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Economics of Exploiting a Marginal Heavy Oil Field in Nigeria: Deterministic and Stochastic Approach

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OPEX- Operating Expenditure

Abstract

When an oilfield is a marginal field, it creates the impression of low revenue to investors because possible recoverable hydrocarbon may fall below 50MMSTB; the issue with marginal heavy oil fields is that the investor is saddled with a burden of low heavy oil price and high CAPEX. This is because the price of heavy oil is discounted by approximately 50% the price of light/medium crude oil. The question the investor would ask is "venture or not to venture?" This paper looks at a shallow water field of 42 meters depth that is both a marginal field and a heavy oil field. It explores the implications of the Nigerian marginal oilfield fiscal policy (royalty and tax rates), heavy oil price and the high cost of recovering heavy oil on the overall field economics. Discounted cash flow model was employed to carry out a deterministic analysis on the field's production profile. The stochastic model has oil price, tax rate, royalty rate, overriding royalty rates to the farmor and capital expenditure are the input variables while the contractor's take, host government take and farmor royalty deductions are the output variables. The results show that the investment is sensitive to changes on the input variables like tax rate, heavy oil price, royalty rates and capital cost. We suggest that modifications be made on the marginal oilfield fiscal policy to encourage more investments on marginal heavy oil fields.

Introduction

A heavy oil field is a field bearing hydrocarbon of API° gravity below 20°API. Heavy oil field economics is often a concern because the price of heavy oil is discounted by 30% to 50% the price of conventional light/medium crude oil [2] and the complex technology of exploiting and producing heavy oil is more capital intensive compare to light and medium oil. In most cases, heavy oil is produced in lower volumes less than 100MMSTB. The volume of recoverable heavy oil from a candidate reservoir given the complex recovery techniques applied makes heavy oil recovery an economic concern to intending investors.

According to the Federal Government of Nigeria and the Department of Petroleum resources, a marginal field is a field that has not produced hydrocarbon in more than ten (10) years (DPR). Many schools of thought have their perspectives to the description of a marginal field.

Fiscal Policy for Marginal Field

The Petroleum Fiscal Structure of the Federal Government of Nigeria is the royalty and tax fiscal structure. This fiscal structure provides that royalties, taxes, and other levies are paid to the Federal Government. There is the Marginal Fields Farm-out Agreements (MFFA) that exists between the license holder (Farmor) and the marginal field holder (Farmee). This agreement provides that the farmee pays an overriding royalty to the farmor who is the license holder of the marginal field. The exact fiscal deductions and payments to be made by the farmee to the farmor and the host government are shown in Figure 1. This royalty and tax rates are reflected in our economic model for this work.

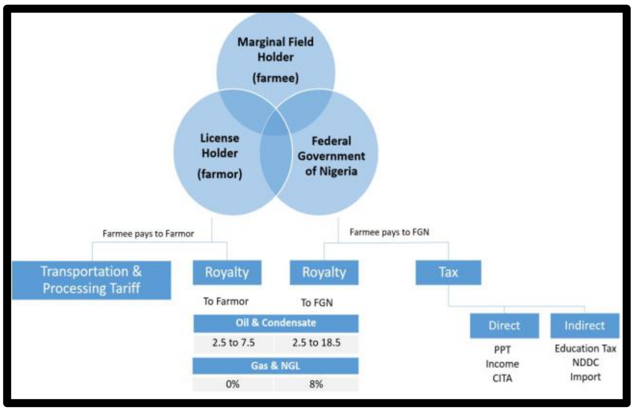

Figure 1 Nigeria Marginal Fields Fiscal Structure

Materials and Methods

Economic Model

Our Economic model applies the use of discounted cash flow model for deterministic economic analysis and Monte Carlos simulation for the probabilistic models. The deterministic model was developed on the Microsoft excel platform, while the probabilistic model was done using @RISK software. @RISK Simulation software functions as an adds-in tool on Microsoft Excel. The @Risk simulation tool uses the theory of Monte Carlos simulation for the stochastic/probabilistic analysis.

The capital and operating costs incorporated into the deterministic model was estimated using the Questo software by IHS. The costs are relatively different for each recovery method although the variance is relatively low. The cost of oil production is divided into technical and non-technical costs.

Cost of Heavy Oil Production

There are two kinds of cost in the oil industry as seen in Figure 1. There are:

- Technical costs
- Non-technical costs

Technical costs include capital expenditure (CAPEX), operating expenditure (OPEX) and abandonment cost. Capital expenditure could be either tangible or intangible. Operating expenditure is either fixed or variable. Abandonment cost is the cost of returning the field to its initial state after exploration and production activities are over, it is a form of technical cost.

Non-technical costs include royalties, bonuses, taxes, levies and legal costs. These costs are provisions of a working fiscal policy.

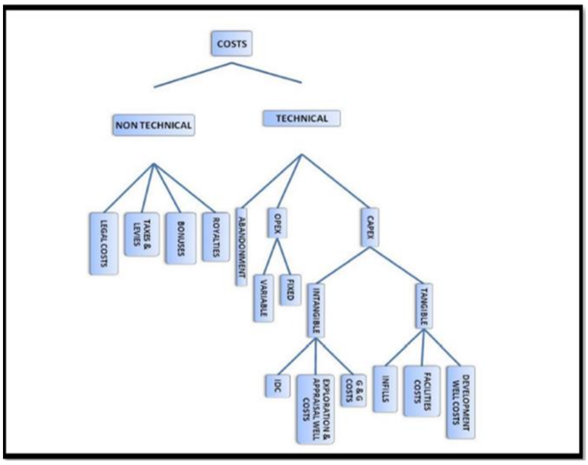

Figure 2 Tree diagram showing kinds of cost in the oil and gas industry. [5]

Capital Expenditure

According to Iledare and Fubara, 2017, Capital expenditure is either tangible or intangible costs. Tangible capital costs are costs of development wells, facilities, infill drilling. Tangible capital expenditures are depreciated in most fiscal policies for the purpose of cost recovery, the petroleum fiscal policies in Nigeria applies straight line depreciation methods. Intangible capital expenditure includes costs of geological and geophysical survey, exploration and appraisal well costs and intangible drilling cost. The cost of heavy oil recovery depends on the technology applied on a particular field. In this work, Questor software is used to estimate the capital expenditure while the operating expenditure is extrapolated using a rule of thumb estimated in our reference [3]. These cost objects are imposed on the cash flow model.

Operating Expenditure

According to Onwuka 2012, operating expenditures is referred to as lease operating expenditure (LOE). It is both fixed and variable. It is a percentage of the capital expenditure or the gross revenue in a cash flow model measured in \$/month, \$/year or \$/bbl. Authors like [1] [4] used 5% of capital expenditure as fixed operating cost and 3% of gross revenue as variable operating cost for the economic evaluation of a heavy oil field. The same is applied for this work. Depending on the provisions of a particular fiscal policy, the operating expenditure is expensed in the same year they are incurred [5]. A detailed representation of operating costs in oil and gas field as follows:

- Production cost – 35% of OPEX
- Evacuation cost – 23% of OPEX
- Insurance Premium – 21% of OPEX
- Maintenance cost – 17% of OPEX
- Overhead – 4% of OPEX

This implies that every operating expenditure in a field are expensed in this pattern. Nigerian’s heavy oil is costly to produce, most operators in Nigeria have suspended the drilling of new well due to high cost. The capital and operating expenditure are high because of the cost of technologies to aid production of the heavy oil.

Profitability Indicators

Different profitability indicators are used to investigate the profitability of a venture; this is so because not all profitability indicators can answer the questions investors may ask before investing. With investment goals of investors, each profitability indicators provide particular information for the investors. The most common profitability indicators used to access project economic performance are:

- Net present value
- Internal rate of return
- Profitability index
- Present value ratio
- Discounted payback period
- Unit technical cost

Net Present Value

The net present value (NPV), also referred to as the present value of cash surplus or present worth, is obtained by subtracting the present value of periodic cash outflows from the present value of periodic cash inflows. The present value is calculated using the weighted average cost of capital of the investor, also referred to as the discount rate or minimum acceptable rate of return. This is simply the sum of the present value of individual cash flows for each year over the entire field project life. A discount rate of 15% is used for our economic analysis in this work based on World Bank standard hurdle rate for oil and gas investments in Nigeria [1]. A positive NPV indicates a profitable investment, while a negative NPV indicates an unprofitable investment. When the NPV is equal to zero, it means the investment is self-sustaining but may become either profitable or unprofitable with time.

It can be calculated thus:

$$NPV = \sum_{t=1}^{n} \frac{NCF}{(1+i_d)^t}$$

Where NCF= Net cash flow, i_d= discount rate, t = time.

A positive NPV means profitability for the contractor and government.

Internal Rate of Return

Internal rate of return (IRR) is another important and widely reported measure of profitability. IRR is reported as a fraction or percentage rather than a dollar or naira figure such as NPV. The internal rate of return (IRR) sometimes called the discounted cash flow rate of return (DCFROR), rate of return (ROR), internal yield, marginal efficiency of capital, and the investor's method. IRR is the discount rate at which the net present value is exactly equal to zero, or the present value of cash inflows is equal to the present value of cash outflows. Another definition of IRR is the interest rate received for an investment consisting of payments (negative values) and income (positive values) that occur at regular periods. The internal rate of return is the discount rate at which the net present value, (NPV) is exactly equal to zero. It can be computed from the contractor's undiscounted cash flow in MS excel spreadsheet from:

IRR (contractor undiscounted cash flow @ year 1: contractor undiscounted cash flow @year 20)

$$NPV = \sum_{t=1}^{n} \frac{NCF}{(1+IRR)^t} = 0$$

Where: NCF is net cash flow, IRR is internal rate of return, t is time (days or years)

It helps the contractor to determine the discount rate at which the venture can yield profit if the investment is funded by a 100% borrowed capital. For profitability, the internal rate of return (IRR) should be greater than the discount rate at which the contractor borrows money from the bank to fund the oil field project.

Profitability Index

The NPV and IRR do not show the size of the investment. These yardsticks pose problems when an investment analyst has to make a choice among several alternative investments of different sizes.

The profitability index (PI) shows the size of the investment. The PI simply answers the question: How much in present value benefits is made per dollar of investment? The PI shows the relative profitability of an investment, or the present value of benefits per the present worth of every dollar invested (i.e., higher net return for each dollar invested). Profitability index is a dimensionless ratio of present value of future operating cash flows by the present value of the investment plus one. It shows how much revenue is generated per dollar invested. It is calculated using the equation below:

$$PI = 1 + \frac{NPV}{PV\ of\ capital\ investment}$$

Where NPV is net present value and PV is present value of capital investment.

Present Value Ratio (PVR)

The present value ratio (PVR) performs the same function as the profitability index. The difference is the index 1 is not included in the formula. It is a dimensionless ratio of the net present value (NPV) to the present value of the capital investment. It shows the present worth of the investment. If the PVR is less than zero then the investment is unprofitable, if PVR is greater than zero, the investment is profitable.

$$PVR = \frac{NPV}{PV\ of\ capital\ investment}$$

Discounted Payback Period

Discounted payback time is a capital budgeting technique. It is the time required to recover from the initial investment cost. It is also referred to as the break-even point. It is the exact time when the cash flow turns positive. Discounted payback period is a modified way of calculating the payback time. It incorporates the discount factor into the payback period calculation to account for the time value of money over the project years. It can be calculated either graphically or by interpolation method. The net cash flow is discounted each year and subtracted from the cost of the investment; the number of years that elapses upon recover from the initial investment is called the discounted payback period. The project is accepted if the payback period shorter or equal to the target time.

Unit Technical Cost

The unit technical cost (UTC) also referred to as the finding cost or long-run marginal cost (LRMC), is another useful indicator for screening capital investment projects. The unit technical cost is defined as the ratio of the total cost (CAPEX and OPEX) over the economic life of a project to the total expected reserves from the project. It is also referred to as the finding cost. It is used in economic analysis relative to the cost of the crude oil to check for profitability.

$$UTC = \frac{Total\ cost}{cummulative\ barrels\ of\ oil\ production}$$

The unit technical cost (UTC) may be undiscounted and/or discounted. The calculation of discounted UTC requires both yearly costs and production be discounted to the present value by using the same discount rate used for the calculation of NPV. The positive point about UTC is that it is independent of the price of the product involved. It gives an indication of what the product is costing to develop and produce. It provides a measure of the cushion available when compared to the actual estimated product prices. The criteria for measuring profitability using the economic indicators are shown in the Table 1.

Table 1 Decision rules for Economic Indicators [4]

PROFITABILITY MEASURES	ACCEPT IF	REJECT IF
NPV	≥ 0	≤ 0
IRR	$>i_d$	$<i_d$
PVR	> 0	<0
PI	> 1	<1
UTC	< product price	> product price

Input data for the deterministic model includes the technical and non-technical costs, oil price, oil price escalation rate, discount rate, depreciation charge, field production profile and the economic indicators coded into the deterministic model on MS Excel.

Cash Flow Model

The input parameters and assumptions on the discounted cash flow model is governed by the expression.

$$Net\ cash\ flow = Receipts - Disbursements$$

The receipts are the cash inflows, while the disbursements are the cash outflows. These terms are properly defined by the cost objects and the fiscal instruments of the working fiscal policies used for this research. Generally, the government and contractor's cash flows are defined as follows:

Contractor's (Farmee) Cash Flow

As seen in the equation below, the contractor net cash flow comprises of continuous deduction once the gross revenue which is the first cash inflow is generated. The contractor is allowed to recover his cost. The net sum after all deduction is the contractors take home pay, calculated as:

$$Contractor's\ Net\ cash\ flow = GRR - ROY - Total\ CAPEX - OPEX - Bonuses - Taxes - levies - Other$$

All deductions and payments are a function of the gross revenue. The Gross Revenue is the first cash sum generated by the contractor after the sales of barrels of oil at the money of the day oil price. It is calculated using this equation

$$Gross\ revenue = barrels\ of\ oil\ produced \times oil\ price$$

License Holder's (Farmor) Cash Flow

The cash flow for the license holder is tied to the gross revenue generated after sales of oil. The rates of royalty paid to the farmor is jumping scale and is a percentage

$$Farmor's\ cash\ flow = Gross\ revenue \times farmor's\ royalty\ rate$$

Host Government Cash flow

As seen in equation below, Government net cash flow consists of royalty, bonuses, rentals, tax and levies.

$$Government\ cash\ flow = Royalty + Bonuses + Rentals + Tax + Levies - abandonment$$

Royalty is a percentage of the gross revenue generated after the sales of heavy oil. It is the first cash payment made to the host government after production commences. The specific fraction is as stipulated the fiscal policy under consideration as discussed in the previous chapter and it is shown in Table 2 for each fiscal policy imposed on the cash flow models.

Bonuses are a single lump sum paid once or periodically. The single lump sum paid before the acquisition of the acreage is known as the signature bonus. The lump sum paid periodically when a production feat is cumulated is known as production bonus.

Rentals are paid to host government by contractors a form of a levy. These levies are used by the government to fund development project for the citizens. Bonuses and rentals are regarded as ancillary elements of the fiscal policy used to fund the NDDC, NCDMB and others.

Taxes are a percentage of the taxable income as stipulated in the working fiscal policy. It is paid after the contractor has recovered all depreciated cost that year. The petroleum profit tax for the royalty and tax fiscal policy, 67.5% in the first five years and 85% in subsequent years. The corporate income tax, which is 30% of the taxable income and the national hydrocarbon tax which is 40% of the taxable income and is a new inclusion in the proposed petroleum industry framework. The education tax (2% of taxable income) is used to fund tertiary education training and development for academia in the Nigerian Universities (TETFUND).

Levies are paid for specific sum paid for a particular purpose as stipulated in the fiscal policy. In the Nigerian fiscal policy, there is the inclusion of Niger delta development levy, used for the purpose of developing the oil producing region. The same fiscal regimes are applied for the four reservoirs but with different cost objects that indicates the cost of the enhanced oil recovery projects done. The input parameters from the deterministic economic models built are shown in Table 2.

Table 2 Input Parameters for deterministic model for Reservoir X (Shallow field) [6]

Field Data	Details	Units
Reserves Size	100	MMSTB
Heavy Oil Prices	20, 15 and 25	$/bbl
Price Escalation rate	2%	
Discount rate	15%	
Total CAPEX	793	$M
Variable OPEX	3%	of gross revenue per year
Field OPEX Field life Initial productio n rate	5% 20 8,000	of CAPEX years bbls/day
Peak productio n rate	Nil	bbls/day
Signature Bonus	300,000	$
Royalty rate	18%	of Gross revenue per year for Shallow field
Tax	67.5%	First five years
	85%	Subsequent years
NDDC levy	3%	of Taxable income
Education Tax	2%	of Taxable income
Cost Recovery Limit	100 %	of Net revenue after royalty
Abandon ment cost	1%	(the host government bears the cost of abandonment)

Our stochastic model is restricted to the base case scenario of $20/bbl. Input parameters for the stochastic model is shown in Table 3, the output parameters for the stochastic model are cumulative royalty to the farmor, host government's take, and contractor's take. The frequency distribution assigned to the input parameters and the reasons for the selection are shown in Table 3.

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Table 3 Frequency Distribution for Probabilistic Model

Input Variable	Frequency Distribution	Reason for Frequency Distribution Selection
Heavy Oil Price	Triangular distribution	It has a most likely value, a minimum and a maximum
Capital expenditure	Triangular distribution	Same as above
Tax rate	Uniform distribution	It is a policy and is constant throughout the life of the field once a contract has been signed on the stipulated rate.
Royalty rates	Log-normal distribution	It increases with increase in input variable and decreases with decrease in input variable, values are always positive.

Results

Results of Our Economic Model

The result of our deterministic Model (Discounted Cash flow) shows that at varying prices between $15/bbl., $20/bbl., and $25/bbl, the reservoir X producing heavy oil remained profitable as seen in Table 4.

Table 4 Profitability Analysis at Varying Heavy Oil Prices

Economic Indicators	Heavy Oil Price at $15/bbl	Heavy oil Price at $20/bbl	Heavy Oil Price at $25/bbl
Discount Rate (%)	15	15	15
Internal Rate Of Return (%)	33%	34%	36%
Net Present Value ($M)	49,889.67	66,519.53	83,149.4
Unit Technical Cost ($/Bbl)	0.93	1.21	1.49
Unit Capex ($/Bbl)	0.097	0.097	0.097
Unit Opex ($/Bbl)	0.84	1.11	1.39
BFIT ($M)	70,515.41	95,481.24	117,527.58
AFIT ($M)	49,889.67	66,519.53	83,149.4
Payback Period (Years)	> 2 years	> 2 years	> 2 years

Deterministic Results for Reservoir X for the different Heavy Oil Prices

The deterministic model was built with heavy oil price of $20/bbl as base case heavy oil price, $15/bbl heavy oil price was used as worst case scenario and $25/bbl was used as best case scenario heavy oil price. This is because heavy oil price is usually discounted by 30% to 50% conventional oil price. Table 3 shows Reservoir X, produced using polymer flooding, enhanced oil recovery methods was found to be profitable. Comparing the results of our economic models in Table 3 with Table 1 showing the criteria for measuring profitability using economic indicators, it can be seen that the discount rate of 15% is lower than the internal rate of return for both reservoirs in all heavy oil price scenarios, the net present value is positive for both reservoirs and recovery methods for all heavy oil price scenarios. The unit technical cost is lower than the worst case scenario heavy oil price of $15/bbl. This implies than the heavy oil field venture is profitable. The unit capital expenditure and unit operating expenditures were found to be profitable because they present very low figures compared with the heavy oil prices applied in all models. The before income tax (BFIT) and after income tax (AFIT) contractor's take were positive although the difference between the before income tax and after income tax contractor take is huge showing the large difference of cash dispensed as tax to host government. The overall field economics is profitable for both contractor and host government. Sensitivity analysis done varying heavy oil price as $15/bbl, $20/bbl and $25/bbl shows an all profitable heavy oil field project.

Stochastic Model Results

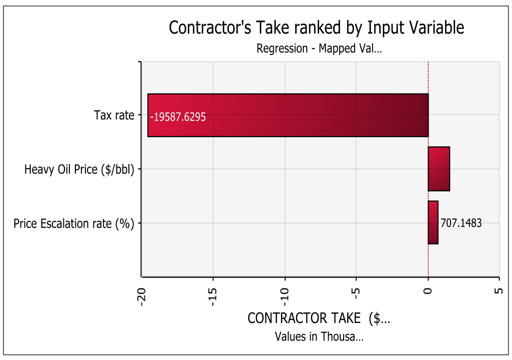

Figure 3 Contractor's take ranked by input variables for Reservoir X at base case heavy oil price of $20/bbls

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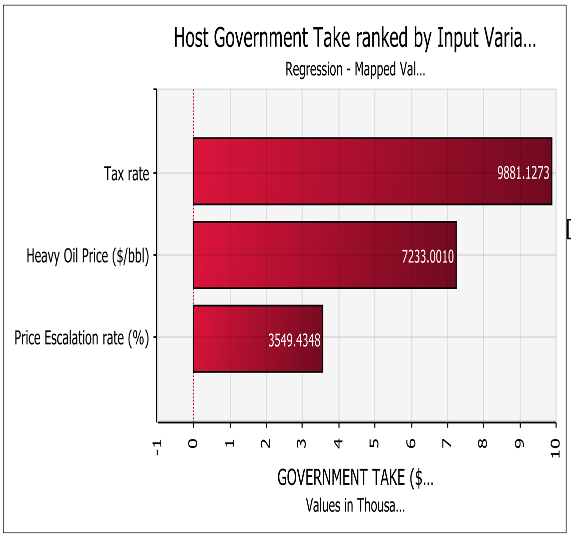

Figure 4 Host Government's take ranked by input variable for Reservoir X at base case heavy oil price of $20/bbl

Figures 3 and 4 presents the results of the stochastic model. Input variables such heavy oil price, tax rate, royalty rates and price escalation rates were ranked on output mean. The contractor loses more due to tax payment to host government while the host government's major revenue booster is the tax accrued from the heavy oil field. Heavy oil price is a positive influence on both host government and contractor's take. This implies that as heavy oil price increases, both host government and contractor revenue increases. Royalty rates are frontloaded deductions hence they do not influence the contractor's take. Price escalation rates are a positive boost on both host government and contractor's takes because they influence the rate money values and profit margin**.**

Conclusions

Heavy oil fields that are marginal can be harnessed with reasonable profit margin made by both contractor and host government from our research. A major influence on the profitability is the heavy oil price and tax deductions. Based on the finding of this paper, we recommend that a friendly tax deduction rate be introduced for marginal fields that produce heavy oil since the price of heavy oil is discounted less than the price of conventional oil in the international oil and gas market.

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Conflicts of interest

There are no conflicts to declare.

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APPENDIX 1

Stochastic Model Summary For Host Government Take (Exponential Decline)

Simulation Summary Information	HOST GOVERNMENT TAKE	
Workbook Name		field economic model exponential.xlsx
Number of Simulations		2
Number of Iterations		5000
Number of Inputs		5
Number of Outputs		2
Sampling Type		Latin Hypercube
Simulation Start Time		14/10/2019 10:32
Simulation Stop Time		14/10/2019 10:57
Simulation Duration		00:24:54
Random # Generator		Mersenne Twister
Random Seed		660298780
Total Errors		0
Collect Distribution Samples		All
Convergence Testing		Disabled
Smart Sensitivity Analysis		Enabled

Summary Statistics for HOST GOVERNMENT TAKE ($MM)			
Statistics		**Percentile**	
Minimum	723.97	**1.0%**	985.21
Maximum	1385.77	**2.5%**	1033.41
Mean	1179.64	**5.0%**	1061.65
Std Dev	71.32	**10.0%**	1093.48
Variance	5086.96753	**20.0%**	1122.56
Skewness	-0.531902397	**25.0%**	1133.21
Kurtosis	4.365830609	**50.0%**	1182.90
Median	1182.90	**75.0%**	1228.83
Mode	1190.06	**80.0%**	1239.72
Left X	1061.65	**90.0%**	1269.26
Left P	5%	**95.0%**	1290.17
Right X	1290.17	**97.5%**	1307.32
Right P	95%	**99.0%**	1323.71
#Errors	0		
Change in Output Statistic for HOST GOVERNMENT TAKE ($MM)			
Rank	**Name**	**Lower**	**Upper**
1	HEAVY OIL PRICE ($)	1087.63	1272.96
2	DISCOUNT RATE (%)	1074.14	1219.33
3	OIL PRICE ESCALATION RATE (%)	1168.73	1200.38
4	CAPEX ($MM)	1165.19	1195.89
5	PEAK PRODUCTION (BOPD)	1171.54	1187.34

APPENDIX 2

Stochastic Model Summary For Contractor Take (Exponential Decline)

Workbook Name	
Number of Simulations	field economic model exponential.xlsx
Number of Iterations	2
Number of Inputs	5000
Number of Outputs	5
Sampling Type	2
Simulation Start Time	Latin Hypercube
Simulation Stop Time	14/10/2019 10:32
Simulation Duration	14/10/2019 10:57
Random # Generator	00:24:54

Random Seed		Mersenne Twister	
Total Errors		660298780	
Collect Distribution Samples		0	
Convergence Testing		All	
Smart Sensitivity Analysis		Disabled	
		Enabled	
Statistics			
Minimum		**Percentile**	
Maximum	698.10	**1.0%**	997.56
Mean	1455.64	**2.5%**	1052.37
Std Dev	1221.66	**5.0%**	1085.65
Variance	81.27	**10.0%**	1123.16
Skewness	6604.961383	**20.0%**	1157.31
Kurtosis	-0.588065994	**25.0%**	1170.05
Median	4.525571678	**50.0%**	1226.05
Mode	1226.05	**75.0%**	1277.42
Left X	1232.44	**80.0%**	1290.19
Left P	1085.65	**90.0%**	1322.66
Right X	5%	**95.0%**	1346.53
Right P	1346.53	**97.5%**	1365.31
#Errors	95%	**99.0%**	1383.12
	0		
Rank			
1	**Name**	**Lower**	**Upper**
2	HEAVY OIL PRICE ($)	1119.49	1325.22
3	DISCOUNT RATE (%)	1096.88	1269.32
4	OIL PRICE ESCALATION RATE (%)	1209.24	1245.32
5	CAPEX ($MM)	1206.91	1238.49
	PEAK PRODUCTION (BOPD)	1212.54	1230.30