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Real Options: Applications to Energy with Focus on Petroleum

Real Options Valuation in the New Economy

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Visit the first real options website: www.puc-rio.br/marco.ind/

Presentation Outline

- Introduction and overview of real options in petroleum E&P (exploration & production) and in energy.
  - Real options in real life: known cases and Brazilian cases.
  - Managerial view of real options (RO). Main options.
  - Intuition with simple examples.
- A recent Brazilian real options application in energy:
  - A case study with *biodiesel* plants.
    - Input flexibility value.
    - A natural hedging business format.

Real Options in Real Life

- **Many real options in real life applications by oil companies has been reported. Some examples:**
  - **Shell in 80's: cases in E&P and refining, Kemma (1993);**
  - **BP: Andrew field, Leslie & Michaels (1997);**
  - **Chevron: mature field farm-ins, Valdmanis (1999);**
  - **Anadarko: Tanzanite track bonus (with a real options premium) in 1990 GoM bid, Coy (1999);**
  - **Texaco: corporate diffusion of RO tools, Triantis & Borison (2001).**

Real Options in Real Life

- **Less known are the Brazilian real life cases on real options. Some examples:**
  - **Marlim oilfield project finance (1998), equity modeling *preserving Petrobras' operational flexibility*, with the profit (equity reward) linked to exogenous *oil prices*, modeled as a stochastic process of *mean-reversion plus jumps.***
  - ***Public debate* on *petroleum concessions timing policy*, with a real options paper (Dias & Rocha, 1998) conclusions being highlighted by a very influent politic (ex-economy minister) in a top newspaper *Folha de São Paulo* (14/4/1999).**
  - **Bolivia-Brazil gas pipeline, TBG x entrants (BG and Enersil) regulatory open access dispute arbitrated by National Petroleum Agency: *11% RO tariff premium over take-or-pay tariff due to the entrants higher flexibility* (2001).**

Managerial View of Real Options (RO)

- In many cases, RO is a *necessary* methodology for a detailed/modern economic valuation of projects and *investment decisions under uncertainty*.
  - It combines the modern corporate finance theory with mathematical tools of optimization under uncertainty.
  - RO *complements* (not *substitutes*) current corporate tools.
  - Strong cash-flow analysis eases real options applications.
  - Corporate diffusion of RO takes time and training.
- RO considers the uncertainties and the options (managerial flexibilities), giving two answers:
  - The *value of the investment opportunity (real option value)*;
  - The *optimal decision rule* (option exercise *threshold* curve).

Managerial View of Real Options (RO)

- RO can be viewed as an optimization problem:
  - Maximize the Net Present Value (NPV) (typical objective function) *by managing optimally the relevant options* (managerial flexibilities), *subject to*:

(a) Market uncertainties (e.g., oil price, exchange rate).

➡ *Wait and see* can be optimal. Option to defer and to expand are important.

(b) Technical uncertainties (e.g., petroleum existence, reserve volume, new technology performance).

➡ *Learning options* are important to reduce uncertainties.

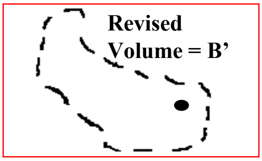
(d) Strategic interactions of *competition* or *cooperation.*

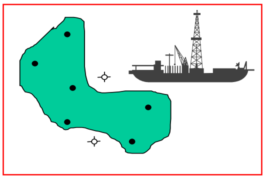
➡ It is necessary to combine *real options with game theory*.

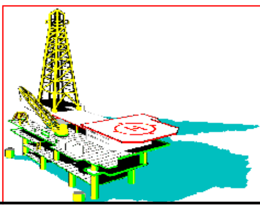
E&P as a Sequential Real Options Process

Oil/Gas Success Probability = p

Expected Volume of Reserves = B







⇒ Concession: Option to Drill the Wildcat

Exploratory (wildcat) Investment

⇒ Undelineated Field: Option to Appraise

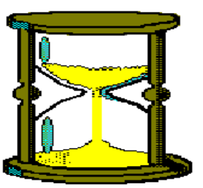
Appraisal Investment

⇒ Delineated Undeveloped Reserves: Option to Develop (What is the best scale alternative?)

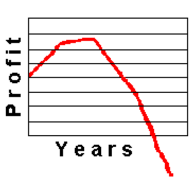
Development Investment

⇒ Developed Reserves: Options to Expand, to Stop Temporally, and to Abandon.

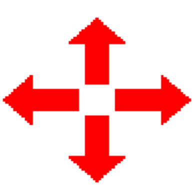
Main Petroleum Real Options and Examples



- **Option to Delay (Timing Option).**
  - Wait, see, learn, optimize before investing.
  - Oilfield development; wildcat drilling.



- **Abandonment Option.**
  - Managers are not obligated to continue a business plan if it becomes unprofitable.
  - Sequential *appraisal program* can be abandoned earlier if generated information is not favorable.

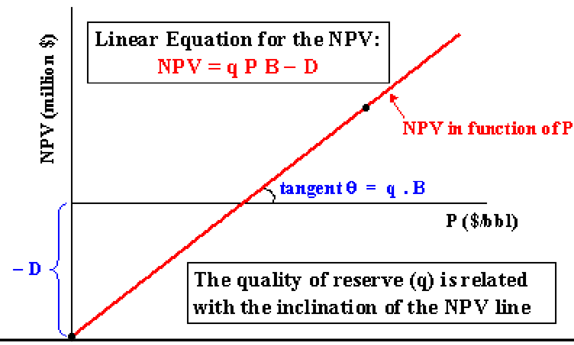


- **Option to Expand the Production.**
  - Depending on market scenario (*oil prices*, *rig rates*), and the petroleum *reservoir behavior*, new wells can be added to the production system.

Jump examples?

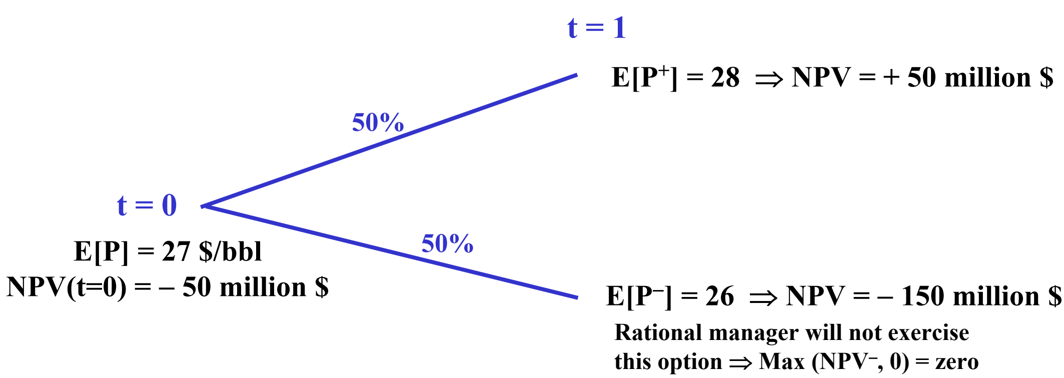
Economic Quality of the Developed Reserve

- The relation between the value for one barrel of (sub-surface) developed reserve v and the (surface) oil price barrel P is named the *economic quality of that reserve* q (higher q, higher v)
- Value of one barrel of reserve = v = q . P
  - Where q = economic quality of the developed reserve
  - The value of the developed reserve is v times the *reserve size* (B)
  - So, let us use the equation for NPV = V – D = q P B – D
    - D = development cost (investment cost or *exercise price* of the option)



Intuition (1): Timing Option and Oilfield Value

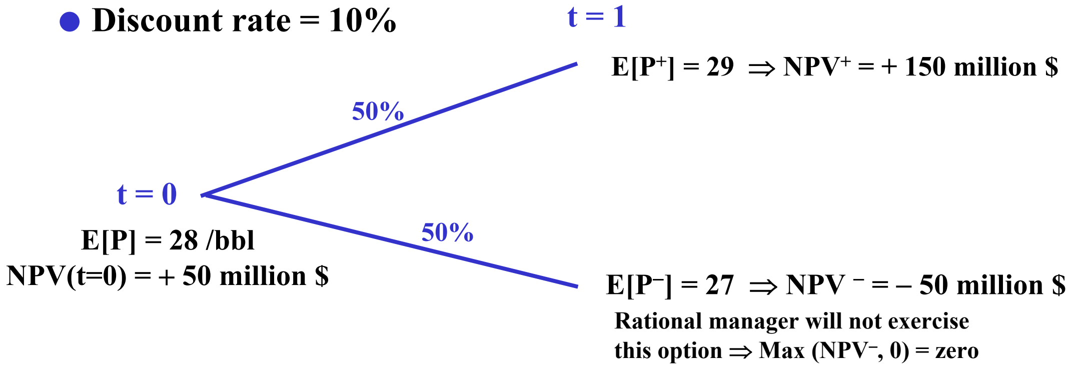
- Assume that simple equation for the oilfield development NPV:
  - NPV = q B P – D = 0.2 x 500 x 27 – 2750 = – 50 million $
  - Do you sell the oilfield for US$ 3 million?
  - Suppose the following two-periods problem with the uncertainty in oil prices P represented by only two scenarios at the second period.



Hence, at t = 1, the *optional* NPV is positive: (50% x 50) + (50% x 0) = + 25 million $

Intuition (2): Timing Option and Waiting Value

- **Suppose the same case, but with a small *positive* NPV. What is better: develop now or wait and see?**
  - **NPV = q B P – D = 0.2 x 500 x 28 – 2750 = + 50 million $**
  - **Discount rate = 10%**

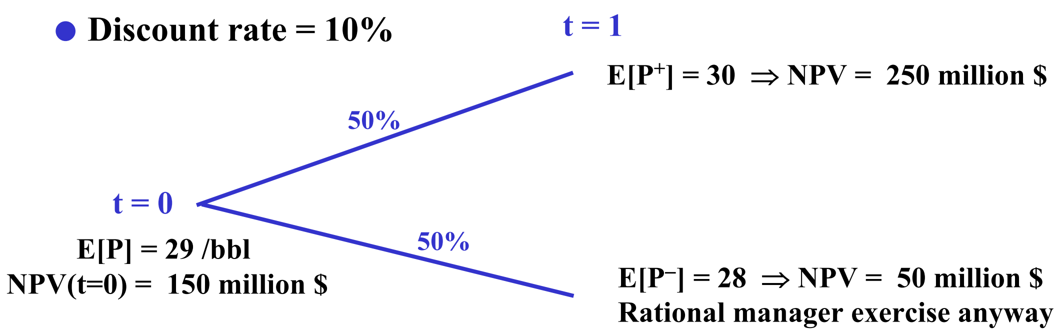


Hence, at t = 1, the project NPV is: (50% x 150) + (50% x 0) = + 75 million $
The present value is: $NPV_{wait}(t=0)$ = 75/1.1 = 68.2 > 50

Hence is better to wait and see, exercising the option only in favorable scenario

Intuition (3): Deep-in-the-Money Real Option

- **Suppose the same case but with a higher NPV (higher P).**
  - **What is better: develop now or wait and see?**
  - **NPV = q B P – D = 0.20 x 500 x 29 – 2750 = + 500 million $**
  - **Discount rate = 10%**

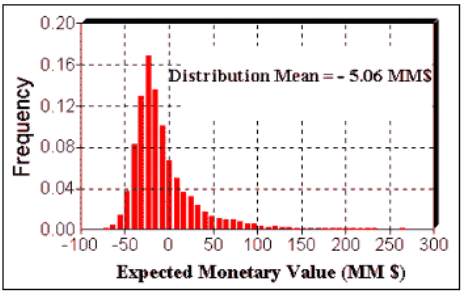


Hence, at t = 1, the project NPV is: (50% x 250) + (50% x 50) = 150 million $
The present value is: $NPV_{wait}(t=0)$ = 150/1.1 = 136.4 < 150

Immediate exercise is optimal because this project is *deep-in-the-money* (high NPV)
There is a *threshold* price P*(0) between 28 and 29 that value of wait = exercise now

A *Visual Equation* for Real Options

- Today exploratory prospect´s value is negative, but drilling rights expires only in 5 years, so that new scenarios will be revealed with the exploration of that basin.



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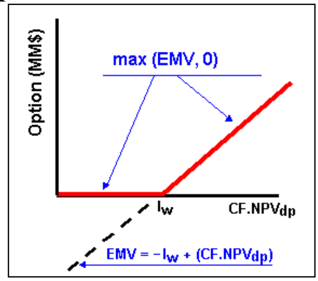

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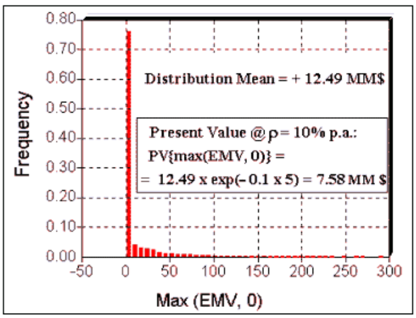


Exploratory Prospect Evaluation
(in million $)

Traditional Value = – 5

Options Value (at T) = + 12.5

Options Value (at t=0) = + 7.6

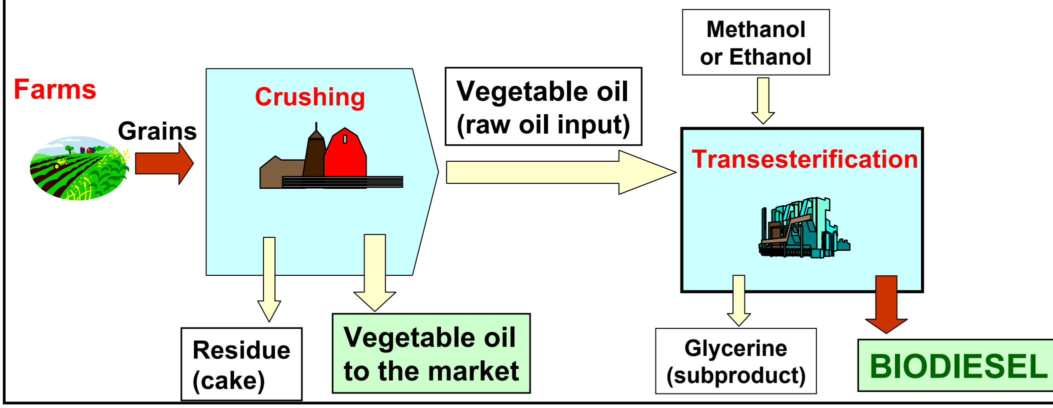
The option is even more valuable (it can be exercised earlier).

Real Life Application: Biodiesel Project

- **Biodiesel fuel for diesel engines has low emission advantage and is produced from vegetable oil or animal fat by the chemical process of transesterification with alcohols.**
  - Commercial biodiesel production in US started in late 1990's.
  - Biodiesel as fuel additive, will be obligatory in Brazil in 2008.
- **We are considering only multi-vegetable biodiesel plants.**
  - So, there is input flexibility to choose the vegetable that maximize the project value. Real options is the natural tool to evaluate this.
  - Some Braziliam vegetable considered were soybean, cotton, castorbean, pinion (jatropha curcas), uricury syagrus palm, etc.
  - In addition, there is input reagent flexibility: methanol or ethanol.
  - The vegetables price (and their oils) and the alcohols are commodities and oscillate in the market.
    - We use stochastic processes to model these uncertain prices.

Biodiesel Plant, Inputs and Outputs

- **A biodiesel plant has two main units:**
  - **The *crushing* unit, the vegetable grain is crushed generating raw oil and residue (pie). Raw (vegetable) oil is the main revenue.**
  - **The *transesterification* unit, that uses raw vegetable oil (cost) and reagent (alcohol), generating biodiesel plus residuals .**
  - **The figure below shows the biodiesel plant and its inputs/outputs.**



Biodiesel Project: The Value of Input Flexibility

- **Petrobras biodiesel business format: owner of *both units*, (crushing and transesterification):**
  - **In order to guarantee the raw oil quality; and**
  - **In order to *capture the flexibility* (real option) *value* in choosing the vegetable grain input.**
- **This flexibility is modeled as a *sequence of European options on maximum of several risky assets*:**
  - **At each period the biodiesel plant choose the vegetable(s) and reagent combination that maximizes the profit in that period.**
  - **We performed Monte Carlo simulations for the stochastic processes of the input prices (several grains, vegetable raw oils, methanol, ethanol) and the output prices (biodiesel = diesel, residues, and vegetable oils to the market).**
    - **Difficulties to estimate some stochastic process parameters (lack of data).**
  - **The flexibility (real options value) added a significant and decisive value for biodiesel project economic feasibility.**

Biodiesel Business Format

- **The biodiesel business format suggested by real options analysis is to enter also in the vegetable raw oil market, by allowing an excess crushing capacity (~small investment) so that we can make biodiesel and vegetable oil to market.**
- **In this way we have two complementary business with a real options *natural hedging* for vegetable oil prices:**
  1. **The biodiesel business, where the vegetable raw oil is *cost* to transesterification (so, a *cheap* raw oil benefits this business); and**
  2. **The vegetable oil to market business, where the vegetable raw oil is *revenue* (so, an *expensive* raw oil benefits this business).**
- **In this format, the vegetable oil is demanded either by biodiesel business or other market (e.g., food).**
  - **It is good for everybody: for the farmers, with grain demand either for biodiesel or for other vegetable oil market; and for Petrobras, capturing the options value from the volatile market.**

Conclusions

- **The real options models provide rich framework to consider optimal investment under uncertainty in energy, recognizing the managerial flexibilities.**
  - **Traditional discounted cash flow is very limited and can induce to serious errors in negotiations and decisions.**
- **The diffusion in corporations takes time and much training. But we can see already important results.**
- **We saw a recent real life Biodiesel plant with input flexibility: real options valuation makes the difference**
  - **The use of Monte Carlo simulation to combine uncertainties in complex RO models has been an important practical tool.**
- **Thank you very much for your time!**

APPENDIX

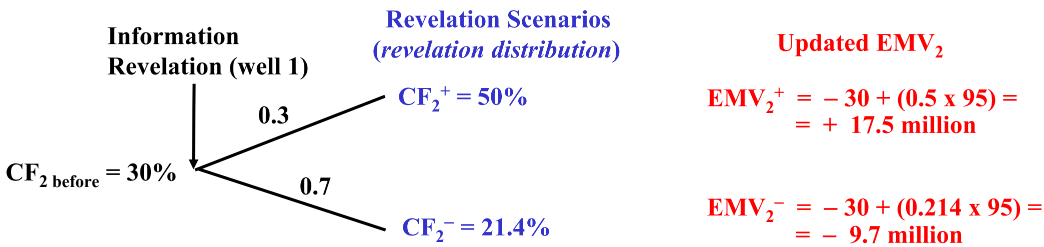
SUPPORT SLIDES

Oil Exploration Example: Information Revelation

- **One exploratory tract has two *correlated* and *equal* prospects, both with *chance factor* of 30%, drilling cost of $ 30 million, and both with expected NPV_{DP} = 95 million, in case of success.**
  - **So, both the *expected monetary values* (EMV) are negatives:**
    $EMV_1 = EMV_2 = -30 + (0.3 \times 95) = -1.5$ million
  - **Other oil company is offering $ 2 million for the tract. Deal?**
- **In this traditional EMV calculus is missing an additional hidden benefit: with the first well drilling we get valuable *information revelation* about the chance factor for the *second* prospect. With this information we update CF_2.**
  - **In case of *good news* (success in first drilling), CF_2 must be updated upward (so, EMV_2 *can* become positive) and vice-versa**
  - **We have an *option* (not an obligation) to drill the well 2**
    - **How much is the *value of information* from well 1 given that the second well is optional? How valuable is the entire tract with two prospects?**

Chance Factor Update with the Information

- In case of success with well 1, we update the CF_2 to $CF_2^+ > CF_2$. In case of failure (well 1 is dry), we update down to $CF_2^- < CF_2$.
  - This updating must obey some probabilistic laws for <u>consistency</u> (*law of iterated expectations* and others), and needs a <u>measure on the degree of correlation</u> between the prospects (a learning measure).
  - Suppose this correlation is so that the revealed CF_2^+ and CF_2^- are:



  - Because we have an *option* (not an obligation) to drill the well 2, we will exercise this option only if the revealed EMV_2 is positive (i.e. EMV_2^+)

How Valuable Is the Entire Tract?

- The cost to get information for the CF_2 is the negative EMV that is expected with the well 1 drilling (= – 1.5 \$ million)
  - But we saw that there are 30% chances to get a positive revelation ($EMV_2^+ = +17.5$ million) and 70% chances of *negative revelation*
    - But in case of *bad news* <u>the prospect 2 value is zero because we don´t need to drill this optional prospect</u> with $EMV_2 < 0$ (options cause asymmetry).
  - So, the entire <u>tract</u> EMV, including the information revelation plus the optional nature of the prospect 2, is:

$$EMV_{tract} = -1.5 + [(30\% \times 17.5) + (70\% \times 0)] = +3.75 \$ \text{ million}$$

OBS: Note that <u>if</u> the prospect 2 is <u>obligatory</u>, $EMV_{tract} = -\$ 3$ million

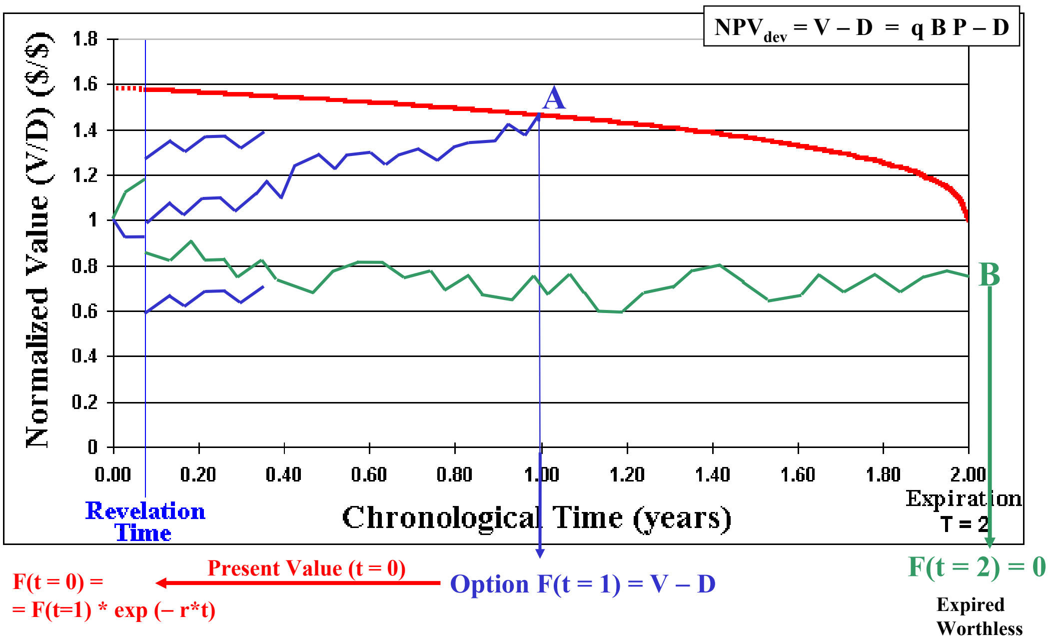
- So, refuse the other company offer of \$ 2 million!
- Now, we discuss quickly the technical uncertainty theory and one oilfield development example with remaining technical uncertainties in the oil reserve *volume* (B) and *quality* (q)

Technical Uncertainty: Threat & Opportunity

- **Technical uncertainty has zero correlation with the *market portfolio*, then the incremental risk-premium is zero**
  - **The discount rate is the same if the project owns technical uncertainty or not, because shareholders are diversified investors**
- **But, in development projects, technical uncertainty decreases both the *net present value* (NPV) and the *real options value***
  - **Technical uncertainty *almost surely* will lead to exercise the <u>wrong</u> development project (plant capacity, nº of wells, pipeline diameter)**
    - **The sub-optimal project generates *overinvestment* or *underinvestment* when compared with the optimal investment level that maximizes NPV or ROV**
  - **Technical uncertainty can lead to exercise options when the best is not exercise the option (for the *true* value) and vice-versa.**
- **Hence technical uncertainty decreases value due to <u>sub-optimal decisions</u> not because the discount rate or "manager utility".**
- **However, it is only *one side of the coin* (the <u>threat</u> side). Technical uncertainty also creates the <u>opportunity</u> to invest in information!**

Real Options Valuation with Investment in Information

- **M.C. simulation combining market (oil price) and technical uncertainties**



Classical Model of Real Options in Petroleum

- Paddock & Siegel & Smith wrote a series of papers on valuation of offshore reserves in 80's (published in 87/88)
  - It is the best known model for oilfields development decisions
  - It explores the analogy financial options with real options

Black-Scholes-Merton's Financial Options	Paddock, Siegel & Smith's Real Options
Financial Option Value	Real Option Value of an Undeveloped Reserve (F)
Current Stock Price	Current Value of Developed Reserve (V)
Exercise Price of the Option	Investment Cost to Develop the Reserve (D)
Stock Dividend Yield	Cash Flow Net of Depletion as Proportion of V (δ)
Risk-Free Interest Rate	Risk-Free Interest Rate (r)
Stock Volatility	Volatility of Developed Reserve Value (σ)
Time to Expiration of the Option	Time to Expiration of the Investment Rights (τ)

Equation of the Undeveloped Reserve (F)

- Partial (t, V) Differential Equation (PDE) for the option F

$$0.5\, \sigma^2 V^2 F_{VV} + (r - \delta)\, V\, F_V - r\, F = - F_t$$

- Parameters: V = value of developed reserve (eg., V = q P B); D = development cost; r = risk-free discount rate; δ = dividend yield for V ; σ = volatility of V

- Boundary Conditions:

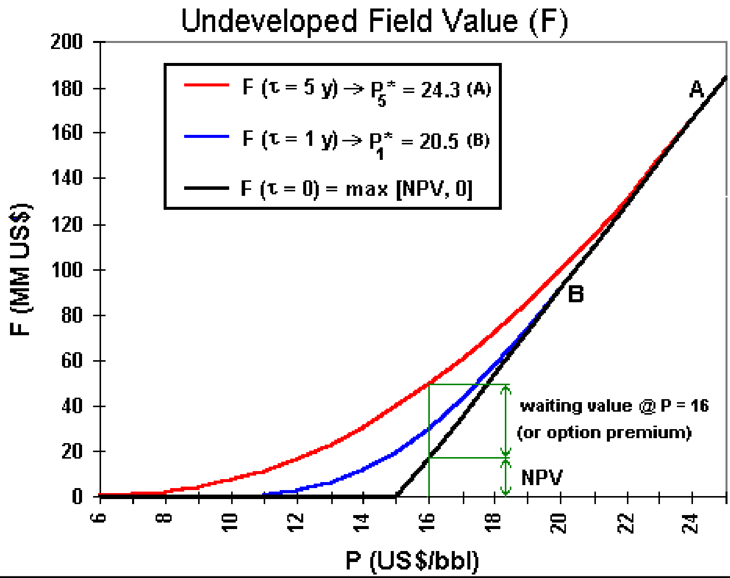
Managerial Action Is Inserted into the Model

  - For V = 0, F (0, t) = 0
  - For t = T, F (V, T) = max [V – D, 0] = max [NPV, 0]
  - For V = V*, F (V*, t) = V* – D
  - "Smooth Pasting", F_V (V*, t) = 1

} Conditions at the Point of Optimal Early Investment

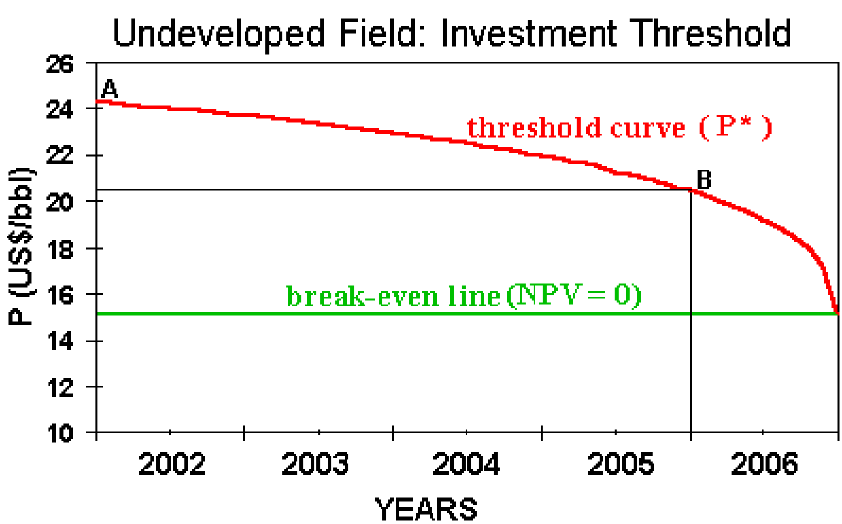
The Undeveloped Oilfield Value: Real Options and NPV

- Assume that V = q B P, so that we can use chart **F x V** or **F x P**
- Suppose the development break-even (NPV = 0) occurs at US$15/bbl



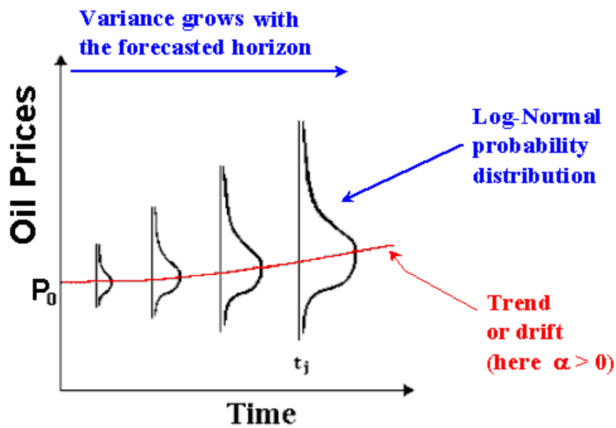
Threshold Curve: The Optimal Decision Rule

- At or above the threshold line, is optimal the immediate development. Below the line: "wait, learn and see"



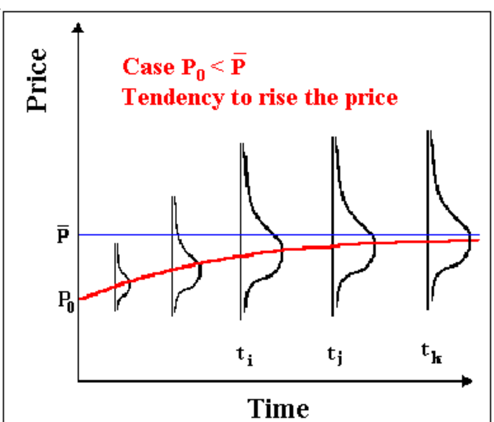
Stochastic Processes for Oil Prices: GBM

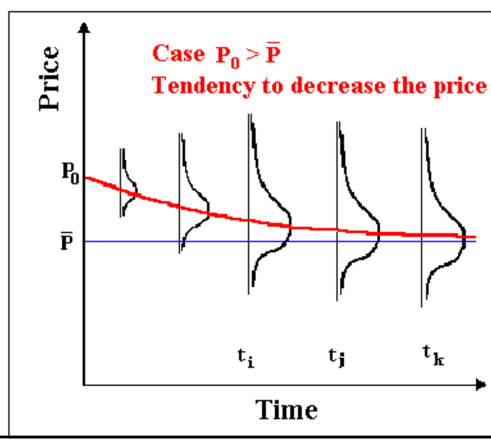
- Like Black-Scholes-Merton equation, the classical model of Paddock et al uses the popular Geometric Brownian Motion
  - Prices have a log-normal distribution in every future time;
  - Expected curve is a exponential growth (or decline);
  - The variance grows with the time horizon (unbounded)



Mean-Reverting Process

- In this process, the price tends to revert towards a long-run average price (or an equilibrium level) $\bar{P}$.
  - Model analogy: *spring* (reversion force is proportional to the distance between current position and the equilibrium level).
  - In this case, variance initially grows and stabilize afterwards





Stochastic Processes Alternatives for Oil Prices

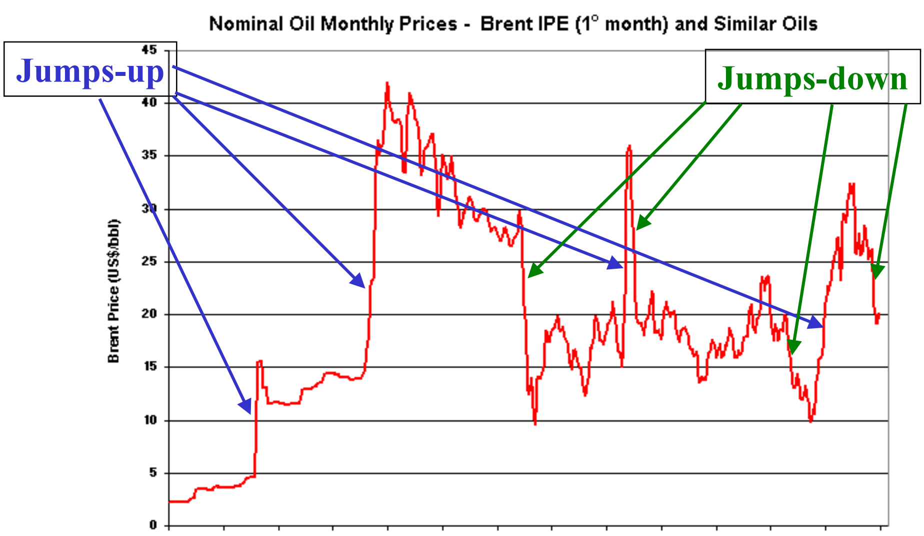
- **There are many models of stochastic processes for oil prices in real options literature. I classify them into three classes.**

Type of Stochastic Model	Name of the Model	Main Reference
Unpredictable Model	Geometric Brownian Motion (GBM)	Paddock, Siegel & Smith (80's)
Predictable Model	Pure Mean-Reversion Model (MRM)	Schwartz (1997, model 1)
More Realistic Models	Two and Three Factors Model	Gibson & Schwartz (1990), and Schwartz (models 2 and 3)
	Reversion to Uncertain Long-Run Level	Pindyck (1999) and Baker, Mayfield & Parsons (1998)
	Mean-Reversion with Jumps	Dias & Rocha (1998)

- **The nice properties of Geometric Brownian Motion (few parameters, homogeneity) is a great incentive to use it in real options applications.**
  - **Pindyck (1999) wrote: "*the GBM assumption is unlikely to lead to large errors in the optimal investment rule*"**

Nominal Prices for Brent and Similar Oils (1970-2001)

- **With an adequate *long-term scale*, we can see that oil prices *jumps* in both directions, depending of the kind of abnormal news: *jumps-up* in 1973/4, 1978/9, 1990, 1999; and *jumps-down* in 1986, 1991, 1997, 2001**



Mean-Reversion + Jumps: Dias & Rocha (98)

- We (Dias & Rocha, 1998/9) adapted the *jump-diffusion* idea of Merton (1976) to the oil prices case, considering:
  - Normal news cause only marginal adjustment in oil prices, modeled with the *continuous-time* process of mean-reversion
  - Abnormal rare news (war, OPEC surprises, ...) cause abnormal adjustment (jumps) in petroleum prices, modeled with a *discrete-time* Poisson process (we allow both *jumps-up* & *jumps-down*)
- Model has more economic logic (supply x demand)
  - Normal information causes smoothing changes in oil prices (marginal variations) and means both:
    - Marginal interaction between production and demand;
    - Depletion versus new reserves discoveries in non-OPEC countries
  - Abnormal information means *very important news*:
    - In few months, this kind of news causes jumps in the prices, due the expected large variation in either supply or demand

Real Case with Mean-Reversion + Jumps

- A similar process of *mean-reversion with jumps* was used by Dias for the *equity design* (US$ 200 million) of the Project Finance of Marlim Field (*oil prices-linked spread*)
  - Equity investors reward:
    - Basic interest-rate + spread (linked to oil business risk)
  - Oil prices-linked: transparent deal (no *agency cost*) and win-win:
    - Higher oil prices $\Rightarrow$ higher spread, and vice versa (good for both)
- Deal was in December 1998 when oil price was 10 $/bbl
  - We convince investors that the expected oil prices curve was a fast reversion towards US$ 20/bbl (equilibrium level)
  - Looking the jumps-up & down, we limit the spread by putting both *cap* (maximum spread) and *floor* (to prevent negative spread)
  - This *jumps insight* proved be very important:
    - Few months later the oil prices *jumped-up* (price *doubled* by Aug/99)
      - The cap protected Petrobras from paying a very high spread