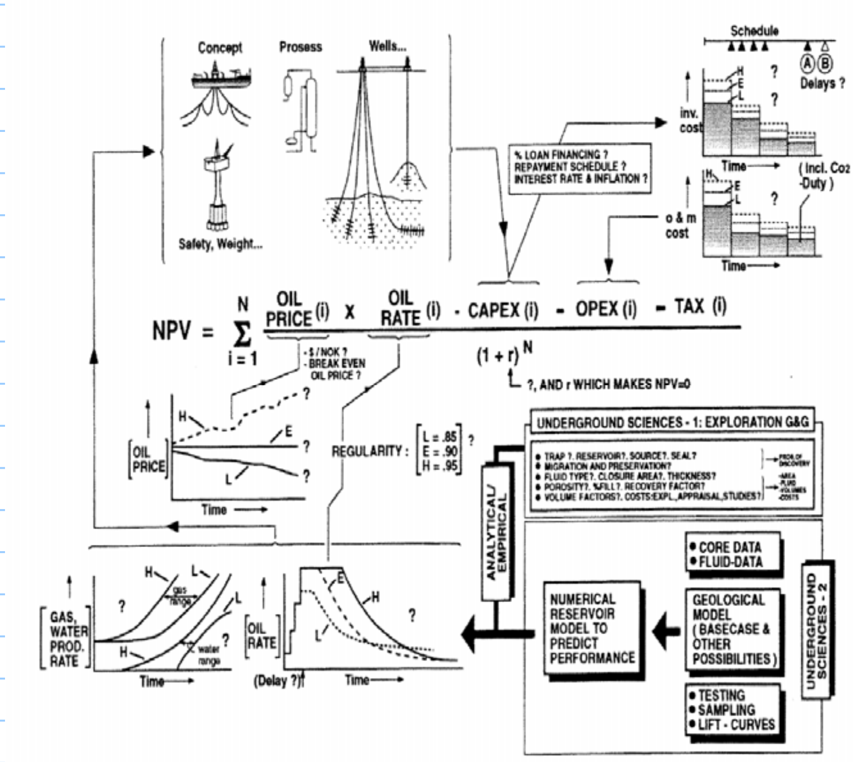
Day 4 05.12.2019 → NPV calculations
→ Reserve estimation
→ probability / decision trees



- Usually royalties and tax must be considered in NPV calculations → will be covered more in detail in petroleum economics course (Trygve Strøm)

  royalties: fixed amount (%) of revenue; tax: (%) of net profit

- Other costs such as EXPEX (exploration expenditures)

  ABEX (Abandonment costs)

might be included in NPV calculations

$$NPV = \sum_{i=1}^{N} \frac{\text{Revenue}(i) - \text{expenses}(i)}{(1+d_c)^i} = \frac{P_o(i)\cdot \Delta N_p(i) + P_g(i)\cdot \Delta G_p(i) - CAPEX(i) - OPEX(i)}{(1+d_c)^i}$$

i: year counter

d_c discount factor ⇝ (6% → 12%)

$$\frac{1}{(1+d_c)^i}$$

for year 1 : 6% $\frac{1}{(1.06)^1} = 0.94$

for year 10 : 6% $\frac{1}{(1.06)^{10}} = 0.56$

class exercise

CAPEX + DRILLEX + OPEX

discounted cash flow

time	ΔG_p	Revenue	CAPEX	DRILLEX	OPEX	Expenses	Cash flow	DCF
1	0	0	(−)	(−)	0	(−)	Revenue − Expenses	$\frac{CF}{(1+d_c)^i}$
2	0	0	(−)	(−)	0	(−)		
3	0	0	(−)	(−)	0	(−)		
4	0	0	(−)	(−)	0	(−)		
5	0	0	(−)	(−)	0	(−)		
6	ΔG_{p6}	$\Delta G_p \cdot P_g$	0	0	(−)	(−)		
7	ΔG_{p7}	"	0	0	(−)	(−)		
8	"	"	0	0	(−)	(−)		
9	"	"	0	0	(−)	(−)		
10	"	"	0	0	(−)	(−)		
11			0	0	(−)	(−)		

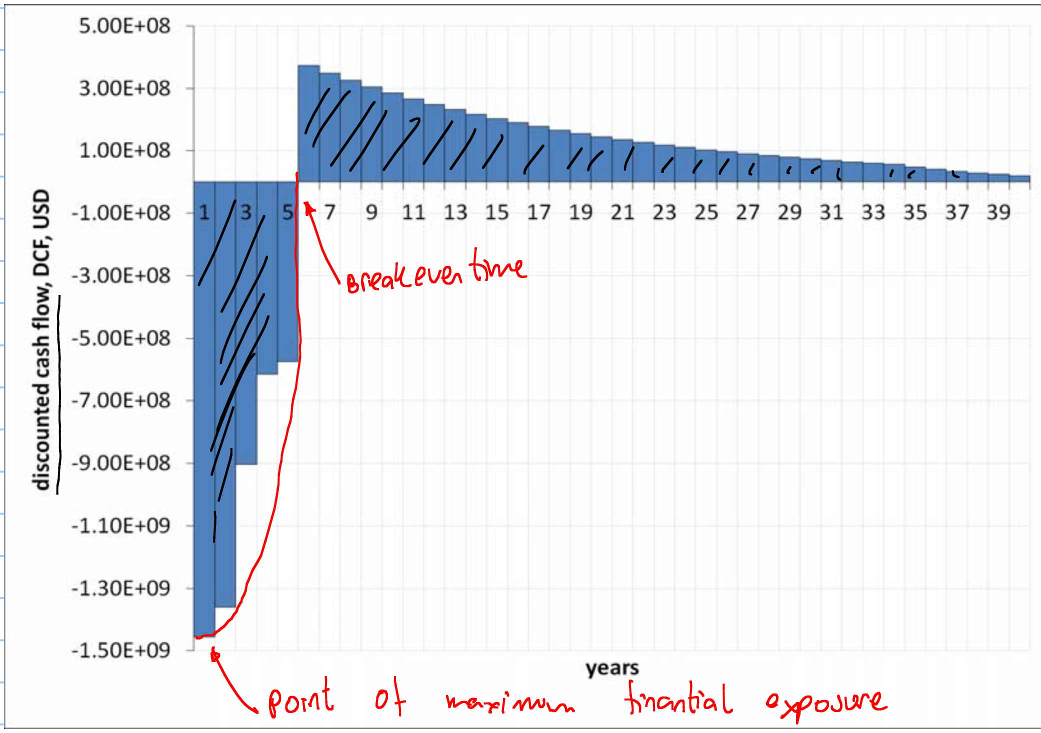
$$\sum \frac{CF}{(1+d_c)^i} = NPV$$

B2 example

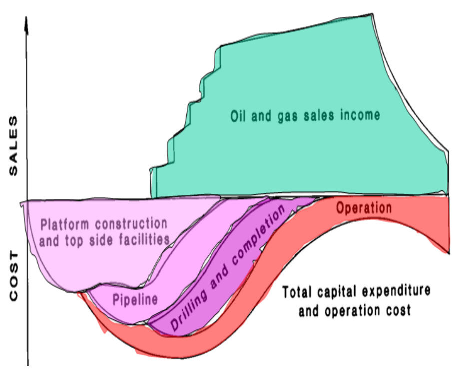
			Observations:
Well drilling cost	150	[1E6 USD]	Maximum 5 wells can be drilled per year
water depth	2500	[m]	all CAPEX is invested evenly during the first 5 years
Discount rate	0.07	[-]	
Uptime	360	days/year	
OPEX	1.20E+08	USD/year	
Gas price	0.11	[usd/Sm^3]	
$CAPEX_{LNG}$	3.48E+09	USD	
$CAPEX_{SUBSEA}$	5.58E+08	USD	

Time end of year	Gas production in year [Sm^3]	Revenue USD	DRILLEX USD	$CAPEX_{SUBSEA}$ USD	$CAPEX_{LNG}$ USD	OPEX USD	Total Cost USD	Cash Flow USD	Discounted Cash Flow: PV(i) USD
1	0	0.00E+00	7.50E+08	1.12E+08	6.95E+08	0	1.56E+09	-1.56E+09	-1.46E+09
2	0	0.00E+00	7.50E+08	1.12E+08	6.95E+08	0	1.56E+09	-1.56E+09	-1.36E+09
3	0	0.00E+00	3.00E+08	1.12E+08	6.95E+08	0	1.11E+09	-1.11E+09	-9.04E+08
4	0	0.00E+00	0.00E+00	1.12E+08	6.95E+08	0.00E+00	8.07E+08	-8.07E+08	-6.16E+08
5	0	0.00E+00	0.00E+00	1.12E+08	6.95E+08	0.00E+00	8.07E+08	-8.07E+08	-5.75E+08
6	6.5E+9	6.80E+08	0.00E+00	0.00E+00	0.00E+00	1.20E+08	1.20E+08	5.60E+08	3.73E+08
7	6.5E+9	6.80E+08	0.00E+00	0.00E+00	0.00E+00	1.20E+08	1.20E+08	5.60E+08	3.49E+08
8	6.5E+9	6.80E+08	0.00E+00	0.00E+00	0.00E+00	1.20E+08	1.20E+08	5.60E+08	3.26E+08
9	6.5E+9	6.80E+08	0.00E+00	0.00E+00	0.00E+00	1.20E+08	1.20E+08	5.60E+08	3.05E+08
10	6.5E+9	6.80E+08	0.00E+00	0.00E+00	0.00E+00	1.20E+08	1.20E+08	5.60E+08	2.85E+08
11	6.5E+9	6.80E+08	0.00E+00	0.00E+00	0.00E+00	1.20E+08	1.20E+08	5.60E+08	2.66E+08
12	6.5E+9	6.80E+08	0.00E+00	0.00E+00	0.00E+00	1.20E+08	1.20E+08	5.60E+08	2.49E+08
13	6.5E+9	6.80E+08	0.00E+00	0.00E+00	0.00E+00	1.20E+08	1.20E+08	5.60E+08	2.33E+08
14	6.5E+9	6.80E+08	0.00E+00	0.00E+00	0.00E+00	1.20E+08	1.20E+08	5.60E+08	2.17E+08
15	6.5E+9	6.80E+08	0.00E+00	0.00E+00	0.00E+00	1.20E+08	1.20E+08	5.60E+08	2.03E+08
16	6.5E+9	6.80E+08	0.00E+00	0.00E+00	0.00E+00	1.20E+08	1.20E+08	5.60E+08	1.90E+08
17	6.5E+9	6.80E+08	0.00E+00	0.00E+00	0.00E+00	1.20E+08	1.20E+08	5.60E+08	1.77E+08
18	6.5E+9	6.80E+08	0.00E+00	0.00E+00	0.00E+00	1.20E+08	1.20E+08	5.60E+08	1.66E+08
19	6.5E+9	6.80E+08	0.00E+00	0.00E+00	0.00E+00	1.20E+08	1.20E+08	5.60E+08	1.55E+08
20	6.5E+9	6.80E+08	0.00E+00	0.00E+00	0.00E+00	1.20E+08	1.20E+08	5.60E+08	1.45E+08
21	6.5E+9	6.80E+08	0.00E+00	0.00E+00	0.00E+00	1.20E+08	1.20E+08	5.60E+08	1.35E+08
22	6.5E+9	6.80E+08	0.00E+00	0.00E+00	0.00E+00	1.20E+08	1.20E+08	5.60E+08	1.26E+08
23	6.5E+9	6.80E+08	0.00E+00	0.00E+00	0.00E+00	1.20E+08	1.20E+08	5.60E+08	1.18E+08
24	6.5E+9	6.80E+08	0.00E+00	0.00E+00	0.00E+00	1.20E+08	1.20E+08	5.60E+08	1.10E+08
25	6.5E+9	6.80E+08	0.00E+00	0.00E+00	0.00E+00	1.20E+08	1.20E+08	5.60E+08	1.03E+08
26	6.5E+9	6.80E+08	0.00E+00	0.00E+00	0.00E+00	1.20E+08	1.20E+08	5.60E+08	9.65E+07
27	6.5E+9	6.80E+08	0.00E+00	0.00E+00	0.00E+00	1.20E+08	1.20E+08	5.60E+08	9.02E+07
28	6.5E+9	6.80E+08	0.00E+00	0.00E+00	0.00E+00	1.20E+08	1.20E+08	5.60E+08	8.43E+07
29	6.5E+9	6.80E+08	0.00E+00	0.00E+00	0.00E+00	1.20E+08	1.20E+08	5.60E+08	7.88E+07
30	6.5E+9	6.80E+08	0.00E+00	0.00E+00	0.00E+00	1.20E+08	1.20E+08	5.60E+08	7.36E+07
31	6.5E+9	6.80E+08	0.00E+00	0.00E+00	0.00E+00	1.20E+08	1.20E+08	5.60E+08	6.88E+07
32	6.5E+9	6.80E+08	0.00E+00	0.00E+00	0.00E+00	1.20E+08	1.20E+08	5.60E+08	6.43E+07
33	6.5E+9	6.80E+08	0.00E+00	0.00E+00	0.00E+00	1.20E+08	1.20E+08	5.60E+08	6.01E+07
34	6.5E+9	6.80E+08	0.00E+00	0.00E+00	0.00E+00	1.20E+08	1.20E+08	5.60E+08	5.62E+07
35	6.0E+9	6.30E+08	0.00E+00	0.00E+00	0.00E+00	1.20E+08	1.20E+08	5.10E+08	4.78E+07
36	5.5E+9	5.81E+08	0.00E+00	0.00E+00	0.00E+00	1.20E+08	1.20E+08	4.61E+08	4.03E+07
37	5.1E+9	5.36E+08	0.00E+00	0.00E+00	0.00E+00	1.20E+08	1.20E+08	4.16E+08	3.40E+07
38	4.7E+9	4.95E+08	0.00E+00	0.00E+00	0.00E+00	1.20E+08	1.20E+08	3.75E+08	2.87E+07
39	4.4E+9	4.58E+08	0.00E+00	0.00E+00	0.00E+00	1.20E+08	1.20E+08	3.38E+08	2.42E+07
40	4.0E+9	4.24E+08	0.00E+00	0.00E+00	0.00E+00	1.20E+08	1.20E+08	3.04E+08	2.03E+07
								NPV	1.92E+08

1) Homework: repeat NPV calculation for $q_{plateau} = 25$ E06 Sm^3/d



Revenue and Cost Profiles



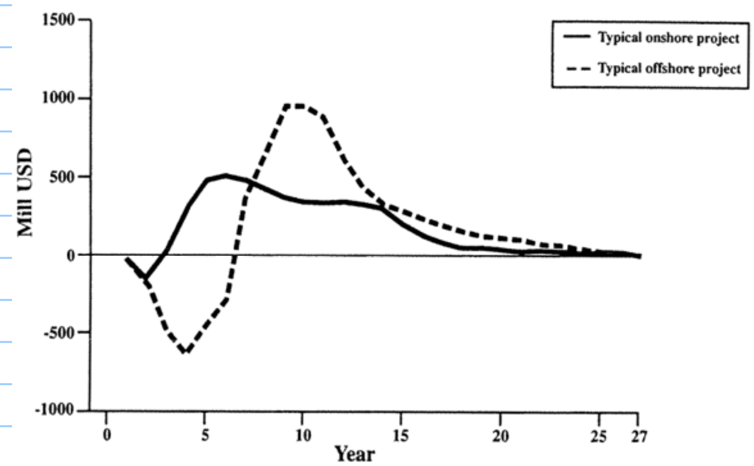


Fig. 9. Typical before tax cash flow profiles for offshore and onshore projects.

we should always evaluate the effect of uncertainty { P_g, P_o ; Cost figures ; production rates

Sensitivity analysis

↳ change one variable at the time while keeping all others fixed

for gas price P_g → $1.2\,P_g$ (+20)%
→ $0.8\,P_g$ (−20)%

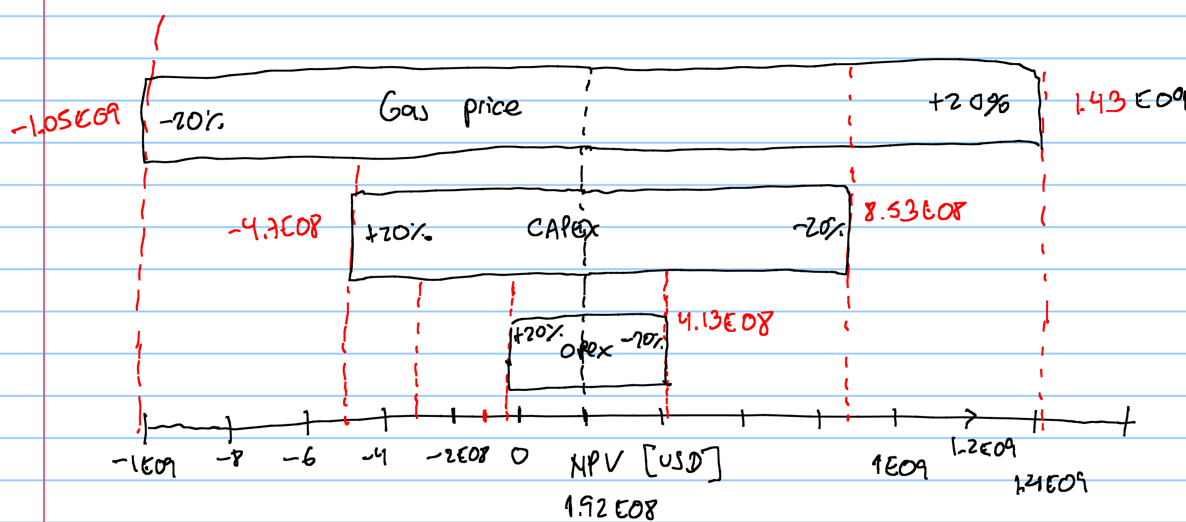
for our problem, evaluate the effect of uncertainty : ±20% gas price
±20% Capex values
±20% OPEX

1) • Change $P_g \to P_g \cdot 1.2$ → Compute NPV → return to P_g

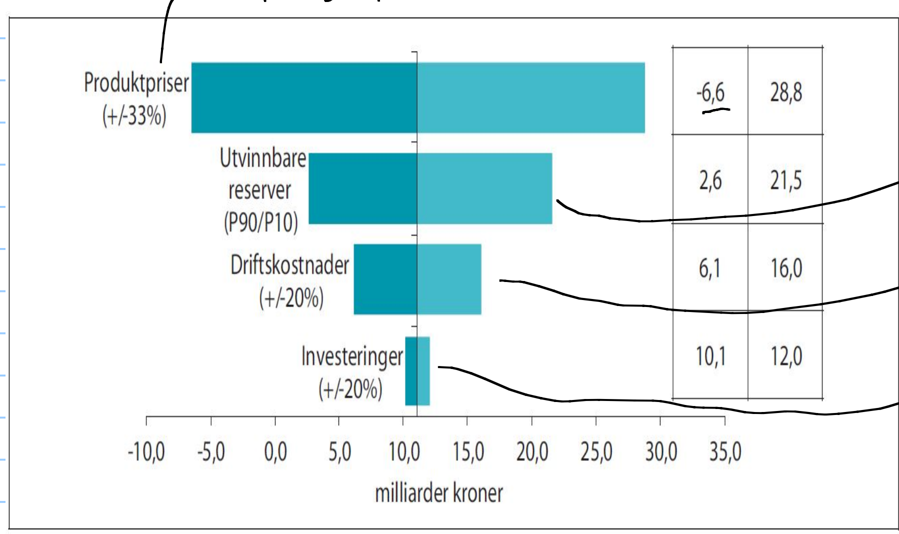
2) • change $P_g \to P_g \cdot 0.8$ → Compute NP → return to P_g

	NPV		
Variable	-20%	BASE CASE	+20%
gas price	-1.05E9	1.92E8	1.43E09
CAPEX	8.53E08	1.92E8	-4.7E8
OPEX	4.13E08	1.92E8	-3E07

tornado chart



oil price/gas price



TRR size

OPEX

CAPEX

Petroleum fiscal systems

Concessionary system
- apply for production licence (30 years)
- operator

HC production
↓
Sales Revenue
→ Royalty (10%: Tanzania?)
↓
Net revenue
→ operating cost, depreciation/amortization
↓
Taxable income
→ goverment TAX
↓
Net income

Contractual system

Service contract
↳ get a fee service in production or in cash

Production sharing contract (PSC)
conglomerate of several companies one of them is typically goverment
TPDC

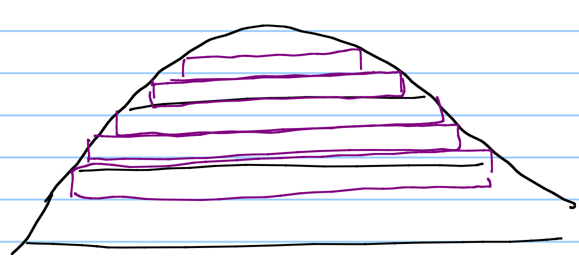
HC Production
→ royalty (or part of production)
↓
Net production
→ opex, depretiation
↓
Profit production
→ % Partner, % Partner, % partner

Partner
→ tax
↓
net profit production

Reserve estimation (D60, D61, D62)

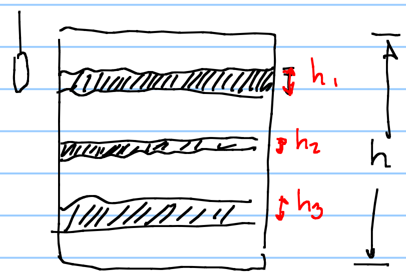
↳ estimating N, G → N_{pu}, G_{pu}

$$N_{pu} = N \cdot F_{RU}$$
$$G_{pu} = G \cdot \underbrace{F_{RU}}_{\text{ultimate recovery factor}}$$



$$N = \frac{V_R \, \phi \, S_o \, N_{TG}}{B_o}$$

N_{TG} --- Net to gross



reservoir rock layers which are not "clean" not "hydrocarbon -bearing" rock

$$N_{TG} = \frac{\sum h_i}{h} = \frac{h_1 + h_2 + h_3}{h}$$

is a multiplier to the total rock volume, to account for the presence of non productive layers.

$$N_{pu} = N\, F_{RU} = \frac{V_R \cdot \phi\, S_o \cdot N_{TG} \cdot F_{RU}}{B_o}$$

the input to this equation is not a single number!

$\phi \rightarrow$

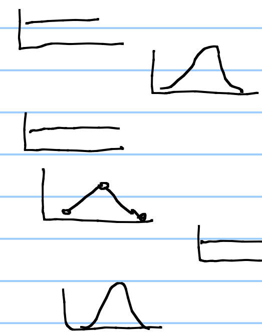
$V_R \rightarrow$

$S_o \rightarrow$

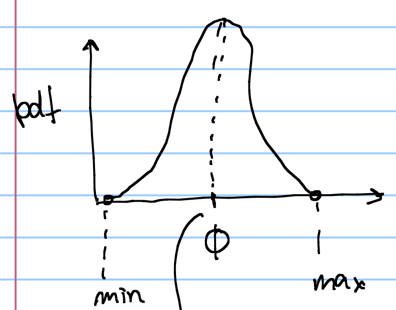
$B_o \rightarrow$

$N_{TG} \rightarrow$

$F_{RU} \rightarrow$



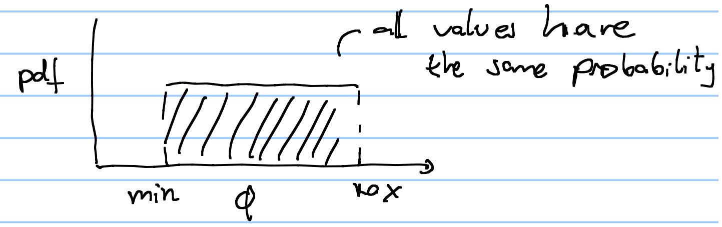
we are also interested in computing N_{pu} as a range, with associated probabilities



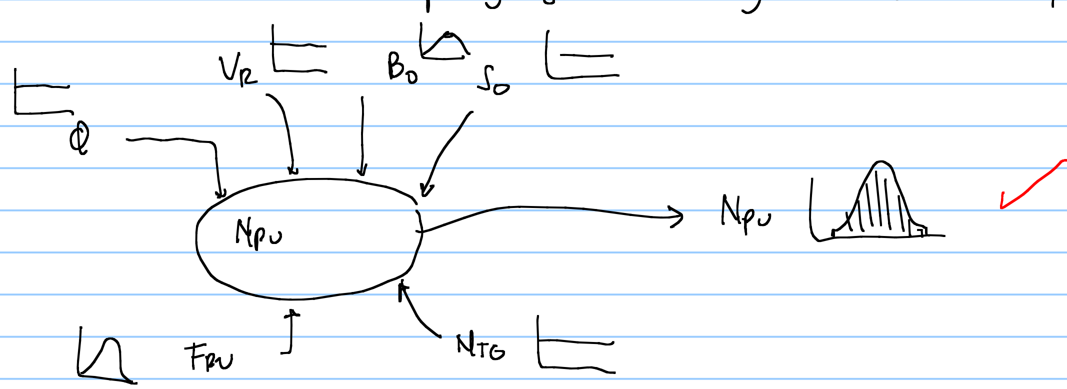
pdf probability density function

pdf probability distribution function

if i have no prior information

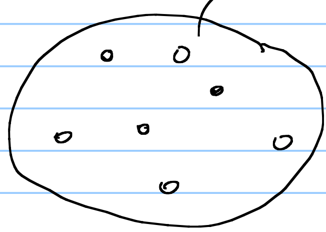


what i am interested in computing is the resulting distribution for N_{pu}



estimating probability distribution using measured data

exploration well sites



"N" samples

Φ
Φ_1
Φ_2
Φ_3
Φ_4
$\vdots$
Φ_N

min
max

frequency analysis

- define certain number of bins n
  n should be much less than N (number of samples)

- determine minimum and maximum values of sample

Φ_{min} $\qquad$ $\Delta\Phi = \dfrac{\Phi_{max} - \Phi_{min}}{n-1}$

Φ_{max}

- generate bins

bins
$$\begin{cases} \Phi_{min} \\ \Phi_1 = \Phi_{min} + \Delta\Phi \\ \Phi_2 = \Phi_1 + \Delta\Phi \\ \vdots \\ \Phi_{max} = \Phi_{i-1} + \Delta\Phi \end{cases}$$

Φ_{min} $\qquad$ $\Delta\Phi = \dfrac{\Phi_{max} - \Phi_{min}}{2}$

Φ_1 –

$$\Phi_1 = \Phi_{min} + \frac{(\Phi_{max} - \Phi_{min})}{2} =$$

Φ_{max}

- look at each value in sample and assign it to a bin

Φ_{min}
Φ_1
Φ_2
$\vdots$
Φ_{max}

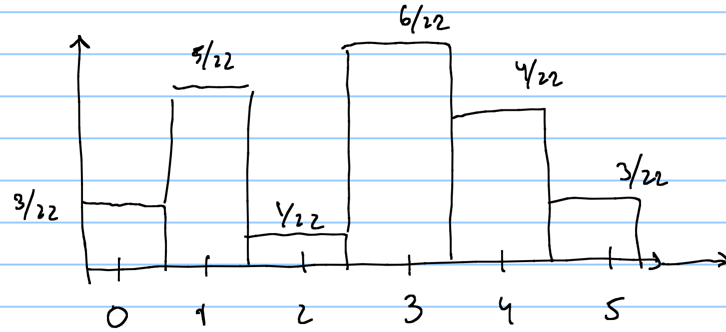
Φ_1
Φ_2
Φ_3
Φ_4
Φ_4
Φ_6
$\vdots$
Φ_n

1 $\quad$ 0
1 $\quad$ 1
$\quad$ 2
1 $\quad$ 3
1 $\quad$ 4
$\quad$ 5

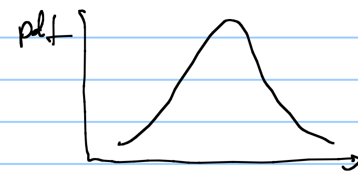
0.5
1.2
2.7
4.5
$\vdots$
N

- count the number of samples assigned to each bin an

	bin	Count	frequency ("probability")
$n=6$	0	3	3/22
	1	5	5/22
	2	1	1/22
	3	6	6/22
	4	4	4/22
	5	3	3/22
		$N=22$	

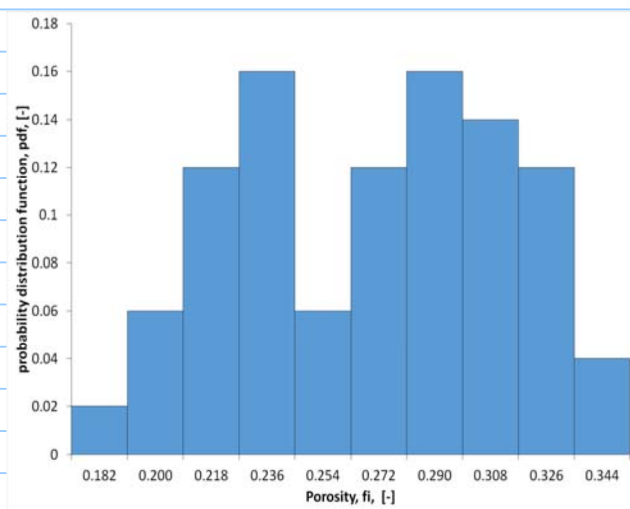


discrete probability distribution

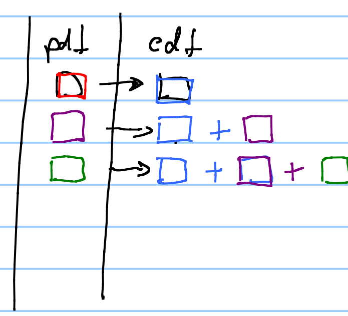


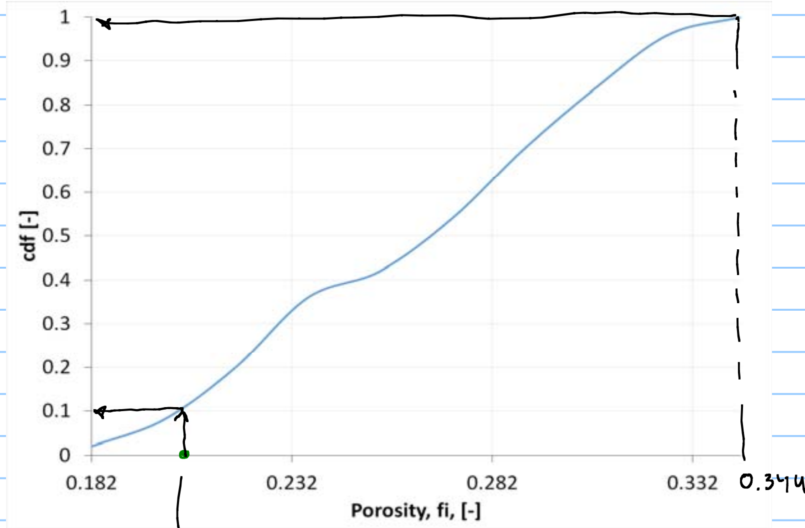
continuous probability distribution

Class exercise → generate discrete frequency distribution for measured porosity data



cumulative distribution function (cdf)

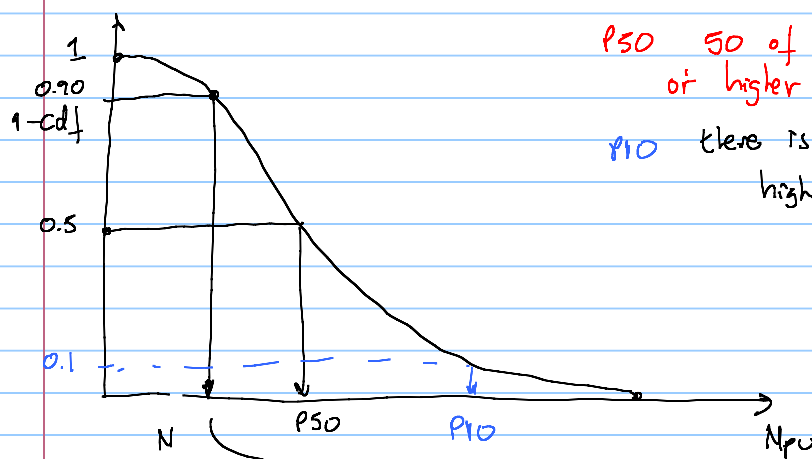




100% of the population has $\phi = 0.344$ or less

$\phi = 0.2 \rightsquigarrow cdf = 10\%$ there is 10% probability that the porosity of my population is equal to $\phi = 0.2$ or less

in reserves



P90

90% of the total population will have Npu of P90 or bigger

P50 50 of the population will have Npu of P50 or higher

P10 there is 10% chance that Npu will be P10 or higher

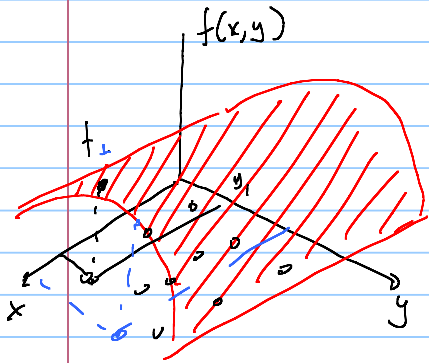
each company uses their own percentiles
90 → 80
50 → 66
10 → 15, 5

P10 P50 P90 P00 Hebron

Hebron Ben Nevis Oil	Upside Volumes		Best Estimate Volumes		Downside Volumes	
	MBO	Mm^3	MBO	Mm^3	MBO	Mm^3
D-94 Fault Block	1601	255	1328	211	1077	171
I-13 Fault Block	252	40	187	30	141	22
Total Hebron Ben Nevis	1870	297	1515	241	1204	191
Total Hebron Ben Nevis Gas	**Upside Volumes**		**Best Estimate Volumes**		**Downside Volumes**	
	GCF	* GSm^3	GCF	GSm^3	GCF	GSm^3
Solution Gas D-94 Block	112	3.2	145	4.1	189	5.4
Solution Gas I-13 Block	10	0.3	14	0.4	22	0.6
Non-associated Gas	n/a	n/a	n/a	n/a	n/a	n/a
Gas Cap D-94 Block only	0	0	0	0	31	0.9

* $GSm^3 = 10^9$ cubic meters

to compute the pdf and cdf of N_{pu}, we will use sampling method called Monte-Carlo



$f(x,y) = x^2 + y^2$ random sampling

$x_1, y_1 \rightsquigarrow f_1$

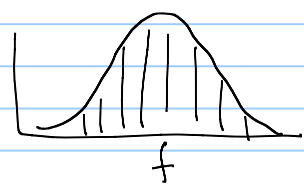
$x_2, y_2 \rightsquigarrow f_2$

⋮

repeat for many random samples

$$\underbrace{(f_1, f_2 \, \ldots\ldots \, f_N)}$$

apply a frequency analysis to the results



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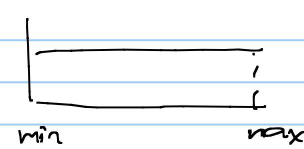
THE MONTE CARLO METHOD

NICHOLAS METROPOLIS AND S. ULAM
Los Alamos Laboratory

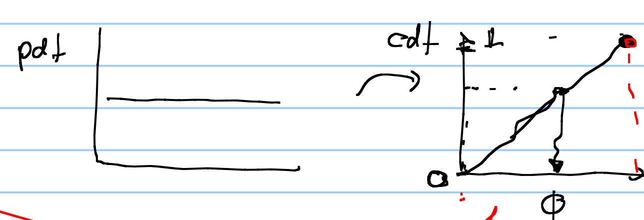
1) • Assign pdf for all input data

ϕ
V_R
B_o
S_o
N_{TG}
F_{RU}



2) • take a random sample for each variable in each range.

$$cdf = \frac{(X - X_{min})}{\underbrace{(X_{max} - X_{min})}_{1}}$$



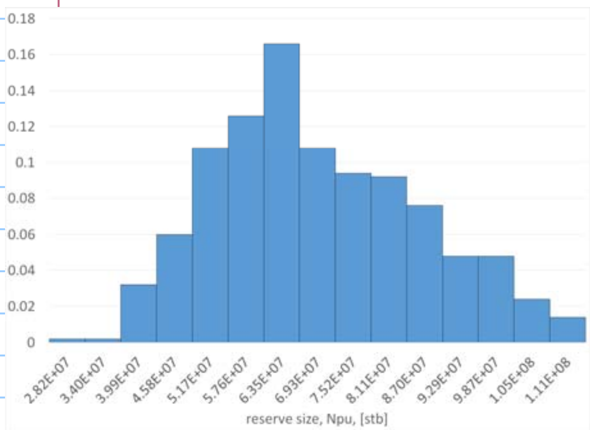
$$X = RAND(0\text{-}1)\,[X_{max} - X_{min}] + X_{min}$$

3) o compute Npu with all random input.

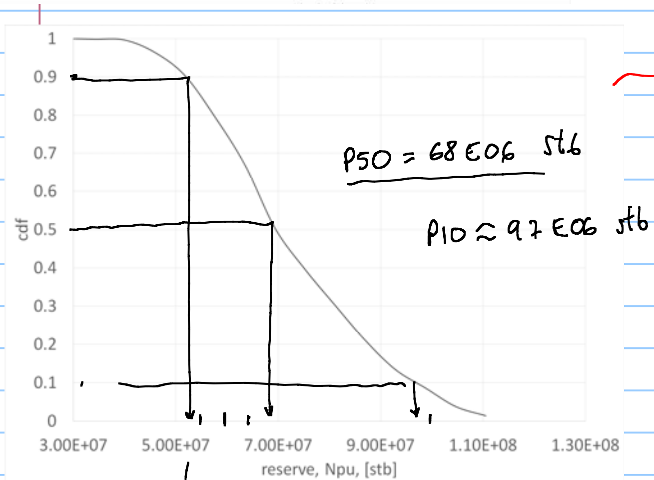
4) o Record Npu value

5) o repeat from step 2. "Many" times (500)

Class exercise



	Rock volume	Porosity	Net to Gros N/G	Oil Saturation So=(1-Sw)	Formation Volume F Bo	Ultimate Recovery Factor Fr	
	bbl	fraction	fraction	fraction	Res bbl/STB	fraction	
Min	2.00E+09	0.18	0.3	0.8	1.35	0.42	
Max	2.50E+09	0.3	0.5	0.9	1.6	0.65	
MC it	Rock volume	Porosity	N/G	So=(1-Sw)	Bo	Fr	Npu
[-]	bbl	fraction	fraction	fraction	Res bbl/STB	fraction	[stb]
1	2.16E+09	1.94E-01	4.97E-01	8.25E-01	1.39E+00	6.10E-01	7.51E+07
2	2.28E+09	2.51E-01	4.17E-01	8.06E-01	1.46E+00	5.76E-01	7.59E+07
3	2.44E+09	2.77E-01	4.31E-01	8.23E-01	1.52E+00	5.77E-01	9.12E+07

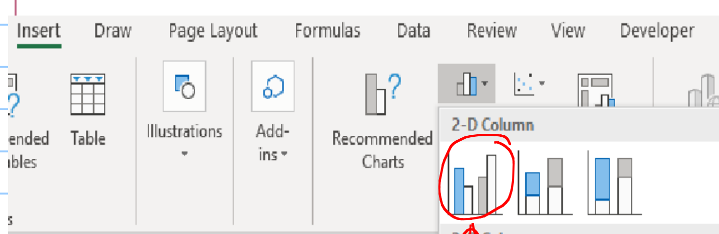


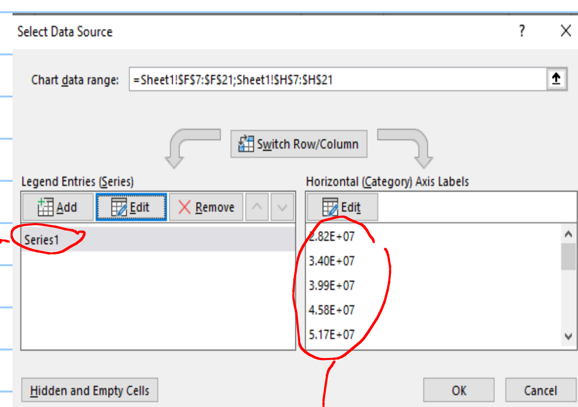
P90 ≃ 52.5 E6 Stb

cdf

nr	bin	count	pdf	cdf
1	2.82E+07	1	0.002	1
2	3.40E+07	1	0.002	0.998
3	3.99E+07	16	0.032	0.996
4	4.58E+07	30	0.06	0.964
5	5.17E+07	54	0.108	0.904
6	5.76E+07	63	0.126	0.796
7	6.35E+07	83	0.166	0.67
8	6.93E+07	54	0.108	0.504
9	7.52E+07	47	0.094	0.396
10	8.11E+07	46	0.092	0.302
11	8.70E+07	38	0.076	0.21
12	9.29E+07	24	0.048	0.134
13	9.87E+07	24	0.048	0.086
14	1.05E+08	12	0.024	0.038
15	1.11E+08	7	0.014	0.014

= +

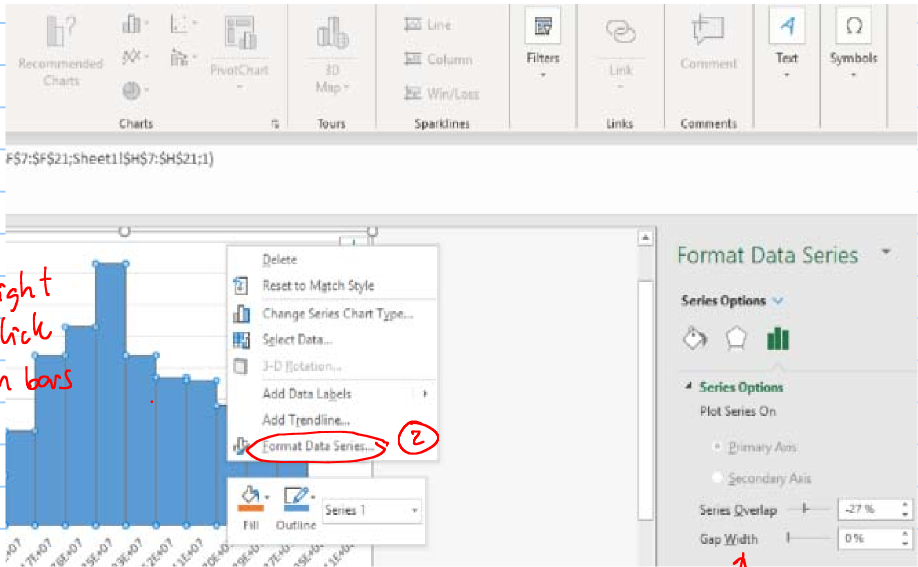




② Homework make plots of pdf / cdf Npu

pdf

select bins



① right click on bars

②

③ set to zero "0"

Tool useful → : An easier way / faster way to quantify the effect of uncertainty instead of using : monte Carlo

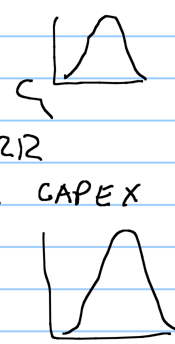
: to provide support when taking decision

Probability trees / decision trees

□ choice node / decision node

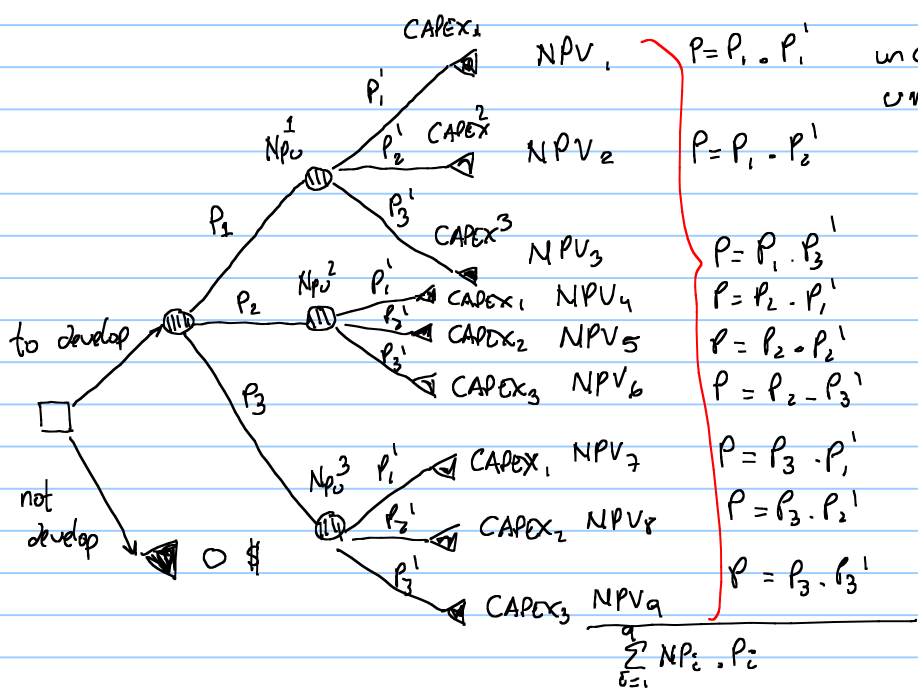
chance

end node



uncertainties TRR

uncertainties in CAPEX



to compare branches, one can use EMV

expected monetary value of branch

Class exercise

08_decision_Tree	xlsx
08_Decision_tree_exercise	docx

Your company is deciding whether to develop a reservoir or not in the Rovuma region. To help them take the decision, you have proposed to use a probability tree.
The value of the development can be estimated using the simplified equation:

$$NPV = TRR*60*0.4-CAPEX.$$

- What is the mean expected value of the development? Is it worth to look further into developing this field?

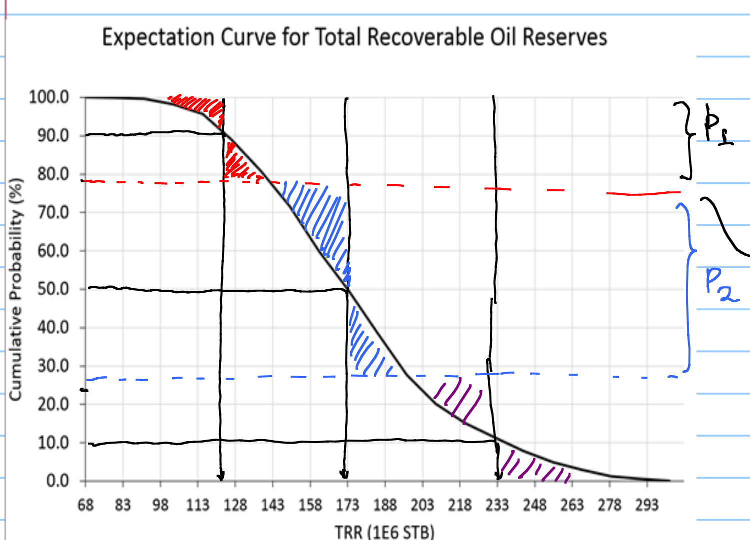
- The capex values exhibit a normal probability distribution. However, it has already been discretized by a colleague:
  - CAPEX1: 0.7 E9 USD, P1: 0.3
  - CAPEX2: 1.1 E9 USD, P2: 0.4
  - CAPEX3: 1.5E9, P3: 0.3.

how to discretize TRR

P90 = 122 E06 stb

P50 = 173 E06 stb

P10 = 233 E06 stb



move the line until two red areas are same

from chart $P_1 = 0.2$

$P_1 + P_2 + P_3 = 1$

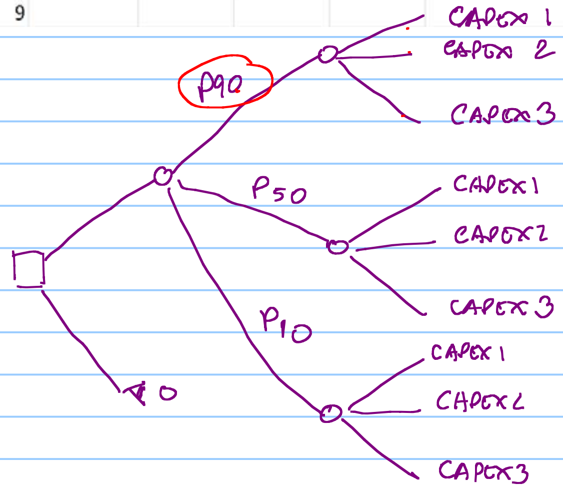
$P_2 = 0.55$

$P_3 = 1-0.2-0.55 = 0.25$

let's make the tree in excel

OPTION	TRR	P_TRR	CAPEX	P_capex	MV = TRR*60*0.4-CAPEX	P=P_capex*P_TRR	MV*P
[-]	[stb]	[-]	[USD]	[-]	[USD]	[-]	[USD]
1	P90	0.2	CAPEX1	0.3	NPV1	0.2 . 0.3	0.0
2	P90	0.2	CAPEX2	0.4	NPV2	0.2 . 0.4	
3	P90	0.2	CAPEX3	0.3	NV3	0.2 . 0.3	
4							
5							
6							
7							
8							
9							

$EMV = \sum(\quad)$



OPTION	TRR	P_TRR	CAPEX	P_capex	NPV = TRR*60*0.4-CAPEX	P=P_capex*P_TRR	MV*P
[-]	[stb]	[-]	[USD]	[-]	[USD]	[-]	[USD]
1	1.22E+08	0.2	7.00E+08	0.3	2.23E+09	0.06	1.34E+08
2	1.22E+08	0.2	1.10E+09	0.4	1.83E+09	0.08	1.46E+08
3	1.22E+08	0.2	1.50E+09	0.3	1.43E+09	0.06	8.57E+07
4	1.73E+08	0.55	7.00E+08	0.3	3.45E+09	0.165	5.70E+08
5	1.73E+08	0.55	1.10E+09	0.4	3.05E+09	0.22	6.71E+08
6	1.73E+08	0.55	1.50E+09	0.3	2.65E+09	0.165	4.38E+08
7	2.33E+08	0.25	7.00E+08	0.3	4.89E+09	0.075	3.67E+08
8	2.33E+08	0.25	1.10E+09	0.4	4.49E+09	0.1	4.49E+08
9	2.33E+08	0.25	1.50E+09	0.3	4.09E+09	0.075	3.07E+08
						EMV	3.17E+09

it is worth to develop the field !

③ Homework : do this exercise by yourselves