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DYNAMIC PERFORMANCE MANAGEMENT IN THE UPSTREAM OIL INDUSTRY

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FOREWORD

It has been an enormous privilege to work with Professor Carmine Bianchi since I met him at the System Dynamics conference in Greece in 2008. His deep insights about the link between firms' behavior and the institutional context that surrounds them has enlightened my research.

I would like to express my gratitude to my Supervisor Professor Erling Moxnes. His vital and expert guidance is gratefully acknowledged.

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My wife Sonia stimulated and supported me during the program. She made it a very gratifying journey.

ABSTRACT

This is a study about investments in the upstream oil industry. The goal is to describe how investments that lead to oil and gas production, are made.

The study of oil supply is central, because it represents 60% of the world's primary energy supply. It is vital for energy renewables policy makers, in order to assess oil supply scenarios and adjust incentives for lower fossils consumption. It is also important for consuming countries. Previous studies have stressed the importance of market volatility for investment appraisal in the UK; irreversibility of investments; and remaining reserves as main drivers of investment and production in the UK.

My study differs, since my results can be compared (over decades) with a diverse production set in the international market: a small US company; a large company; a country; two regions; and OPEC. My hypothesis is that expected profit per barrel and market share are production and investment drivers.

I have used the Dynamic Performance Management method, as it fits the process followed by managers in the oil industry. That is, focus on end results, while balancing resources for sustained growth. I have built and tested a dynamic model which replicates the production attained by the above mentioned firms, regions, and OPEC, over decades. I claim that expected price per barrel and market share are the drivers of investment and production. This study contributes to the literature in investments, petroleum and system dynamics, by integrating the three fields.

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1. INTRODUCTION

1.1 Background: This is a study about investments in the upstream oil industry. The goal is to describe how investments that lead to oil and gas production, are made.

The study of oil supply is central, because it represents 60% of the world's primary energy supply (BP, 2016). It is vital for energy renewables policy makers, in order to assess oil supply scenarios and adjust incentives for lower fossils consumption. It is also important for consuming countries; for example, OECD governments earned 50% of the total pump fuel price, while OPEC earned half of it, in 2015 (OPEC, 2016). Previous studies have stressed the importance of market volatility for investment appraisal in the UK (Favero et al., 1994); irreversibility of investments (Pindyck, 1994); and remaining reserves as main drivers of investment and production in the UK (Kemp and Kasim, 2003).

My study differs, since my results can be compared (over decades) with a diverse production set in the international market: a small US company (Murphy Oil); a large company (ExxonMobil); a country (Norway); two regions (OECD and Asia Pacific); and OPEC. My hypothesis is that expected profit per barrel (as defined by the ratio of oil price to investment breakeven cost); and market share (as guided by international oil demand) are production and investment drivers.

1.2 Method: I have used the Dynamic Performance Management method, as it fits the process followed by managers in the oil industry. That is, focus on end results, while balancing resources for sustained growth.

1.3 Results: I have built and tested a dynamic model which replicates the production attained by the above mentioned firms, regions, and OPEC, over decades.

1.4 Conclusions: I claim that expected price per barrel and market share are the drivers of investment and production. This study contributes to the literature in investments, petroleum and system dynamics, by integrating the three fields.

1.5 Outline: Chapter 2 presents a review of DPM; oil markets and investments; financial oil markets; and OPEC. In chapter III, I present the rationale for using the underlying simulation method for DPM (System Dynamics); then the production and investment model is presented and tested using a sample project; and then the six cases are simulated and analyzed. Chapter IV presents the conclusions.

2. LITERATURE REVIEW

2.1 Dynamic Performance Management (DPM)

Bianchi (2012) proposes the DPM scheme to study performance and viable growth in organizations. According to DPM, they possess strategic resources required to fulfill their goals. These resources are built over time, and they are subject to growth and depletion rates. Performance -end result- is then defined as the net rate of increase of strategic resources. The latter control drivers that impact end results. In this context, it is the duty of policy makers to identify the resources, drivers and end results that lead to success. They are also in charge of keeping resources balanced and at proper levels over time.

DPM entails linking goals with performance measures. Products, services and relations with the external ambiance are defined. An internal value chain map is defined, as well. Policy analysis would require the upgrade structure to be made explicit.

DPM is suited to study the upstream oil sector because unique plans and boards handle project portfolio, oil reserves, production capacity and financial strategic resources. Net increase of these resources are common measures of performance. Balanced resources enable investment loans and investors equity. Expected profit in investments, verified demand for production projects and financial reserves are main drivers of the change of strategic resources.

Moreover, DPM also centers attention in the external ambiance. Its impact should not be undervalued. Changes in regulations and rules in countries (i.e., taxes) may affect market supply and demand of oil. These changes may impact oil prices. The latter affects expected profit in investments and new projects. New projects govern production capacity and production. Thus, performance may be impacted by these factors beyond sterile supply and demand. In this research, oil upstream DPM is presented within this context shaped by global markets.

2.2 Oil Markets

Oil is the world’s leading fuel. It accounts for 32.9% of global energy consumption (Dale, 2016). Value of oil exports relative to GDP in the 12 OPEC countries amounts to 45% in the 1986-2010 period. Oil is a source of revenues for importing countries too. In 2015, OECD countries charged taxes on every liter of pump fuel sold to consumers (50.4%), whereas OPEC producers got only 19.9% (OPEC, 2016). World oil demand is deemed to be 94 million barrels per day (MMBD). OECD absorbs 49% of it. China demands 11 MMBD. Middle East takes up 8 MMB. IEA (2016) predicts world demand to be 102 MMBD for year 2021. From this increase, 74% is expected in Asia. Out of the 58 MMBD non-OPEC supply, OECD takes up 41% of it. IEA (2016) predicts OECD to absorb 100% of the net demand add-ons for 2021.OPEC supplies 36 MMBD. Saudis produce 34% of it. Iran, Iraq and the UAE are expected to lead OPEC’s capacity expansion. non-OECD Asia imports are almost 17 MMBD.

It might not be easy to grasp what drives oil markets. Morse (2016) notices that except from China, demand add-ons in the last decade have come mainly from oil producing countries, and new supply has come from consuming countries. Supply risk is higher. Oil exporting countries face oil prices 50% below their fiscal needs. Saudis defend their market share. They do not lower oil output to raise prices as expected by some OPEC members. This section offers an outline about spot and contract oil markets and how oil is traded. Market size and prior studies are revealed. A causal account is given.

Spot and Contract Markets: Oil is sold through term supply contracts or prompt shipment in the spot market. The former entails knowing the quality of crude oil; the actions to take in case of shipment problems, and the pricing method. Oil crudes are priced according to their quality, when compared to crude benchmarks. Higher crude quality than a benchmark demands higher price. Each type of crude has a set of refined products (i.e. gasoline) that can be obtained from it based on the process used to refine it. More than 150 types of crudes are traded in the world markets.

WTI (West Texas Intermediate), Brent and Dubai-Oman are the major crude oil benchmarks. Almost all crude markets outside America and the Far East use the Brent marker. The latter is a mix of North Sea crude with an API gravity of 38.3 degrees and a sulfur content of only 0.37%. It is a "sweet crude". WTI is the benchmark for crude imported to the U.S. and has an API gravity of 39.6 degrees and only 0.24% sulfur content. The Dubai-Oman marker is used for Middle-East Gulf crudes sold in the Asia-Pacific market, and its gravity is 31 degrees, with a 2% sulfur content (Fattouh; Mabro, 2006). WTI became a benchmark spot crude oil in 1983. It was selected as the main marker grade for the Nymex (New York Mercantile Exchange) new crude oil futures contract (EI, 2006).

Oil Markets Models: Herce et al. (2006) focus on long-term oil investments. They discount short-term volatility from long-term oil price. They assess the impact on reserves value and assert that oil firms might incur in long term debt based on price bubbles. Two key oil market issues are tacit. The first is how to access oil prices since expected profit of investments depends on them. All oil projects need future price appraisals. The last oil price is usually taken, as most experts claim that prices follow a random walk, so they cannot be predicted. The second issue is that oil firms can get bank loans based on the level of developed reserves. These are reserves being produced. Hence, since new projects imply new reserves, they improve the loan base of firms. New reserves that result of price peaks could also be sold in the market, adding to cash-flow, cash stocks and assets.

Hamilton (2008b) examines the factors responsible for changes in oil prices and concludes that the behavior of oil prices during 1970-1997 is influenced by vulnerabilities of oil supply to disruptions, the peak in the oil production in USA, and the low price elasticity of demand and supply in the short term.

Naill (1972) studied the discovery cycle of gas resources using a system dynamics (SD) model. He assumes finite resources, and considers resource utilization goals in the short and long term. He tests the effects of price regulations and tax incentives on the short and medium term rates of gas discovery and production. In this model, resource level impacts exploration costs. As resources are discovered and become reserves, costs increase. This means that operators tend to work with easy to discover resources first. The model also claims that a larger reserve to production ratio leads to additional exploration investment. This is dubious, since the oil industry operates on the base of projects expected profit. Hence, every project is subject to evaluation and only then can it influence the discovery rate. The model adds delay between investments and discovery rate, showing the lead time to discover reserves. The author asserts that, although there is abundant statistical data on these factors, the interaction of these variables over time was not intuitively obvious. In summary, the model allows testing, through simulations, of the likely effects of alternative policies on the discovery cycle of gas resources.

Morecroft (2007) built a model to study the long-term dynamics of the global oil industry. The model has five key sectors: (a) flexible OPEC producers with capacity to handle significant changes in production policy; (b) opportunistic OPEC producers; (c) OPEC quotas; (d) independent producers; and (e) price and market demand. Oil price is formed according to the gap between supply and demand. Demand is driven by price and GDP growth. Profit per barrel enables production capacity in construction, which then becomes production capacity after the construction time. Thus, production is enabled. Operating and capital expenditures increase as the level of resources decrease.

Mashayekhi (2001) built a model to explain changes in oil prices. He suggests that when prices rise, liquid assets of oil exporting nations increase; their need to export oil decreases too. This leads to a decrease in the supply of oil and a price increase over time. However, this increase would reduce demand in oil importing countries. Regarding this, the depletion rate of oil fields is a matter of national policy. But, once investments are made, there are few incentives to produce oil below capacity. Even with low oil prices, oil exporting countries resist policies aimed at reducing production to increase price. They dispute that their market share would decrease. In the end, there is no certainty that such a policy would lead to an oil price increase.

The upstream (exploration and production) value chain features:

Production: Measured in barrels per day. It responds to the production capacity of the oil firm. Once an investment has been made in production capacity, firms tend to produce at rates nearby capacity. It occurs because oil wells have technical problems when used at lower capacity. Notice that the owner of the oil resource sets the rate at which fields are to be produced. It may also be in the interest of the oil firm to produce at rates lower than production capacity. This would be the case of OPEC members in November 2016. The objective would be a decreased global oil supply that could spark a price increase.

Production Capacity: Measured in barrels per day. It accumulates the difference between the annual new projects that become actual production capacity and the capacity loss of oil fields. The former are completed projects out of the construction phase. The latter is due to damage or changes in the physical properties of oil wells. Production capacity is the highest level of stable and economically efficient production that can be achieved from a reservoir. This under optimum operating conditions, with available wells connected to surface production facilities. Among them flow stations, gas plants, pipelines, storage tanks and flow lines.

Production Capacity in Construction: Measured in barrels per day. It accumulates the difference between new projects being built and those that become actual production capacity. It takes years to develop oil wells and start commercial operation. Capacity is then stabilized, most probably with new investments, before the abandonment phase is reached. Technical advances have reduced some oil shale projects lead time to months.

Oil Reserves: The amount of oil barrels deemed to exist in oil fields is called reserves. They are called developed when they are ready for production. New production capacity projects, then, develop reserves. The amount depends on the expected exploitation time of the oil field. Hence, developed reserves accumulate the difference between new reserves arising out of the new production capacity, and production.

New Capacity in Construction: Measured in barrels per day per year. They arise out of the investment decision process. This, in turn, depends on expected oil prices. Variations in prices lead to variations in projects under construction. Changes in the later impact new developed reserves and production capacity. This leads to diverse production rates. Hence, these fluctuations influence revenues. Also, production impacts global supply, and then again, oil prices.

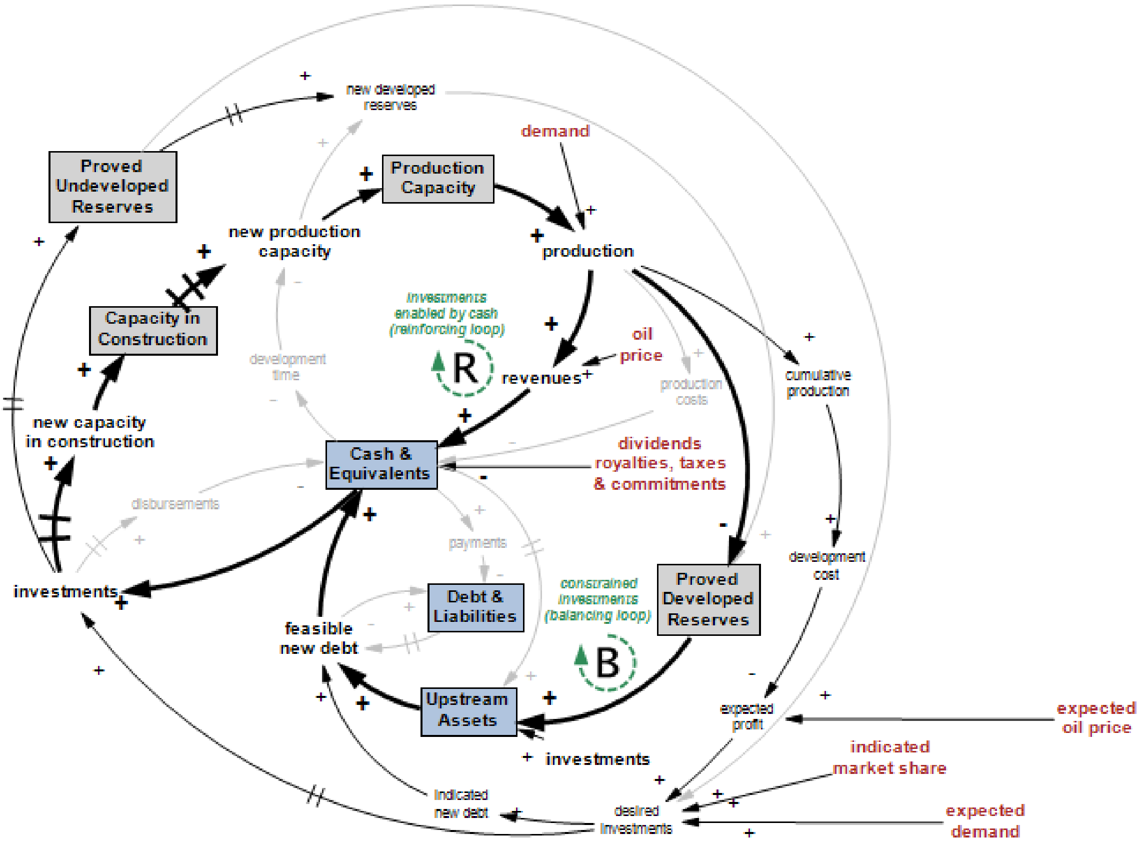

Figure 1, Upstream Oil Causal Diagram

Upstream investments are split into new production capacity projects, exploration efforts, and acquisition of assets and reserves. The investment process is fully assessed in the next section. Performance is measured (end results) as the rates of new capacity in construction, new reserves, new developed reserves and new production capacity. Reserves are split into undeveloped and developed. The latter being the result of the construction and setup process. The whole process is triggered (driven) by the investment evaluation process. Oil firms must balance the four strategic resources in order to cope with their production strategy. The resources are: production capacity in construction, production capacity, undeveloped reserves, and developed reserves. These in turn must be balanced with the financial resources.

Balancing resources is of the essence because lead times for production capacity might take years. At the same time, capacity loss begins after production starts. Developed reserves are depleted by production. Physical properties of oil fields, maintenance and recovery techniques impact capacity loss. Moreover, projects are executed in distinct countries. Not all producing reserves are developed by the same oil firms. They may buy them from other firms. They may also buy undeveloped reserves. All of this to keep a smooth production schedule that may enable them to commit to oil demand.

Notice the two major feedback loops in Figure 1. The first is the investments enabled by cash loop. Higher production leads to more revenues and cash assets. New investments are made. Projects are built. This leads to higher production. The second is the constrained investments balancing loop. Since production depletes developed reserves, upstream assets decrease. A weaker balance sheet may not allow proper funding of projects, leading to lower investments. This, in turn, leads to lower production and revenues. As seen, it is not enough to balance the four strategic resources mentioned above. They must be balanced with financial resources.

2.3 Oil Investments

Beyond profit, research offers three main factors that impact investments: demand growth given by global GDP; legal context where restrictions and changes in exploitation regimes create uncertainty about licensing and fiscal terms that may constrain investments (Hvozdyk and Mercer Blackman, 2010; Penrose, 2009; Kochhar et al., 2005); and financial situation of the host country, where desired spending is believed to create pressure for oil revenues.

Changes in oil prices may create uncertainty, lowering investments (Dixit and Pindyck, 1994). Feasible oil reserves, services and tools may impact notion of growth. Patent rights, high costs of entry into new areas and OPEC spare capacity might act as obstacles to projects. Local content needs with increasing costs, refined products subsidies prices and higher country tax take may reduce them too (Penrose, 2009; Dada, 2006; Hvozdyk and Mercer Blackman, 2010).

Regarding profit motives, Keynes (1936; Eklund, 2013) and Fisher (1930; Eklund, 2013) stated that investments are made until the present value of expected future revenues, at the margin, equals the opportunity cost of capital. Keynes did not look at it as a stability seeking process. Fisher saw it as an optimal capital stock process. Penrose (2009) argued that growth follows prospects to increase long run profits, while paying dividends. Jorgenson (1967) asserted that the goal of asset accretion is to maximize present value. Hvozdyk and Mercer Blackman (2010) claim that investments increase with higher expected price of oil.

From a financial stance, Penrose (2009) affirmed that the cash reserves needed for investments are linked to how the firm has built up (or depleted) its funds. They are also thought to be linked to the way it has used its credit. Marcel (2006; Hvozdyk and Mercer Blackman, 2010) claims that NOC´s investments are quite linked to the host state´s policies. Eller et al. (2007, Hvozdyk and Mercer Blackman, 2010) assert that the financial status of NOC´s and their investments may be impaired because of their dual role of oil producers and wealth purveyors. Further constrains to NOC´s investments come as effect of ceding cash flow to national budgets through gas subsidies (Hvozdyk and Mercer Blackman, 2010). Martinez and Ferrando (2008) state that cash flow and debt burden are key in explaining capital outlays.

Timing plays a crucial role. Robinson (1953) observed that present value may be altered by events that occur within the time gap between outlays and profits. Jorgenson (1967) stated that the feasible outlay rate may depend on the choice time of investors. Dixit and Pindyck (1994) claim that most investments share three aspects: a degree of irreversibility, uncertainty about future rewards, and flexibility in timing to get data; they also notice that delays matter, and that the present value approach should include the cost of keeping the option alive. Senge (1978) adds inventory, backlog and supply line corrections; as well as expectations forming and delays in the capital ordering process. Moxnes (1982) specifies desired state spending as driver of desired oil production, which leads to investments.

Market share is of the essence. Buzzell et al. (1975) found positive correlation between return on investment (ROI) and market share. They suggest that higher market power raises clout in market prices. Bloom and Kotler (1975) contend that higher market share implies greater risks as well, hinging on the resources of the other parties, which may set up competing coalitions. They argue that the optimal market share has been attained when departure from it – in any direction – could decrease long run profits or increase risks.

Oil firms tend to invest based on oil prices. They are used to assess future cash flows in projects. In a study by investment bank Lehman Brothers in mid-2005, with rising oil prices, oil firms planned to invest USD 192 billion in exploration and production. This amount was more than twice the amount six months earlier (EI, 2006). According to a recent study by the energy consultancy Wood Mackenzie, USD 400 billion of investments on new oil and gas projects have been cut since mid-2014, due to the 50% oil price collapse (FT, 2016).

The upstream (exploration and production) financial value chain features:

Cash and Equivalents: Measured in USD. It accumulates the difference between inflows and outflows. The former includes revenues collection and new debt. The latter includes actual payment of investments, production costs, debt repayment and interests. It also includes payment of commitments, taxes, royalties and dividends. New debt is enabled by feasible new debt. The latter is a fraction of indicated investments, as most projects include debt loans. The feasible fraction depends on the financial assessment made by banks. The ratio of upstream assets to liabilities is a good example.

Debt and Liabilities: Measured in USD. It accumulates the difference between new debt and liabilities and their payments. High values of this stock relative to upstream assets lead to reduced feasible bank loans. This may constrain investments and production.

Upstream Assets: Measured in USD. It aggregates cash and equivalents, new investments and the assessed value of developed reserves. High values of it relative to debt and liabilities lead to higher feasible bank loans.

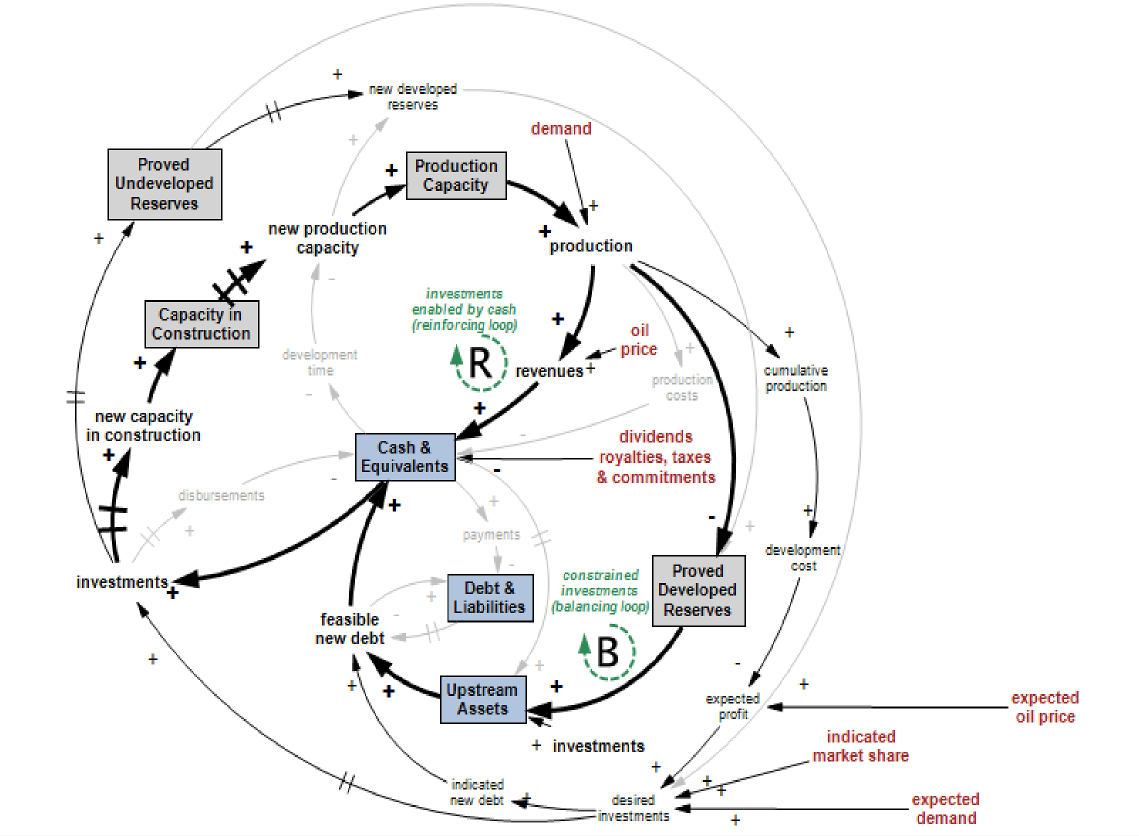

Figure 2. Upstream Investments

Desired investments arise out of proved reserves, expected profit, intended market share, and expected demand. In the case of NOC's, desired fiscal spending matters too. A fraction of investments is financed with debt. However, the new amount of debt feasible depends, mainly, on how the company has used and accrued its liquid assets. The latter emerge from the link between upstream assets and the stocks of debt and liabilities.

Investments are driven by free funds and cash flow. The unique type of reserves rules the oil fields development strategy. Diverse oil fields have varied exploitation time spans, production schedules and depletion curves. New investments take time to become new production capacity. Taxes, royalties, dividends, and operating charges drain the funds of oil firms and constrain investments in new capacity. Some NOC´s (i.e. PDVSA) deplete the cash stock at a higher rhythm than others; hence, delay investments to the point of not being able to maintain production capacity and production. The investments enabled by cash reinforcing loop reveals that accrued funds enable new projects that increase production capacity, production and revenues, further increasing funds again.

It is critical to keep a balanced level of cash and equivalents stock. Oil firms must have proper control of dividends, debt, and liabilities. These factors drain the stock of cash and equivalents. Decreasing funds lead to lower production capacity. The short term loop in charge of producing this effect is dormant under prudent financial management. However, when the funds allotted to pay for investments fall below the required value, the payment of investments rate decline. This leads to a higher time to pay investment invoices, above the normal 90 days. Construction time may increase, and as a result, new production capacity is delayed. Production may be reduced. Capacity loss rate might increase too, as a result of lower budget for maintenance of oil wells and enhanced production techniques. This may lower production even more. These effects add up to delays in new projects.

The link from proved developed reserves to feasible new debt is backed by empirical evidence. Lenders may assess a fraction of these reserves as assets for lending purposes. This leads to higher investments. Investment timing relative to oil prices is crucial. Oil firms may invest cyclically or counter cyclically relative to the rhythm of oil prices. The new production capacity created would diverge in both cases. The net present value (NPV) approach would suggest investments directly linked to high oil price expectations; oil companies may decide to wait for further information, or use a counter cyclical investment process taking into account the ups and downs of oil prices.

2.4 Financial Oil Markets

Upstream processes involve risk. Beyond exploration risks, oil price or market risk is critical. Oil prices have swung between USD 29 and USD 145 between 2008 and 2016. Changes in oil prices induce cash flow variations. Low prices may impact expected bankruptcy. This may give reasons to equity holders to under invest in the oil firm. Producers face the risk of lower oil prices in the future. This entails lower revenues, impacting operations, investments, and dividends. On the other side (downstream), crude oil refiners face a contrary risk: high oil prices. This happens because refiners input is crude oil, which is used to make refined products (i.e., gasoline).

Oil markets have faced severe swings, including: the crisis in the Suez Canal in 1956; price shocks in 1973, 1974 and 1979; the collapse of prices in 1986 and 2014; the Exxon Valdez accident; and the Gulf crisis (Foster, 1994). It is though that volatility of oil prices is the main problem.

Derivative contracts are financial tools that are valued according to the worth of an underlying asset. Unlike stocks, they do not give the owner a right of property in the reference asset. The benchmark asset can be a commodity (i.e. oil), local or foreign currency, bonds, shares, notes, securities, etc. For example, a refiner may enter into a forward contract to buy oil in the future; dodging swings in oil prices; as well as storage costs. These contracts lay out the type, quality and volume of oil to be shipped; as well as when and where the shipment will be made. They also define a price or pricing formula. These private contracts allow both the seller and buyer, to reduce uncertainty linked to oil prices in the future. This may lead to better planning of commercial and financial activities. Forwards are traded in OTC markets **(**Chique 2014).

As in forwards, in future contracts the parties agree to trade oil at a price set in the contract, at a future date. However, parties do not transact directly, and oil barrels are seldom shipped. They connect through a formal exchange. For example, a producer wishing to sell a crude oil contract in June can sell a thousand WTI (West Texas Intermediate) barrels contract to a refiner, in NYMEX (New York Mercantile Exchange). The price and amounts traded in June are public; they help put in motion the offers to buy and sell (bid, ask). If the price in June goes below the agreed price, the producer profits if he sold the contract. If the price is higher than the agreed price, the refiner profits if he bought the contract. This is a zero sum game. If the buyer of the contract opts out, he can do it by selling a contract for June, in the same amount, at the prevailing price. The contrary applies to the seller. Since the buyer has bought and sold a futures contract for June, he has fulfilled its duties to the Exchange (Chique 2014).

Over the counter (OTC) trades are mostly private, tailored contracts. Along with forwards and futures, they relate to the spot market. They are thought to reflect market conditions. They attract firms that handle contracts with alike crudes, or those who wish to trade in the same region. These contracts support risk analysis and mitigation efforts (hedging). They also attract speculation (EI, 2006). Some analysts call speculation to the fact that some holders of futures contracts do not have a commercial interest in the real barrel of oil and then their only interest is speculative.

Swaps, which are traded OTC, involve the exchange of cash flows for a period of time, against a fixed price. For example, an oil producer wishing to receive a fixed income for a given volume of oil barrels, may enter into a swap contract. The producer would pay for changes in spot oil price relative to an agreed index. He would receive the agreed fixed price, thus netting the swap with the income gotten in the cash market. This may lead to better control over oil income.

Options, also traded in exchanges, offer the option buyer (holder) the right but not the obligation to buy (call option) or sell (put option) a volume of oil barrels at an agreed “strike” price, at a future “expiry” date. As in futures, oil barrels are seldom shipped. The buyer pays a premium to the seller (writer) for this right. Hence, if the price at the expiry date goes over the strike price, the buyer profits if he holds a call. If the price is lower than the strike price, the buyer profits if he holds a put. When there is no profit from the option, the buyer just does not exert it. In all cases the writer receives the premium from the holder. Oil producers may prefer to hold put options when facing low oil prices because they lower the value of their “long” positions in the “cash” markets, like inventories, raising risk. Oil refiners may prefer to hold call options when facing high oil prices as they raise their costs, raising risk **(**Chique 2014).

Oil producers may also use options based “collars”. They offer shelter against lower prices and profits above a threshold price. The producer sets up two options. The first is a put at a strike price (floor price) lower than the current oil trading price. This is called an “out of the money” put that protects against prices below the strike price. The second is a call at a strike price (ceiling price) that is higher than the current oil trading price. This is an “out of the money” call that gives profits when prices are above the strike price. Prices between the ceiling and the floor are in the loss area for the producer, where no wins are possible, and no options are exerted. The producer is only liable for the premium paid for both options.

These markets attract liquidity. They offer readings on the changing value of future supply, impacting oil trading, which occurs at a premium or discount to the spot barrels. The future value of a benchmark is related to the current level of inventories of crude oil; the cost of storage, and perceptions about future supply and demand. Prices are in "contango" when the futures price is higher than the spot. They are in "backwardation" when the futures price is lower than the spot (EI, 2006).

Volatility in the price of oil upholds futures markets, able to offer market players means to adjust their risk profile. All of this without coping with real trading of oil barrels; its production, processing, transportation, storage, or shipment. Trading, then, happens in "paper"; its low cost is based on standard contracts, and pre specified volume, quality and date of maturity. Thus, futures markets offer low transaction costs and high transparency; perhaps because the volume of contracts relative to real supply is high. Also, the investment needed to meet future margin calls is small relative to the economic value of the oil volume defined in the contract, granting high leverage (Foster, 1994).

Agents willing to take risks are essential to close these contracts. Speculators play this role by promoting market liquidity by trading frequently. Trading may take place in exchanges (i.e. NYMEX) where set contracts are offered, overseen by the Commodities Futures Trading Commission (CFTC). They may also occur in OTC markets, where contracts are dealt between private parties.

Commercial agents include both producers and consumers. Non commercial agents include speculators, banks and funds in search of profits on short term changes in prices. Both types of agents are needed in the exchange. In essence, hedging demands same amount counter positions in the cash and futures markets. It is the mix of both that may lower the risk exposure of the hedger.

Oil producers are said to be long because they carry inventories. They may protect against the risk of falling prices by selling (short) oil futures contracts in NYMEX. If prices fall, they can offset the loss in value of their production with the profits in the futures markets. If prices rise, the higher value of production can be used to offset the loss incurred with the "paper" barrels. In both cases the producers have higher certainty with respect to the future income.

An oil producer that wants to secure a price of 50 USD per barrel for 2 million barrels in March, might take a “short” stance in NYMEX. So, if the WTI price in March is, for example, 45 USD per barrel, it would profit 10 USD million (5 USD per barrel). This profit can then be used to offset the loss in the “cash” market, since the price shielded inventory has dropped its value in the same amount. If the WTI price in March is, for example, 53 USD per barrel, it would lose 6 USD million (3 USD per barrel). This loss can be offset by the profit in the “cash” market, since the price shielded inventory raised its value in the same amount.

The stance taken by this producer needs liquidity. These funds are most often granted by non commercial agents. They which might take the risk of going “long” when the producer goes “short”. They would lose money when the WTI price goes lower than 50 USD per barrel. They would profit when the WTI price goes higher than 50 USD per barrel. Notice, though, that another commercial agent (an oil refiner) could have taken the long stance, because refiners face the risk of crude oil price increases. In this case the oil refiner would have got the same results than the non commercial agent.

Several studies have been made to address hedging related issues in the oil industry, using data sets based on the 1311 industrial classification code in the U.S., which identifies oil and gas companies involved in operations, services, exploration, production, drilling, completing and equipping wells, and oil and gas preparation. Notice that a current search of companies in this category yields results that include upstream and downstream companies, whether they are integrated or not **(**Chique 2014).

Pincus and Rajgopal (2000), study 139 firms in the period 1993-1996. They find that oil and gas firms sampled use forwards 44%, swaps 33%, futures 13%, and options 10% of firm years. Jin and Jorion (2004) study 119 companies in the period 1998 and 2001. They affirm financial distress is the reason for hedging 33% of next year´s production on average. They also maintain that 45% of firms in their sample hedged in the period. Mnasri et al. (2013) study 150 US oil and gas producers in the period 1998-2010. They maintain that investments and financial constraints are hedging motives. Kumar and Rabinovitch (2013) claim that hedging is driven by financial distress. Smistad and Pustylnick (2012) verify that firms claim not to speculate with derivatives; they also confirm that all of them try it to a certain degree. Hedging tools used were swaps, collars, futures and forward contracts.

Haushalter (2000) studies 100 oil and gas companies in the period 1992-1994. He upholds a clear link between hedging and leverage; that is, between the fraction of production hedged and the debt to total assets ratio. This study verifies that hedging helps a firm to get the funds needed to pursue investment projects. It also ratifies that hedging helps to sustain cash flows, while reducing the prospect of a default. Acharya et al. (2010) study the futures market using limits to arbitrage. They use data from 525 oil and gas production, refining and service firms. In their model, speculators have capital constraints. They maintain that these limits to arbitrage translate into limits to hedging by producers.

Hence, hedging policy protects a fraction of assets or expected income. This, in order to insure available funds for capital outlays and operating expenses. Large funds may help reduce the payment time of liabilities. Leading to lower chance of financial distress. Hedging may enable growth and enhance sustainability.

Other authors inspect the links between the financial and physical oil markets. Pindyck (2001), inspects oil cash and storage markets. The author unveils links between spot and futures prices, production and inventories. The study supports the notion that volatility of oil prices impacts risk strategies of oil firms. The IMF (2008) tried to find causality between investments by non commercial agents and oil prices, or the contrary. The study did not find the desired causality. Dees et al. (2007) maintain that much of the increase in oil prices in the 2004-2006 period can be linked to contango. Two vital factors emerge from this study. First, the authors support that expectations of investors about the state of the oil markets shape their behavior. Second, the authors uphold that production capacity takes years to build. Slopek and Reitz (2008) study oil prices in the 1986-2006 period. They argue that technical agents impact price formation by forecasting past data. This would be a kind of "positive" feedback which attempts to reinforce the observed trend. They claim that fundamentalist agents expect prices to converge towards the long run equilibrium value. This would be a kind of "negative" feedback which attempts to balance the observed trend towards equilibrium. Foster (1994), asserts that the causality between the oil spot and futures prices may be impacted by institutional quality and market structure.

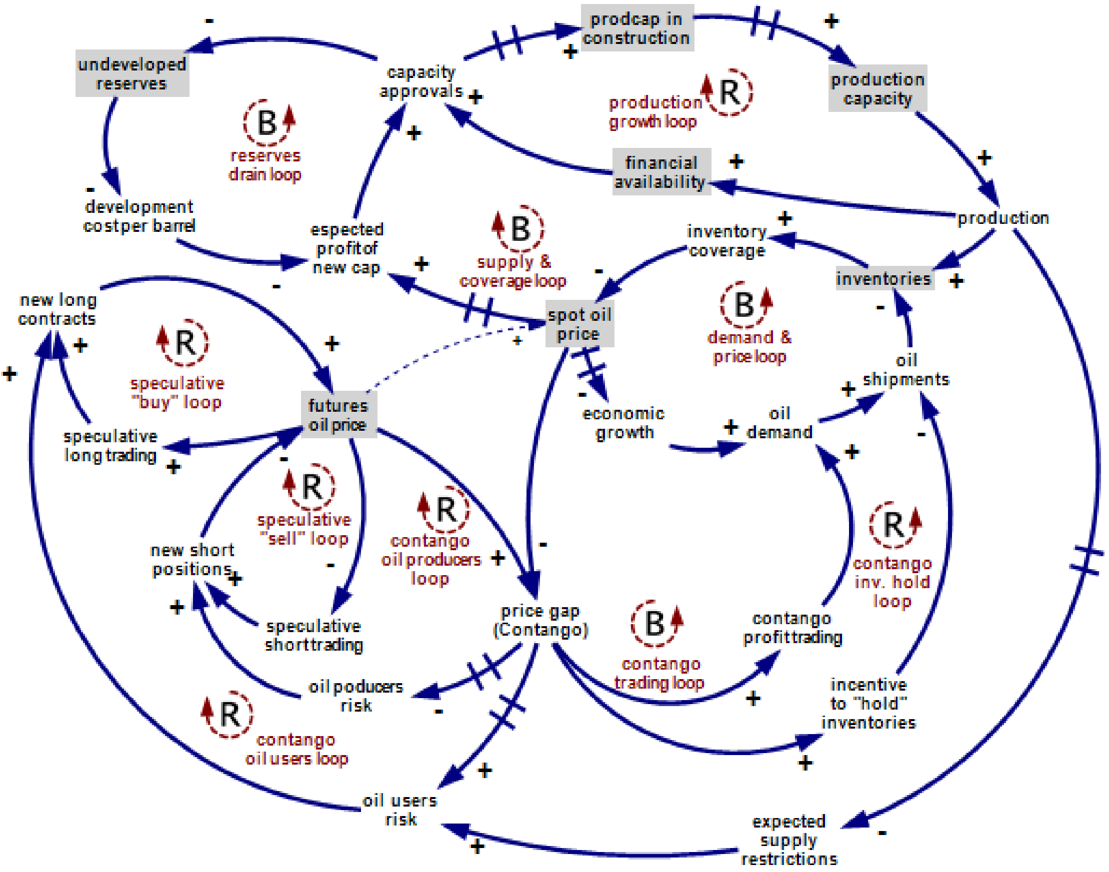

Figure 3, Oil Physical and Financial Markets

The figure depicts links between the physical and futures oil markets. It is assumed that non commercial agents do passive opposing trades to commercial agents. Since oil users (i.e. refiners) face the risk of high oil prices, they react to contango. Hedging the risk of price (cost) increases implies buying new long contracts in the exchange, which may reinforce the initial contango.

Oil producers react to low prices. A decreasing price gap (basis), would be a signal that their future income could be lower than expected and required. The hedging response calls for new short trades (selling of contracts) that end up reinforcing the initial condition. Notice that the actions of these commercial agents should be related to the price risk actually faced; this requires aligning hedging efforts to the funds required to maintain cash flow and investments.

The activity of technical traders (those that follow trading patterns) is represented by the two speculative reinforcing loops. As the futures price goes up, technical traders may buy more contracts. When the price goes down, they may sell more contracts.

Contango may also trigger profit motives: greater demand of oil barrels and decisions to hold inventory, both to profit from the higher oil price in the future. Higher demand may balance contango by lowering inventories and increasing the spot price. Holding inventories reinforces contango by not decreasing them, avoiding a lower spot price.

A major loop linking the physical and futures oil markets may arise out of expected supply restrictions. In this balancing loop, a higher futures price may prompt contango profit trading that lowers inventories and increases spot price. New production may be set up, reducing commercial users risk of high prices. This may lower the number of contracts bought, and the futures price. Notice that this loop goes around the slow production capacity set up process; however, lead times vary greatly in the oil industry.

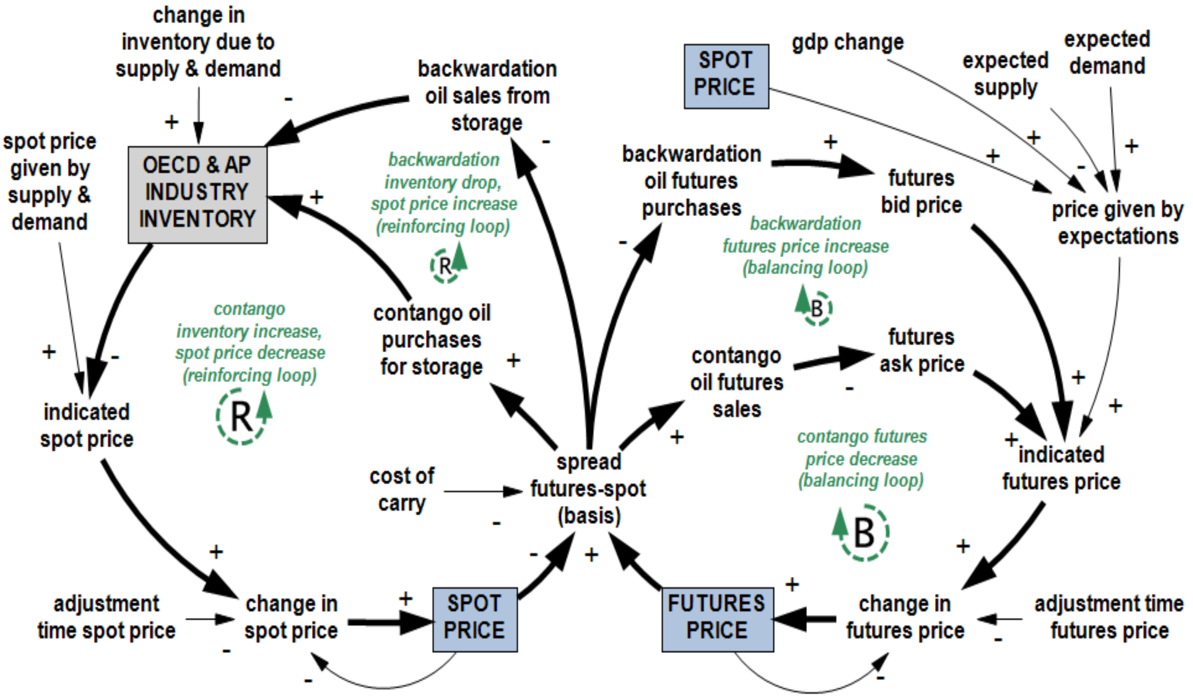

Figure 4, Oil Price

Spot and contract oil prices are driven by supply and demand. Cost of carry includes storage cost plus interests paid in the contract period. Bid and ask prices depend also on changes in inventories. In between, two pairs of feedback loops are of the essence. Traders, when contango is beyond the cost of carry, may try to buy oil barrels, and sell futures contracts. This, ideally, would entail a risk free profit, since the basis is high enough to earn a profit. Buying barrels for storage increases inventory. This tends to lower price, and make the basis even bigger. This contango reinforcing loop may lead to inventory increase and lower spot price. Traders at the same time, may act on the futures markets. They may sell short contracts lowering the ask price, the futures price, and the basis. This contango loop balances towards backwardation.

Also, traders have motives to sale oil from inventory in backwardation. But, at the same time, they may enter into long contracts in the futures markets. As a result, inventory drops and spot price raises. Backwardation is reinforced. At the same time, the futures bid price increases, and the futures price too, balancing towards contango.

The loops depicted may reinforce or balance price fluctuations. Price anchors subject to this are the oil price given by supply and demand and the price given by expectations. The latter may be driven by changes in GDP, demand and supply. Current spot price could act as anchor too. From this view, then, oil price is shaped by expectations, perceived supply and demand, and changes in inventories. However, Traders in search for profit or price shields impact realized spot and futures prices. There may be limits to their actions too. Funds available for trading depend also on the return of spot and future markets relative to other commodities. This implies that funds may not be available to trade in full as indicated, and the full arbitrage process may take longer than expected. That is, adjustment times may longer.

As described, this causal account depicts actions by traders acting in both spot and futures markets at the same time. However, it may subject to swings brought about by momentum or technical traders that may amplify price moves up or down. This may happen because they tend to buy futures when prices are going up, and sell them when prices are going down. Further swings may arise, as investment funds may trade futures as a portfolio diversification strategy, without trading on the physical side.

2.5 Organization of Petroleum Exporting Countries

OPEC acts within the oil spot, contract and futures markets context defined above. Among its goals we find long term petroleum revenues for members; fair and stable prices; its share of world oil supply; the stability of the world oil market; and the security of a regular supply to consumers (OPEC-LTS, 2010). However, securing a steady income to producers has not been an easy task. A study by Drollas (2003) reveals that OPEC average export revenues swung between 422 and 163 USD billion (constant 2001 US$) between 1973 and 2002. Exports as a percentage of production decreased from 92% to 60% from 1960 to 2015.

Yet, reliance on oil has raised in spite of higher revenues. It has also led to larger spending pledges. OPEC's current account surplus 1974 and 1980 (69 and 111 USD billion) was gone by 1978 and 1982. Saudi Arabia ran both a budget and a foreign exchange deficit; massive imports of goods and services and spending in foreign currency are thought to be liable. This backs the view of OPEC exporters as highly indebted firms (IMF, 1986; Adelman, 1986). This view has recent support as the negative current account balance of Saudi Arabia for 2015 and 2016 is estimated at 3.5 % and 4.7% of GDP; and their fiscal break even oil price is estimated at 100 $/barrel (IMF-REO, 2015).

OPEC studies: Its production behavior has been studied in detail. Griffin (1985; Brémond et al., 2011) proposes partial market sharing as the best fitted model for OPEC. Hnyilicza and Pindyck (1976) split OPEC in two groups, (savers and spenders); the spenders with an instant need for cash and rate of discount lower than the savers. Both groups with diverse bargaining power.

There is also the OPEC dynamic pricing power dimension; that which allowed for cohesive output cuts and oil price upturn from 10 to 23 USD per barrel from 1998 to 1999; that which has needed distinct models to explain diverse events (Fattouh and Mahadeva, 2013).

Saudi Arabia's role within OPEC is of special concern. It tends to maintain plenty of spare capacity; and its production is negatively correlated with that of other OPEC producers. This has led to models with Saudi Arabia as a distinct producer (Fattouh and Mahadeva, 2013). In this line of research, Griffin and Neilson (1994; Fattouh and Mahadeva, 2013) affirm that Saudi Arabia has opted to punish members for producing above their quotas. As in 1998, when Saudi Arabia is thought to have replied to Venezuela's higher output by increasing its own output.

Saudi Arabia’s and other OPEC members’ exports sway at a similar rhythm during “normal” times. That is, the correlation is 0.7 when there are no supply disruptions. However, it is negative during supply disruptions. This implies that when demand declines, both Saudis and rest of OPEC reduce exports. When rest of OPEC exports are interrupted, Saudis increase exports (Alkhathlan et al., 2014). Haltwinger and Harrington (1991; Fattouh and Mahadeva, 2013) assert that incentives to produce beyond what has been agreed increase when demand expectations are falling. Hence, it is harder to maintain collusion under falling demand. In any case, there may be limits to OPEC investment strategy; its exports as a fraction of production have gone from 92% to 60% in the 1960-2015 period. OPEC’s challenge is to have a smaller consumption to increase export revenue (Aissaoui, 2015).

Cremer and Weitzman (1979; Al-Roomy, 1987) modeled OPEC with production costs based on the cumulative reserves extracted. Fringe producers are price takers that follow OPEC price signals. However, the oil demand was assumed to be linear, growing over time. The concept of costs increasing with cumulative production is in sync with oil operations where firms usually extract the low cost barrels first. There may be a great difference between the number of oil wells a large firm may have, and the number of active wells. This happens since wells are only profitable under certain conditions.

3. METHODOLOGY AND SIMULATION RESULTS

3.1 Rationale for Adopting Methodological Approach

The System Dynamics (feedback thought) method is used in this research. Yet, most oil markets studies use the equilibrium paradigm. Both paradigms are presented. Then, we inspect both methods for modeling oil market issues, since they may lead to different problem framings.

Introducing the equilibrium paradigm:
It refers to the price stability that is alleged to arise out of the joint balance of market supply and demand. As asserted, this leads to the efficient allocation of goods and services. The U.S. Department of Energy (DOE, 2005) model uses this method. It is used for midterm projections through 2030. The Model used by the International Energy Agency (IEA, 2014) uses this method too. It is used to project scenarios for their world energy outlook.

The IMF (Pesenti, 2008) uses general equilibrium (in diverse markets) models. They study production, consumption and oil trading. This model serves as base for the Bank of Canada´s (Elekdag et al., 2007) study of shocks driving oil prices. It assumes perfect competition and long run equilibrium. The Norges Bank (Golombek et al., 2014) uses an equilibrium based model to study oil markets.

Research on oil markets: Extant model based research about oil market has been done. This outline presents models according to purpose and method used.

Model purpose: Al-Qahtani et al. (2008) present more than 50 models for oil market studies. They include oil prices, OPEC´s behavior and other topics. Oil price is one of the most vital market topics. Thus, most of the studies refer to it.

Topics on oil prices include: price response to changes in the actions of economic agents; price swings due to market share policies of OPEC´s members; OPEC´s production quotas impact on price; OPEC´s production capacity impact on price; projections of supply, demand and oil prices; short term price elasticity; optimal price paths to maximize surplus by producers and consumers, and the net present value of income and reserves.

Among OPEC´s topics we have: Cartel and competitive behavior; impact of taxes on OPEC; Cartel´s stability and optimal price paths; and optimal production to cover the call on OPEC. Other topics include oil demand forecast; mid and long term trends in oil markets; and the appraisal of utility for OPEC and non OPEC producers.

Method used: According to Huntington et al. (2013), models are classified depending on the method used: structural, computational, and reduced form or financial models.

Structural models use economic theories about the goals, constraints, and behavior of market players. They provide the root for formulas where players relate to the market. Each sector in the model is often based on economic, political, or rule of thumb mechanisms. They usually focus on a single market (for example, generic world crude oil supply) with few agents or players (for example, OPEC and oil firms).

The oil market model by Dées et al. (2007) is an example of the structured approach. The authors present a model of the world oil market. The key premise is that the coefficients represent the long run link among variables (equilibrium). They assert the model can be used to analyze oil market changes and risks. The model, built in 20015, is composed of several equations that are computed each quarter, in the period 1995 to 2001. The main exogenous variables (those that while being independent, affect the model behavior, without being affected by it) are: OECD oil stock; OPEC production capacity; oil production costs; and OPEC quota. The main endogenous variables (those linked by equations within the model) are: oil demand; non OPEC oil production; oil price; and OPEC production. For example, the formula to compute the OPEC production is:

OPEC oil production = total oil demand + variation in OECD oil stocks
– (Non OPEC oil production + production of non-gas liquids + refining gain)

Their conclusion is that the model generates fairly accurate past prices. This model is thought to capture changes in oil supply and demand that have caused real oil prices to swing over the last two decades. Their tests suggest that non OPEC supply is rather inelastic to changes in price.

Computational models allow much detail, as they use extensive computing resources. For example, refining capacity in Europe, refined products in a region, oil inventories at country level, several producers and multiple qualities of crude oil. The underlying logic of these models is the search for partial or full general equilibrium with other energy or other sectors in the economy. Both modeling approaches, the structural and the computational, provide explanations about the determinants of markets and oil price behavior, with emphasis on the long term.

As an example of the computational approach, we present the National Energy Modeling System (NEMS). It was developed by the U.S. Energy Information Administration (EIA). This agency is responsible for official energy information used by the federal government. This large scale model contains numerous modules (and more than fifteen hundred equations). Within NEMS, the Oil and Gas Supply Module (OGSM) is used for projections of reserves and production of crude oil and natural gas at the regional and national level. There are two key assumptions in the OGSM; the first is that drilling for oil and gas is projected using the expected net present value of the drilling efforts. The second is that the model must be able to pass tests for “orderly” futures and “disorderly” ones; that is, constant drilling activity around an equilibrium level, and fluctuations around equilibrium (NEMS Conference Proceedings, 1993).

Reduced form or financial models center their attention, mainly, on short or midterm oil price formation; with less account of market behavior than the structural and computational approaches. They have become more popular given the impact that financial motives, markets and institutions have on commodity and oil trading. They attempt to unveil the behavior of the financial markets, and predict futures prices and volatility. They often focus on oil price and its time series properties. These models are based on linear and nonlinear time series, and use statistical relations between oil prices and other variables. Vector auto-regression (VAR) is the most conspicuous representative of this approach; its relevant feature is the premise that past values have an effect on the current value. Thus, future values are estimated based on a weighted sum of past values. This method is used to forecast inter related time series; and for the impulse response analysis of a system of variables. The structured vector auto regression

(SVAR) enhances the VAR approach by adding elements of the structural models; hence, allowing for better economic explanations.

Among these reduced form or financial models, we find ARMA, a single variable, auto regressive moving average model. It may capture the time variation of a time series, and use it to forecast future prices. This model is also used to represent random walk processes derived from the efficient market hypothesis (EMH). It assumes that price changes are just “pure noise”, and that no player can outperform the market. ARMA models can also serve as the base to imply a mean reverting process; in which case oil prices converge to a long-term equilibrium, at a speed specified in the model. This framework is supported by Pindyck (1999) who asserts that “non-structural forecasting models should incorporate mean reversion to a stochastically fluctuating trend line. That trend line reflects long-run (total) marginal cost, which is unobservable”.

Epistemology in the research on oil markets: A sample of models used for oil market research has been assessed. Diverse purposes and methods have been laid out. Now, questions are made to help us grasp the criteria used to justify this knowledge.

Which paradigm do they depart from?

Let´s first take a look at some of the findings in this review of models of oil market research:

The claim that the coefficients estimated, by using a model, represent the long-run relationship among the variables. This may be read as: there is an underlying, pre-determined equilibrium towards which the relation between variables must converge. A suggestion to model oil prices using two components: a mean reversion process where prices converge to an assumed long term equilibrium; and a fluctuating component. A study where a key assumption is that the model must be able to pass tests for “orderly” futures and “disorderly” ones; that is, constant drilling activity around an equilibrium level, and fluctuations around equilibrium. The usage of random walk processes derived from the efficient market hypothesis (EMH). The assumption that price changes are just “pure noise”, and that no player can outperform the market. In some studies, though, the methods used allow past values to have an effect on current value.

There seems to be a focus on equilibrium, and, how is it justified?

Richey (2005) asserts that market equilibrium is justified by its efficiency in allocating scarce resources and capital supply. It arises out of the aggregation of supply and demand. His thesis is that “equilibrium is well-enshrined in the philosophical and economic literature as the basis by which individual activity (whether corporate, institutional, or otherwise, and always satisfying all assumptions of competitive equilibrium), driven by self-interest qua profit motive, leads to an efficient outcome for the system as a whole”.

Looking at the salient features of this review, we may see that, as Richey (2005) claims, commodity (oil) prices are optimal, regulated endogenously to the market system, and they tend to equilibrium. The assumption that oil production (or drilling activity that enables it) should be modeled around an equilibrium level leads to the maximally efficiently attainable.

However, not all the modeling approaches analyzed conform to the claim made by Richie (2005) that the self-adjustment of markets to their equilibrium point is always instantaneous. Modelers may consider allowing for the adjustment process to take some time. The other reason brought in by Richey (2005) is that markets “know best”; that is, they show a collective rationality that beats the available information or knowledge by any agent.

The observed claims, are in some way, nearby the search for certainty that typifies natural sciences. They could be compared with the view that the search for constant or perfect relationships should not be the target of economics (Mises, 2003). According to him, this knowledge is not quantitatively definite.

Given this, is instantaneous equilibrium possible?

Mises (2003), who is thought to interpret the economy as the science of “human actions”, asserted that action distinguishes between the present and the future; he stated that it takes time to go from one to the other, and therefore, all changes could only be felt, or perceived, over a period of time.

This may have led him to claim that certain time must pass before a new equilibrium is achieved, hence, equilibrium could not be reached immediately. This could have provided insights to the view that general equilibrium should not be applied to problems regarding capital; given the time lag between the moment when the decision is made to order capital and the moment when it arrives.

The introduction of time in the equilibrium issue brings new questions. If we depart from actions that take time, there is a gap between the moment when a decision to act is made and the moment when, ceteris paribus, the desired action is accomplished. What happens if the conditions that exist when the action is accomplished are different than we assessed? What are the underlying assumptions behind the equilibrium design features in the oil models surveyed?

The answer might be found in Simon (1955) who expressed that “Traditional economic theory postulates an 'economic man', who, in the course of being 'economic' is also 'rational'. This man is assumed to have knowledge of the relevant aspects of his environment which, if not absolutely complete, is at least impressively clear and voluminous. He is assumed also to have a well-organized and stable system of preferences, and a skill in computation that enables him to calculate, for the alternative courses of action that are available to him, which of these will permit him to reach the highest attainable point on his preference scale. “.

It could be argued, though, that decisions could be irrational if results are not optimal, then. But, if decision makers are confronted with not only time lags for actions to come true, but also with unexpected events that might arise in the ambiance, could decisions still be tagged as irrational? Mises (2003) asserts that this is not the case. He states that they just don´t have the correct information, and that if they had it, they would decide differently. He goes further and states that “Only a perfect being, whose omniscience and omnipresence would enable him to survey all the data and every causal relationship, could know how each erring human being would have to act at every moment if he wanted to possess the divine attribute of omniscience”. What are the implications?

Models arising from this perspective are empirical and correlational; they may provide explanations about the short or long term determinants of markets and oil price behavior. Explanations of the underlying causal mechanisms modeled are provided only in models of the structural or computational type. In any case, their epistemic and scientific value depends on their predicting power. Hence, validation is a formal process based on accuracy (Barlas and Carpenter, 1990).

The caveat is that, to depart from wrong assumptions does not seem to be a problem for oil analysts and modelers if the predictions turn out right. Hausman (1992; Little, 2002) favors an approach where assumptions should be realistic; this entails paying closer attention to the institutions shaping the problem under study. Leplin (1984; Little, 2002) argues that the best approach for a theory to explain observable phenomena is by postulating mechanisms that operate in reality.

Introducing System Dynamics (feedback thought):

According to Sterman (2000), “System Dynamics (SD) is a perspective and set of conceptual tools that enable us to understand the structure and dynamics of complex systems”.

System dynamics enables us to build computer simulation models that can be used in the design of better policies and organizations. The goal of SD is to increase the understanding of an organization´s performance and internal structure and operating policies in connection to its stakeholders, and then design better policies.

It has origins in nonlinear dynamics and feedback control theory. SD focuses on social systems, and therefore draws on economics, social psychology, and other sciences. The emphasis on policy making requires learning about how to effect sustained organizational change. SD centers its attention in the dynamics of the system under study. To do so, it aims at identifying the stocks and flow structures, time delays and non linearities that along the feedback processes are thought to cause such dynamics.

SD poses that all interactions arise out of two types of feedback loops, the positive (self-reinforcing) and the negative (self-correcting). The former tend to reinforce whatever is happening in the system. For example, in an oil company, finding oil reserves through the production process increases the stock of reserves; this may enable more production. The latter tends to correct whatever is happening in the system. For example, higher oil prices may induce higher oil production, over time; which in turn may affect the oil price downward. These negative loops are self-limiting processes that seek balance and equilibrium.

Mental models are important for SD, Forrester (1961; Sterman, 2000) asserts that all decisions are based on models, usually mental models. In SD, the term “mental model” embraces our beliefs about causes and effects that define how a system operates, the boundary of the model (which variables are endogenous and which are exogenous) and the time horizon we consider relevant to the problem.

Research on oil markets: Few studies are listed in the literature. Nail (1972) built a model to study new gas resources in USA. Morecroft (1990, 2007) built a model to study the medium term dynamics of the oil industry; it takes into account OPEC and international oil firms, as well as price formation. Genta and Anderson (1994) built a strategy model for an international oil company to help shape future scenarios. Mashayekhi (2001) built a model to explain oscillations in oil prices, and how these processes could be related to the behavior of national oil companies.

Epistemology of System Dynamics: The focus is placed on salient features of the System Dynamics method: its assessment of decision making, focus on operators, endogenous perspective, feedback loops and knowledge.

Decision making: In this perspective, the non optimizing nature of decisions by the operators (problem owners) is generally a given; bounded rationality is implied. This non optimizing element is related to Simon (1986), who claims that decision making is also framed by beliefs, expectations and expected utility. It is about cognitive limitations, time and cost constrains, and imperfect information. According to Simon (1976; Naughton, 2003) these features highly constrain the optimization chance of decision makers. Hence, they are prone to use simplified mental models to solve for complexity.

Focus on operators. According to Pruyt (2006), System Dynamics entails the study of social systems in close interaction with the decision-makers and stakeholders. It requires all the constructs used in this simulation method (variables, constants) to exist in the actual system under study (Forrester, 1961; Pruyt, 2006). Since knowledge search is related to the perception of the problem owners, causality is justified by the beliefs of the operators and modelers (Zolfagharian and Fartookzadeh, 2013). It is justified by theoretical constructs grasped from other disciplines too. This combination of causal mechanisms may end up providing a theory about how structure drives behavior. Given these elements, such models can be used for both prediction and explanation (Barlas and Carpenter, 1990).

Endogenous perspective: This method departs from the belief that observed phenomena emerges out of the structure creating behavior. It doesn´t presuppose the existence of equilibrium. It assesses the social processes using an endogenous perspective. This means that the method requires the formulation of dynamic hypothesis that explain the dynamics of the problem as endogenous consequences of the feedback structure. In other words, System dynamics posits that the interaction of the positive and negative loops is what creates, induces o generates effects on the observed problem or behavior. The usage of the word "endogenous" in SD is primarily devoted to variables contained "within" a feedback loop that is thought to represent the way the system under study works in reality.

Feedback loops: System Dynamicists focus on understanding the main feedback structures to enhance decision making (Olaya, 2009); this includes negative and positive loops; they are considered as integral part of the system being analyzed. The interaction of such feedback loops is considered responsible for observed phenomena, over time. Such loops are also thought to explain counter-intuitive behavior and policy resistance in social systems (Richardson, 1991).

Knowledge: There is not a unified perspective about knowledge in the field of System dynamics. Some System dynamicists hold a realistic view, and they also engage in modeling in organizations; they promote organizational learning and change (Lane, 2001). For them, the process of model validation is continuous, and building confidence in the model built with the stakeholders is a cumulative process, over time; while they build a theory or provide insights for organizations. Other System dynamicists take a more objective view, and they focus on building theories based on the models they build, in order to make significant contributions to academia and society.

Oil market issues:

From the above discussion, there seem to be some difficulties to build explanatory (referring to the past) or policy (referring to the future) models of the oil markets. These difficulties are present even in aspects that have been under scrutiny for decades, like supply, demand and oil price mechanisms. The equilibrium paradigm has provided laws for these three elements. The interpretation of these laws ranges from those in search for certainty and precision (like the analysts in our models review), to those that like Mises (2003) do not perceive such a degree of certainty in the results of the economic analysis. But, what if we raise the degree of complexity of the analysis? What if we now include other claims by experienced analysts about additional reasons affecting the supply, demand and price mechanisms?

In this regard, how could we better test the following hypothesis about elements that may also affect the availability of oil reserves and the oil production? Can they be ignored because no reference to the economic concept of equilibrium is evident in them? Can these elements be tackled with the random walk approach?

- Every oil price regime has reflected the balance of power prevailing at that time (Mabro 2006).
- Oil price decisions just respond to the vested interests of critical participants in the markets (Bridge and Le Billon, 2012: Barros, 2012; Noreng (2007).
- Iraq´s invasion in 2001 was all about securing oil (Noreng, 2007; Greenspan (2007; Nell and Semmler, 2007).
- Major players in the industry have the capacity to act in critical moments, as to block or permit a change (Barros, 2012).
- History (path dependency) may shape the course of actions in the energy field; there are specific aspects that may lead Petro-states to poor performance in the future (Karl,1997; Barros, 2012).
- Western policies aimed at securing oil supplies in the Middle-East over time, shape supply policies (Paul, 2002).

We have agency based, history and path dependency like narratives, suitable as backstage for the statement made by North (1993): "institutions are not necessarily or even usually created to be efficient: rather they are, or at least the formal rules, are created to serve the interests of those with the bargaining power to create new rules".

We now turn our attention to the definitions of "mechanisms" that may help in grasping the assessments that could be made of these issues, using the equilibrium paradigm and the feedback thought approach.

Machamer et al. (2000) introduce mechanisms as complex systems which underlie behaviors. They state that a description of a mechanism describes the relevant entities, properties, and activities that link them together. They also point out that frequently, mechanisms are continuous processes. Cartwright (1989; Machamer et.al, 2000) add that entities have capacities which provide them with the "disposition to act". For Salmon (1984; Machamer et.al, 2000) mechanisms are composed of processes, and interactions that create change in the processes, over time.

Ruling paradigm, power issues: There is no consensus on the availability of mechanisms able to explain power interactions, other than at the narrative level. Maxwell´s (Cooper, 2008) Governor´s equations don´t seem to apply directly to the analysis of, for instance, western and Middle-East power interactions.

There are no laws that describe – consistently – the struggles for oil reserves in the Middle-East by western companies and governments; at least in the sense implied by Schaffner (1993; Machamer et.al, 2000), when he mentions "universal generalizations". That is, mechanisms that would produce similar changes under similar conditions.

Little, D. (2012) stresses the differences between natural and social phenomena, and warns against the availability of strong "laws of nature" describing the latter. He states that although there are regular mechanisms, like the decrease of infant mortality when states devote more resources to public health, generalizations are dangerous. According to this, there are no laws of exact behavior than can be applied in the analysis of power issues. This contrasts with, for example, Ohm´s law used to access current, voltage and resistance in electrical circuits.

Modeling power issues in the oil market with this paradigm would imply, then, a focus on predicting outcomes, without recurring to causal mechanisms creating observed behavior. The historic context would be explained in narrative form, and equations would provide predictions from the present initial conditions to the ending period of study. It would be assumed that initial conditions “contain” all relevant information pertaining to the problem, and that agents would have perfect information. The deviations from the expected, fundamental values of the predictions would be explained using events. These events would be exogenous; they would enter the analysis in the moment they occur, not before.

Feedback thought, power issues: Modeling power issues in the oil market with this paradigm entails a focus on explanatory power, by recurring to causal mechanisms creating observed behavior. The underlying base would be the notion that the feedback mechanisms generate consequences that are spread over time and space. This is an endogenous perspective.

The caveat comes with the focus on variables that must exist in the system under study. Notice that the power of explanation comes from a design that “replicates” past behavior. And, where would the structural data from a power issue like the western´s approach to Middle-East oil reserves come from? Was the Iraq War about the US revealed preference of dismantling weapons of mass destruction, or was it motivated by geopolitical and oil supply security concerns? (Noreng, 2007). How to model this dilemma between the western´s stated vs revealed preferences?

However, for explanatory, non-precision oriented analysis, System Dynamics might provide a schema to assess the consequences of past western´s actions in the Middle-East, in the search for oil reserves. Take, for example, the case of the U.S. invading the Middle-East in 1973. Paul (2002) asserts that, a declassified British memorandum indicated that the US thought of launching troops to seize oil fields in Saudi Arabia, Kuwait and Abu Dhabi, during the 1973 embargo. The answer lies in path dependency.

Sterman (2000) describes path dependence as “a pattern of behavior in which small, random events early in the history of a system determine the ultimate end state, even when all end states are equally likely at the beginning. Path dependence arises in systems whose dynamics are dominated by positive feedback processes; they can lock into a particular equilibrium”.

Hence, the method might shed light on the accumulation of conflicts and oil supply disruptions in the Middle-East; but, and here comes a caveat, would the causal mechanisms considered be stable enough to provide answers to most events in the region?

A next caveat is related to the validation aspects posted by Barlas and Carpenter (1990). Since model equations in System Dynamics claim to be causal mechanisms, each one has to be justified. Hence, the model may be refuted if the causality in at least one of the mechanisms assessed is not properly supported; even if the output fits observed phenomena. The lack of consensus about the mechanisms that explain the power interaction conspires against this method.

To prevent this from happening, Barlas and Carpenter (1990) suggest a relativist, functional and holistic approach to model validation. According to this, building confidence in the usefulness of a model becomes a must. Confidence is assumed to accumulate over time.

Financial oil markets issues:

Oil futures contracts are transacted by: (a) players in the oil physical supply chain, (b) financial players, and (c) players in search of profit or portfolio diversification. These transactions allow both risk diversification and speculative strategies (EI, 2006). There are divergent views on the effect that these financial markets have on oil price formation, in a context where prices have fluctuated between \$150 and \$29 per barrel, in the period 2008-2015. These views range from those that blame the activity of non-commercial traders (those without a commercial interest in the underlying commodity) for the oil price increase and fluctuations (US Senate, 2006), to those that consider that there has been no evidence of such behavior (Harris and Buyuksahin, 2009).

There seems to be consensus about the stable equilibrium states that can be attained in the consumer good markets (Cooper, 2008). However, there isn´t when it comes to capital inputs, asset markets. Can the mechanisms that lead to equilibrium in consumer good markets be used to explain asset markets?

Equilibrium paradigm, financial markets issues: This paradigm perceives that markets are efficient, and that they exhibit collective rationality about the value of the commodities;

according to this, markets prices seem to be guided to the proper and “real” value of commodities (Smith 2003; Richey, 2005). The underlying assumption is the Efficient Market Hypothesis (EMH)

EMH assumes frictionless markets, full information availability and transparency, investor rationality and arbitrage (Barros, 2012). Given this, markets move naturally only toward equilibrium, and remain there until influenced by external events (Cooper, 2008). In this view, exogenous events cause markets to move; prices are therefore, unpredictable. They follow a “random walk”; all available and relevant information is fully and instantaneously reflected in the price of a market security (Barros, 2012). EMH allows for the calculation of potential future financial assets return Cooper (2008).

In summary, EMH assumes that “market knows best”. The rational, efficient supply of commodities responds to the distributed aggregation of single decisions. This argument lies in the core of the resistance to market regulation (Richey, 2005).

One caveat about EMH is that it does not consider asset price bubbles or busts; wild asset price swings are, accordingly, just markets responding to changing fundamentals (Cooper, 2008). As per this analysis, the changes in oil prices (from 154 to 29 dollars per barrel) in 2008-2015, have been just that, a change in fundamentals. No speculation, lack of regulation, herding or agency issues took place to influence price moves.

Another caveat is Veblen’s (1899; Cooper, 2008) assessment about asset markets where demand increase with price. This is a different mechanism to that which rules the markets for goods and services Cooper (2008).

Which mechanisms to model? EMH based or Veblen´s? EMH would argue that agents sell their financial assets when they perceive them to be overvalued; undervalued assets would attract buyers. Both mechanisms lead to different worlds. EMH would lead to an equilibrium condition, Veblen’s mechanism would lead to positive feedback trading, that is, reinforcing of positive or negative price pressures. In Veblen´s world, then, bubbles are possible.

Against the equilibrium paradigm claim that exogenous events cause markets to move, Minsky (1992) reasons that financial markets can generate their own internal forces – an endogenous perspective. This is called the Financial Instability Hypothesis.

From this standpoint, raising prices in financial assets (for example, oil futures) improve the debt to equity ratio (DER) of companies. This happens because these assets are "marked to market", and the assets value increase with raising prices. Improvement in DER leads banks to offer more loans to companies, which they may use to buy more financial assets, which builds momentum for further price increases.

When prices are going down, DER deteriorates and banks request further loan collaterals from companies, which liquidate some of their positions to comply. These selling signals build momentum for further price decreases.

This interplay between financial agents is claimed to be a source of oscillation in credit (expansion-contraction) and asset prices (inflation-deflation). Hence, Minsky (1992) puts forward a framework where financial markets are not self-optimizing, and not in equilibrium (Cooper, 2008).

This leads to the "lighthouse" caveat. Which side to take? EMH or else? A "disequilibrium approach" requires at least, a way to model and keep track of the two-way causal mechanism arising out of the interaction of financial players. Besides, for the two-way mechanism to function, information flow must be delayed, which leads to accumulation. But, accumulation denies the idea of random walk.

Modeling financial oil futures markets with the EMH paradigm would imply that equilibrium would be attained through the interaction of commercial, non-commercial and financial agents. As efficient markets, futures values of oil contracts would show the "correct" price at all times. The assessment of their returns could be used safely as a guide for capital budgeting and allocation (Barros, 2012).

Validation of EMH based models would be shaped by the true-false (verifiability or falsifiability) dichotomy arising from forecasting power. Explanatory power would not be an issue. This empiricist philosophy of model validation would see validation as a "confrontational" process because the model is assumed to be an objective representation of the real system (Barlas and Carpenter, 1990).

Feedback thought, financial markets issues: From this perspective, when analyzing financial markets, system dynamicists may be tempted to take into account the underlying structure in the financial instability hypothesis offered by Minsky (1992). According to this, there are forces that over time, move the activity of financial players from a conservative one (hedge positions to reduce risk) to positions where balance sheets are illiquid and highly leveraged (Minsky, 1986; Tymoigne, 2006). The dominant forces shaping this activity would be justified by the interaction of positive and negative feedback loops. The change in dominance would be triggered by accumulation processes.

Working with the claimed underlying structure that creates the observed phenomena, would further allow the dynamicists to assess the potential for firms to engage in speculative finance (Tymoigne, 2006). This contrasts with the EMH approach, in which prices always reflect all the information available. Furthermore, several studies about the activity of oil producers in the futures markets show that instead of just hedging their long positions in the physical markets, they also use "collar" financial instruments. These collars allow for hedging activity and profit seeking behavior (Chique, 2014).

Remarks:

I examined two approaches for modeling oil markets power related and financial markets issues. Feedback thought may prove useful to access historic and path dependency issues that impact production and prices, over time. The financial instability hypothesis, originated from the same discipline as EMH, provides a new theory to access financial markets; feedback thought, though, seems to offer a method to tackle it within a disequilibrium perspective.

3.2 The Production Model and Behavior Test of Production and Investments

Figure 5 presents an initial capacity model for the investment process. Stocks are measured in barrels per day. Rates are measured in barrels per day per year. New projects arrive to the oil firm’s portfolio from the investment process. The projects in the portfolio stock are those that the oil firm has decided to execute. However, market or financial constrains can make the change in portfolio negative, leading to a lower stock. This stock accrues the balance between the new projects and the projects that enter the construction stage, often within three years. Once there, it takes some time for projects to become real capacity. Lead times vary. They may depend on technology, project support funds, location and type oil fields and wells, and crew experience. Hence, the production capacity in construction stock accrues the balance between new construction projects, and those that are ready to produce. Capacity to produce is subject to loses. The later may arise out of physical (decreasing reservoir pressure, or increased water cut); and other factors, such as under investment, damage or sabotage (Höök et al. ,2014). So, the production capacity stock accrues the balance between the new production capacity rate and the loss rate.

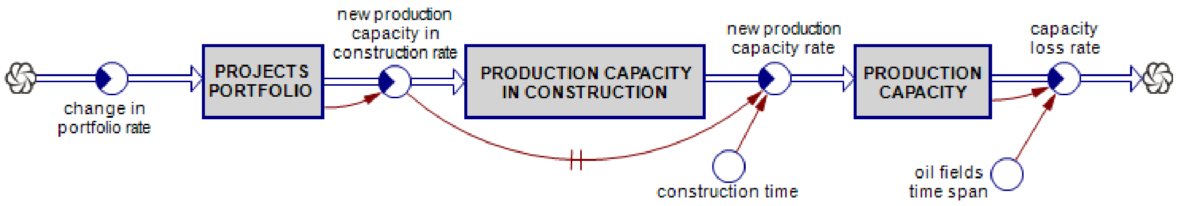

Figure 5, Starting Production Capacity Model

Notice that both portfolio of projects and production capacity are drained by negative feedback loops. These strategic resources decrease at the rhythm of output rates. Balancing them is of the essence, if the oil firm desires to keep or increase production capacity.

The starting model is now tested using a 10000barrels per day (BPD) impulse new project in the portfolio stock.

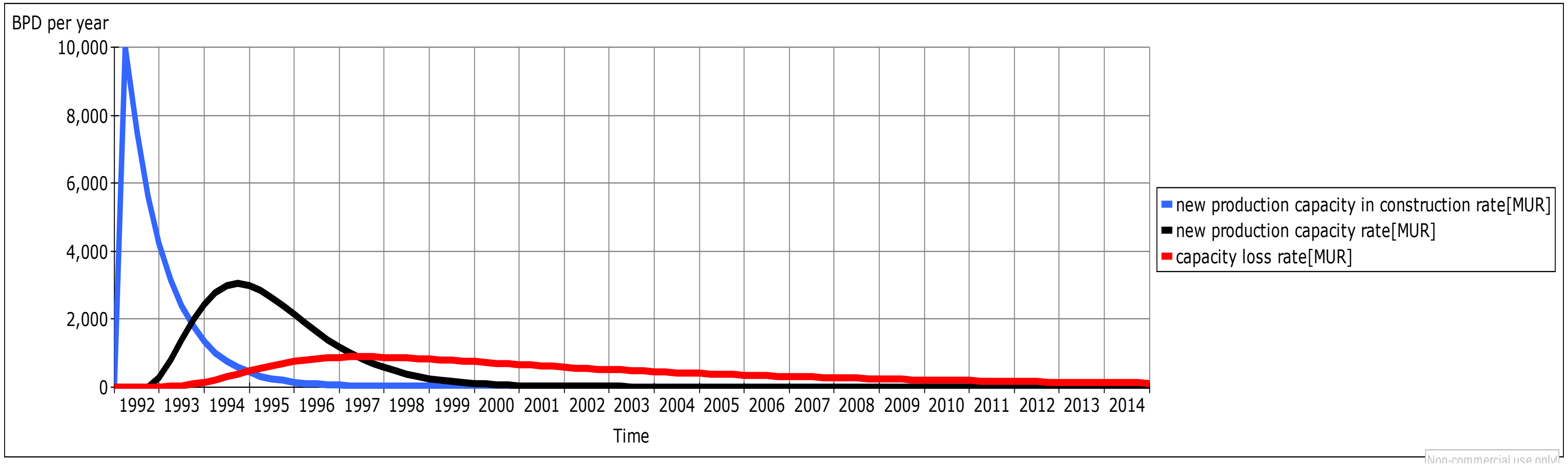

Figure 6, Rates response to a New Project

Figure 6 presents the impulse response to a new 10000 BPD project. The new production capacity in construction emerges from portfolio of projects. It takes time for upstream projects to start the construction phase. Negotiations, environmental permits and delays in partners' decisions take much time. Also, terms must be met before phasing projects into existing upstream setup. Among them, that spare capacity is present; and that expected production matches the process, and the storage and transport systems (NPD, 2014). The new production capacity arises out of the stock of projects in construction. Note that construction time impacts the new capacity add ins. High construction times lowers add ins. The area under the black curve equals 10000 BPD, as implied by the project. Capacity loss varies with oil fields. Capacity loss in the Gulf of Mexico is higher than in the UK; this one is higher than in Norway; and this one is higher than in Russia; according to Bernstein Research (2013). Giant fields of over 1 Giga barrels (Gb) have lower decline rates than small fields, according to Höök et al. (2014).

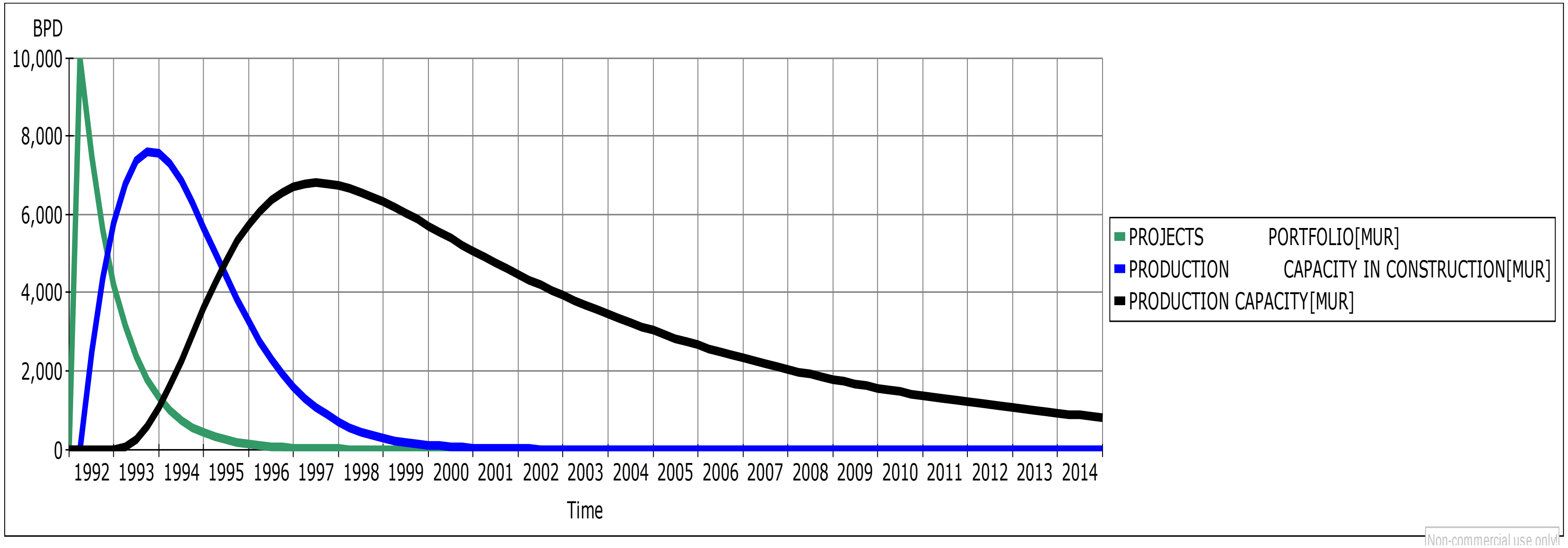

Figure 7, Stocks Response to a New Project

Figure 7 depicts the behavior of stocks (strategic resources). Portfolio surges with the new project, then shrinks as project portions start being built. Projects in construction boost while construction time holds projects in this phase. This stock takes its maximum vale when the new capacity rate equals the construction starts rate. At this point projects become capacity at a higher speed, and the stock sinks. Production capacity accrues the balance between new capacity and loses. It raises while the former is higher than the loses. It takes its maximum value when new capacity equals the loses. It starts declining when loses' speed take over new capacity. It keeps dropping in the absence of new capacity out of the construction phase. Three stages may be seen in the shape of the production capacity stock. Growing stage, plateau stage above a threshold (i.e. above 4500 BPD), and decline stage.

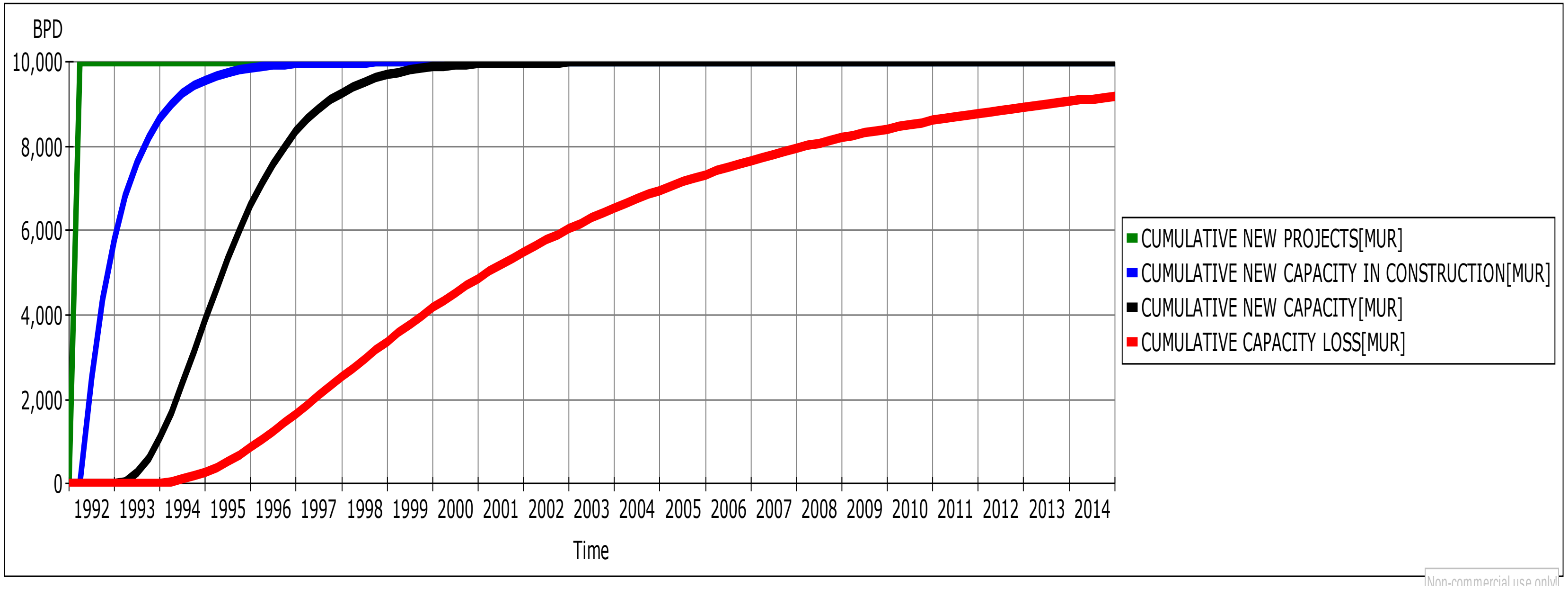

Figure 8, Cumulative Stocks Response

Figure 8 shows the projects sequence. First, all project barrels (green line) enter the value chain in 1992. Second, all barrels have moved to the construction phase (blue line) three years later. That is, three times the term (1 year has been used in the test) it takes projects to leave the portfolio. Third, all projects in construction barrels become new production capacity (black line) after the delay implicit in the construction time. It can be asserted, then, that it takes around 7.5 years for projects to become capacity. That is, three times the construction time (2.5 years) used in the test. Fourth, capacity loss almost equals the added capacity, in the 1992-2014 period. This occurs because the oil fields time span used is 7.75 years, and full loss of capacity could be expected by the 23rd year, or 3 times the oil fields time span.

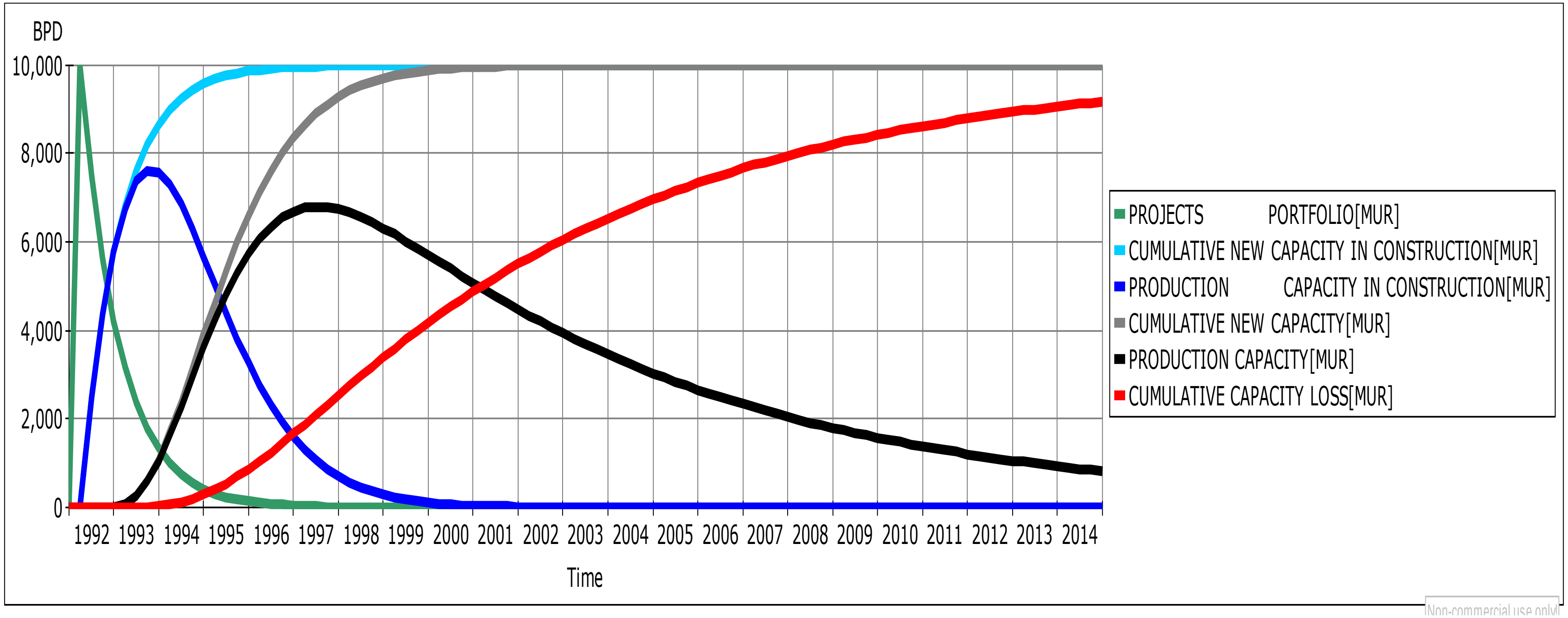

Figure 9, Cumulative Stocks Response Comparison

Figure 9 reveals the shape of the production capacity in construction, without an outflow in this stock. This is exposed by the cumulative new production capacity in construction. The same happens with production capacity and cumulative new capacity. In the test, capacity never arrives to the intended 10000 BPD because loses prevent it from happening. As a result, knowing the stream of new capacity arrivals is not enough to assess where the capacity is heading to. It is essential to know how loses occur.

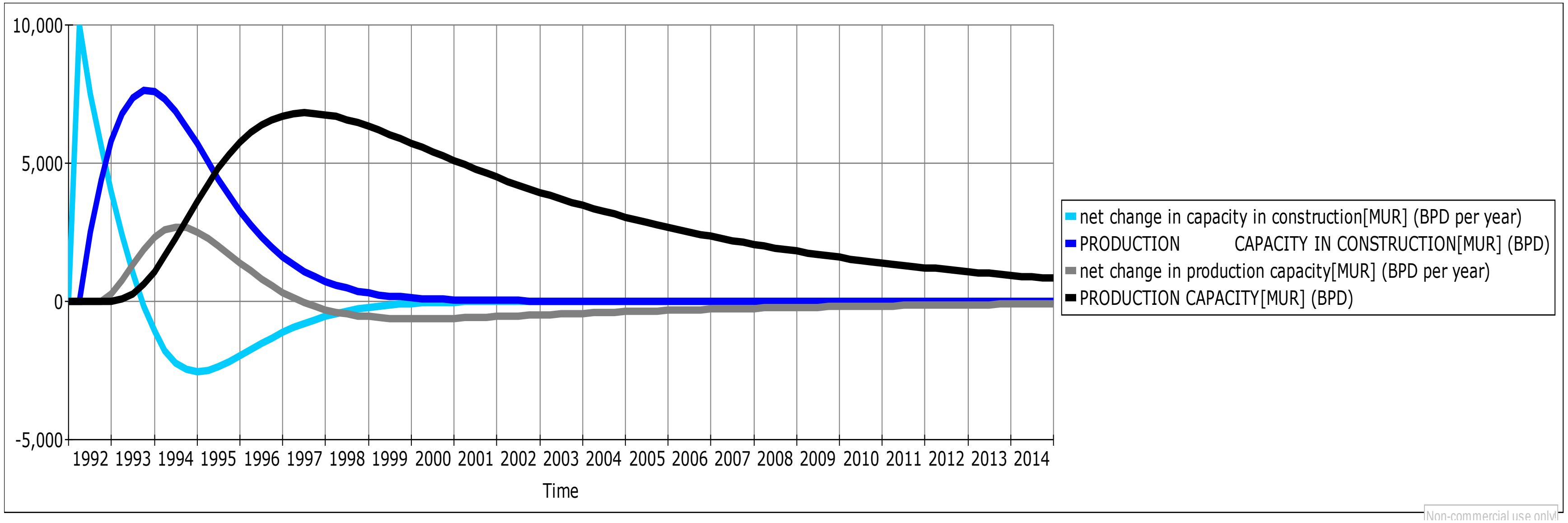

Figure 10, Net Change (end results) in Stocks (strategic resources)

Figure 10 unfolds the interplay between end results and strategic resources. Projects in construction peak when the net change in capacity in construction drops to zero BPD per year. The stock declines after this, as the net inflow turns negative. Production capacity peaks when the net change in production capacity turns negative. The stock declines after this, as the net inflow turns negative. The shape in the capacity stock reflects an upstream structure subject to decline given capacity loss.

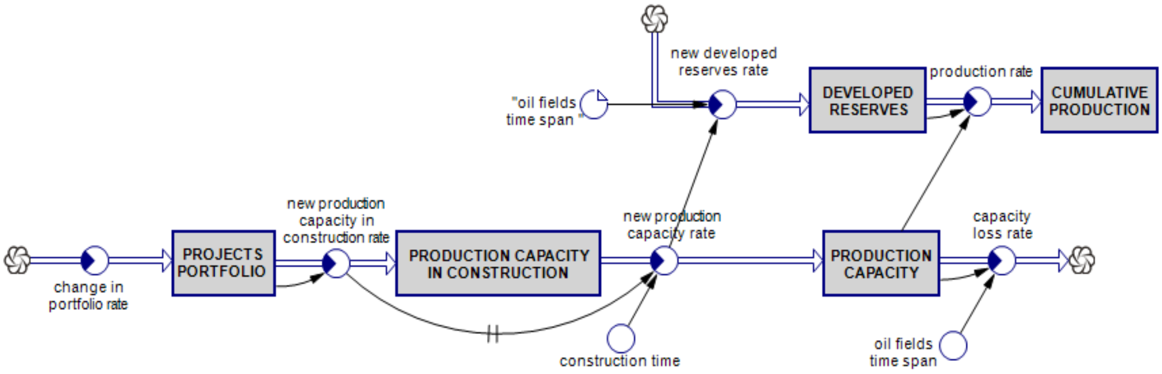

Figure 11, Starting Production Capacity Model with Reserves

Figure 11 displays production capacity with added reserves. The model assumes that there are enough proved undeveloped reserves to draw from. Production cannot be enabled without proved developed reserves. This is the pool of reserves known to exist with at least 90% certainty. In addition, production facilities must exist to extract these reserves. This is where current production comes from. New production capacity rate signals that reserves can be produced during the life span of oil fields. Hence, new developed reserves are governed by the product of both variables. The stock is depleted by production. A small fraction of this stock may be bought in the market. Also, they can be re assessed or changed suddenly, as oil firms unveil further data about the oil fields in the production process. The net rate at which this stock (strategic resource) is filled up or depleted (end result) is a critical source of performance. It tells how many years of production are left at the current production rate. This stock is key in the Resource Based Lending (RBL) schema, as a collateral, to get the loans oil firms need to pursue their investment programs.

Figure 12 offers the response of the developed reserves stock to the 10000 BPD impulse new project in the portfolio stock.

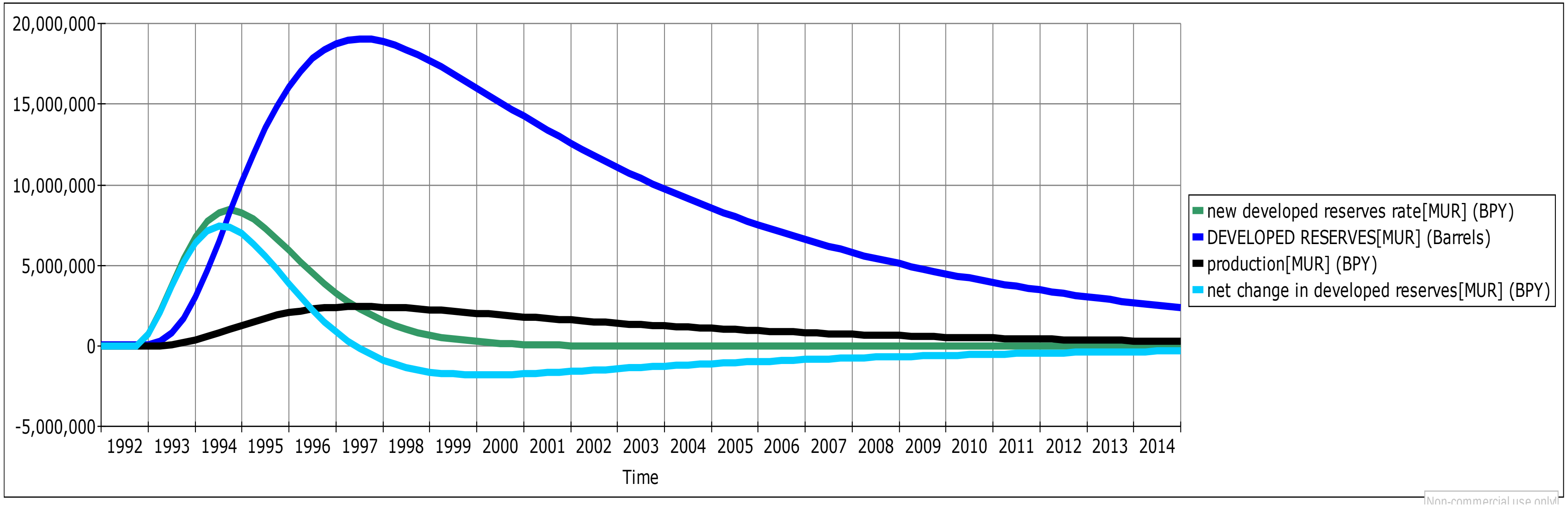

Figure 12, Reserves Response to New Project

Figure 12 helps unfurl the upstream capacity development process. New developed reserves (access to reserves to be produced) boost the value of the reserves stock. The process may allow access to a number of barrels equivalent to the product of the new capacity in BPD and the oil fields time span. Reserves (strategic resource) sink as production depletes the stock. Maximum value attained occurs when the net change in developed reserves (end result) drops to zero. This signals that the outflow of the reserve stock (production) is larger than the inflow (new developed reserves).

Figure 13 unfolds the investment model. It now covers the decision process. Investment pressure pushes new projects. The higher the pressure, more projects step up the portfolio. These projects become new production capacity after being constructed. This process enables, or ‘develops’ reserves. Upstream cost tends to slow down, as oil firms favor new projects that can use existing infrastructure. Without previous infrastructure, the upstream cost tends to be higher. They aim to extend the oil fields producing time spans. They achieve this because costs for modifications and new investments can be shared (NPD, 2013).

Firms assess projects profits based on oil price and breakeven costs. The higher the ratio between the two, there may more incentives to pursue projects. This creates a pressure to invest, which accumulates over time; and which may be released based on various factors. First, willingness to invest may depend on the assessment of business context made by investors. Second, oil firms may decide to slow down the reserves development rhythm, or it could be mandated by local authorities, owners of the oil crude ‘resource’. Third, projects may exist in a country that belongs to OPEC, in which case, it might be recommended not to pursue new projects for some time. Fourth, the producer may decide that it is not in its best interest to increase its market share in a local or global market. Fifth, the oil firm may be partially banned to trade its oil in the market, as was the case of Iran, recently.

The higher the investment pressure, further adjustments to portfolio and construction are made. This creates a reinforcing major loop which adds projects, when investment pressure raises, leading to higher production. However, it also tends to reinforce a declining production when investment pressure drops. The latter may be curtailed by the oil price to breakeven ratio. Hence, geology matters. It is hard for oil firms to boost production if the project’s development cost is high. This may be due to the nature of the oil field involved: or the quality of the oil crude; or the distance of the oil field to existing capacity to store and transport the extracted volumes. Operating costs may be high too. Extraction techniques may be outdated; or the oil firm may have more employees than required. The latter occurs in mismanaged National Oil Companies (NOC’s). All these factor boost the upstream cost per barrel, shrinking the oil price to breakeven cost ratio.

A major investing balancing loop tends to weaken the production raise cycle examined. Since oil firms tend to extract the low cost barrels first, operating costs surge as time elapses. Hence upstream cost goes up as oil fields are depleted. This lowers the oil price to breakeven cost ratio. This leads to lower investment pressure, smaller projects, capacity and production; leaving oil price as a key factor. It may raise the oil price to breakeven cost ratio and enable projects.

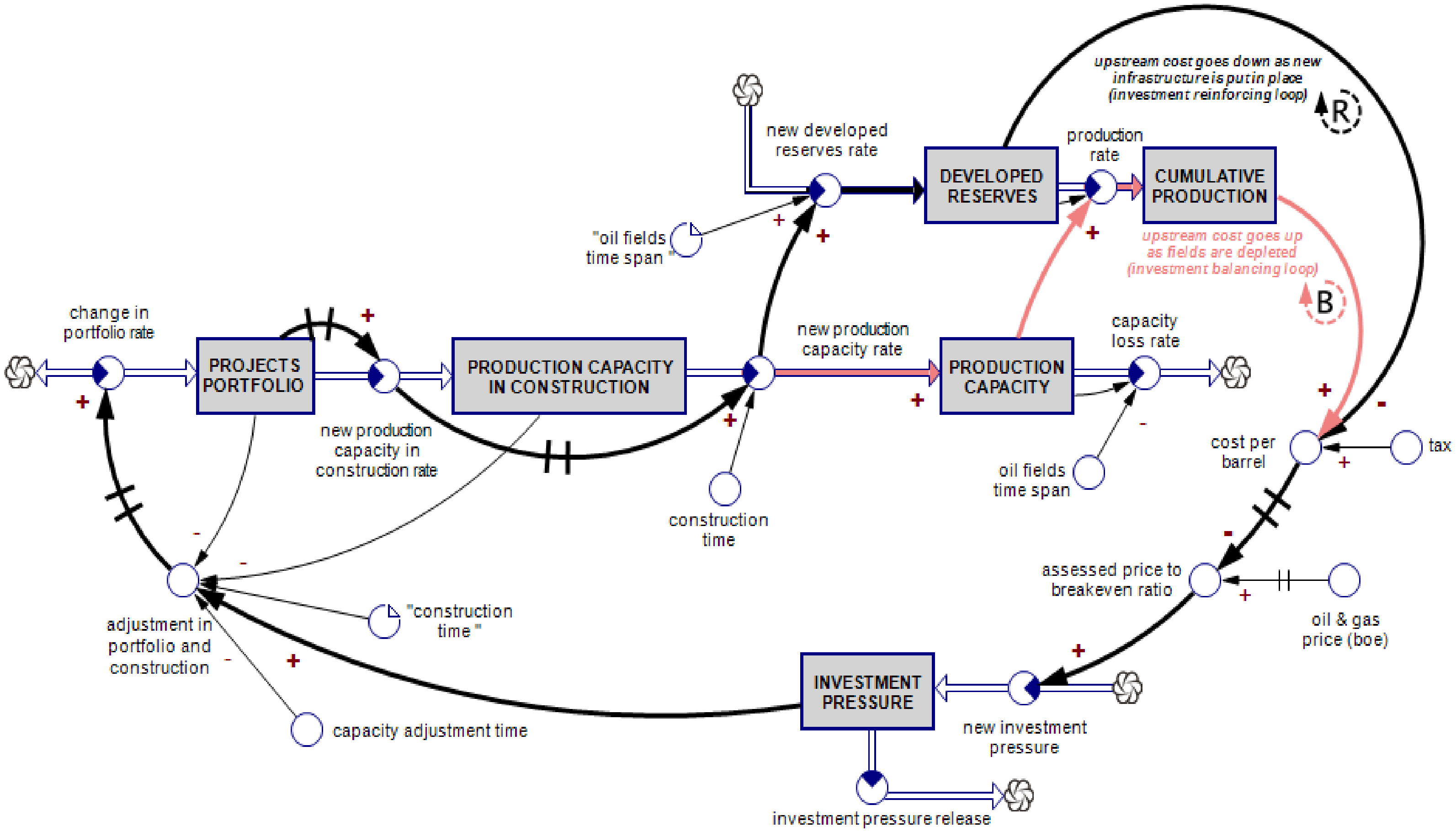

Figure 13, Production Model with Decision Process.

Projects adjust as in Figure 14. How much to adjust capacity arises out of the product of investment pressure and current capacity, with an adjustment time. Pressure values above 1 create capacity rate add-ons; values below 1 do not. This creates the capacity reinforcing loop. Capacity add-ons drive a goal oriented adjustment in construction. The tune up is made as to have enough projects in the portfolio given the projects lead time. Hence, the correction equals the indicated change in capacity times the construction time; minus current capacity in construction, in a year. This change goal for the construction rate is then used to obtain the size of the portfolio. Given that there may be more projects in the portfolio than needed, a further change is made. Change in portfolio equals the goal minus the current value of the stock, in a year. Projects enter and leave the portfolio this way. A bigger portfolio implies add-ons to construction, new capacity, and capacity.

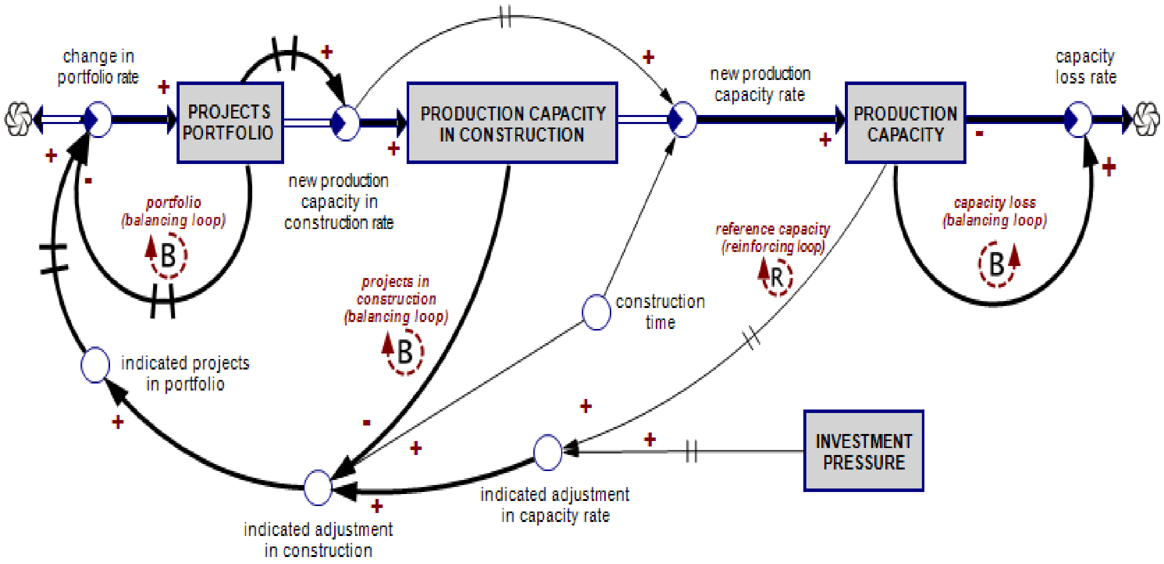

Figure 14, Capacity loss and Adjustment to Projects in Portfolio and Construction.

The portfolio balancing loop prevents it to take values beyond its goal. The projects in construction loop prevents this stock to go beyond the desired value. That is, the value of the capacity stock required to adjust capacity, given the lead, or construction time. The capacity loss loop drains this strategic resource, over time, at the rhythm of the oil fields time span.

Figure 15 unveils the full production and investment model.

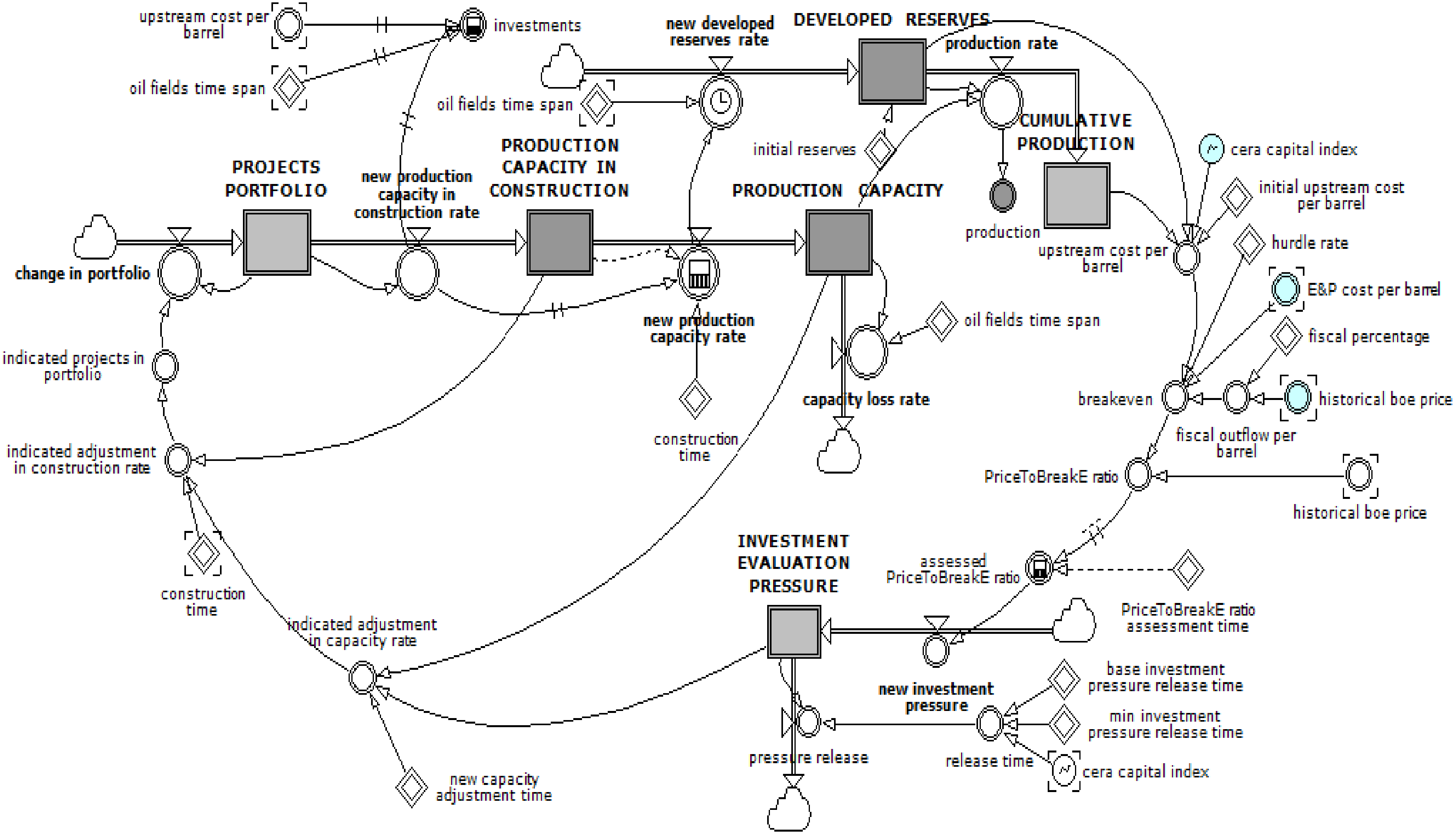

Figure 15, Production Model with Investments.

Figure 16 presents the model response to an assessed price to breakeven ratio equal to 0.8 until 2001, and 1 afterwards.

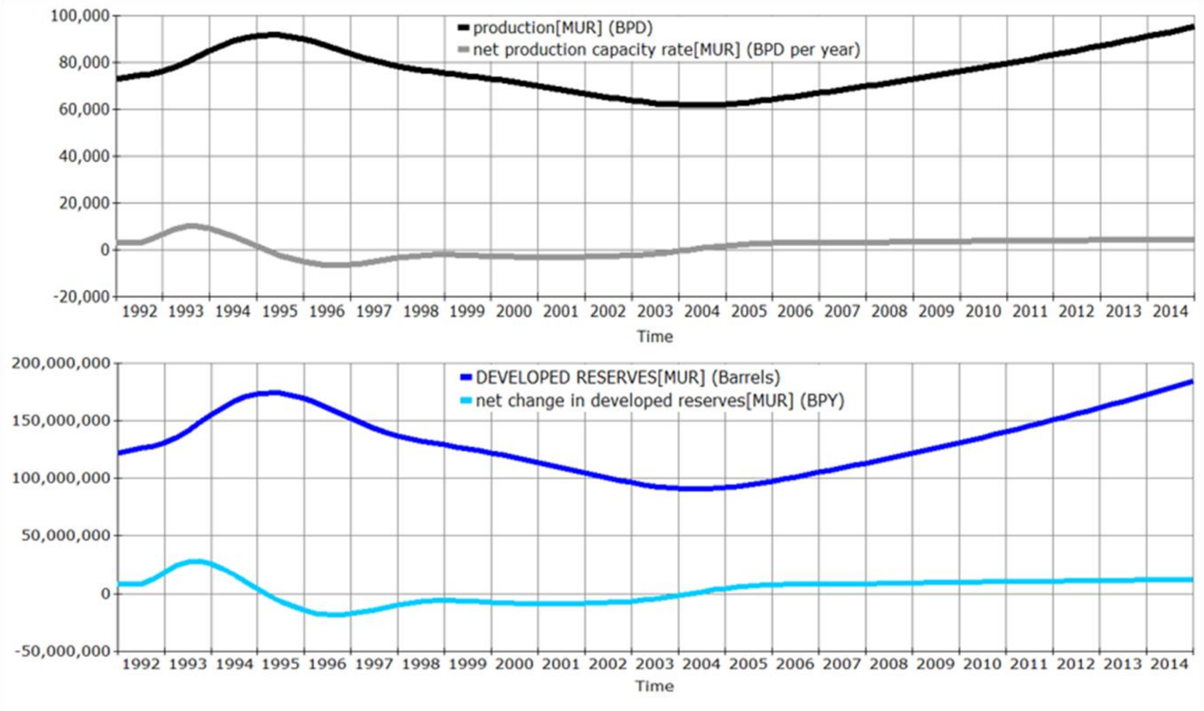

Figure 16, Model Response to Price to Breakeven ratio

The stocks now have initial values. Production Capacity and Projects Portfolio 73: BPD; Production Capacity in Construction: 31 BPD; and Developed Reserves: 122 million barrels (MMB). The assessed price to breakeven ratio is set to 0.8 in the 1992-2001 period. It is set to 1 afterwards. Initially, Projects flow from the portfolio to the in construction stock. The former drops and the latter raises. The 1992 peak of projects in construction translates to production capacity in 1995, after the construction time (2.75 years). Developed Reserves step up too, as new production capacity has been created. Production gets higher than new developed reserves, making the net change in reserves negative. At the same time, capacity loss gets higher than the new production capacity, making the net production capacity rate negative. Production sinks.

After this transient, both net production capacity and reserves rates remain negative while the assessed oil price to breakeven ratio is smaller than 1 (2001). Then, then investment pressure starts to rebuild as it takes its new value (1). The Project portfolio and production capacity in construction stocks grow as more projects are pursued. Yet, this does not translate into a positive net production capacity or reserves rate. The lead time to build capacity and develop reserves holds the new barrels until 2004. Note, again that the construction time is set to 2.75 years. Net inflow to the production capacity and developed reserves stocks becomes positive in 2004. Those are the end results of the growth policy tested. Capacity and reserves stocks of strategic resources start to grow.

Growth in both stocks, at almost a constant rate (or slope in the figure) is consistent with a net inflow or end result that is positive and constant or almost constant. This can be verified by looking at the net change in both stocks in the figure.

Investments:

The oil production life cycle may be divided in four stages. Discovery and evaluation of fields, development of capacity to produce, production, and abandonment. Upstream investments refer to development costs. The other unit costs are bundled into the model variable "E&P cost per barrel".

Development implies planning and building actions. Among them: drilling wells according to objectives; using adequate techniques to recover, separate and treat fluids and gases inside the reservoirs; building facilities to support production activities (i.e., platforms), storage and transport systems; and integrating new facilities with existing ones.

Investments are appraised in the model. They arise out of the new production capacity in construction rate, the upstream cost per barrel and the oil fields time span. A surge in any of the three variables may step up desired investments. The model assumes that the oil firm has a prudent financial management. It means that it has the money required by investments; usually 50% is financed with new debt. Figure 17 reveals the investment cycle impulse response to a 10000 BPD new project. Notice (year 1993) that 37% of investment is made without any capacity being productive yet. Also (year 1994) a 4000 BPD capacity is active (40% of total), with 60% of the total investment.

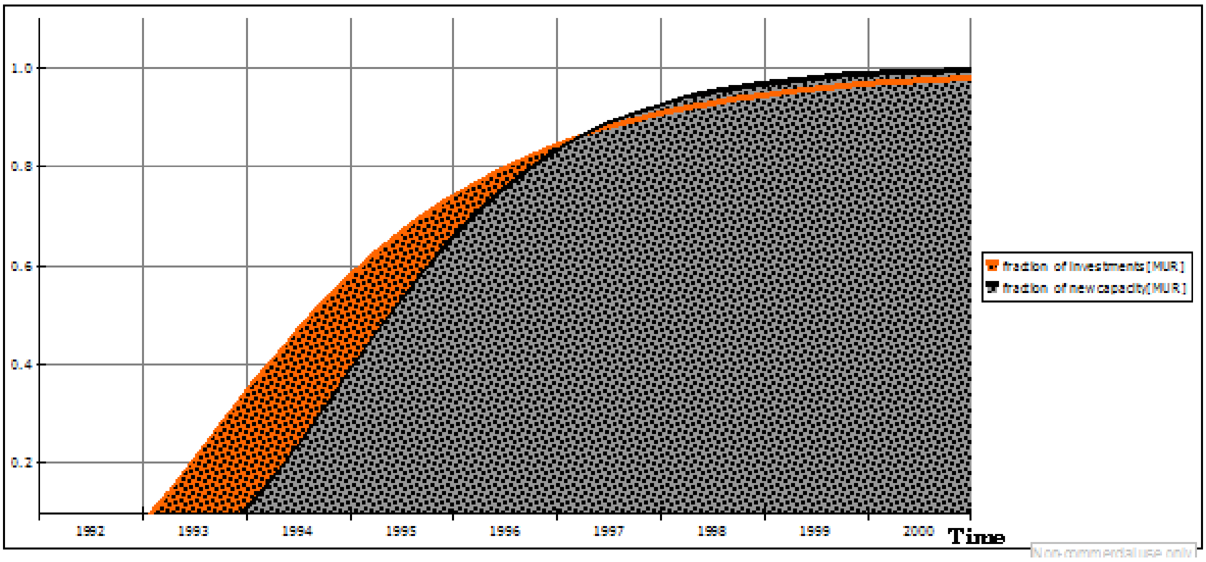

Figure 17, Financial Investment.

Model Equations:

$$\boldsymbol{upstream\ cost\ per\ barrel} = Max\left(initial\ upstream\ cost\ per\ barrel, cera\ capital\ index * initial\ upstream\ cost\ per\ barrel * \frac{Cumulative\ Production}{Developed\ Reserves}\right) \quad (1)$$

Development cost of reserves to create production capacity. The initial cost is escalated by the cera capital index. This index tracks the costs of equipment, facilities, materials, and personnel used in the construction of projects. The sample is a geographically diversified portfolio of onshore, offshore, pipeline and LNG projects. It offers a benchmark for tracking a complex and dynamic environment (HIS, 2015). The index is thought to signal rent seeking actions by steel, cement and materials supply firms; oil field services firms; and states that grant drilling and production licenses (ETA, 2014). Upstream cost tends to be lower in the presence of previous infra structure and developed reserves. It tends to be higher as oil fields are depleted and production accrues. Operators usually produce low costs reserves first. **Units: USD (2015) per barrel**.

$$\boldsymbol{breakeven} = (E\&P\ cost\ per\ barrel + upstream\ cost\ per\ barrel + fiscal\ outflow\ per\ barrel) * (1 + hurdle\ rate) \quad (2)$$

Summary of costs used in the evaluation process. E&P cost per barrel refers to exploration and production costs. Fiscal outflow is the government’s take per barrel. It is a fraction of the boe price (fiscal percentage * boe price). As oil firms produce oil and gas, boe denotes “barrels of oil equivalent”. Hurdle rate is the minimum return on investment expected by the oil firm. This low return may be linked to higher capex; and the restore of declining high return legacy assets with higher cost, higher taxed projects (ETA, 2014). **Units: USD (2015) per barrel**.

$$\boldsymbol{PriceToBreakE\ ratio} = \frac{boe\ price}{breakeven} \quad (3)$$

Profit indicator per barrel. The higher the ratio, more projects may be pursued. **Unitless**.

$$\boldsymbol{assessed\ PriceToBreakE\ ratio} = Average\ (PriceToBreakE\ ratio, assessment\ time) \quad (4)$$

Average PriceToBreakE ratio, as perceived by the oil firm, in the assessment time. **Unitless**.

$$\boldsymbol{new\ investment\ pressure} = (assessed\ PriceToBreakE\ ratio)/1\ year \quad \textbf{(5)}$$

Input to the investment pressure stock, in one year. **Units: per year.**

release time = Max (min investment release time, base investment release time/cera capital index) **(6)**

Captures the aversion and constraints of investors to pursue projects. A high release time depletes the investment evaluation pressure stock sooner; leading to smaller production capacity projects. Low release time values signal willingness of investors (or lack of constraints) to pursue projects. It is assumed that a high cera capital index leads to less projects since it tends to reduce the expected profit, and investors may pursue other opportunities in non-oil projects.

$$\boldsymbol{Investment\ Evaluation\ Pressure} = \int (new\ investment\ pressure - pressure\ release) * dt + Investment\ Evaluation\ Pressure(0) \quad \textbf{(7)}$$

Accrues the balance between new investment pressure and pressure release. The latter seeks to capture the aversion and constraints of investors to pursue projects. **Unitless**.

$$\boldsymbol{indicated\ adjustment\ in\ capacity\ rate} = Max(0, Production\ capacity * (Investment\ Evaluation\ Pressure - 1))/(new\ capacity\ adjustment\ time)) \quad \textbf{(8)}$$

Capacity increase as indicated by investment evaluation pressure. Adjustment is made over the number of years specified. **Units: Barrels per day BPD per year**

Indicated adjustment in construction rate

*= Max (0, (indicated adjustment in capacity rate*construction time-production Capacity in Construction)/1 year* **(9)**

Indicated adjustment in new production capacity in construction rate. Adds projects to the portfolio and in construction stocks to match the required capacity rate. Notice that the change takes into account the lead time to build new capacity. **Units: BPD per year**.

$$\boldsymbol{indicated\ projects\ in\ portfolio} = (indicated\ adjustment\ in\ npcicr)/\ \text{(1 year)} \quad \textbf{(10)}$$

Projects in portfolio to sustain the required construction rate. **Units: BPD**.

$$\textit{change in portfolio} = (\textit{indicated projects in portfolio} - \textit{Projects in Portfolio}) / 1\ \textit{year} \tag{11}$$

Portfolio balance. Adds projects to portfolio or removes them, to match the new construction rate. **Units: BPD per year**.

$$\textit{new production capacity in construction rate} = \textit{Projects Portfolio} / (1\ \textit{year}) \tag{12}$$

Sixty-five percent of projects in portfolio are assumed to start construction within one year. It is assumed that all projects start construction within three years. **Units: BPD per year**.

$$\textit{new production capacity rate} = \textit{Delay Material (new production capacity in construction rate, construction time, delay type=3, initial value= production Capacity in Construction/construction time)} \tag{13}$$

New production capacity in place. It is the result of the upstream construction process. The Delay Material function returns the 3rd order exponential material delay of new production capacity in construction rate, using an exponential averaging time given by the construction time, and an initial value given by production Capacity in Construction/construction time. A material delay is a delay resulting from the time necessary to process physical material. **Units: BPD per year**.

$$\textit{capacity loss rate} = \textit{Production Capacity} / \textit{oil fields time span} \tag{14}$$

Loss in the capacity to produce. It is assumed that an existing capacity of an oil field would lose 65 % of its capacity to produce in the oil field time span. **Units: BPD per year**.

$$\text{Projects Portfolio} = \int (\text{change in portfolio-new production capacity in construction rate})*dt + \text{Projects Portfolio } (0) \tag{15}$$

Accrues the balance between changes in the portfolio and the new projects being built. **Units: BPD**.

Production Capacity in Construction

$$= \int (\text{new production capacity in construction rate} - \text{new production capacity rate}) * dt + \text{Production Capacity in Construction}\ (0) \qquad \textbf{(16)}$$

Accrues the balance between the new projects being built and those that are completed. **Units: BPD**.

New developed reserves rate

$$= \text{new production capacity rate} * \text{oil fields time span} \qquad \textbf{(17)}$$

Oil and gas fields are prepared to be produced over a time span. Creating new capacity to produce implies having access to reservoirs during such period. New developed reserves reflect this operating assumption. **Units: Barrels per year (BPY).**

Production rate

$$= \text{Production Capacity} * \text{production fraction} \qquad \textbf{(18)}$$

Once capacity is installed, operators tend to produce at maximum capacity. However, there may be reasons to produce at a lower capacity. First, the resource owner may have a policy to deplete reservoirs at a lower rhythm (for instance, 97%) to avoid wells damage. Second, a fraction of the reserves may be perceived as to have more value in the future, leading to a production fraction lower than 100%. Third, a group of oil firms (i.e., NOC's in OPEC) may decide to impact prices by decreasing the production fraction, possibly leading to higher oil prices. Four, an oil firm with enough market power to influence prices (i.e., Saudi Aramco) may decide to have spare capacity to stabilize the market in case of supply disruptions. **Units: Barrels per day (BPD).**

Developed Reserves

$$= \int (\text{new developed reserves rate} - \text{production rate}) * dt + \text{Developed reserves}\ (0) \qquad \textbf{(19)}$$

Accrues the balance between the new developed reserves and production. **Units: Barrels**.

Cumulative production

$= \int (\text{production rate})*\text{dt} + \text{Cumulative Production } (0)$ **(20)**

Accrues production. **Units: Barrels**.

investments

*= Delay Material (new production capacity in construction rate * upstream cost per barrel * oil fields time span, delay time = 2 years, delay type=1, initial value of investments at start of simulation)* **(21)**

Cash flow view of how financial investments are paid. Units: **USD (2015) per year**.

Behavior testing:

The model is tested with oil & gas upstream activities. The goal is to understand the factors that govern production and the investment needed for production capacity. The sample includes a small international oil company (Murphy Oil, or MUR); a large international company (ExxonMobil, or XON); and a large oil region (Norway). Focus is placed in production capacity, developed reserves and investments. Data for the 1975-2014 period is gathered from the Securities and Exchange Commission annual 10-K reports, and the Norwegian Petroleum Directorate. A barrel of oil equivalent basis (boe) is used for oil price and production. The latter includes natural gas, crude oil, condensate and natural gas liquids. Six thousand cubic feet of natural gas equals one barrel of oil.

3.2.1 Murphy Oil:

MUR Oil has operated in USA, Canada, United Kingdom, Ecuador, Malaysia, Australia, Brunei, Vietnam, Indonesia, Equatorial Guinea, Cameroon, Suriname, Republic of the Congo, and Namibia. Total worldwide 2015 production was 208 thousand boe per day (MBD).

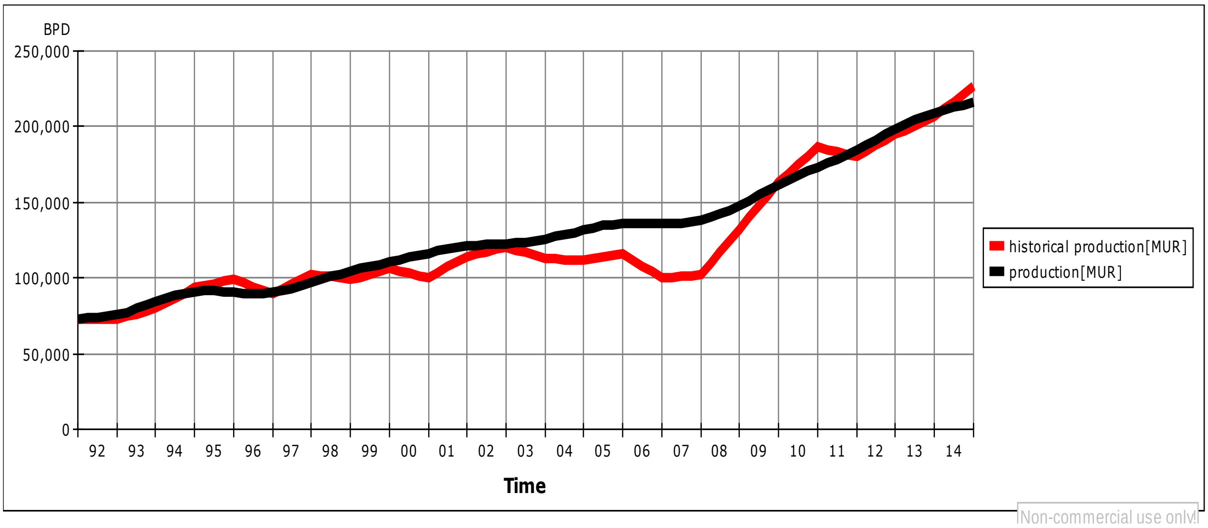

Figure 18, Murphy Oil Simulated Vs Historical Production

Figure 18 displays MUR's simulated values. The results follow the trend in historical production. Yet, simulated values are higher in certain periods. Possible reasons for this may be found in MUR's annual 10-K reports to the Securities and Exchange Commission (MUR, 2016). In the year 2000, liquids production in USA dropped 21% due to non expected declines (capacity loss in the model) in the Gulf of Mexico (GOM); lower share of production in Canada due to maintenance down time; and a production fall in Ecuador due to transportation constrains. In 2003, production in the U.K. was down 20%, due to sale of oil fields. In 2006, worldwide liquids (crude oil, condensate and natural gas) production dropped 13% due to major maintenance in Canada; declines in USA; along with a worldwide drop of 17% in natural gas, due to sale of fields in GOM. In 2007, natural gas production dropped 19% due to declines in GOM.

Most of the empirical evidence supports the hypothesis that production reductions are driven by geological problems. Not by commercial reasons only. Thus, production capacity may be constrained by the above listed geological problems.

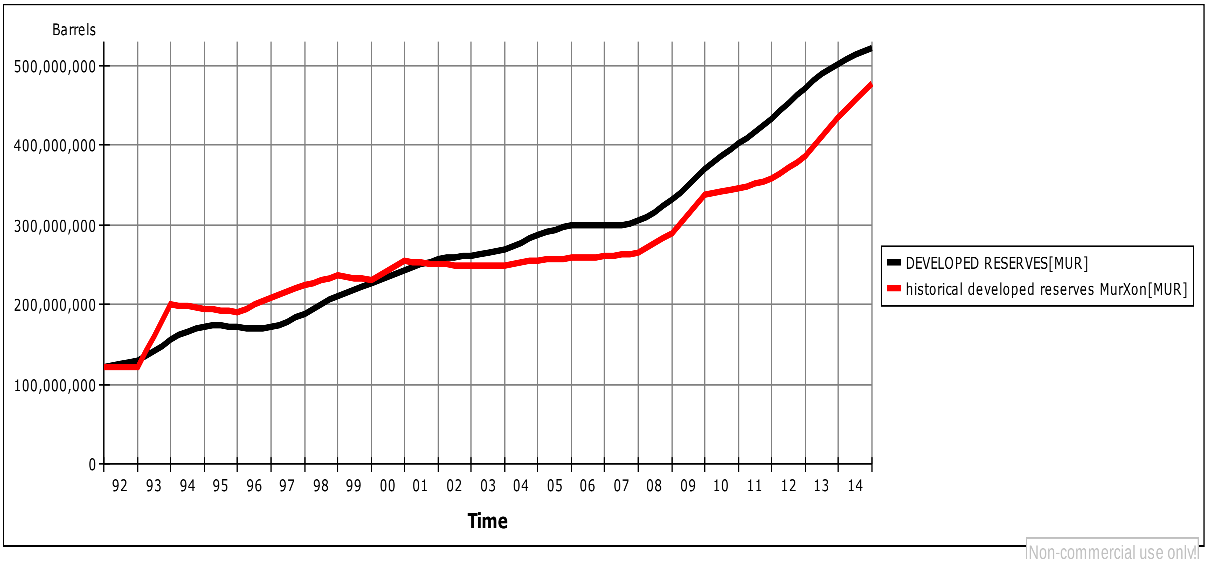

Figure 19, Murphy Oil Simulated Vs Historical Developed Reserves

Simulated reserves are higher than historical. In 2006, Access to reserves could have been curtailed, given the worldwide drop of 17% in natural gas production, due to sale of fields property in GOM Notice that reserves values may be affected by revisions. They allow changes in previous reserves estimations as new exploration and production efforts are made. Better geologic or production data may be collected leading to revisions. Proved reserves volumes previously thought of as economically feasible to produce may return to unproved status with low oil prices.

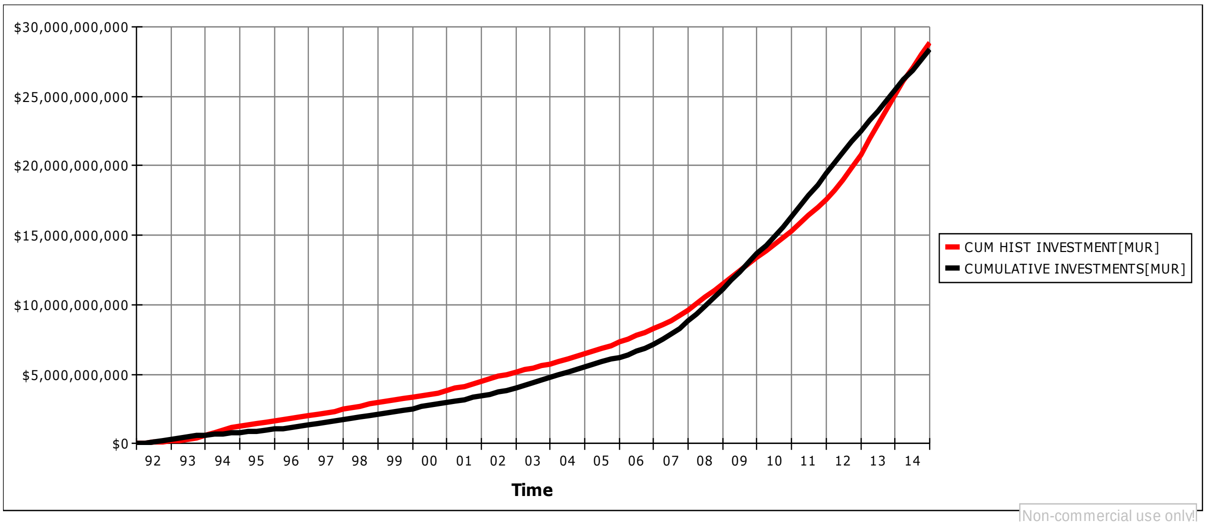

Figure 20, Murphy Oil Simulated Vs Historical Cumulative Upstream Investments

The model matches the cumulative upstream investments very well, in the study period (23 years). Investment is computed as the product of new production capacity in construction, upstream cost per barrel and oil fields time span. Thus, these variables seem to take plausible values in the period of study. This effort has been made in a context of rising capital expenditures (capex) and falling capex productivity. Capex per barrel stepped up 10 times from 1999 to 2013, compared to the 1985-1999 period (ETA, 2014).

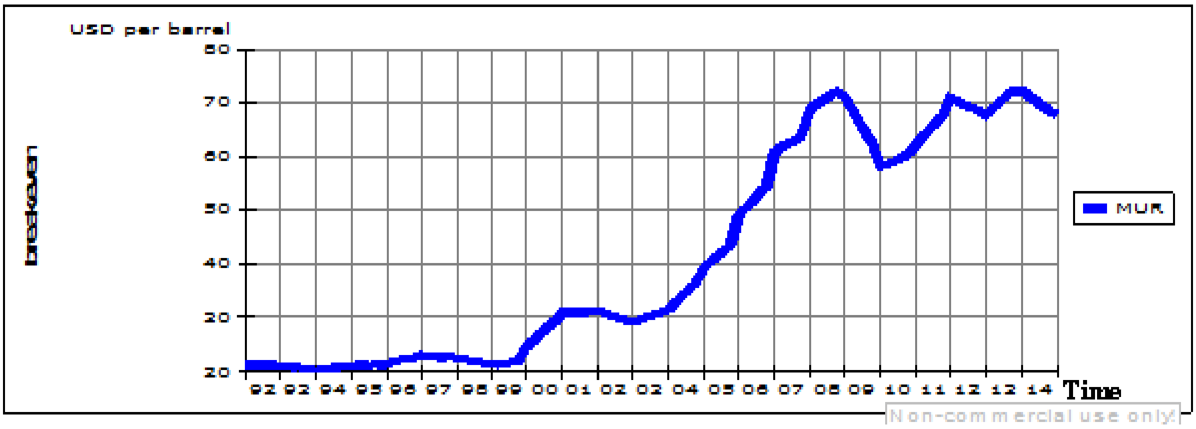

Figure 21, Murphy Oil Simulated Breakeven Costs

This poses risks. Breakeven costs were above USD 60 per barrel in 2014, and WTI price is USD per barrel in December 2016. The price to break even ratio is low, curtailing investments. As a result, Moody’s Investor Services downgraded the firm’s debt notes, reducing the firm’s credit to below investment grade status. The ability of the firm to fund operations has been downgraded (MUR, 2016).

3.2.2 ExxonMobil

XOM operates upstream in 40 countries in the five continents. It controls 1800 fields and more than 50000 production wells. Total worldwide 2015 production was 4000 thousand boe per day (MBD).

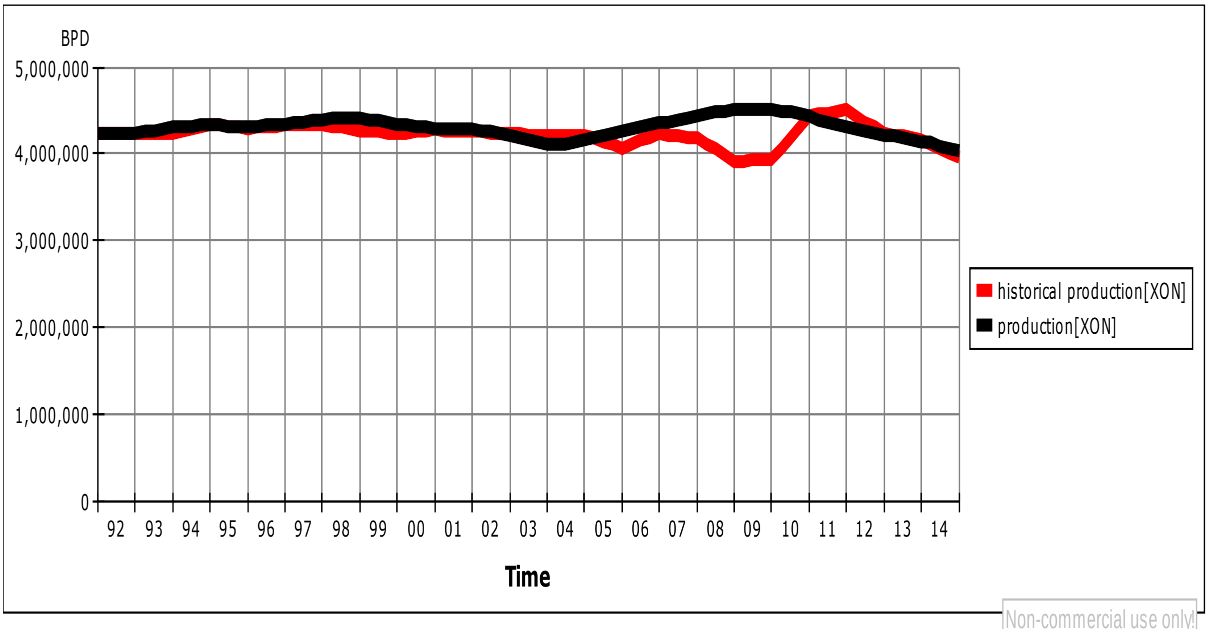

Figure 22, ExxonMobil Simulated Vs Historical Production

The model matches the historical production in the study period (23 years). Simulated values are higher in the 2008-2009 period. Likely reasons for this can be found in XON's annual 10-K reports to the Securities and Exchange Commission (XON, 2016). In the year 2008, total boe production fell 6%, due to assets seizure in Venezuela, divestments and lower take in shared efforts.

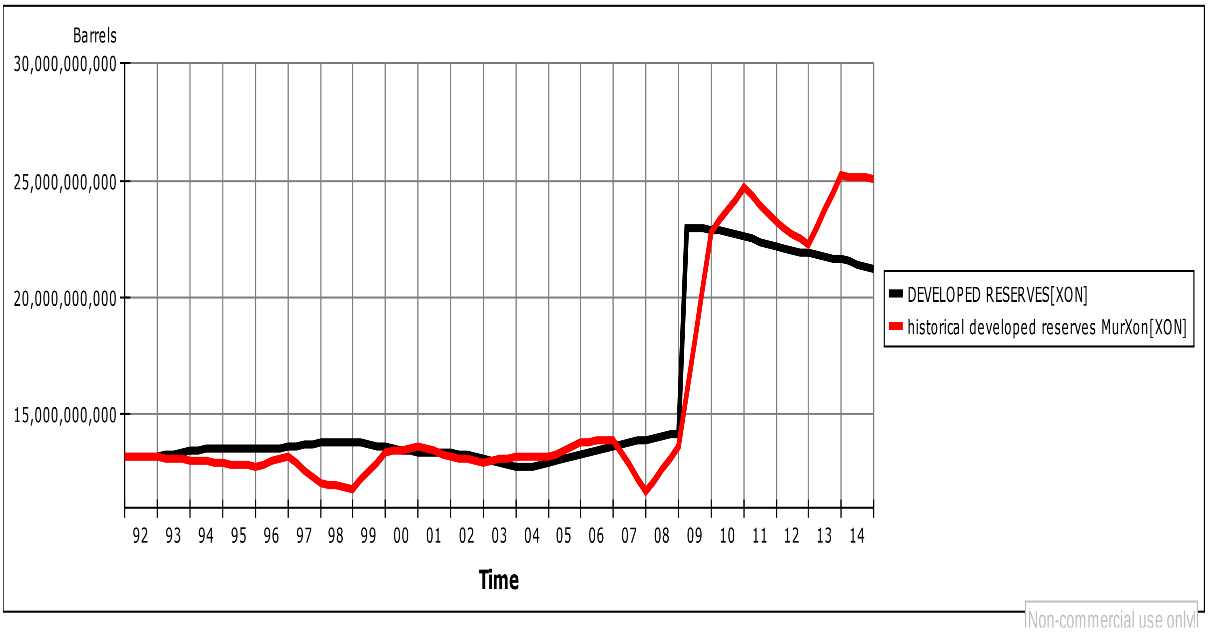

Figure 23, ExxonMobil Simulated Vs Historical Developed Reserves

A fraction of reserves may be purchased too. XOM purchased 9 billion barrels of developed reserves in 2009. This has been modeled as an impulse function that raises both new developed reserves and investments, in that year. Although all reserves bought add to the stock in the same year, this capital cost was not completely paid in 2009. Thus, the investments variable contains a payment delay structure where 67% of the purchase is paid within three years.

The rationale for this deal may start with the oil price context at the beginning of 2009. WTI Price has fallen from USD 145 to USD 30 per barrel, in six months. Mabro (1986) asserts that lower oil prices reduce revenues, raising unpaid taxes and debt. They also reduce the value of oil inventories in the balance sheet assets account. Equity and access to credit are reduced. This creates further cash flow problems that increase bankruptcy risk. At the same time, less exploration efforts slow down development of new fields and reserves accrual. This may reduce production. It might also lead to transfer of producing assets from firms in problems to those with strong balance sheets.

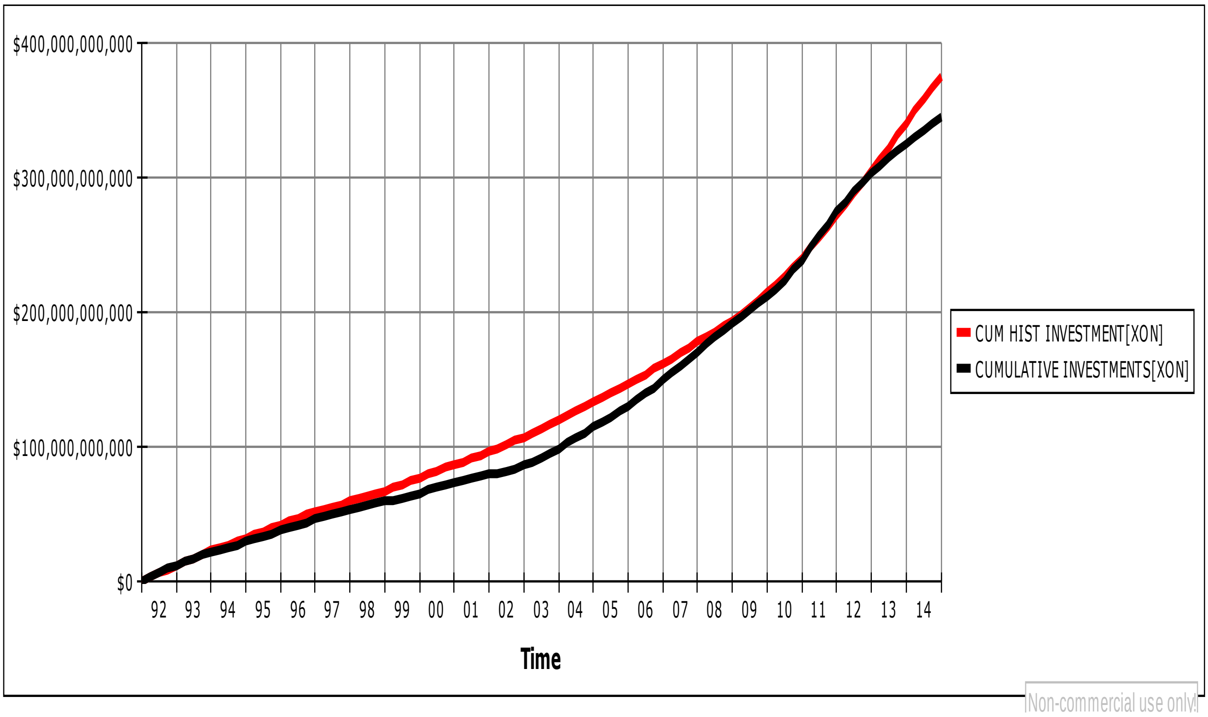

Figure 24, ExxonMobil Simulated Vs Historical Cumulative Upstream Investments

The model matches the cumulative upstream investments very well, in the study period (23 years). Investment is computed as the product of new production capacity in construction, upstream cost per barrel and oil fields time span. Thus, these variables seem to take plausible values in the period of study.

3.2.3 Norway Region

Oil and gas operations in Norway are included. Data source is the Norwegian Petroleum Directorate (NPD).

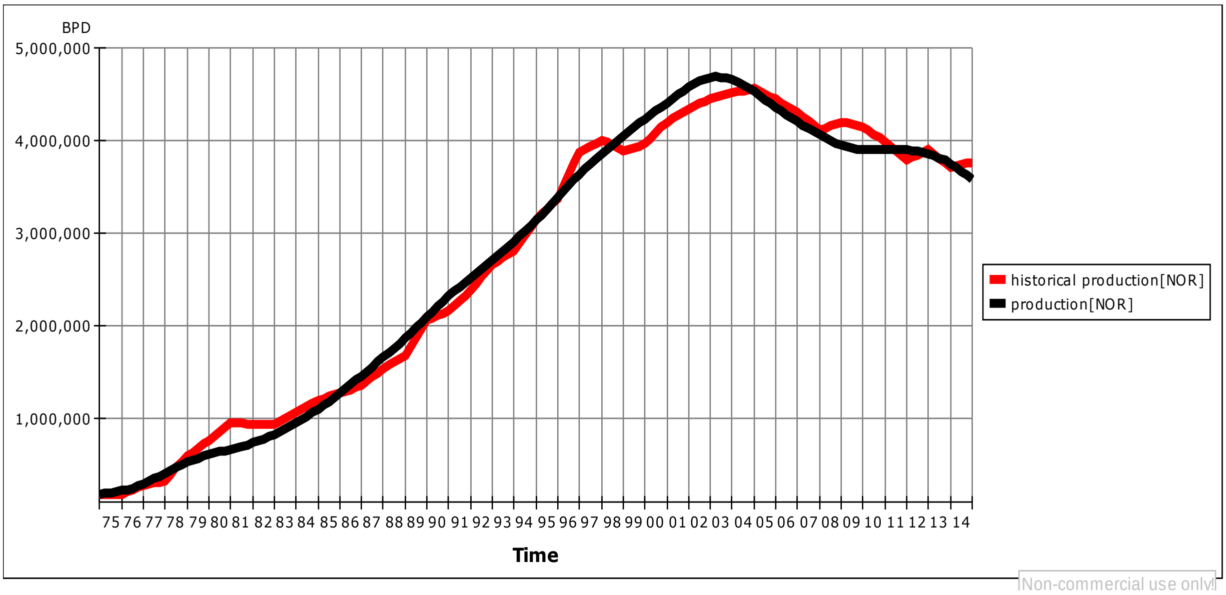

Figure 25, Norway Simulated Vs Historical Production

The model matches the historical production in the study period (42 years). Production peaked in 2003. It can be seen from Figure 26, that net production capacity rate is zero in 2002. That is, capacity loss gets higher than new production capacity rate in that year. Notice that oil prices increased afterwards, leading to lower than potential revenues.

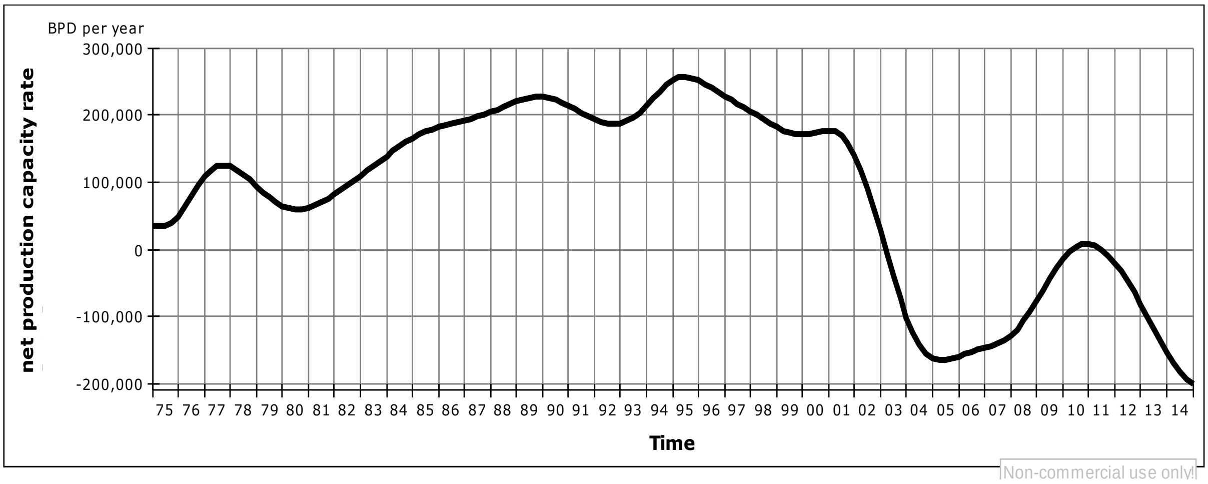

Figure 26, Norway Net Production Capacity Rate

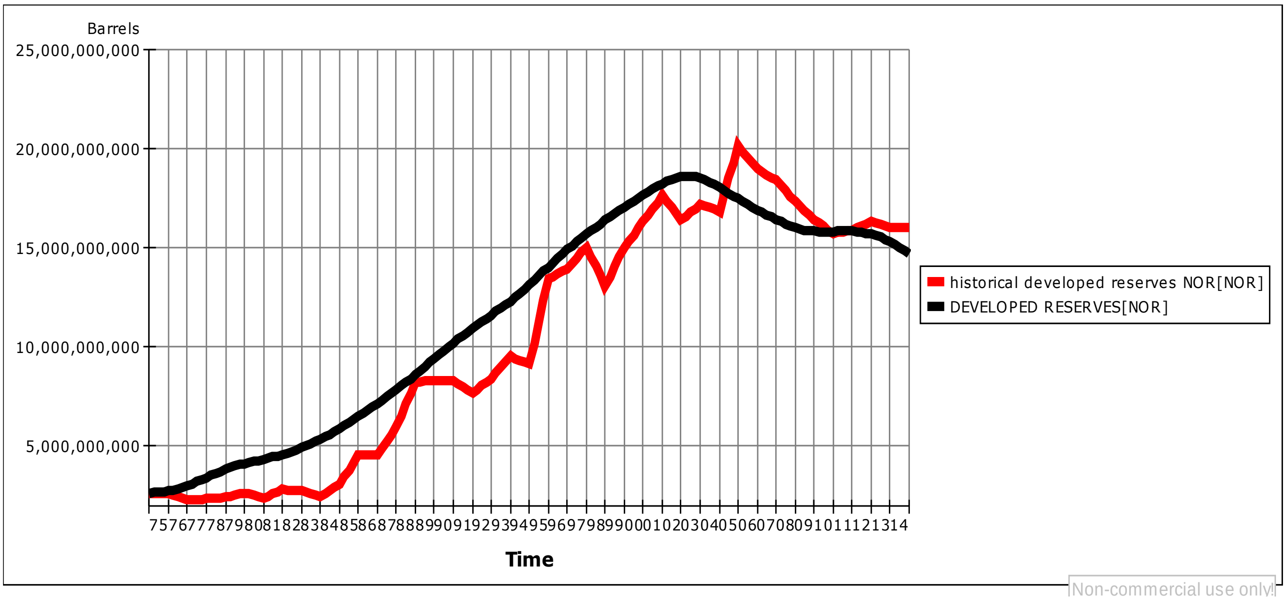

Figure 26, Norway Simulated Vs Historical Developed Reserves

The model has a similar pattern to the historical developed reserves in the study period (42 years). Developed Reserves arise out of the new production capacity rate, which peaked in 2001. However, the peak in reserves occurs later (after 2003). This delay is related with the reserves stock, since it accrues the difference between new developed reserves and production. The model computes the peak in reserves after 2003, which is the moment when production gets higher than new developed reserves.

New ventures are on its way in this region, even in the presence of 2016 low oil prices of 50 USD per barrel. For instance, small operator Lundin, with 32 MBD of boe production and operating costs near 12 USD per barrel (as computed by the model for the region), has agreed to take a RBL facility.

This resource based lending facility aims to fund development of the Johan Sverdrup field through to first oil. It is a seven years, USD 5 billion facility, supported by 23 international banks, with grace period of five years. This may bring support to the idea of investment pressure being driven not only by average expected profit per barrel, but also by availability of capital to pursue projects.

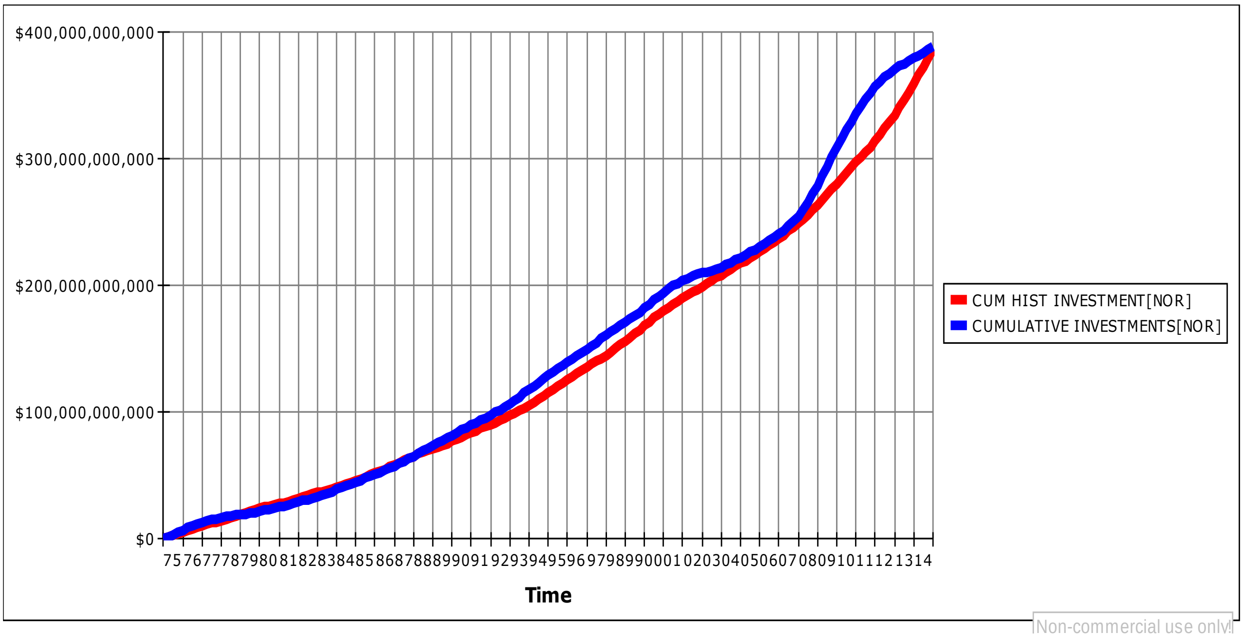

Figure 27, Norway Simulated Vs Historical Cumulative Upstream Investments

The model matches the historical investment in the study period (42 years). Higher upstream costs per barrel are thought to be the main reason of higher investments. As can be seen in the next figure, average breakeven has raised 2.7 times since 2003, to 80 USD per barrel.

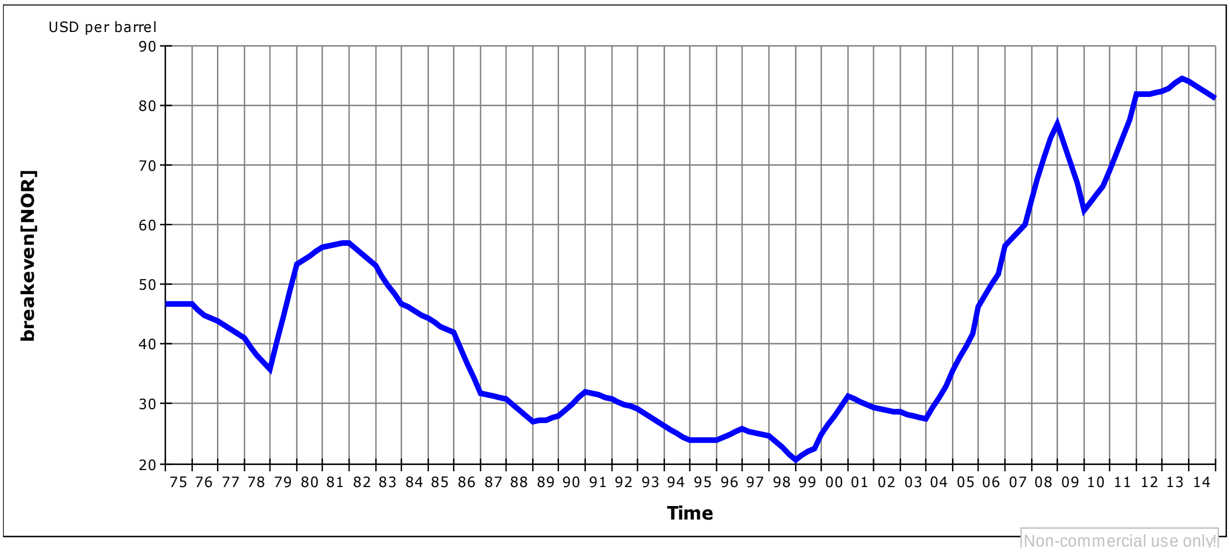

Figure 28, Norway Breakeven Costs

Table 1. Parameters used in the model				
Name	**Murphy Oil**	**ExxonMobil**	**Norway**	**Units**
Construction time	2.5	3	4	years
Delay Type in new production capacity rate	3	3	3	Unitless
Oil fields time span	7.75	10	9.9	years
Initial upstream cost per barrel	6.80	4.50	5	USD per barrel
Hurdle rate	10	10	10	%
Fiscal percentage relative to boe price	15	22	45	%
Price to breakeven ratio assessment time	1	1	2	years
New capacity adjustment time	1.5	1	2	years
Base investment pressure release time	1.65	1.54	1.52	years
Minimum investment pressure release time	1.51	0.93	1.15	years
Initial Projects Portfolio	72800	1300000	850200	BPD
Initial Production Capacity in Construction	30800	1300000	220200	BPD
Initial Production Capacity	72800	4231833	189500	BPD
Initial Developed Reserves	121.7	13200	2600	Million Barrels
Initial Cumulative Production	0	0	0	Barrels
Initial Investment Evaluation Pressure	0.3	1	3.5	Unitless
Initial investments	195	11205	5600	Million USD per year

3.3 The International Demand Model and Behavior Test of Production

Slight changes are made to the production model to adapt it to the analysis of the international oil market. This focus implies computing the demand not satisfied by production in net importer regions (OECD and Asia Pacific, as defined by the US Department of Energy). It is stated in this study that the Asia Pacific region's adjustment in construction rate responds also to changes in capacity loss. It is also asserted that OPEC also responds to changes in the international market demand; that is, the net volume required by importing regions, beyond their production.

$$\boldsymbol{upstream\ cost\ per\ barrel} = Max\left(initial\ upstream\ cost\ per\ barrel, cera\ capital\ index * initial\ upstream\ cost\ per\ barrel * cost\ fraction * \frac{Cumulative\ Production}{Developed\ Reserves}\right) \qquad \textbf{(1a)}$$

A cost fraction is included to account for distinct cost impact. This is a value between 0 and 1, where 1 has the highest impact. **Units: USD per barrel**.

$$\boldsymbol{new\ production\ capacity\ in\ construction\ rate} = indicated\ adjustment\ in\ construction\ rate \qquad \textbf{(12a)}$$

Portfolio of projects stock is no longer used, as it not deemed essential. New production capacity in construction rate is now equal to indicated adjustment in construction rate. **Units: BPD per year**.

E&P cost per barrel was an exogenous variable before. Now, it is computed as:

$$\boldsymbol{E\&P\ cost\ per\ barrel} = initial\ upstream\ cost\ per\ barrel * cera\ capital\ index \qquad \textbf{(22)}$$

It allows the cost to escalate with the cera capital index. **Units: USD per barrel**.

Investment pressure release time is set as a constant (k), to reflect a broader international market. **Units: years**.

$$\boldsymbol{release\ time} = k \qquad \textbf{(23)}$$

k = constant. **Units: Years**.

Indicated adjustment in construction rate

*= capacity loss adjustment +Max (0, (indicated adjustment in capacity rate*construction time-production Capacity in Construction)/1 year* **(9a)**

Capacity loss adjustment equals 0 for OECD and OPEC, it is only a computed value in the case of the Asia Pacific region. **Units: BPD per year**.

The one-year adjustment time in indicated construction rate has been changed in the OECD case. From 1986 to 1993 it is a convex function with an initial value of 3 and a final value of 0.5 years. It remains with this value until 2015.

Capacity loss adjustment[AP]

*= MAX (0, 1.35*AVERAGE (capacity loss rate[AP], 1 year, initial value = 0) - indicated adjustment in capacity rate[AP])* **(24)**

Capacity loss adjustment for Asia Pacific will be equal to the difference between capacity loss and the indicated adjustment in capacity rate, only when the loss is higher. **Units: BPD per year**.

Indicated adjustment in capacity rate [OPEC]

= MAX (0, MAX (international market demand -PRODUCTION CAPACITY [OPEC], Production capacity(Investment Evaluation Pressure[OPEC]-1)) /new capacity adjustment time[OPEC])* **(8a)**

Adjustment in production capacity rate now responds to the maximum value between the indicated by the investment pressure and the market. This means that OPEC may adjust its capacity up when the international market grows, beyond investment pressure. This behavior suggests a learning effect. Prior to 1986, OPEC reduced its production in the search of higher prices and the result was a loss of market share. Recent actions by Saudis within OPEC reveal that losing market share is not in their plans. **Units: Barrels per day BPD per year**

International market demand is now introduced.

International market demand

= Demand[OECD] + Demand [AP] – production [OECD] -production [AP] **(25)**

It equals the import needs of major importing regions OECD and Asia Pacific. OPEC and Rest of the World are net exporters. **Units: BPD**

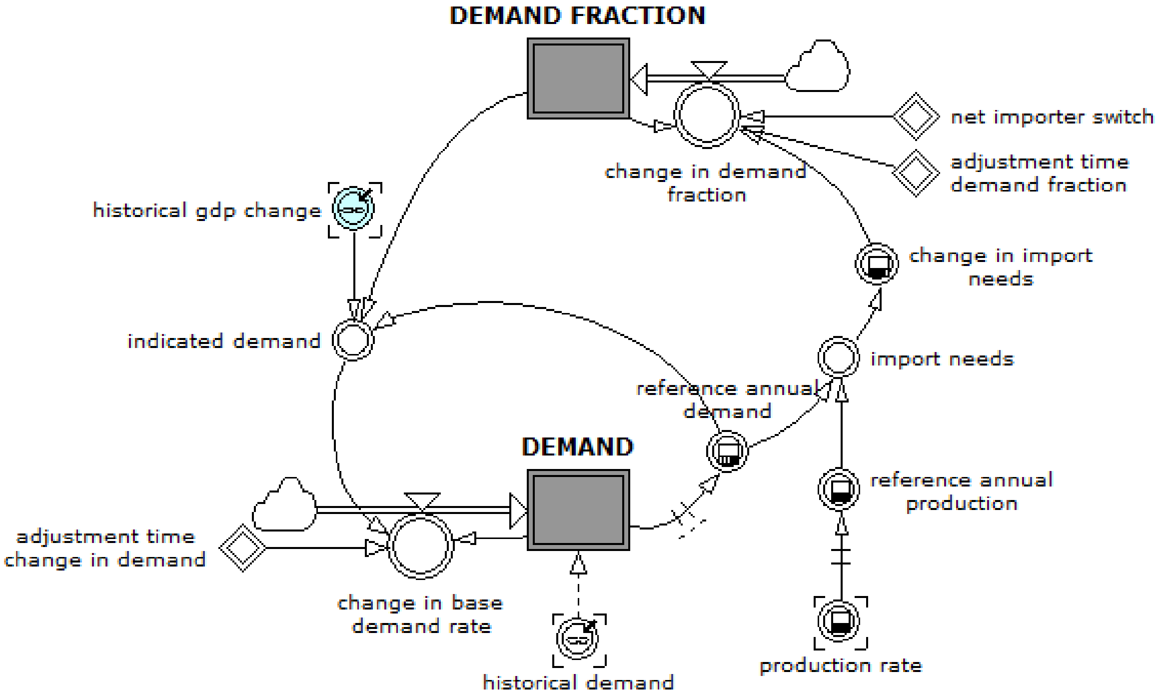

Figure 29, Demand model

In this demand model, changes in base demand are driven by the reference demand, changes in GDP and demand fraction. The latter has been a matter of national policy in OECD and Asia Pacific, for a long time. It means that this fraction has been decreasing as policies destined to lower consumption have been put in place. These policies have come along with a general raise in the use of renewables. This has not been the case in the OPEC region, where subsidized fuel creates incentives for higher consumption. The encounter of reference demand and annual production governs the import needs of the regions. OECD and Asia Pacific regions are assumed to enact stronger policies when the change in their import needs raises (Mabro, 1984). That is, when the magnitude of the energy problem boosts, the change in demand fraction may be lower. Hence we have two main loops in the model. First, a reinforcing loop going from demand to reference annual demand and indicated demand; and a balancing loop that lowers the demand fraction when the import needs boost. A lower demand fraction may lead to lower indicated demand, which after an adjustment time may shrink demand. GDP change governs indicated demand as growth calls for larger energy needs. On the other side, increases in production rates within the regions lower their import needs.

change in base demand rate

= (indicated demand – demand)/adjustment time change in demand **(26)**

Units: BPD per year

Reference annual demand

= AVERAGE (Demand, 1 year) **(27)**

Units: BPD per year

Demand

*= ∫ (change in base demand rate)*dt + demand (0)* **(28)**

Accrues changes in base demand rate. **Units: BPD**

Import needs

= MAX (0, AVERAGE (Demand-production, 1 year)) **(29)**

Greater than zero for OECD and Asia Pacific, net importers. **Units: BPD**

Change in import needs

= (import needs/Initial (import needs) **(30)**

Change relative to starting date (1986). **Units: Unitless.**

Change in demand fraction

*= net importer switch * ((1/ change in import needs) - Demand Fraction)*
/adjustment time demand fraction **(31)**

An upturn in import needs speeds up the drop in demand fraction, given the adjustment time. The net importer switch allows the change in import needs to act only on OECD and Asia Pacific regions (importers); OPEC’s demand fraction is a fixed value. **Units: Unitless.**

$$\mathit{Demand\ Fraction}$$

$$= \int (\mathit{change\ in\ demand\ fraction}) * dt + \mathit{Demand\ Fraction}\ (0) \tag{32}$$

Accrues changes in base demand fraction. **Units: BPD**

$$\mathit{Indicated\ demand}$$

$$= \mathit{reference\ annual\ demand} * (1 + \mathit{historical\ GDP\ change}) * \mathit{Demand\ Fraction} \tag{33}$$

Collects the impact of GDP and Demand Fraction on the reference demand. **Units: BPD**.

3.3.1 OECD Region

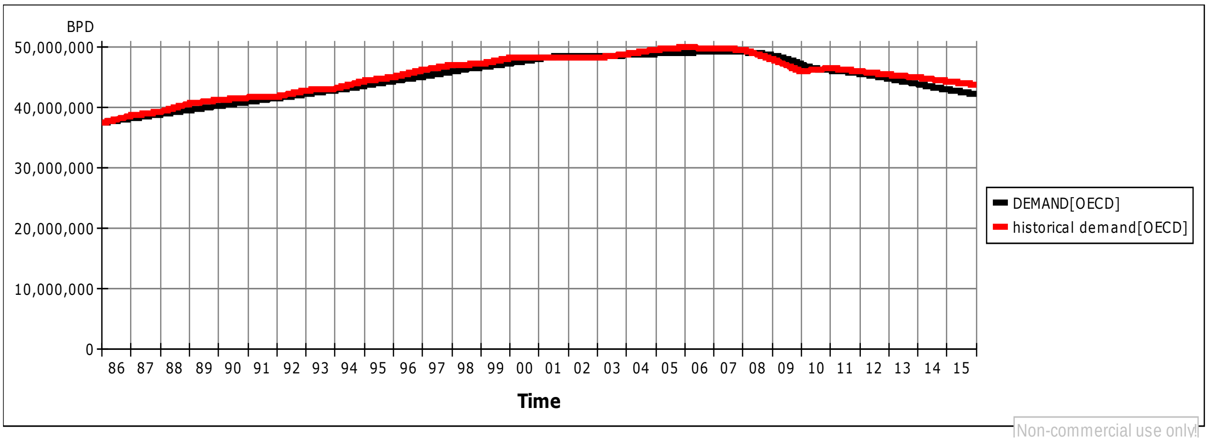

Figure 30, OECD Simulated Vs Historical Demand

The simple demand model captures OECD demand behavior over the 1986-2015 period. Notice that demand starts to descend in 2007, as policies destined to lower consumption trigger descent. Yet, the slope of the demand curve changes by 2009; the rhythm of descent is slower than before. This may be linked to the rate of change of import needs for the region. As seen in the next figure, production boosts after 2008, due to a surge of US production.

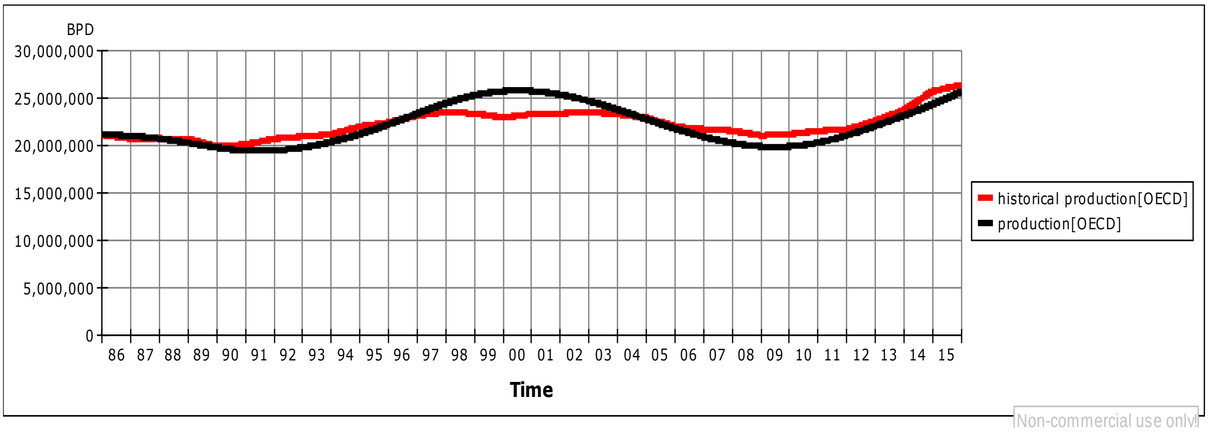

Figure 31, OECD Simulated Vs Historical Production

The next figure displays the simulated import needs of the OECD region. The steep drop may support the idea that regions may, to some extent, relax enforcement of oil consumption reduction policies when the change in their import needs drops.

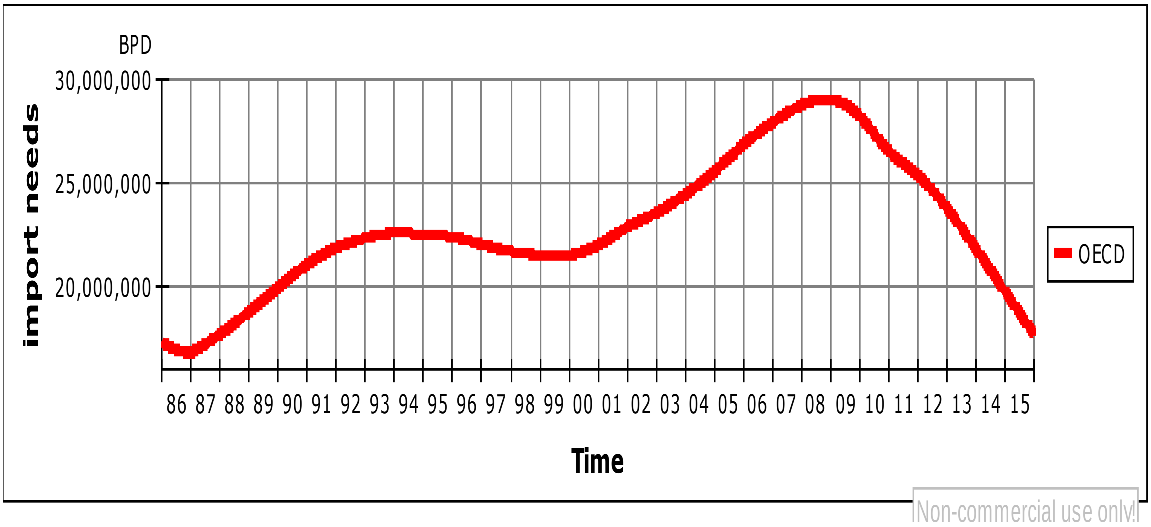

Figure 32, OECD Simulated Import Needs

3.3.2 Asia Pacific Region

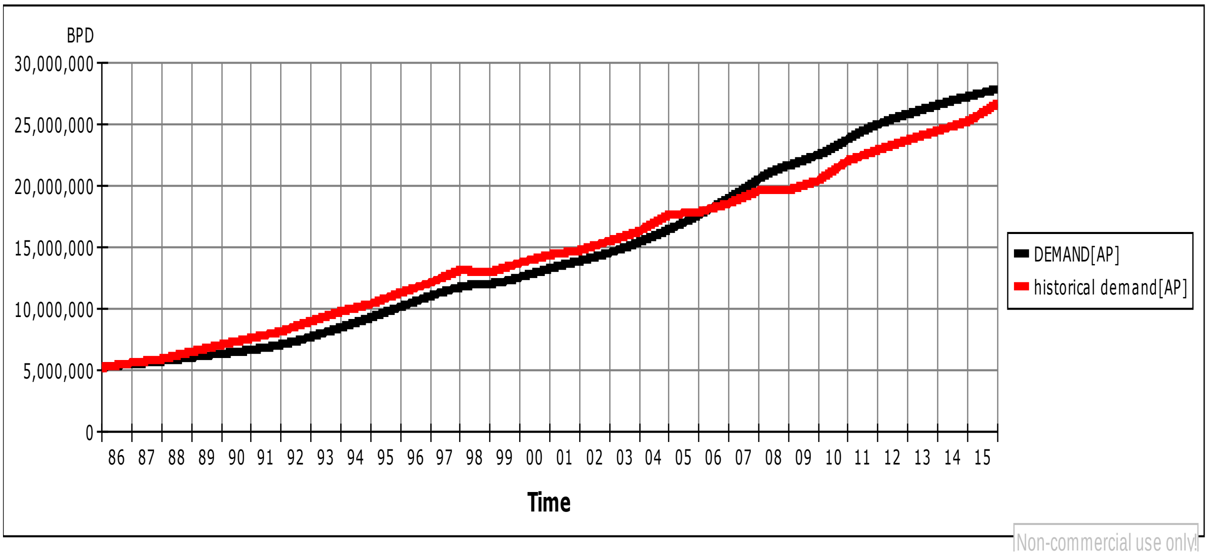

Figure 33, Asia Pacific Simulated Vs Historical Demand

The model only captures the general trend of oil demand in the Asia Pacific region, led by China. As expected, OPEC targets this region, given its relative importance in the market. The next figure displays simulated production in the region without correction for capacity loss.

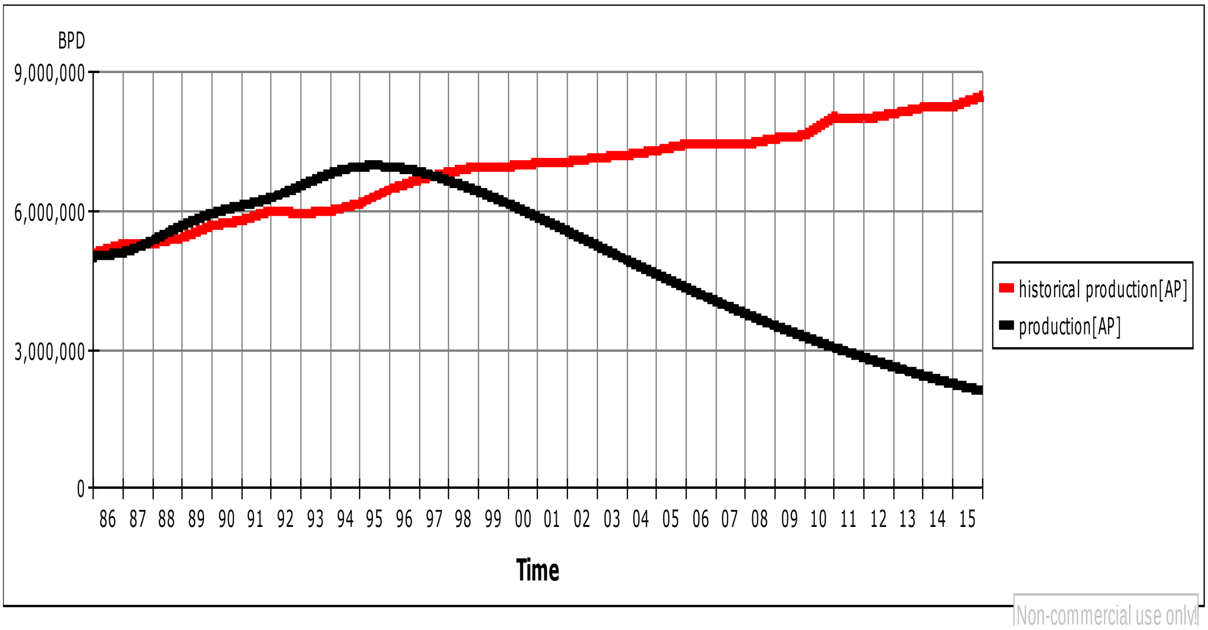

Figure 34, Asia Pacific Production without Correction for Capacity Loss

Production is lower when driven only by the investment pressure as modelled. Now, the correction for capacity loss is included, and production gets close to the pattern of historical values.

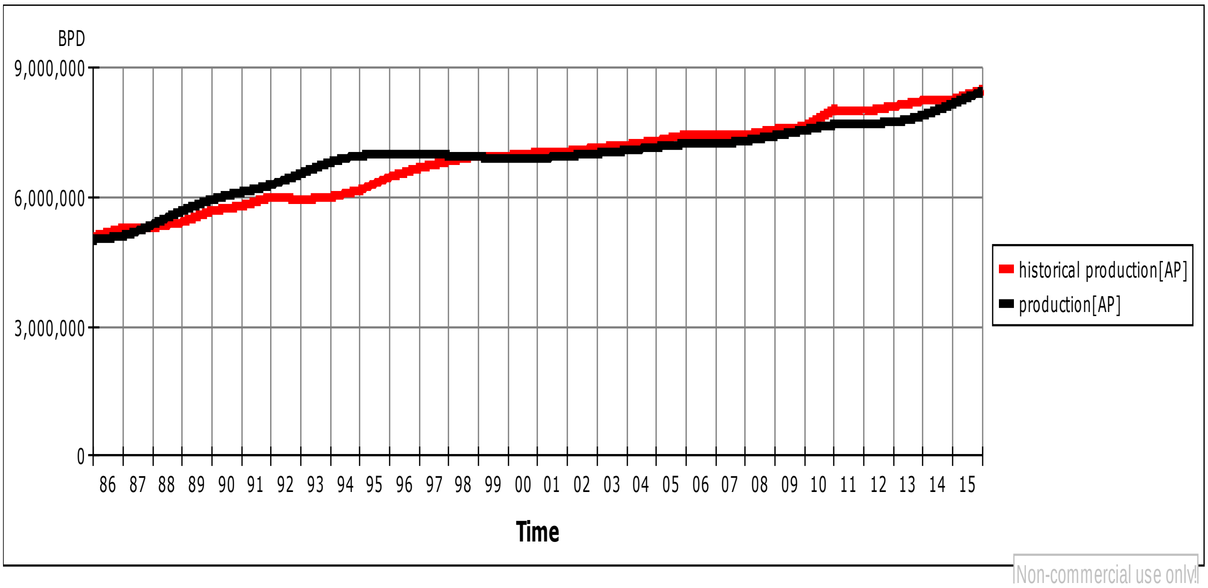

Figure 35, Asia Pacific Simulated Vs Historical Production

Hence, it is asserted that when confronted with indicated changes in new capacity rate lower than recent capacity loss, operators decide for the higher value. They may do this because the mix of production capacity factors and delays involved may shrink capacity, over time. The next figure depicts the adjustment, in BPD per year.

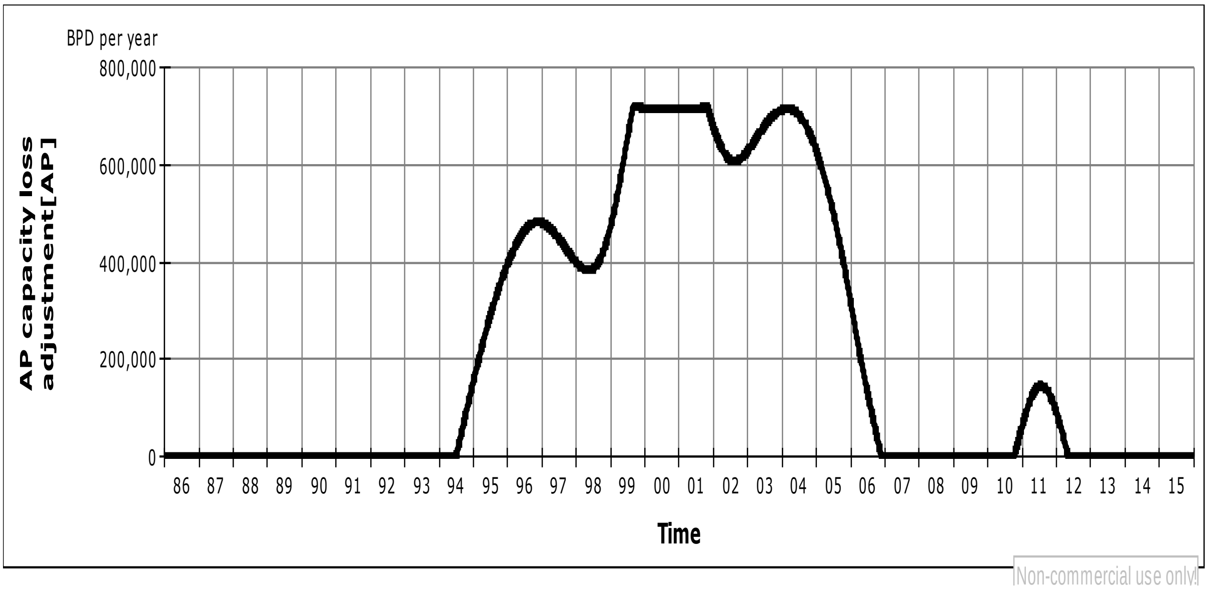

Figure 36, Asia Pacific Simulated Capacity Loss Adjustment

3.3.3 OPEC

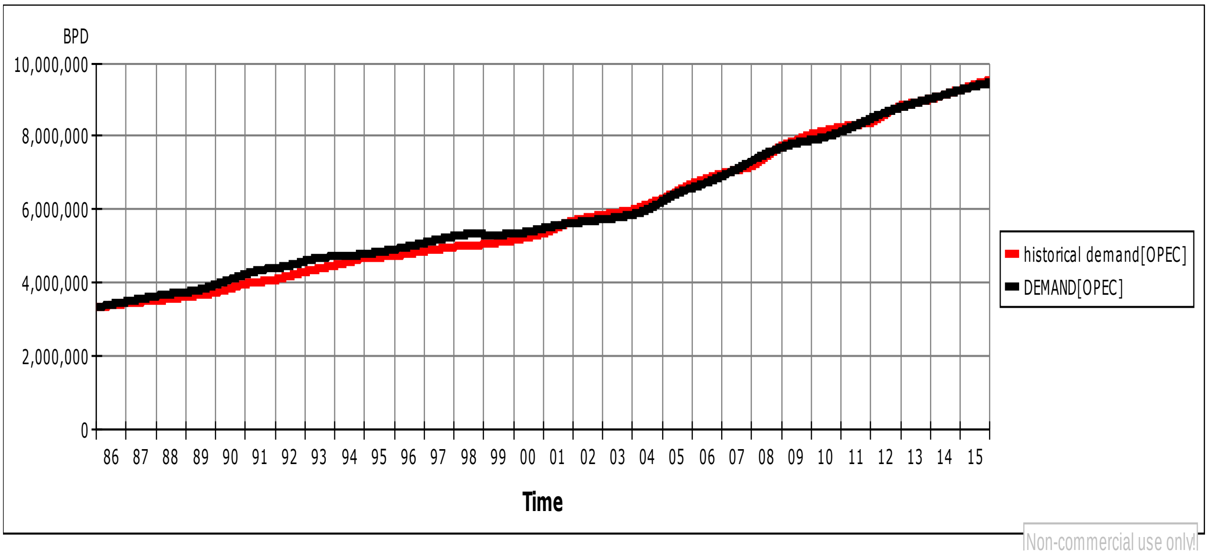

Figure 37, Simulated Vs Historical Demand in OPEC Countries

Figure 37 depicts simulated demand in OPEC countries. It matches historical values. This demand has tripled in the last thirty years; probably because of gasoline subsidies and lack of policies to lower oil consumption and higher use of renewables.

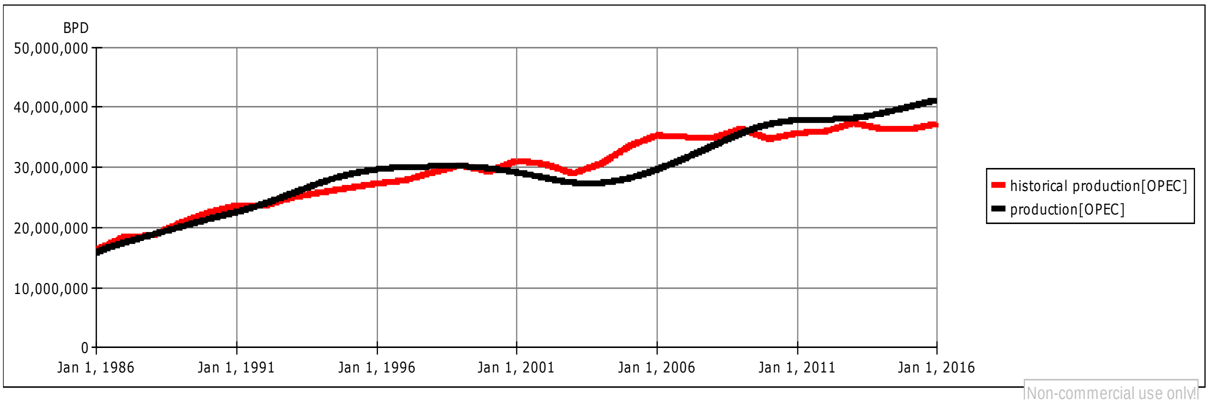

Figure 38, OPEC Simulated Vs Historical Production

Simulated production follows the general patter of historical behavior. This is the simulated response to two drivers. First, the Investment pressure that emerges out of the expected oil price to breakeven relation. Second, a policy to pursue additional projects when the international market grows.

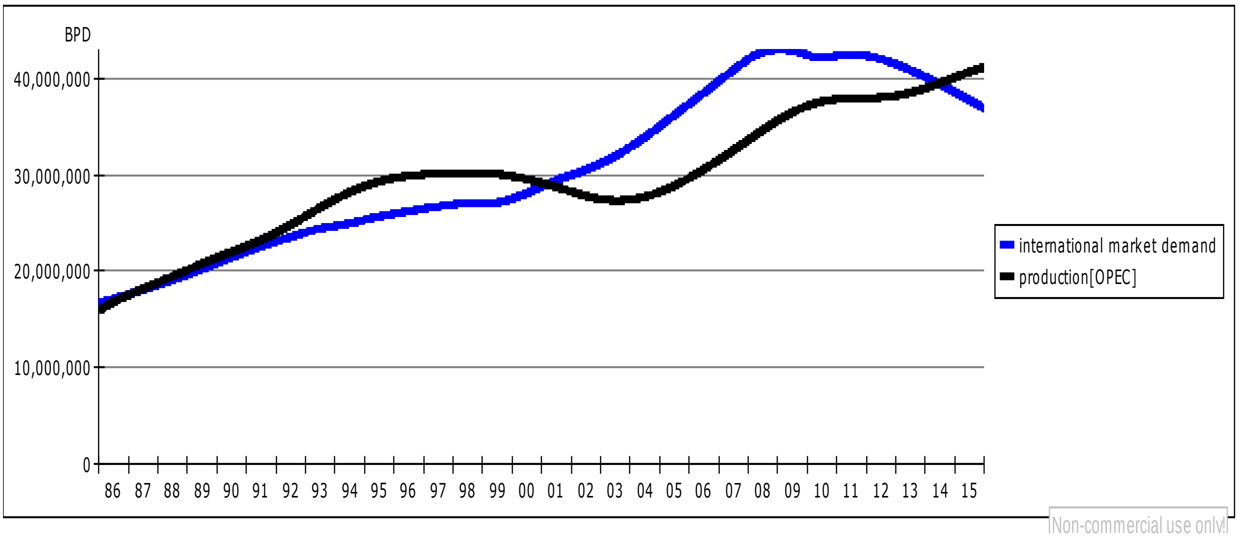

Figure 39, OPEC Production Vs International Demand

The figure unfolds simulated values of the international market demand, and OPEC’s production. The former signals how many barrels per day are not covered by net importer regions (OECD and Asia Pacific). In this result, OPEC over produces international demand until 2001; oil prices were very low in this time period. After 2001, OPEC produces at a much lower rate than demand; prices set up in this period. In 2014, OPEC starts producing more than demand; prices dropped.

Table 2. Parameters used in the model

Name	OECD	Asia Pacific	OPEC	Units
Construction time	6	4	4	years
Delay Type in new production capacity rate	3	1	1	Unitless
Oil fields time span	10	13	15	years
Initial upstream cost per barrel	5	7.1	3.5	USD per barrel
Hurdle rate	10	10	10	%
Fiscal percentage relative to boe price	48	45	50	%
Price to breakeven ratio assessment time	2	1.5	1	years
New capacity adjustment time	1	1.4	1.5	years
Base investment pressure release time	Na.	Na.	Na.	years
Minimum investment pressure release time	Na.	Na.	Na.	years
Release time	1	1.04	1.02	years
Initial Projects Portfolio	Na.	Na.	Na.	BPD
Initial Production Capacity in Construction	7500000	2020200	12500800	BPD
Initial Production Capacity	21097511	5000000	15871000	BPD
Initial Developed Reserves	77006	18250	57929	Million Barrels
Initial Cumulative Production	0	0	0	Barrels
Initial Investment Evaluation Pressure	Na.	Na.	Na.	Unitless
Initial investments	Na.	Na.	Na.	Million USD per year
Demand Fraction	1.02	1.01	1	Unitless
Net importer switch	1	1	0	Unitless
Adjustment time demand fraction	32000	170000	275	days
Adjustment time change in demand	480	150	325	days
Demand	37.5	5.2	3.3	Million Barrels

4. CONCLUSIONS

4.1) Summary of Findings: Expected profit per barrel and market share may stand as main oil production and investment drivers. DPM provides a powerful method to assess the causal interplay between drivers and oil supply strategic resources. To use it, however, it is crucial to identify the main elements in the value chain. I have built a general model of such a structure, taking into account the production capacity in construction, the production capacity, and the developed reserves as main resources. The latter seems to be a better structural element than the reserves used in the literature. I pose that new project development costs may decrease as reserves are developed and new infrastructure is in place. This differs from studies where reserves are not differentiated. Notice that this has led to a production assessment in diverse regions of the world, which is similar to historical values. Hence the dynamic model that has been built may be used in supply oil studies to identify policies to lessen problems like the fluctuations in oil revenues of OPEC countries.

4.2) Contribution to Existing Knowledge: This study contributes to the literature in investments, petroleum and system dynamics, by integrating the three fields.

4.3) Limitations of the Research: A longer time is needed to assess properly the data on upstream financial investments for OECD, Asia Pacific and OPEC. Getting this data would help to validate further the financial investment results obtained for Murphy Oil, Exxon Mobil and Norway.

4.4) Directions for Further Research: To test the oil price model formulated in the theoretical part of this thesis; and use it to test OPEC policies.

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APPENDIX: DPM of PDVSA

DYNAMIC PERFORMANCE MANAGEMENT OF THE VENEZUELAN NATIONAL OIL COMPANY

Presented at the Conference: The Paradigm Shift from Output to Outcome Measures in the Public Sector and the “Azienda Pubblica” May 2016, University of Palermo, Italy

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1) INTRODUCTION

1.1) Problem Relevance

PDVSA, the Venezuelan National Oil Company (NOC) generates approximately 85 percent of the country's total export revenue. Its proved oil reserves increased from 80 to 280 billion barrels five years ago, due to additions in the Orinoco Belt. The number of remaining years of production at the prevailing production rate passed from 70 to 255 years. In the meantime, the price of WTI oil went from 26.18 $/barrel in 2002 to 99.67 $/barrel in 2008; the average price in the period 2008-2014 was 88.74 $/barrel. Notwithstanding, a plan to increase production capacity to 5.8 MMBD (million barrels per day) by 2012 achieved only 3.1 MMBD; and oil production decreased 10% in the last five years. Fiscal proceeds to the state also show a decline pattern. We use the Dynamic Performance Management (DPM) framework (Bianchi, 2012) and we also integrate elements of institutional and policy analysis to find what causes the performance of this oil company. Using DPM, we confirm that end results, strategic resources and drivers must be synchronized over time to provide sustainable growth. This oil case uses three strategic resources: proved reserves, production capacity and financial availability. We also estimate that the solidarity policy aimed at providing cheap oil to Caribbean neighbors caught disproportionate attention in the agenda of policy makers, whereas the deterioration of the financial and operational conditions of the oil company did not. The Dynamic Model of Choice for Public Policy (Baumgartner and Jones, 2005) was used to explain the change in the institutional agenda that led to focus on the solidarity policy from 2007 on. As Bianchi et al. (2010) put it, ignoring the political priorities that permeate through the institutional system may lead to incomplete analysis of its corresponding organizational structures.

1.2) Research Question and Objective

Research Question: What has been the impact of the solidarity policy put in place by PDVSA on its performance? In particular, what has been the impact on the cash received by the government from the oil company?

Research Objective:

To develop a dynamic, causal explanation that associates structural factors with the performance of PDVSA during 1999-2014, in order to assess the impact on the cash received by the government from the oil company.

1.3) Paper Outline

In order to provide a dynamic causal explanation of the performance of PDVSA, the second part of the paper examines the relevant theory and conceptual framework. We introduce the oil markets, performance and previous system dynamic models of interest. Then we present relevant institutional and policy constructs that interact with the operation of National Oil Companies (NOC´s). The section ends with the introduction of the conceptual analysis framework used in this research: Dynamic Performance Management, introduced by Bianchi (2012). The third part justifies the DPM analysis of PDVSA; the required performance elements are selected, a system dynamics model is built; a DPM assessment is made, and simulation results are discussed in light of the institutional and policy dynamics literature presented. The fourth part presents a brief summary of the findings, contributions, limitations of the research, and directions for future research.

2) RELEVANT LITERATURE AND CONCEPTUAL FRAMEWORK

2.1) Performance and Dynamic Models of the Oil Industry

Oil is sold using supply contracts or in the spot market. Oil price formulas are generally pegged to the price of reference –benchmark- crudes, plus a price differential that reflects the quality of the crude oil on sale, relative to the benchmark. This differential, which is calculated by each producer should reflect differences in the refined products obtainable (Fattouh, Mabro, 2006). Spot prices are generally used as reference to estimate future cash flows; key determinants of investment in production capacity projects. WTI (West Texas Intermediate), Brent and Dubai-Oman are the major crude oil benchmarks in the current price regime; almost all crude markets outside America and the Far East use the Brent reference. WTI is the benchmark for crude imported to the U.S; most of the crude oil futures contracts traded worldwide are referenced to WTI. The Dubai-Oman is used as a reference for the Gulf crudes (Saudi Arabia, Iran, Iraq, UAE, Qatar and Kuwait) sold in the Asia-Pacific market (Fattouh, Mabro, 2006).

In addition to the spot market for immediate physical transactions, different markets have developed for oil transactions: the "forward" market for transactions made several months before the delivery of cargos, organized futures contracts exchanges, transactions over the Internet, and OTC –over the counter- trades for tailored transactions. The availability of forwards and futures transactions allows both risk diversification and speculative strategies (EI, 2006). The future value of a benchmark is based on several factors, among which are the cost of money, the current level of excess commercial inventories of crude oil, the cost of storage, and the general perception about future supply. It is said that prices in a market are in "contango" when it is estimated that the futures price will be higher than the spot, and it is said to be in "backwardation" if the expectation is that the futures price will be lower than the spot (EI, 2006).

Oil exploration efforts generate new proved reserves. These reserves are depleted by production. Oil companies tend to produce the more profitable barrels first. Projects for new production capacity must compete with other projects in the portfolio. Minimum project requirements are: availability of reserves for the life span of the reservoir(s); a verifiable demand for the production; profitability in the investment, and financial availability. Other considerations include environmental, political and economic context studies.

Production capacity represents the highest level of stable and economically efficient production that can be achieved from a reservoir. It takes years for the development wells and infrastructure to be set up, before the commercial operation of the new production capacity can be initiated. This increases risk. Mabro (1986) asserts that lower oil prices reduce revenues, increasing unpaid taxes and debt; this reduces access to credit, creating further cash flow problems that increase bankruptcy risk. This may trigger reductions in exploration efforts that slow down the accumulation of reserves and the development of new fields. This may lead to a decrease in production.

National Oil Companies (NOC´s) control about 80% of world oil reserves. As in any profit seeking company, their performance can be measured via market capitalization, reserves and production distributions, as well as financial indicators. However, Government´s oil policy may result in different strategies in the case of NOC´s (Victor, 2007). Thurber et al. (2011) measure – in the case of NOC´s - how effective are the upstream operations in generating the revenue needed to satisfy the short term and long term objectives of the government.

Different dynamic energy and oil models exist in the literature. Naill (1972) studied the main factors controlling the discoveries of new gas resources in the U.S., assuming finite resources, and taking into account resource utilization goals in the short and long term. He studied the effect of government policies - such as price regulations and tax incentives - on the behavior of short and medium -term rates of discovery and resource production. His dynamic model included initial levels of gas reserves, investment in exploration, resource price, revenues, proved reserves, demand and production. He stated that the interaction of these variables over time was not intuitively obvious.

Morecroft (2007) designed a model to study the long-term dynamics of the global oil industry; he focused on the representation of the behavior of oil producers. It contains five key sectors: (a) flexible OPEC producers with capacity to handle significant changes in production policy; (b) opportunistic OPEC producers; (c) OPEC quotas; (d) independent producers, which represent the rest of the producers; and (e) price and market demand. Price is set according to the imbalance between supply and demand; demand is obtained according to the short and long term influence of price, growth in GDP, and other non-economic elements. In this model, profitability per barrel enables production capacity in construction, which then becomes production capacity after the construction time, enabling production; operating and capital expenditures increase as the availability of resources decrease, as in the Naill (1972) study; this last aspect is of significant value from an operational point of view.

Genta and Anderson (1994) created a model to analyze future scenarios to support the strategy of an oil corporation. They studied a scenario of global stability where NOC´s take greater control of their operations and production, over time. The influence on price and world's oil supply was then assessed. The availability of capital for projects is included too.

Mashayekhi (2001) designed a model to explain the oscillatory behavior of oil prices; he suggests that when prices rise, the financial resources of the oil-exporting nations increase in the short term, while their need to export oil decreases temporarily; this leads to a decrease in the supply of oil and consequently, to a price increase over time; however, this increase would reduce demand in oil importing countries, over time.

Sterman (1981) studied the relative importance of the interconnections between energy and the economy; he created a platform for evaluating the effects of rising energy prices on economic growth, inflation and other key economic and energy indicators. It is based on an explicit theory of behavior on decision-making by individuals and firms at the microeconomic level.

Dyner (1990) developed an integrated energy policy model that initially considered the energy system of the United Kingdom; the model was used to analyze issues related to the volatility in the electricity sector and the strategic possibilities of arbitration through the gas and electricity markets.

2.2) Institutions, Policies and National Oil Companies

According to Pieters and Pierre (1998) Institutions refer to rules, values, norms and practices that shape or constrain political behavior. They claim that attempts to understand observed behavior independent of the structure will only lead to biased descriptions of individual motives. Institutions are flexible. As North (1990) points out, institutional change arises out of the relationship between: (a) institutions and the organizations that evolve from the incentives provided by the former; and (b) the feedback process where policy makers and entrepreneurs react to available opportunities. He postulates the existence of a threshold value that triggers institutional change, out of the perception of policy makers and entrepreneurs that to change is in their best interest.

Windfalls are defined as revenues in excess of expectations (Hildreth, 1998; Wilson and Sylvia, 1993). Oil producing states experienced high oil prices in the last decade. Several responses to windfalls are presented in the literature. Policy makers could isolate the windfall from conventional budget by creating funds. However, depletion of the funds may lead to increased vulnerability. Depletion of funds reacts to politician´s desires to build coalitions. Under these circumstances, budgeting becomes chaotic. This leads to relaxation of authority and managerial responsibilities in the budgeting process, as dominant coalitions form to control the allocation of the funds (Levine et al., 1981; Wilson and Sylvia, 1993). According to Jones and Weinthal (2010), among the reasons for economic stagnation in oil dependent economies we have the Dutch disease, where non mineral sectors reduce competitiveness and collapse; and the effect of export windfalls on corruption and indebtedness. The authors claim that beyond that, it is the structure of ownership (degree of participation and relationship between public and private oil operators) that they choose to manage their mineral wealth what matters most. It shapes incentives for subsequent institution building. In particular, it affects the type of fiscal regime that emerges and hence the prospects for building state capacity and achieving long term growth.

According to Jones and Baumgartner (2005; Jensen et al., 2016) policy making is not neccesarily incremental; that is, information processing is not proportional, but disproportional. They claim that policy makers, in response to information from the environment, pass from under-reaction to overreaction. This is called the Dynamic Model of Choice for Public Policy (DMCPP). Changes in the environment, that might require changes in policy, are sometimes ignored, primarily, because of bounded rationality and agency concerns. However, these ignored signals do not necessarily vanish. They build up pressure that may produce policy action in the future. This implies that the response of policy makers to these signals do not always adjust smoothly; they may become bursts of changes once attention to these previously ignored signals is granted. In this model, then policy response is not always synchronized with signals from the environment. The authors claim that signals require strength beyond certain dynamic threshold to deserve special attention. New signals must "compete" with the existing agenda. Notice the accumulation process in the response: when the signal strength is below the threshold, the response is partial and proportional to the signal; over time, response pressure builds until the threshold is reached, and the response is proportional not to the instantaneous value of the signal, but to the accumulated value of it.

2.3) Conceptual Framework: Dynamic Performance Management (DPM)

Bianchi (2012) proposes a framework to study performance (in terms of a dynamic flow, or change in strategic resources in a period of time) and sustainable growth in organizations. The strategic resources (built over time, to help their sustainability) are defined as stocks that have accumulation and depletion rates, therefore defining performance as the net between these two rates. Performance is conceptualized as the net rate of increase of the strategic resources. It is the responsibility of the policy makers to identify the proper strategic resources that lead to success; guarantee that the strategic resources are kept at the appropriate levels, over time; and keep the strategic resources consistently balanced, over time. Initially, the framework calls for an objective view of organizational performance where the products, services and relationships with the external environment are defined, and an internal and external value chain map is defined, as well. Then, an instrumental view of organizational performance is taken, where improvement mechanisms are made explicit; the end results and their respective drivers are identified; and every responsibility area, in charge of influencing the drivers, must nurture the appropriate strategic resources; all of which must be consistently balanced, over time, at the organizational level. A subjective view of performance requires linking the goals and objectives of the organization with the performance measures.

This approach provides a solid framework for the oil industry because upstream and financial managers carry actual responsibilities to configure the portfolio of projects that lead to enhanced proved reserves and production capacity; appropriate liquidity in terms of cash availability; and sustainable equity growth; required not only as a shareholder´s return signal; but also as an enabler of the external financial resources (loans) that oil companies require to pursue their capital projects. It is also the responsibility of managers to keep the proved reserves, production capacity, cash and equity at appropriate levels, over time. Most of all, high level management strives to keep formal track of the balance of resources, over time.

3) METHODOLOGY AND SIMULATION RESULTS

3.1) Rationale for Adopting Methodological Approach:

The research objective is to develop a dynamic, causal explanation that associates structural factors with the performance of PDVSA during 1999-2014; in order to assess the impact on the cash received by the government from the oil company. As noted in the previous section, DPM fits properly to analyze oil companies; therefore, we use it in the research, concurrently with its underlying representation, simulation and testing method System Dynamics (SD). The latter may help to understand what factors cause the observed behavior, over time, in an organization, while providing a causation theory of behavior Lyneis (1980). A model of the PDVSA upstream oil operations is developed. We center our attention on the proved reserves, production capacity and financial availability strategic resources. We also make an explicit representation of the government policy to delay the collection of a fraction of accounts receivables. This solidarity policy aimed at Caribbean Countries was triggered by the increase of oil prices in the last decade. We show how the cash received by the government from the oil company decreases over time, in spite of high oil prices.

3.2) DPM: The case of PDVSA Reserves, Production, and Financials

Figure 1 shows the inter-relationships that make possible three fundamental end results in the PDVSA upstream operations:

- **Change in proved reserves**: It is the result of the addition of new reserves via exploratory efforts, and the subtraction of reserves (depletion) via production.
- **Change in production capacity**: New production capacity is added when projects start producing. Natural and mechanical effects create, concurrently, capacity loss. The change is the difference between the two.
- **Change in financial availability**: Financial availability is an approximation to cash and equivalents. Hence the change is an indication of the net cash flow of the company.

The accompanying strategic resources are the following:

Proved Reserves Strategic Resource: Accumulates the changes in proved reserves. This enables the “current reserves relative to required” driver. The latter, along with the expected profit and the verifiable demand help in the definition of the desired indicated capacity. Notice that the “expected profit relative to benchmark” driver increases with higher oil price, lower tax rate, or lower (benchmark) return rate; it decreases as production accumulates over time, since oil companies tend to extract (or produce) the cheaper barrels first.

Production Capacity Strategic Resource: The indicated production capacity signals the new production capacity rate that needs to be built. It generates new projects in the portfolio. These projects, in turn, create projects under construction. These projects are built according with the construction time. However, it is the financial availability that allows the construction of projects, once “indicated”. This means that in the presence of financial restrictions, the new projects under construction would be fewer than without restrictions. Once built, projects become new production capacity, increasing the production capacity strategic resource. The latter enables production

Financial Availability Strategic Resource: The two main sources of cash are the collection of account receivables (AxR) and new debt. The payment of Debt (capital and interest) and commitments deplete this strategic resource. Since the company requires a certain level of cash to pay for the average outflow, indicated amounts of debt are generated. The latter may be constrained by the current debt to assets ratio; hence the cash level may be lower than the indicated. The stock of commitments accumulates pending payments of capital expenditures, field costs and all pending payments to government (taxes, bonuses, royalties, and other outflows). Notice that the solidarity policy implemented in the last decade implies delaying the collection of a fraction of AxR.

A feedback perspective:

Capacity growth loop (reinforcing): Higher (lower) indicated capacity leads to more (less) projects in construction. More (less) projects in construction leads to more (less) production capacity (after the construction time). Given lead times for new production capacity and capacity loss – which increases with production capacity- oil companies strive to increase indicated capacity; unless lack of profitability, proved reserves or demand indicates otherwise.

Development costs loop (balancing): Development costs increase as production accumulates - Companies develop cheap barrels first; this decreases profitability of projects, indicated capacity, projects in construction, new production capacity and production capacity. This, in turn, decreases production.

Reserves depletion loop (balancing): Production depletes proved reserves. Lower reserves relative to required lowers profitability of projects; indicated capacity, projects in construction, new production capacity and production capacity. This, in turn, decreases production.

New reserves loop (reinforcing): Higher exploratory efforts increase proved reserves; this increases reserves relative to required; profitability of projects increases as well as indicated capacity, projects in construction, new production capacity and production capacity. This, in turn, increases production, accounts receivable (AxR) and collections; this increases financial availability, leading to further exploratory efforts.

New reserves loop (balancing): Higher exploratory efforts increase proved reserves; this increases reserves relative to required; profitability of projects increases as well as indicated capacity, projects in construction, new production capacity and production capacity. This, in turn, increases commitments, leading to higher payments of commitments and depletion of the financial availability, decreasing –balancing- exploratory efforts.

Investment loop (reinforcing): Higher (lower) financial availability may lead to more (less) projects in construction. This leads to higher (lower) new production capacity and production capacity. This, in turn, increases (decreases) production, accounts receivable (AxR) and collections. Financial availability increases (decreases), leading to more (less) projects in construction.

Investment loop (balancing): Higher financial availability may lead to more projects in construction. This leads to higher new production capacity and production capacity. This, in turn, increases commitments, leading to higher payments of commitments and depletion of the financial availability, reducing –balancing- projects in construction.

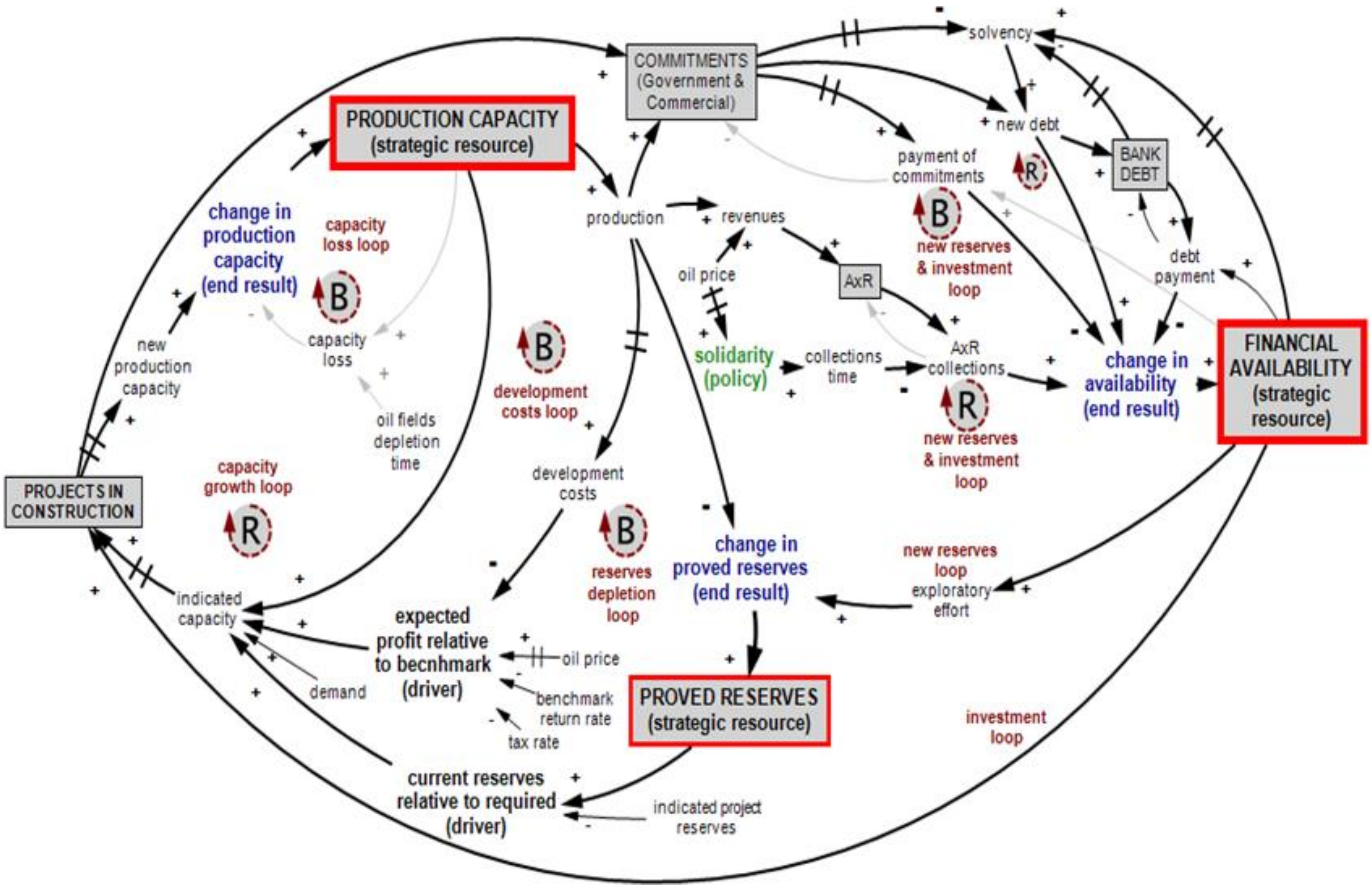

Figure 1, PDVSA Dynamic Performance Management Elements

3.3) Results and discussion:

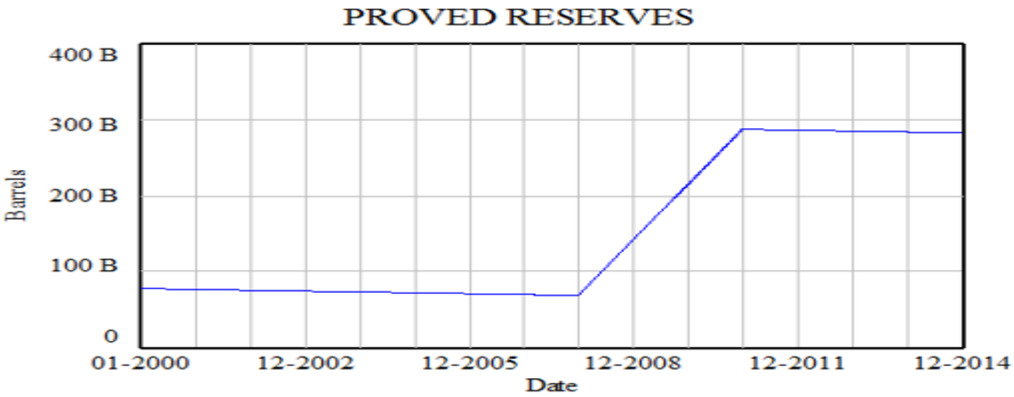

Figure 2, Simulation of Proved Reserves

The net incorporation of reserves changes the strategic resource from 80 to 280 billion barrels during the study period, due to additions in the Orinoco Belt. The number of years of production at the prevailing production rate passes from 70 to 255 years. The magnitude of the proved reserves, although important, is not sufficient to generate an increase in production capacity and production. The simulated values are consistent with observed behavior.

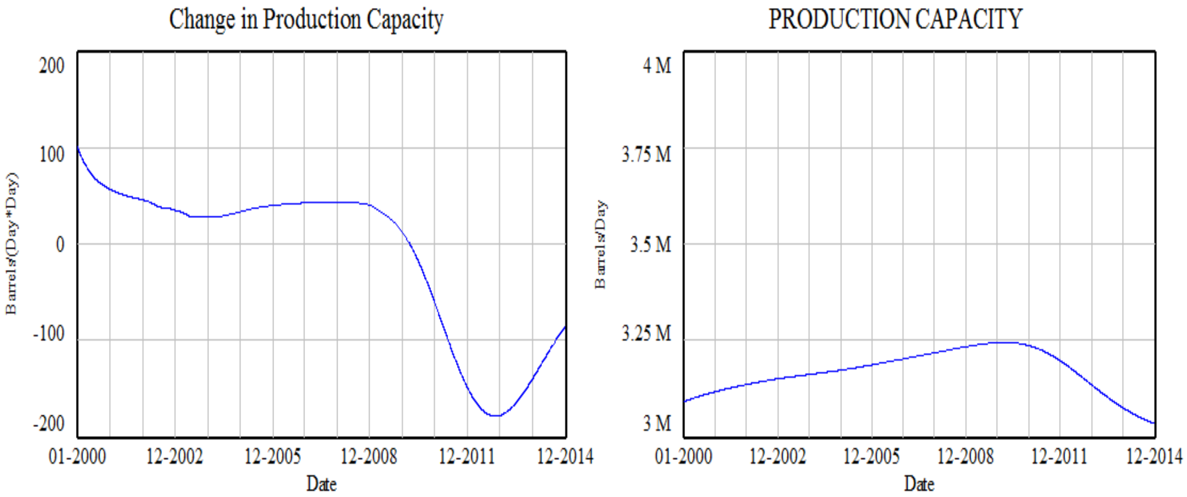

Figure 3, Simulation of Production Capacity

The net incorporation of capacity made the strategic resource decrease 10% in the period of study. The price of WTI oil went from 26.18 $/barrel in 2002 to 99.67 $/barrel in 2008; the average price in the period 2008-2014 was 88.74 $/barrel. Production capacity decreases in the presence of sustained high oil prices. The company published in its web site a plan to increase production capacity to 5.8 MMBD (million barrels per day) by 2012; it achieved 3.1 MMBD. The financial availability strategic resource constrains growth in production capacity. The simulated values are consistent with overall observed behavior.

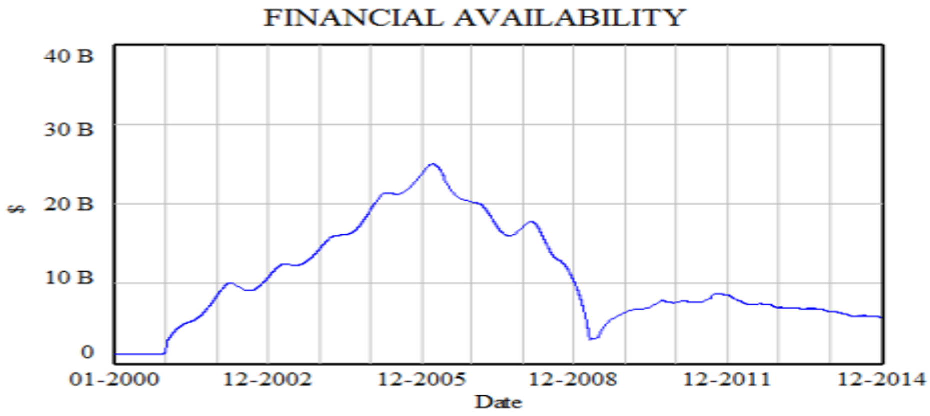

Figure 4, Simulation of Financial Availability

The financial availability strategic resource decreases in the presence of high oil prices. The solidarity policy – triggered by high oil prices in 2007 - that delays collection of a fraction of accounts receivables helps deplete the resource. In the presence of diminished financial resources, the company delays payments to contractors, further increasing the stock of commitments and future outflows that constrain financial availability even more. Concurrently, the increase in commitments weakens the debt to assets ratio. New loans become scarce and more expensive to obtain, again, impacting availability negatively.

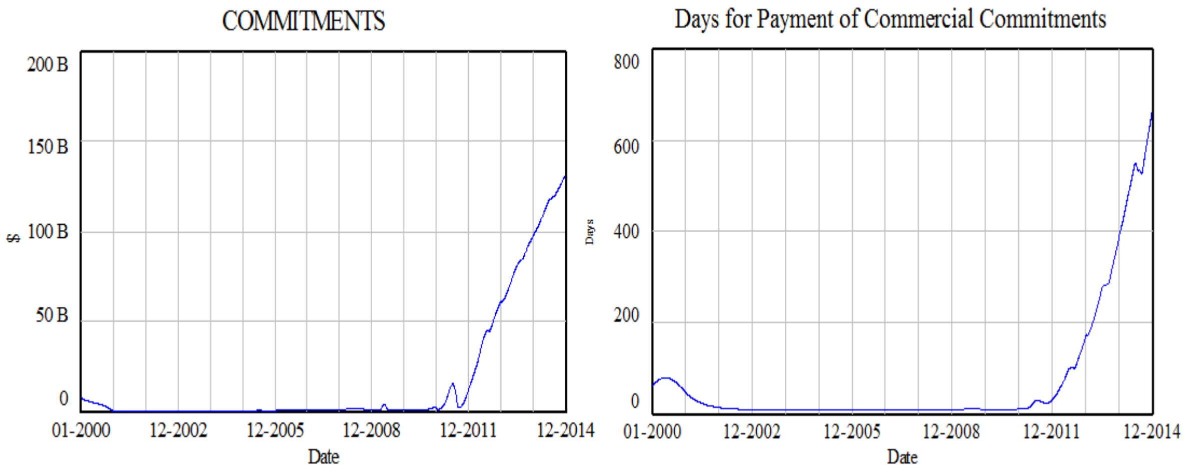

Figure 5, Simulation of Commitments

The stock of commitments increases as availability stagnates and then decreases. The average collection time of contractors increases. Payment delays increase commercial risk of contractors, therefore increasing costs to the oil company, that reflect on the stocks of commitments over time, again increasing future outflows and deterioration of the financial availability strategic resource.

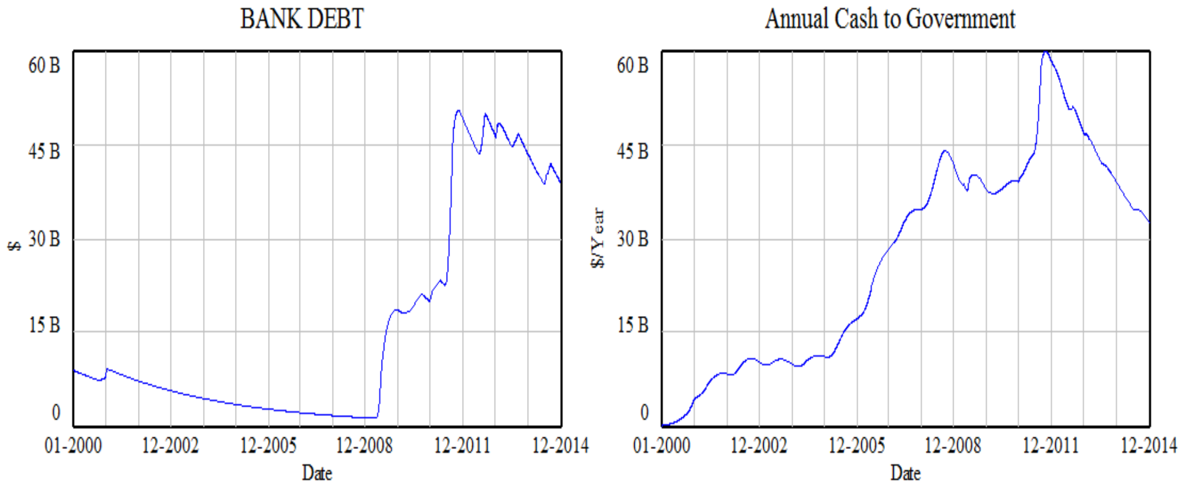

Figure 6, Simulation of Bank Debt and Government Take

Bank debt increases when oil prices increase, it then stagnates as new loans become scarce and costlier. Annual cash to government peaks and starts declining with financial availability. The simulated values are consistent with overall observed behavior.

The case shows the potential consequences of the lack of institutional mechanisms to prevent relying heavily on the mineral sector and high spending policies; as indicated by Jones and Weinthal (2010). The situation may worsen in the presence of a commodity shock, as 2015 shows. The institutional mechanisms that may control the ability of the state to tax and spend do not seem to be synchronized with the performance of the oil company. In any case, the solidarity policy did not arise out of technical reasons. The institutional framework existent at the time decided the rules to allocate the associated oil proceeds, as suggested by the World Bank (2007) in cases of high oil rents.

As theorized by John and Margetts (2003) the solidarity with the Caribbean agenda gathered momentum once the government had enough impetus to implement it. The political image was high, and the oil prices increased enormously, actually creating a windfall. Once decided in 2007, the program expanded in a non-linear fashion. It did not look as an incremental process; rather, it gained disproportionate attention from policy makers that same year, as posited by Baumgartner and Jones (1993; John and Margetts 2003). The observed behavior of policy makers seems compatible, then, with the Dynamic Model of Choice for Public Policy (DMCPP) stated by Baumgartner and Jones (2005).

The disproportionate attention obtained by the solidarity program contrasts with the lack of action to cope with the deterioration of the financial fundamentals of the oil company; and the lack of risk mitigation strategies against an oil commodity shock, or price reduction. Baumgartner and Jones (2005) postulate that policy makers are frequently biased; government bought the idea that the era of cheap oil prices was over. Activists with political positions close to the government supported the idea with public documents, including books. Experienced analysts alerting that high oil prices would favor also international oil companies, increasing supply and decreasing prices later on, were ignored.

4) CONCLUSIONS

4.1) Summary of Findings

DPM shows that once identified the end results, strategic resources and drivers; they have to be synchronized over time to provide sustainable growth. This oil case has been built relying on three strategic resources: proved reserves, production capacity and financial availability. The last two show decaying patterns while the first grows enormously without leveraging the other two to achieve the expected production of 5.8 MMBD by 2012. On the contrary, production decreases 10% and cash to government shows sustained decline. The solidarity policy caught disproportionate attention in the agenda of policy makers, whereas the deterioration of the financial and operational conditions of the oil company did not caught it at the same speed. The Dynamic Model of Choice for Public Policy (DMCPP) was used to explain the change in the institutional agenda that led to focus on the solidarity policy from 2007 on. As Bianchi et al. (2010) put it, ignoring the political priorities that permeate through the institutional system may lead to incomplete analysis of its corresponding organizational structures.

4.2) Contribution to Existing Knowledge

Based on empirical evidence about the upstream oil industry in Venezuela, this study contributes, first, to the dissemination of the Dynamic Performance Management framework proposed by Bianchi (2012); second, it provides a reference application of the framework at the inter-institutional level, specifically by providing an endogenous perspective of the links between the operational and financial aspects of an oil company, and the institutions that shape and constrain its behavior and performance.

4.3) Limitations of the Research

Only public information about the oil company was used. No group model building effort was performed.

4.4) Directions for Further Research

To analyze OPEC using this framework for a better understanding of policy making in NOC´s, oil supply and oil prices.

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