ESTIMATION OF ECONOMIC AND GEOLOGICAL UNCERTAINTIES OF ENHANCED OIL RECOVERY PROJECTS

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For accounting economic and geological uncertainties to efficiency of enhanced oil recovery (EOR) projects is offered to use Latin Hypercube simulation method and density distributions of input economic and geological factors. Results of imitating modeling is shown the total uncertainty of EOR project is not the sum of economic and geological uncertainties separately and for planning of EOR project efficiency to use a median of NPV iteration results.

Oil fields enhanced oil recovery (EOR) projects realizing in oil production unit (OPU) is risky activity. Primary sources of uncertainty of EOR projects are geological (effective thickness of the productive stratum, current stratum pressure, oil saturation, etc.), and as technology factors. Other sources of uncertainty for OPU are financial and economic. It is necessary to note, that though EOR costs according to the current tax laws of the Russian Federation carry on the cost price of made production, under the economic contents are the costs directed on restoration of serviceability of objects of development - are investment expenses. Hence, expenses for EOR project should be considered as the investment project and to do an estimation of economic efficiency of these costs according the formula of net present value (NPV_{ij}):

$$NPV_{ij} = \begin{cases} -K_{ij} + \sum_{t=1}^{T} \frac{[P_t - (VC_{jt} + SORT_t + TP)] \cdot \Delta Q_{ij} \cdot k_t}{(1+RD)^t}, & WC_1 \geq WC_0 \\ -K_{ij} + \sum_{t=1}^{T} \frac{[(P_t - (VC_{jt} + SORT_t + TP)] \cdot \Delta Q_{ij} \cdot k_t + \Delta Q_{wij}^t \cdot C_{wt} \cdot k_t}{(1+RD)^t}, & WC_1 < WC_0 \end{cases}, \quad (1)$$

where K_{ij} – enhanced oil recovery project costs, thous. roubles.

P – transfer oil price in month number t, roub./ton;

VC_{jt} – oil production variable costs in oil fields in month number t, roub./ton;

$SORT_t$ – sub oil recourses tax in month number t, roub./ton;

TP – rate of tax profit, share of a unit;

C_{wt} – fluid (water) production variable costs in month number t, roub./1000 m^3;

ΔQ_t, ΔQ_{wt} – accordingly enhanced oil recovery production and restriction of water production in oil fields in month number t;

k_t – factor which is taking into account non-uniformity of a gain of an oil recovery and restriction of water-inflow, share of a unit;

RD – monthly rate of discount, share of a unit;

T – normative duration of technological EOR effect, months;

i – EOR project number; j – oil fields number; t – month number, $t = \overline{1,T}$.

WC_0, WC_1 – watercut of oil before and after EOR project, %;

It is follows from the formula (1), that to the economic forces, influencing on realizations of the project efficiency of EOR project is concerned the transfer oil price l for OPU, oil and fluid production variable costs in oil fields, SORT. Hence, changes of these parameters during realization of the EOR project can affect its efficiency essentially. If to take into account, that the SORT under the formula (2) also P_U and RE influence on efficiency of the EOR project:

$$SORT_t = 419 \cdot (P_{Ut} - 9) \cdot \frac{RE_t}{261}, \tag{2}$$

where P_{Ut} - monthly mean of oil price “Urals”, USD/barr.

RE_t - monthly mean of rate exchange USD to roubles, roubles /USD.

Parameters of geological uncertainty, apparently, are EOR oil production and restriction of water production (if watercut of production is reduced).

For economic and geological uncertainties parameters accounting is offered to use a kind of imitating modeling, namely a method of a Latin hypercube which help to make statistical processing the authentic data and receive the same results after smaller quantity of recurrences and consequently is faster with. It is technique of sample of the data on layers. It effectively uses generating random numbers of the Monte Carlo program for a choice of the data on concrete layers from total curves of distribution of frequencies. It expands a spectrum of casual values of variables at rather small efforts considerably. However it is necessary to establish density distribution of entrance parameters of the formula (1) and (2) for applications offered method.

It is offered as possible laws distribution of model inputs parameters to use 17 continuous laws distribution: ***β***-distribution, χ^2-distribution, Erlang distribution, Exponential distribution, Extreme Value distribution, gamma-distribution, uniform, logistic distribution, log-logistic distribution, log-normal distribution, normal, Pareto distribution, Pearson distribution, Rayleigh distribution, Student's "t" distribution, triangular distribution, Weibull distribution. And as 4 kinds of discrete distributions: binomial, geometrical, binomial, Poisson and Bernoulli. It is used by criteria of a choice of density distribution ***is*** χ^2-statistics, Kolmogorov's statistics and Ω^2 Mises (Anderson-Darling statistics).

It was established on empirical data of monthly means of oil prices "Urals" and means of rate exchange USD to rouble for a period 01.2002-10.2006 the density distribution of the first parameter has Weibull distribution and the second – Pearson distribution (see table 1). The density distribution of EOR project costs is established with empirical data of EOR costs for 2000-2005 for each oil field development object and each kind of EOR method. Apparently from table 1, density distribution of EOR project costs is gamma-distribution limited minimal and maximal values of the costs. Density distributions of oil production VC and transfer oil price are normal, but truncate minimal and maximal limits. Density distributions of EOR oil production established with one of the West-Siberian oil fields (only positive technological effect) in 30 wells-operations of acid processing "Helium" for 2000-2005 is logarithmic normal, truncated at the left economically limiting EOR oil production, certain at the determined initial economic data, and on the right - the maximal EOR oil production for the considered period. It is necessary to note, that before an establishment of density distribution of EOR oil production is recommend to carry out operation of identification (grouping), i.e. allocation concerning homogeneous groups of development objects. At the decision of this a task the principal component analysis was used. The principal components are new variables being linear combinations of initial measured parameters which concern porosity, permeability, oil factor, oil rate before EOR project of development objects, etc. to After grouping objects inside each group it is offered to censore EOR oil production, i.e. procedure of detection of outliers. The next evaluation step of economic and geological uncertainties is carrying out of 500 iterations of model of efficiency of EOR project.

It is necessary to note to provide reliability and adequacy of the results received during imitating modeling, it is necessary to observe a condition when between inputs parameters of model was not linear correlation. In figure 1 it is possible to see a matrix of linear regression graphs of inputs model parameters from each other, and as histograms of each parameter. The parameter of Pearson linear correlation between inputs model parameters makes from -0,05 up to 0,07, that testifies to absence of linear dependence among them.

Table 1

Laws and density distributions of inputs parameters for ***NPV*** of EOR project

Parameters	Laws distribution	Density distributions
1. EOR project cost	Truncated gamma-distribution	$f(x) = \frac{1}{46,1 \cdot \Gamma(25,97)} \cdot \left(\frac{x}{46,1}\right)^{24,97}$ $min\|K_{ij}\| < x \le min\|K_{ij}\|$ (3)
2. Monthly mean of oil price “Urals”	Truncated Weibull distribution	$f(\xi) = 0,017576 \cdot \xi^{0,42} \cdot e^{\frac{\xi}{22,04}}$ $15 < \xi \le 70$ (4)
3. Monthly mean of rate exchange USD to rouble	Truncated Pearson distribution	$f(\omega) = \frac{1}{175,02 \cdot \Gamma(26,42)} \cdot \frac{e^{-175,02/\omega}}{\left(\omega/175,02\right)^{27,42}}$ (5) $26 < \omega \le 35$
3. VC oil production	Truncated normal distribution	$f(\psi) = \frac{1}{200 \cdot \sqrt{2\pi}} \cdot e^{-\frac{1}{2}\left(\frac{\psi - 904}{200}\right)^2}$ (6) $700 < \psi \le 1500$
4. Transfer oil price	Truncated normal distribution	$f(\theta) = \frac{1}{400 \cdot \sqrt{2\pi}} \cdot e^{-\frac{1}{2}\left(\frac{\theta - 5000}{400}\right)^2}$ $3500 < \theta \le 7500$ (7)
5. EOR oil production	Truncated log-normal distribution	$f(y) = \frac{1}{y \cdot \sqrt{2\pi \cdot 1,92}} \cdot e^{-\frac{1}{2}\left(\frac{lny - 9,28}{9,27}\right)^2}$ $\Delta Q_{ij}^{BEP} < \theta \le max\|\Delta Q_{ij}\|$ (8

$\Gamma(...)$ – gamma-function.

ΔQ_{ij}^{BEP} – break-even point of EOR oil production.

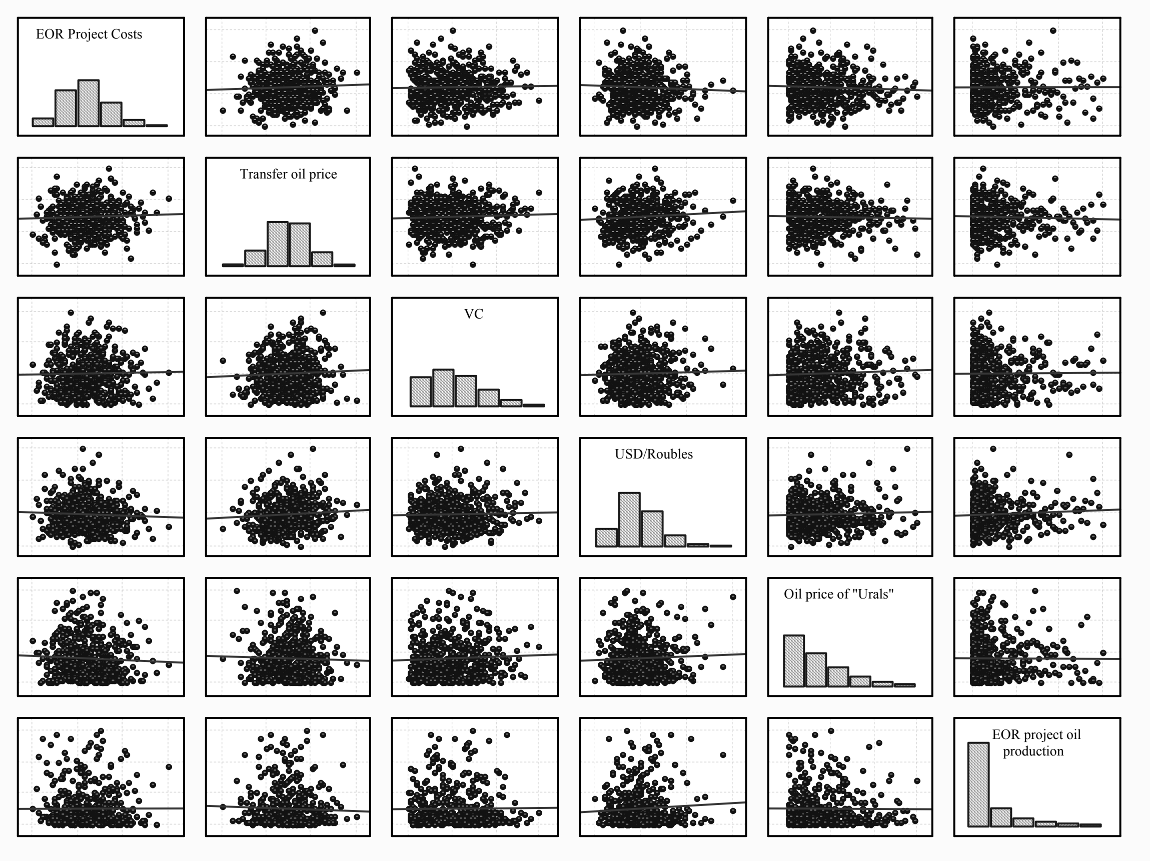

Figure 1. Matrix of linear regression graphs of inputs model parameters from each other

Let's note, that for definition a break-even point of EOR oil production (ΔQ_{ij}^{BEP}), it is necessary to find at the determined values of inputs economic parameters under the formula:

$$\Delta Q_{ij}^{BEP} = \sum_{t=1}^{T} \frac{(1+RD)^t \cdot K_{ij}}{(P-(VC_{j0}+SORT_0+TP))}, \qquad (9)$$

where $SORT_0$, VC_{j0} - accordingly the sub oil recourses tax and VC oil production, roubles / ton.

Results of imitating modeling of the EOR project with the account only economic uncertainty, only geological uncertainty and economic and geological uncertainties are calculate in table 2.

Table 2

Results of imitating modeling of the enhanced oil recovery project

Parameters	Economic uncertainty	Geological uncertainty	Economic and geological uncertainties
1. Minimum of ***NPV***, thous. roubles	-950,77	-224,87	-1 473,49
2. Maximum of ***NPV***, thous. roubles	2 826,52	15 472,96	20 634,51
3. Mean of ***NPV***, thous. roubles	1 322,28	2 310,25	1 835,05
4. Standard deviation ***NPV***, тыс.руб.	621,42	3 217,42	2 882,32
5. Median of ***NPV***, тыс.руб.	1 374,85	990,43	729,60
6. Mode of ***NPV***, тыс.руб.	1 555,50	-207,79	-90,77
7. Variation of ***NPV***, %	47,00	139,27	157,07
8. Skewness of ***NPV***, доли ед.	-0,43	1,96	2,42
9. Kurtosis of ***NPV***, доли ед.	3,17	6,58	10,59
10. P(***NPV***<0), %	2,82	15,84	23,49
11. P(0< ***NPV*** ≤1000),%	26,42	34,44	33,43
12. P(1000< ***NPV*** ≤2000), %	57,22	15,28	13,82
13. P(2000< ***NPV*** ≤3000), %	10,00	8,81	8,29
14. P(3000< ***NPV*** ≤4000) ,%	3,54	5,69	5,67
15. P(***NPV*** >4000), %	0,00	19,94	15,30
16. Mean of EOR project oil production, tons	1742,44	1481,48	1481,48
17. Median of EOR project oil production, tons	-	767,58	787,39
18. P(250<***ΔQ***≤1000), %	-	56,17	56,15
19.P(1000< ***ΔQ*** ≤2000), %	-	20,8	20,91
20.P(***ΔQ*** >2000), %	-	22,94	22,94

Apparently from table 2, the account simultaneously economic and geological uncertainties raises risk of the project considerably (the factor of a variation makes more than 157 %). Besides the probability of negative ***NPV*** makes 23,49 %, whereas at economic uncertainty initial 2,82 % given only, and at geological uncertainty - 15,84 %. We shall note as, that probability reception ***NPV***> 4000 thous.roubl. at economic uncertainty - 0,00 %, at geological - 19,94 %, and at the account of both kinds uncertainties - 15,30 %. In figure 2 the histogram of generated values ***NPV*** of the EOR project is submitted at the account economic and geological uncertainties.

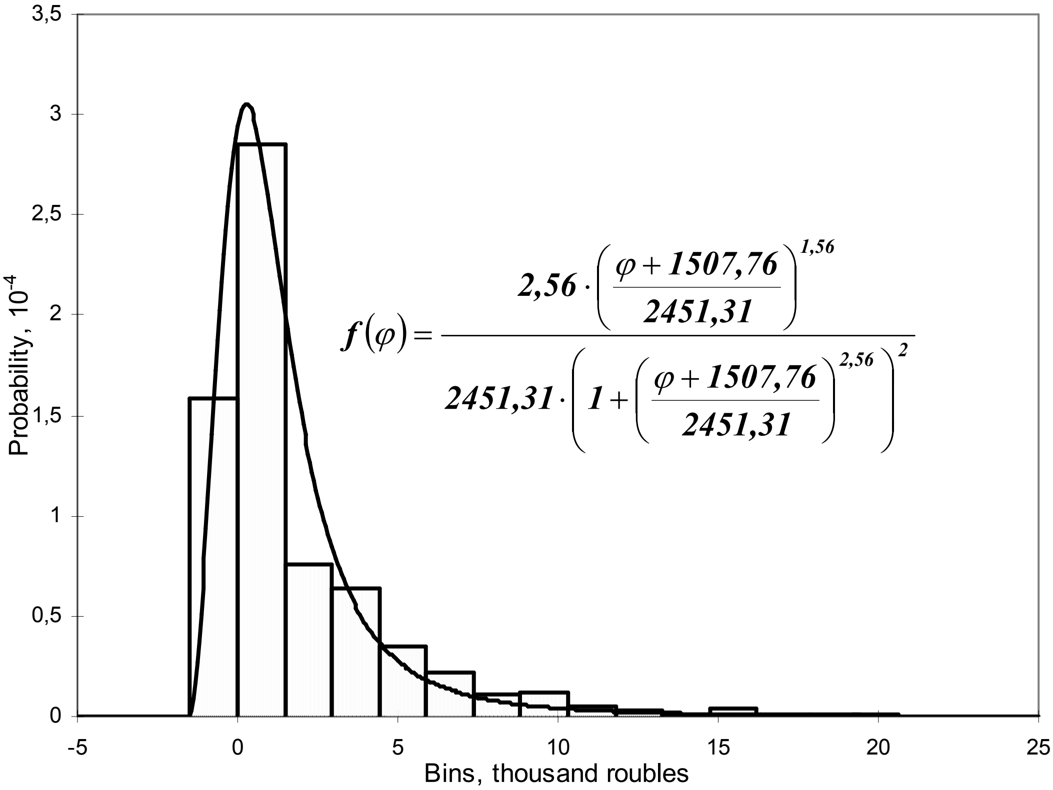

Figure 2. Histogram of generated NPV of the EOR project

Apparently from figure 2, ***NPV*** the EOR project has log-logistical density distribution and, hence, erroneous will use in quality of the most probable value ***NPV*** of the project its mean. The most exactly predicted ***NPV*** is a median of the established distribution which makes 943,55 thous. roubl. And the most probable value of a EOR oil production will be not mean of 1481,48 tons, but a median - 787,39 tons. We also can note, that at the determined initial data and at mean EOR oil production of 1742,44 tons makes value ***NPV*** 5617,58 thous.roubl., that almost on 500 % exceeds the most probable.

In figure 3 integrated functions of distributions ***NPV*** of the EOR project are submitted at the account of separate kinds of uncertainties. Dynamics of change of these curves characterizes dynamics of change of probability of this or that outcome of the EOR project.

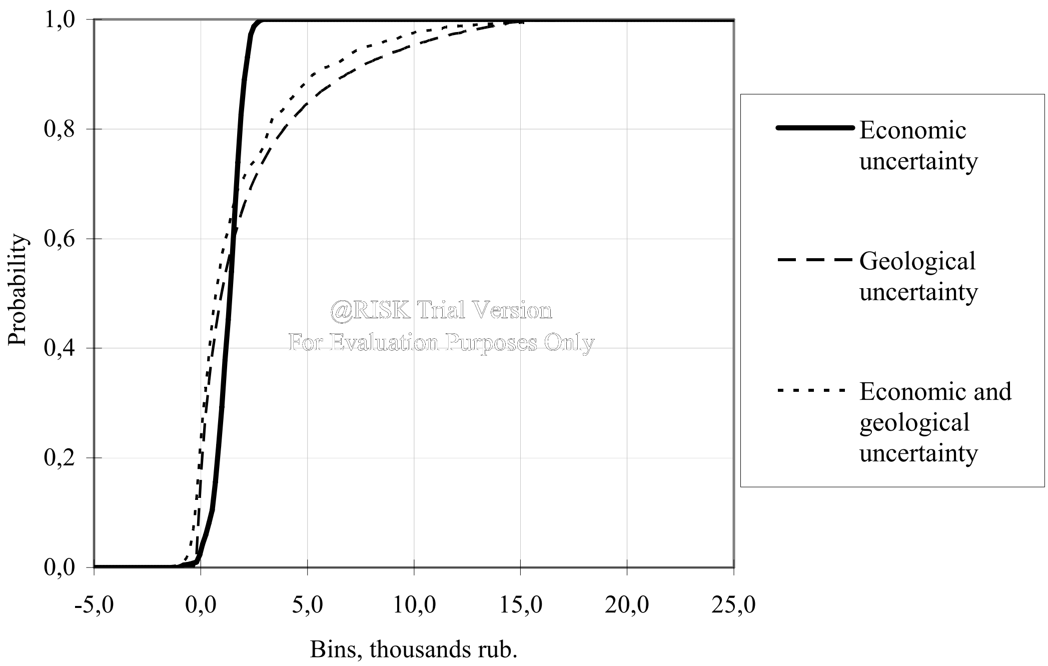

Figure 3. Cumulative distribution function of NPV EOR project

It is possible to make the conclusion of this figure, that total uncertainty of economic and geological parameters is not the sum of separate kinds of risks.

Important point of use of the offered approach at uncertainties estimation of EOR projects is an opportunity of carrying out of the analysis of sensitivity of the project on inputs parameters of model. In figure 4 the graph such as "tornado" which it is visible is submitted, that the greatest influence on efficiency of realization of the EOR project render on a degree of decrease: EOR oil production, oil price "Urals", transfer oil price, VC oil production, EOR project cost, a rate exchange USD to rouble.

Thus, the offered model can become the effective decision-making tool on expediency of carrying out and a choice of the EOR project.

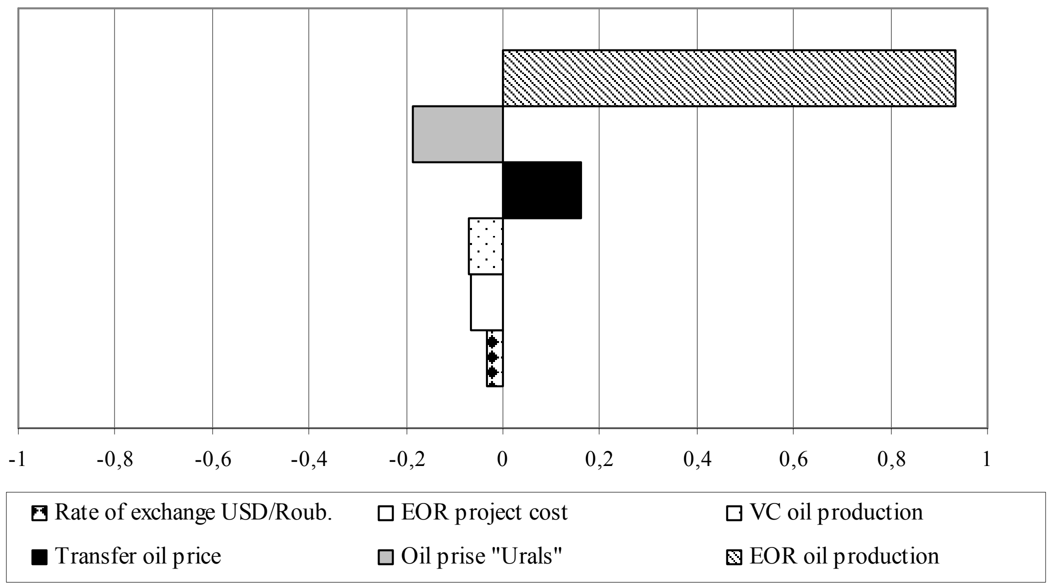

Figure 4. The sensitivity-analysis of the EOR project

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