in the form of cash flow from freightage;
- Return generated by rig freight charge increases at a rate α, due to its associated risk, discounted by a risk-adjusted rate μ. As a consequence, the present value is obtained by: $\int_0^\infty P.e^{\alpha t}.e^{-\mu t} = P / (\mu - \alpha) = P / \delta$;
- Operational cost is constant and discounted by risk-free rate r. Its present value is given by: C/r;
- In the suspension state, we cannot determine *a priori* the time interval (may become definitive) and the present value of the conservation cost is obtained by: M/r;
- In the temporary suspension to reactivation, there is a marginal cost which present value, given by: (C – M)/r;
- There is no time interval between the option exercise (abandonment, suspension, reactivation, entry) and the corresponding cash flow. Consequences are immediate, without waiting time or deferments;
- There is no obsolescence during the rig useful life. If so, the thresholds P_H and P_L would be increased by a factor associated with a depreciative effect.

3 MATHEMATICAL MODELING

The three current states for the rig (0, m, 1) can be represented from the optimization equations given by the CCM method (Dixit & Pindyck, 1994).

For each state a partial differential equation is obtained by a general solution composed by terms representing possible opportunities and adequate boundary conditions. The terms include constants to be determined (A_1, A_2...) and quadratic equation roots (β_1 positive, β_2 negative) that represent the stochastic variable modeling. These roots are calculated by:

$$\beta_1 = ½ - (r - \delta) / \sigma^2 + \sqrt{w} \quad (1)$$

and

$$\beta_2 = ½ - (r - \delta) / \sigma^2 - \sqrt{w} \quad (2)$$

where

$$w = [(r - \delta) / \sigma^2 - ½]^2 + 2 . r / \sigma^2 \quad (3)$$

and

$\beta_1 > 1$, $\beta_2 < 0$, $r > 0$, $\delta > 0$.

For state 0 (idle) that occurs in the interval $[0, P_H]$ we have:

$$½ . \sigma^2 . P^2 . V_0''(P) + (r - \delta) . P . V_0'(P) – r . V_0(P) = 0 \quad (4)$$

The general solution is:

$$V_0(P) = A_1 . P^{\beta 1} + A_2 . P^{\beta 2} \quad (5)$$

Where the terms represent the option to enter in activity. As in the inferior limit 0 the option value tends to be null ("absorbent barrier"), A_2 (corresponding to negative root β_2) is also null and the solution is reduced to:

$$V_0(P) = A_1 . P^{\beta 1} \quad (6)$$

For state 1 (active), that occurs in the interval $[P_L, \infty]$, we add to the previous differential equation a term corresponding to cash flow due to the actuation, leading to:

$$½ . \sigma^2 . P^2 . V_1''(P) + (r - \delta) . P . V_1'(P) – r . V_1(P) + (P – C) = 0 .. \quad (7)$$

The general solution is:

$$V_1(P) = B_1 . P^{\beta 1} + B_2 . P^{\beta 2} + (P/\delta) – (C/r) \quad (8)$$

Where the first term corresponds to the abandonment option, the second temporary stop and the last two terms to keep activity. In the superior limit ∞, the abandonment option value tends to be null, and B_1 (corresponding to positive root β_1) goes to 0 and the solution is restricted to:

$$V_1(P) = B_2 \cdot P^{\beta 2} + (P/\delta) - (C/r) \quad (9)$$

For state m ("lay-up") that occurs in the interval [P_L, P_R], a term corresponding to the maintenance cost is added to the differential equation, as follows:

$$\tfrac{1}{2} \cdot \sigma^2 \cdot P^2 \cdot V_m''(P) + (r - \delta) \cdot P \cdot V_m'(P) - r \cdot V_m(P) - M = 0 \quad (10)$$

The general solution is:

$$V_m(P) = D_1 \cdot P^{\beta 1} + D_2 \cdot P^{\beta 2} - (M/r) \quad (11)$$

Where first term corresponds to the option to reactivate, the second term to abandonment, and the last term to keeping the temporary suspension. As the limits are intermediary regions, no term can be eliminated.

In the four boundary terms occur the alterations of activity state. As we have three states (n), six (n *(n – 1)) changing points can occur.

In P_H, we pass from state 0 to 1, at a cost I.

In P_R, we pass from state m to 1, at a cost R.

In $P_{M,}$ we pass from state 1 to m, at a cost EM.

In $P_{L,}$ we pass from state m to 0, at a cost ES; or from state 1 to 0, at a cost E.

There is no possibility to pass from state 0 to m since there would not make sense that a rig owner out of the activity enters in it, keeping the rig idle. It would be more logical to wait for a value that could justify an effective entry without the payment of conservation costs in this time interval.

In these boundary conditions managerial actions are incorporated to the model. Using relationships given by four out of the five mentioned boundary conditions and recalling that in a optimum stoppage problem with binary decision to stop or to continue, there is a boundary-free region (free diffusion of Geometric Brownian Motion) in which the value of the first derivatives of the alternatives are equal.

Therefore, each state change corresponds to an option exercise. A compound option set is formed and the solution implies the simultaneous prices for all the options.

We have eight equations with eight positive unknowns: the boundaries P_L, P_M, P_R, P_H and the coefficients A_1, B_2, D_1 and D_2. They can be solved in two blocks. The first one considers the interaction between temporary stopping and reactivation that generates four equations to four unknowns (P_R, P_M, D_1, B_3 where $B_3 = B_2 - D_2$). Then,

$$- D_1 . P_R^{\beta 1} + (B_3 . P_R^{\beta 2}) + (P_R /\delta) - (C - M)/r - R = 0 \quad (12)$$

$$- \beta_1 . D_1 . P_R^{\beta 1-1} + (\beta_2 . B_3 . P_R^{\beta 2-1}) + (1 /\delta) = 0 \quad (13)$$

$$- D_1 . P_M^{\beta 1} + (B_3 . P_M^{\beta 2}) + (P_M /\delta) - (C - M)/r + EM = 0 \quad (14)$$

$$- \beta_1 . D_1 . P_M^{\beta 1-1} + (\beta_2 . B_3 . P_M^{\beta 2-1}) + (1 /\delta) = 0 \quad (15)$$

Considering conditions of abandonment and entry (or reentry) and the determination of the unknowns, P_L, P_H, A_1 and D_2 are generated by Equations 16 to 19, as seen as follows.

$$- A_1 . P_H^{\beta 1} + (B_2 . P_H^{\beta 2}) + (P_H /\delta) - (C /r) - I = 0 \quad (16)$$

$$- \beta_1 . A_1 . P_H^{\beta 1-1} + (\beta_2 . B_2 . P_H^{\beta 2-1}) + (1 /\delta) = 0 \quad (17)$$

$$(D_1 - A_1) P_L^{\beta 1} + (D_2 . P_L^{\beta 2}) - M/r + E = 0 \quad (18)$$

$$\beta_1 . (D_1 - A_1) . P_L^{\beta 1-1} + (\beta_2 . D_2 . P_L^{\beta 2-1}) = 0 \quad (19)$$

4 CASE STUDY

The present study considers a jack-up platform similar to the MLT 116C (Marathon Le Torneau, cantilever) with top drive and capacity for 100m water depth. Costs considered in the study are not related to a specific drilling rig, or to a given business condition. However, they correspond to average values for the operation of an ordinary rig.

Some of them were obtained consulting specialized publications like Offshore Rig Locator, The Platou Offshore Rig Market Status Report and The Bassoe Offshore Monthly (trimester historical data classified for rig type and geographic region and updated by the Consumer Price Index - USA). Others costs were obtained with brokers (professionals who join rig owners with oil companies intending to complete business). Finally an oil company, but with drilling rigs in its portfolio, has provided additional information about customized data related with the Brazilian market. Rig costs in Brazil are usually higher than Gulf of Mexico (bigger, more developed and nearer consumer market), lower than North Sea (more rigorous safety and labor rules) and more similar to the West Africa.

A basic condition was defined by the following parameters: I = 90 (40 for a second-hand unit), EM = 1.2, E = - 30, R = 0.8 (in million of dollars); C = 8.3, M = 1.0 (in millions of dollars per year); σ = 25 (35 for semi-submersible unit), δ = 4, r = 7 (in % per year). The jack-up rig day rate as US$ 30000 (10.8 in million of dollars) and tax rate as 36%. All this figures was estimated for the Brazilian market conditions in a specific time interval.

To solve the "hysteresis" model proposed by Dixit & Pindyck, adapted for the current study, mathematical optimization software Maple was utilized. It solves non-linear equation systems, differential equations and numerical integration problems. The successive approximation method was employed (Vollert, 2003).

In the first trials for solving both sets of four equations, each one with four unknowns, non-convergence problems and solutions without economic sense have occurred. An initial solution for the non-convergence problems was considered difficult due to the quantity of parameters, some of which with no intuitive pertinence region. It was observed that coefficients D_1 and B_3 in the first block of equations presented linear behavior in the non-linear equations, allowing to place them as function of boundaries P_R and P_M. System was then reduced to two non-linear equations, making the graphics feasible for visualizing the significant roots of the problem (*i.e.* points where the equation value is zero).

The same procedure of variable substitution by equation elimination was performed for the second set of equations, since coefficients A_1 and D_2 also have linear behavior and can be determined as function of P_H and P_L. This makes the graphic drawing feasible, facilitating the determination of the root occurrence intervals and the numerical process for equation solving.

Coefficients are, as a result, determined by:

$$D_1 = (\beta_2 . B_3 . P_R^{\beta 2 - 1} . \delta + 1) / (\beta_1 . P_R^{\beta 1 - 1} . \delta) \quad (20)$$

$$B_3 = (-P_M^{\beta 1 - 1} + P_R^{\beta 1 - 1}) / (\beta_2 . \delta . (P_M^{\beta 1 - 1} . P_R^{\beta 2 - 1} - P_M^{\beta 2 - 1} . P_R^{\beta 1 - 1})) \quad (21)$$

$$A_1 = - (- P_L^{\beta 1} . r . D_1 - D_2 . P_L^{\beta 2} . r + M - E . r) / (P_L^{\beta 1} . r) \quad (22)$$

$$D_2 = (- P_L^{\beta 1} . r. D_1. \beta_1 . P_H^{\beta 1 - 1} \delta + P_L^{\beta 1} . r . \beta_2 . P_H^{\beta 2 - 1} . \delta . B_3 + P_L^{\beta 1} . r + M . \beta_1 . P_H^{\beta 1 - 1} . \delta$$
$$E . r . \beta_1 . P_H^{\beta 1 - 1} . \delta) / (\delta . r . (- P_L^{\beta 1} . \beta_2 . P_H^{\beta 2 - 1} + P_L^{\beta 2} . \beta_1 . P_H^{\beta 1 - 1})) \quad (23)$$

And the final equations, after a great deal of algebraic work and transformations, are the following:

$$P_R^{(2 . \beta 1 - 2 + \beta 2)} . r . \beta_2 - P_R^{(2 . \beta 1 - 1)} . r . \beta_2 . P_M^{\beta 2 - 1} + P_R^{(\beta 1 + \beta 2 - 1)} . r . \beta_1 . P_M^{\beta 1 - 1} - P_R^{(2 . \beta 1 - 2 + \beta 2)} . r . \beta_1 - P_R^{(\beta 1 + \beta 2 - 1)} . r . \beta_1 . \beta_2 . P_M^{\beta 1 - 1} + P_R^{(2 . \beta 1 - 1)} . r . \beta_1 . \beta_2 . P_M^{\beta 2 - 1} + P_R^{(\beta 1 - 2 + \beta 2)} . \delta . C . \beta_1 . \beta_2 . P_M^{\beta 1 - 1} - P_R^{(2 . \beta 1 - 2)} . \delta . C . \beta_1 . \beta_2 . P_M^{\beta 2 - 1} - P_R^{(\beta 1 - 2 + \beta 2)} . \delta . M . \beta_1 . \beta_2 . P_M^{\beta 1 - 1} + P_R^{(2 . \beta 1 - 2)} . \delta . M . \beta_1 . \beta_2 . P_M^{\beta 2 - 1} + P_R^{(\beta 1 - 2 + \beta 2)} . R . \delta . r . \beta_1 . \beta_2 . P_M^{\beta 1 - 1} - P_R^{(2 . \beta 1 - 2)} . R . \delta . r . \beta_1 . \beta_2 . P_M^{\beta 2 - 1} = 0 \quad (24)$$

$$P_R^{(\beta 1 - 2 + \beta 2)} . P_M^{\beta 1} . r . \beta_2 - P_R^{\beta 1 - 1} . P_M^{(\beta 1 + \beta 2 - 1)} . r . \beta_2 + P_M^{(\beta 1 + \beta 2 - 1)} . r . \beta_1 . P_R^{\beta 1 - 1} - P_R^{(2 . \beta 1 - 2)} . P_M^{\beta 2} . r . \beta_1 - P_R^{(\beta 1 - 2 + \beta 2)} . P_M^{\beta 1} . r . \beta_1 . \beta_2 + P_R^{(2 . \beta 1 - 2)} . P_M^{\beta 2} . r . \beta_1 . \beta_2 + P_R^{(\beta 1 - 2 + \beta 2)} . \delta . C . \beta_1 . \beta_2 . P_M^{\beta 1 - 1} - P_R^{(2 . \beta 1 - 2)} . \delta . C . \beta_1 . \beta_2 . P_M^{\beta 2 - 1} - P_R^{(\beta 1 - 2 + \beta 2)} . \delta . M . \beta_1 . \beta_2 . P_M^{\beta 1 - 1} + P_R^{(2 . \beta 1 - 2)} . \delta . M . \beta_1 . \beta_2 . P_M^{\beta 2 - 1} - P_R^{(\beta 1 - 2 + \beta 2)} . EM . \delta . r . \beta_1 . \beta_2 . P_M^{\beta 1 - 1} + P_R^{(2 . \beta 1 - 2)} . EM . \delta . r . \beta_1 . \beta_2 . P_M^{\beta 2 - 1} = 0 \tag{25}$$

$$- P_L^{(2 . \beta 1 + \beta 2 - 1)} . r . D_1 . \beta_1 . P_H^{\beta 1 - 1} . \delta . \beta_2 + P_L^{(2 . \beta 1 + \beta 2 - 1)} . r . \beta_2^2 . P_H^{\beta 2 - 1} . \delta . B_3 + P_L^{(2 . \beta 1 + \beta 2 - 1)} . r . \beta_2 + P_L^{(2 . \beta 1 + \beta 2 - 1)} . r . \beta_1^2 . P_H^{\beta 1 - 1} . D_1 . \delta - P_L^{(2 . \beta 1 + \beta 2 - 1)} . r . \beta_1 . \beta_2 . P_H^{\beta 2 - 1} . \delta . B_3 - P_L^{(2 . \beta 1 + \beta 2 - 1)} . r . \beta_1 - M . \beta_1 . \delta . \beta_2 . P_L^{(2 . \beta 1 - 1)} . P_H^{\beta 2 - 1} + P_L^{(\beta 1 + \beta 2 - 1)} . M . \beta_1 . P_H^{\beta 1 - 1} . \delta . \beta_2 + E . r. \beta_1 . \delta . \beta_2 . P_L^{(2 . \beta 1 - 1)} . P_H^{\beta 2 - 1} - P_L^{(\beta 1 + \beta 2 - 1)} . E . r . \beta_1 . P_H^{\beta 1 - 1} . \delta . \beta_2 = 0 \tag{26}$$

$$P_L^{(2 . \beta 1)} . P_H^{\beta 1} . r - \beta_2 . P_H^{(\beta 2 - 1)} . P_L^{(2 . \beta 1)} . I . r . \delta + P_L^{(\beta 1 + \beta 2)} . \beta_1 . P_H^{(\beta 1 - 1)} . I . r . \delta + P_L^{(\beta 1 + \beta 2)} . \beta_1 . P_H^{(\beta 1 - 1)} . \delta . C - P_L^{(\beta 1 + \beta 2)} . \beta_1 . P_H^{\beta 1} . r - P_L^{\beta 1} . P_H^{(\beta 1 + \beta 2 - 1)} . \beta_1 . M . \delta + P_L^{\beta 1} . P_H^{(\beta 1 + \beta 2 - 1)} . \beta_1 . E . r . \delta + P_H^{(\beta 1 + \beta 2 - 1)} . \beta_1 . P_L^{(2 . \beta 1)} . r . D_1 . \delta - P_L^{(\beta 1 + \beta 2)} . \beta_1 . P_H^{(\beta 1 + \beta 2 - 1)} . r . \delta . B_3 - P_L^{\beta 1} . P_H^{(\beta 1 + \beta 2 - 1)} . \beta_2 . E . r . \delta - \beta_2 . P_H^{(\beta 2 - 1)} . P_L^{(2 . \beta 1)} . \delta . C + P_L^{\beta 1} . P_H^{(\beta 1 + \beta 2 - 1)} . \beta_2 . M . \delta + r . P_L^{(2 . \beta 1)} . P_H^{\beta 2} - P_H^{(\beta 1 + \beta 2 - 1)} . \beta_2 . P_L^{(2 . \beta 1)} . r . D_1 . \delta + \beta_2 . P_H^{\beta 2} . P_L^{(2 . \beta 1)} . r + P_L^{(\beta 1 + \beta 2)} . \beta_2 . P_H^{(\beta 1 + \beta 2 - 1)} . \delta . B_3. R = 0. \tag{27}$$

For the basic condition, the following values were obtained:

P_H = 23.02, P_R = 9.17, P_M = 5.69, P_L = 5.66 (in million of dollars per year);

V_0 (P_H) = 373.20, V_0 (P_L) = 43.43, V_m (P_R) = 134.48, V_m (P_M) = 74.79, V_1 (P_H) = 463.20, V_1 (P_R) = 135.28, V_1 (P_M) = 73.59, V_1 (P_L) = 73.43 (in million of dollars);

β_1 = 1.5168, β_2 = -1.4168, A_1 = 3.2061, B_2 = 650.8748, B_3 = 360.728, D_1 = 4.7825, D_2 = 290.1468.

The boundary values are better understood if converted to unit of dollars per day, in which freight charges are usually defined. Thus, we have: P_H = 63070, P_R = 25120, P_M = 15590, P_L = 15510.

This implies that if day-rate of a jack-up would reach US$ 63070, it would be attractive to enter in the business or expand by acquiring a new unit. For day-rates exceeding US$ 25120, it would be economic to reactivate a temporarily suspended unit. Between this value and US$ 15590 per day, current status would be maintained (activity or temporary suspension). When this limit is achieved, it would be attractive to interrupt operation, keeping the asset ownership. For rates below US$ 15510 per day the indication would be the exit from business.

As the market day-rate for this type of rig is, on average, US$ 30000, it is attractive to keep the asset and its operation. A daily operating cost for the rig of US$ 22800 has been established, and therefore the obtained values show coherence. However, it is observed that for values used in the basic condition, temporary suspension option is very restricted since only US$ 80 separates it from a complete exit (approximately 0,5%). Thus, with small variations in initial input data for costs and rates, this range may increase or even disappear, leading to a condition of entrance in (or exit of) the business without intermediate steps. These limits are indicated in the sensitivity analysis for all variables.

The comparison of the obtained results for option values V_0, V_1 and V_m at the boundary points also presents coherence with equations 12 to 15. The opportunity values are placed at high levels, as $V_1(P_H)$ reaches almost half billion dollars, between operation portion (measured by NPV) and the available options. In the interval $[P_L, P_H]$ the difference between V_1 and V_0 corresponds to incremental value for activation/deactivation; in the interval $[P_M, P_R]$ the difference between V_1 and V_m corresponds to incremental value for suspension/reactivation.

After the solution of the proposed basic condition, sensitivity analyses were performed for all parameters, changing one at a time, observing their influence on boundary values and the attitudes derived from that. Figures 2 to 9 present the sensitivity analyses (D'Almeida, 2000).

5 CONCLUSIONS

According to this paper, in case of investment or re-entry, the more significant variables are acquisition cost, operating cost, volatility and discount rates (net and risk-free) and, at a lower level, the abandonment cost.

For reactivation and temporary stoppage, operational and maintenance costs are the most important variables. Lump-sum costs for suspension and reactivation and the volatility have, however, a smaller influence.

For abandonment the more sensible parameters are the exit cost (residual value) and operational cost. Acquisition cost, volatility and discount rates have a smaller influence.

The strong link between decisions to enter and to exit the business is once again configured.

Changes in one parameter are, in general, followed by changes in others, resulting in complex final effects. This may render impracticable the conditions of temporary suspension or may create them where they do not exist; or may even increase or reduce the hysteresis intervals, contributing for the inertia on attitudes. It is advisable to use Scenario techniques, to complement the Real Options evaluation. It is also essential the availability of up-to-date, reliable cost database.

Moreover, one emphasizes that the calculated values for P_H were always high, showing that very attractive conditions are required to justify investments of such a magnitude. However, the option of the partnership for acquisition of a rig can be extremely attractive, as it reduces the risk for each partner, especially in case of big scope projects.

Rig market is a very sensitive one showing high day-rate volatility along the time and being remarkably affected by the oil prices. This study, although focused to the Brazilian market, can be amplified by external ones. We can realize that the conditions changes a lot with time: Brent oil barrel price (international petroleum reference) was US$ 10 in 1999 and seven years later achieved US$ 75, contributing to eliminate rig idleness and raising the rig day-rates in worldwide. In the last years of the last century many oil companies reduced their activity level and some rig owners abandoned the segment. More recently we can clearly realize that it was a mistake since decisions in oil sector must be taken place admitting the high volatility and strong changes overtime.

Further studies can be developed analyzing semi-submersible units (higher day-rate volatility) and rig obsolescence overtime. With oil drilling activity achieving deeper waters each day new rigs must be built or old ones must be updated with more rigorous requirements, reducing the market value of the other offshore units. This process is less significant to onshore units.

And Real Options Theory is essential to study this kind of sector, with huge investments and high volatility, indicating that economic evaluations based on the net present value (NPV) are inadequate.

Bibliography

BRENNAN, M.J., Schwartz, E.S., 1999. Evaluating Natural Resource Investments. Journal of Business 58, 135 – 157.

D'ALMEIDA, A.L., 2000 Estruturação e Dimensionamento de Frota e Pessoal numa Empresa de Sondagem e Serviços Especiais em Petróleo. D.Sc. Thesis, COPPE/UFRJ, Rio de Janeiro, Brazil.

DIAS, M.A.G., 2005. Opções Reais Híbridas com Aplicações em Petróleo. D.Sc. Dissertation, PUC/RJ, Rio de Janeiro, Brazil.

DIXIT, A.K., Pindyck, R.S., 1994. Investment under Uncertainty. Princeton University Press, New Jersey.

PADDOCK, J.L., Siegel, D.R., Smith, J.L., 1988. Option Valuation of Claims on Real Assets : The Case of Offshore Petroleum Leases. Quarterly Journal of Economics, 479-508.

VOLLERT, A., 2003. A Stochastic Control Framework for Real Options in Strategic Valuation. Birkhäuser Boston.

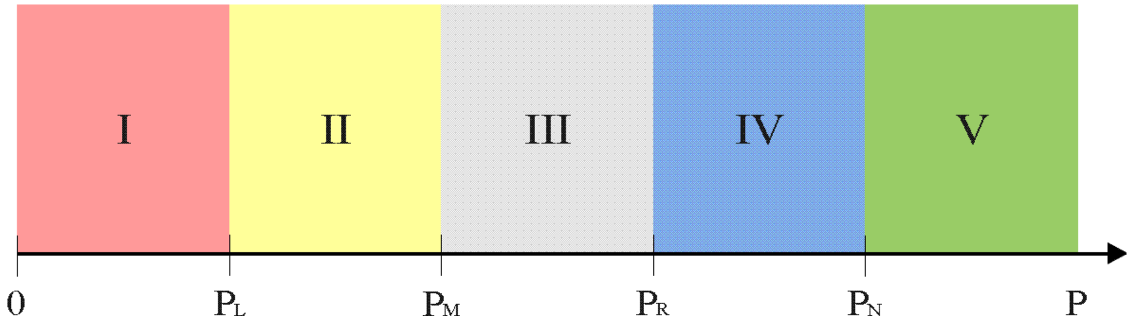

Figure 1 – Option value as function of current price

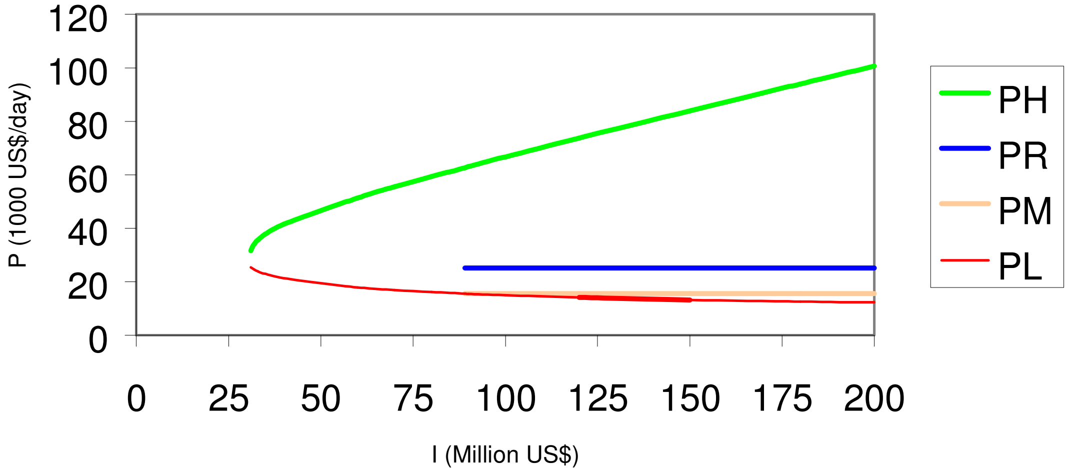

Figure 2 - Critical thresholds as functions of Acquisition Cost (I)

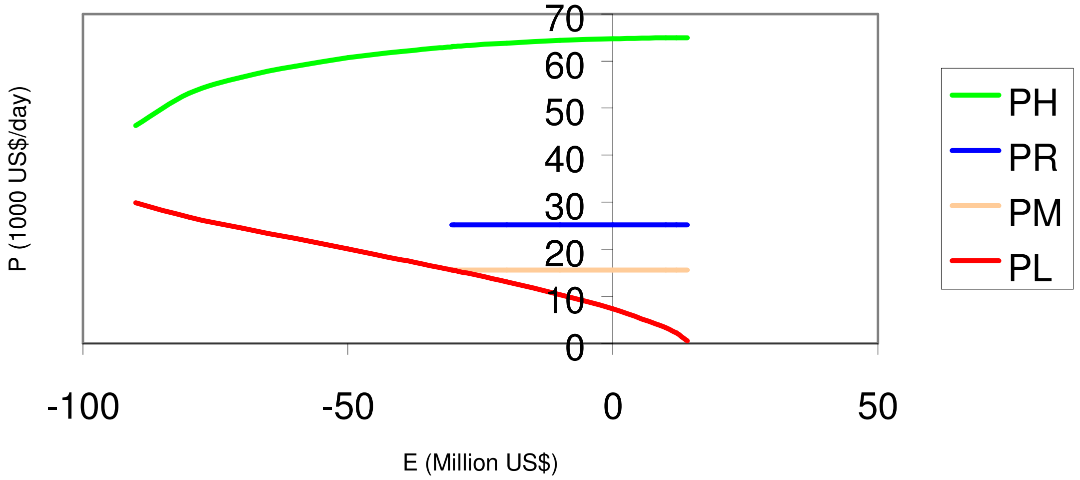

Figure 3 - Critical thresholds as functions of Abandon Cost (E)

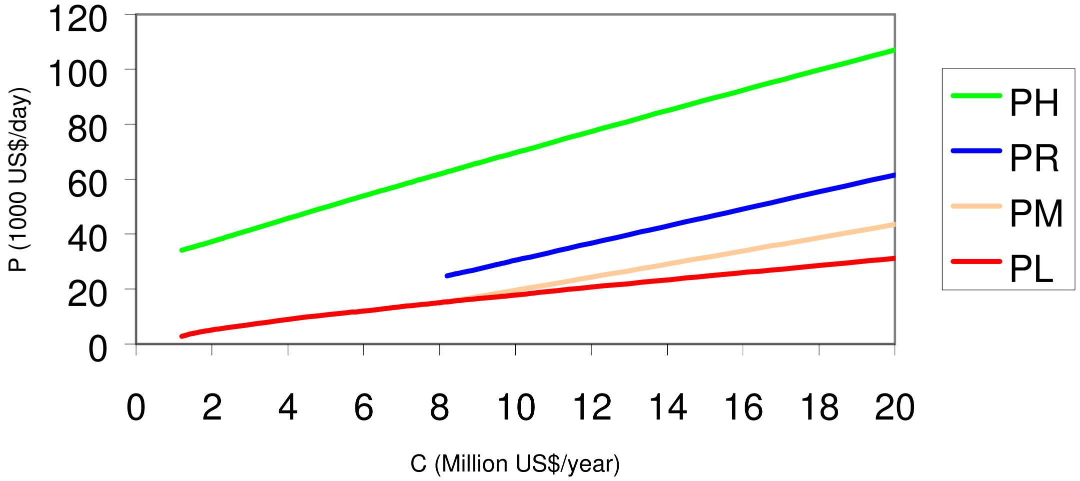

Figure 4 - Critical thresholds as functions of Operational Cost (C)

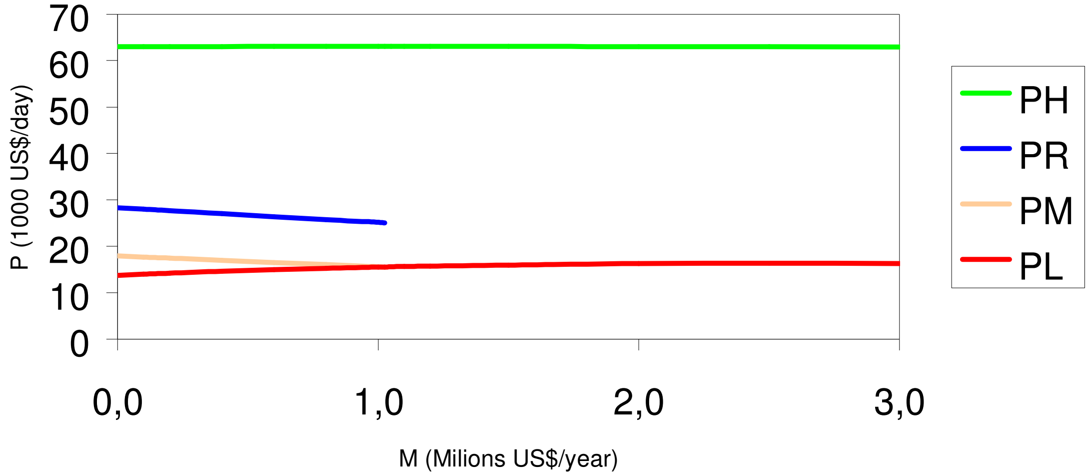

Figure 5 - Critical thresholds as functions of Maintenance Cost (M)

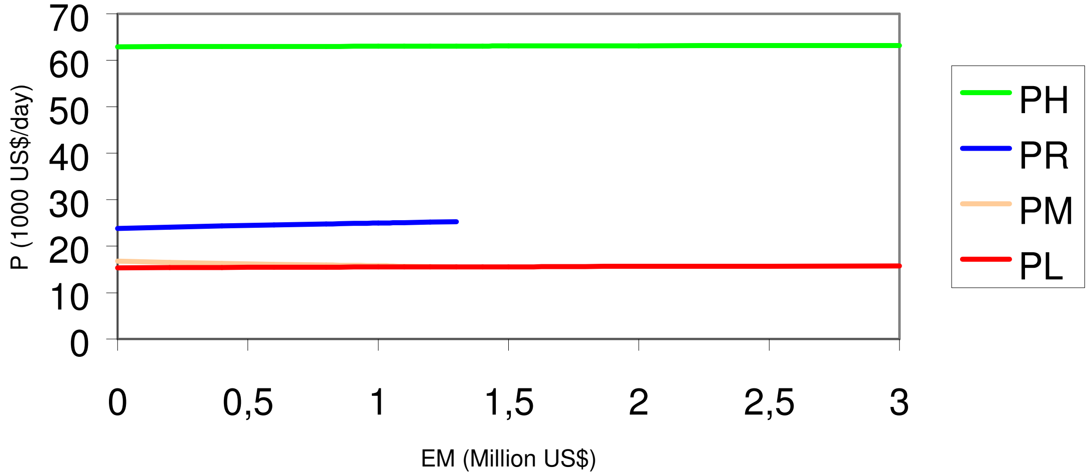

Figure 6 - Critical thresholds as functions of Temporary Suspension Cost (EM)

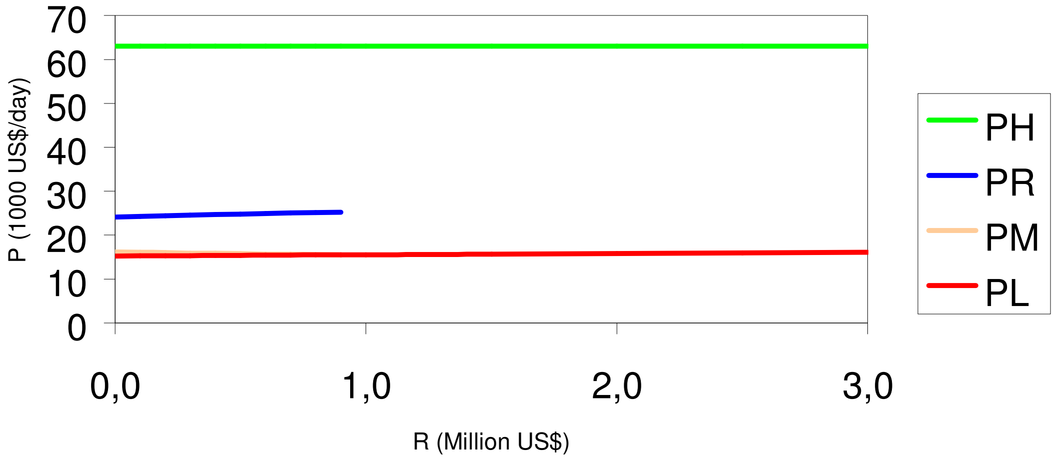

Figure 7 - Critical thresholds as functions of Reactivation Cost (R)

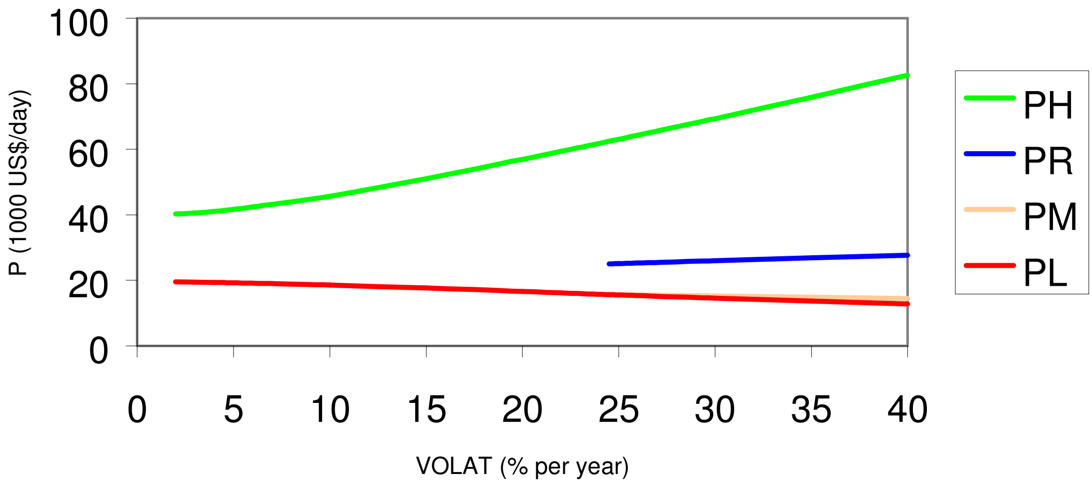

Figure 8 - Critical thresholds as functions of Volatility (σ)

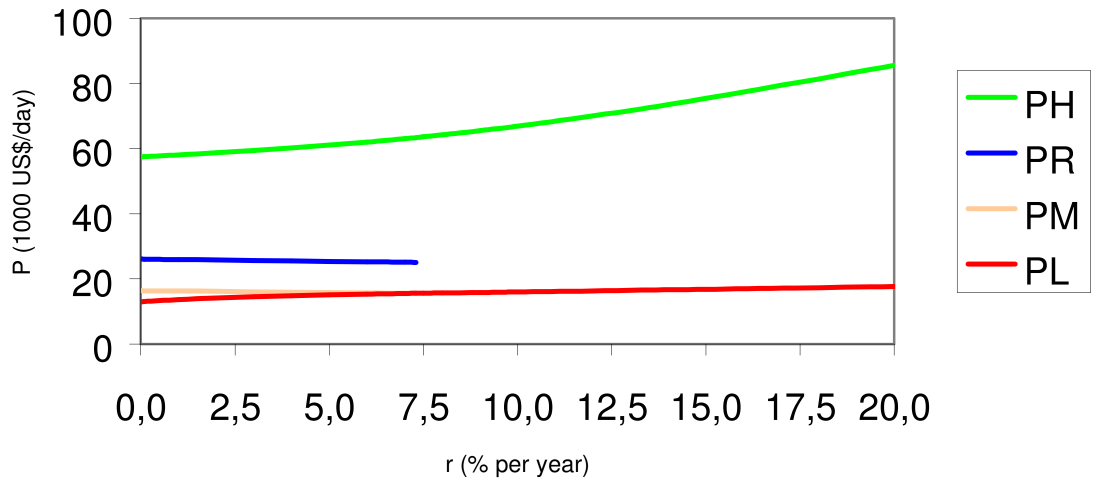

Figure 9 - Critical thresholds as functions of Risk-free discount rate (r)