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## **ECONOMIC AND MATHEMATICAL MODEL OF THE DISTRIBUTION OF THE BORROWED MONEY AS DEBT MANAGEMENT TOOL**

**Abstract.** Investment activity plays a key role in ensuring the sustainable economic growth of the country, the implementation of the structural modernization of the economy and increase of its competitiveness. As a source of debt investment recourses can serve external borrowing, internal borrowing, public funds, and foreign direct investment. The instability of the economic situation in the country determines the probabilistic nature of the inflow of these resources. In turn, the lack of financing investment projects leads to losses, as far as they can not be realized in a timely manner. To reduce the risk of the volume losses, it is advisable to have some reserve funds. Whereas the optimal allocation of the available financial resources and the creation of a reserve allows you to achieve the best result. Therefore, the model means of distribution for optimal control of the national debt is created. The empirical example of effective and proportional distribution between the branches of borrowed funds for updating the production capacities, as well as the increase in trust in our economy from investors are given.

**Keywords:** the national debt, the investment, the probability value, the model, the investment distribution.

**JEL Classification:** C50, H63

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## **ЕКОНОМІКО–МАТЕМАТИЧНА МОДЕЛЬ РОЗПОДІЛУ ЗАПОЗИЧЕНИХ КОШТІВ ЯК ІНСТРУМЕНТ УПРАВЛІННЯ ДЕРЖАВНИМ БОРГОМ**

**Анотація.** Ключову роль у забезпеченні стійкого економічного зростання країни, здійсненні структурної модернізації економіки та підвищенні її конкурентоспроможності відіграє інвестиційна діяльність. Джерелом боргових інвестиційних ресурсів можуть служити зовнішні запозичення, внутрішні запозичення, державні кошти, а також прямі іноземні інвестиції. Створено модель розподілу коштів для оптимального управління державним боргом. Наведено емпіричний приклад ефективного й рівномірного розподілу між галузями запозичених коштів для оновлення виробничих потужностей, підвищення довіри в інвесторів до власної економіки.

**Ключові слова:** державний борг, інвестиції, ймовірність, модель, розподіл інвестицій.

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## **ЭКОНОМИКО–МАТЕМАТИЧЕСКАЯ МОДЕЛЬ РАСПРЕДЕЛЕНИЕ ЗАЕМНЫХ СРЕДСТВ КАК ИНСТРУМЕНТ УПРАВЛЕНИЯ ГОСУДАРСТВЕННЫМ ДОЛГОМ**

**Аннотация.** Ключевую роль в обеспечении устойчивого экономического роста страны, осуществлении структурной модернизации экономики и повышении ее конкурентоспособности играет инвестиционная деятельность. Источником долговых инвестиционных ресурсов могут служить внешние, внутренние заимствования, государственные средства, а так же прямые иностранные инвестиции. Создана модель распределения средств для оптимального управления государственным долгом. Приведен эмпирический пример эффективного и равномерного распределения между отраслями заемных средств для обновления производственных мощностей, повышение доверия у инвесторов к собственной экономике.

**Ключевые слова:** государственный долг, инвестиции, вероятность, модель, распределение инвестиций.

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**Introduction.** The financial and economic crisis, military operations and the high level of corruption–shadow part of the national economy led to a decline in the investment activity of Ukraine. The government should do the first effective investment steps under the terms of the acute shortage of investment resources in the real, scientific social and economic sectors of the national economy and the limited capacity of state investment along with the simultaneous presence of a high degree of risk. Showing an example of effective and equitable investments between the sectors of the budget and the debt, the government will get credit from foreign and domestic investors to its economy and it will gradually develop the joint public–private investment and the innovation spiral. Together with the creation of the investment processes management the effective system of the state should encourage investment activity of the population, motivating people to convert their savings not only into deposits but also into stock of private and public business sectors.

The creation of the creation of the regulating mechanism of the effective investment processes needs to improve a number of existing instruments of state investment policy and to introduce the new tools. A rational and optimal allocation of investment resources is a prerequisite for successful overcoming of the above mentioned trends.

**The analysis of the recent researches.** The scholars such as T. Bondaruk [1], T. Vakhnenko [2], V. Vitlinskyi [3], V. Danylov [4], O. Zaruba [5], S. Boiko [6] etc. made an important contribution to the solving of the problems of the mathematical methods and the models application in the management of the complex socio–economic systems, including the debt management. There is a wide range of literature dealing with the influence of the public debt on the national economies. Among the main channels through which high debt adversely affects the economy are: capital accumulation and growth constraining via higher long–term interest rates [7, 8]; future distortionary taxation [9, 10], inflation [11, 12].

**The aim of the research** is to create a stochastic optimization model of the distribution of investment resources that allowed to develop debt investment program in which the implementation of the projects takes place using four kinds of resource – work (number of employees), the physical and natural capital (the factors of land and capital), human capital (the mental and physical abilities and professional skills of employees) and innovation.

**Results.** Stochastic programming models use the knowledge of distributions of data probabilities or their estimations for the purpose of finding such a solution which will be acceptable to the majority of possible data values and maximization of the mathematic expectation of a function. As practice shows that such models create and implement analytically or numerically and their results analyze. Then, on their basis the appropriate decisions are taken.

Stochastic programming and, in particular, stochastic enhancement allow to make operational analysis, on the basis of which you can take a difficult administrative decision. It is important to choose not only the type of objective function, but the limit for this kind of tasks because in stochastic models they can be defined in different ways, and thus the gained optimal plans will have the appropriate level of their implementation probability [6].

In case of M–statement the random variable is replaced with its mathematical expectation, and thus the task comes down to optimization of the determined objective function of a type:

$$E = \sum_{j=1}^n \bar{c}_j x_j \rightarrow extr \quad (1)$$

where  $\bar{c}_j$  is a mathematic expectation of the random variable  $c_j$ .

Let's consider the task of distribution of n types of resources for the implementation of m types of projects in case of the unknown distribution law of a random variable. The problem model is as follows:

$$\begin{aligned} E &= \sum_{j=1}^n c_j x_j \rightarrow extr \\ \sum_{j=1}^n a_{ij} x_j &\leq b_i \\ d_j &\leq x_j \leq D_j, j = \overline{1, n} \end{aligned} \quad (2)$$

The random variables in the task are  $a_{ij}, b_i, c_i$ . Thus in case of M–statement the problem model will be the following:

$$\begin{aligned} E &= \sum_{j=1}^n \bar{c}_j x_j \rightarrow extr \\ P \left[ \sum_{j=1}^n \bar{a}_{ij} x_j \leq b_i \right] &\geq \alpha_i, i = \overline{1, m}; \\ d_j &\leq x_j \leq D_j, j = \overline{1, n}, \end{aligned} \quad (3)$$

where  $\alpha_i$  is the set probabilities of the corresponding restriction accomplishment.

To solve the task in M–statement it is necessary to switch to its determined equivalent:

$$\begin{aligned} E &= \sum_{j=1}^n \bar{c}_j \cdot \bar{x}_j \\ \left\{ \sum_{j=1}^n \bar{a}_{ij} \cdot x_j \leq \bar{b}_i - t_{\alpha_i} \sqrt{\sum_{j=1}^n \sigma_{ij}^2 \cdot x_j^2} + \delta^2 \right. \\ & \left. d_j \leq x_j \leq D_j, \right. \end{aligned} \quad (4)$$

where  $t_{\alpha_i}$  is a parameter determined from the tables. Its reciprocal coefficient depends on the variable  $\alpha_i$ .

Now we will consider the task of distribution of  $n$  types of resources for the implementation of  $m$  types of projects according to the known distribution law of a random variable – an appropriate resource.

Let us assume that the random variable of  $y$  is subordinated to the indicative distribution law:

$$F(t) = 1 - e^{-\lambda t}, \quad (5)$$

where  $\lambda$  is some unknown parameter.

According to the probability calculus it is known if the continuous random variable  $y$  is subordinated to some distribution law with distribution function, then the probability of occurrence of the random variable in the interval will be:

$$N(b \leq y \leq c) = F(c) - F(b) \quad (6)$$

From a formula (6) for the exponential distribution law we have:

$$N(b \leq y \leq t) = F(t) - F(b) \quad (7)$$

The task with chance constraints must have four options of statement:

$$N(y \leq 0) \geq \alpha, \quad (1)$$

$$N(y \leq 0) \leq \alpha, \quad (2) \quad (8)$$

$$N(y \geq 0) \geq \alpha, \quad (3)$$

$$N(y \geq 0) \leq \alpha, \quad (4),$$

where  $\alpha (0 \leq \alpha \leq 1)$  is some constrained parameter.

To determine the parameters of the exponential distribution law in case of which for some set  $\alpha$ , the statement (1) is carried out. Let's perform the following transformations. Basing on (5–6) we will write down:

$$\begin{aligned} N[y \geq 1] &\geq \alpha, \\ N[y \geq 1] &= N[1 \leq x \leq \infty] = F(\infty) - F(1) \\ F(\infty) &= 1, \quad F(1) = 1 - e^{-\lambda}. \end{aligned} \quad (9)$$

The mathematical expectation of the random variable distributed according to the indicative law will be:

$$-\bar{y} = -\frac{1}{\lambda} \quad (10)$$

Thus:

$$F(1) = 1 - e^{-\frac{1}{\bar{y}}} \quad (11)$$

Therefore the restriction takes a form:

$$N[y \geq 1] = e^{-\frac{1}{\bar{y}}} \quad (12)$$

Using the formula (9) and (12), we will write down:

$$e^{-\frac{1}{\bar{y}}} \geq \alpha \quad (13)$$

Having found a logarithm of expression (12), we determine inequality for establishment of population mean of the random variable distributed under the exponential law:

$$\bar{y} \leq \frac{1}{\ln \frac{1}{\alpha}} \quad (14)$$

The constraint (9) is satisfied for some mathematic expectation  $\bar{y}$  determined from the formula (14).

To solve the designated task we will consider the stochastic formulation of the objective function and restrictions. In case of linear programming task the formula of the objective function of E is as follows:

$$E = \sum_{j=1}^n c_j x_j \rightarrow \max(\min) \quad (15)$$

If  $c_j$  – random variables, then they accept maximization (or minimization) of the mathematical expectation of the objective function:

$$E = \sum_{j=1}^n \bar{c}_j x_j \rightarrow \max(\min), \quad (16)$$

where  $\bar{c}_j$  is a mathematic expectation of random variable  $c_j$ .

In the task of stochastic programming the following options of restrictions are possible:

$$N \left[ \sum_{j=1}^n a_{ij} x_j + 1 \leq b_i \right] \geq \alpha_i \quad (17)$$

$$N \left[ \sum_{j=1}^n a_{ij} x_j + 1 \leq b_i \right] \leq \alpha_i \quad (18)$$

$$N \left[ \sum_{j=1}^n a_{ij} x_j + 1 \geq b_i \right] \geq \alpha_i \quad (19)$$

$$N \left[ \sum_{j=1}^n a_{ij} x_j + 1 \geq b_i \right] \leq \alpha_i, \quad (20)$$

where  $\alpha_i$  is the set probability levels.

Let's designate through:

$$y_i = b_i - \sum_{j=1}^n a_{ij} x_j + 1, \quad (21)$$

Where  $y_i, a_{ij}, b_j$  are random variables which submit to the exponential distribution law.

Having added the expression (21) in the formula (17) – (20), we will receive the following options:

$$N [y_i \geq 1] \geq \alpha_i \quad (22)$$

$$N [y_i \geq 1] \leq \alpha_i \quad (23)$$

$$N [y_i \leq 1] \geq \alpha_i \quad (24)$$

$$N [y_i \leq 1] \leq \alpha_i \quad (25)$$

It is known from the probability calculus that the random variable (21) in case of independent  $a_{ij}, b_j$  will have the following mathematical expectation:

$$\bar{y}_i = \bar{b}_i - \sum_{j=1}^n \bar{a}_{ij} x_j + 1 \quad (26)$$

In the case (20), based on (22) we have:

$$\bar{y}_i \leq \frac{1}{\ln \frac{1}{\alpha_i}} \quad (27)$$

Having added (26) in the formula (27) we will have:

$$\bar{b}_i - \sum_{j=1}^n \bar{a}_{ij} x_j + 1 \leq \frac{1}{\ln \frac{1}{\alpha_i}} \quad (28)$$

After the transformations the formula (28) is the following:

$$\sum_{j=1}^n \bar{a}_{ij} x_j + \frac{1}{\ln \frac{1}{\alpha_i}} - 1 \geq \bar{b}_i \quad (29)$$

The permissible values  $x_j$  are designated by the determined parameters  $d_j$  i  $D_j$ :

$$d_j \leq x_j \leq D_j, j = \overline{1, n} \quad (30)$$

We will enter an additional variable of a residual resource  $\delta_i$  into the in equation (29) and we will write down the next restriction:

$$\sum_{j=1}^n \bar{a}_{ij} x_j + \frac{1}{\ln \frac{1}{\alpha_i}} - 1 + \delta_i \geq \bar{b}_i, \quad (31)$$

where  $\sum_{j=1}^n \bar{a}_{ij} x_j - 1$  is the consumed quantity of a resource calculated on the mathematical

expectation of expense rates;  $1/\ln \frac{1}{\alpha_i}$  is the additional quantity of the resource, caused by the

probabilistic nature of expense rates of the  $i$  resource;  $\delta_i$  is a residual resource.

The model of the investing program is based on an author's production function taking into account the debt investments, worked out in [13]. The resources which are involved for the implementation of the investing program are labour (number of workers), the physical and natural equities (factors: soil and capital), human capital (mental and physical capacities and professional skills of workers) and innovations.

Let us enter four types of projects into the investing program of economic development. Average cost of each project implementation which is set by a vector  $\bar{C} = \{c_1, c_2, c_3, c_4\}$  is known. The projects are implemented with the use of four types of resources. The distribution law of each type of a resource is subjected to the exponential function of a random variable distribution. To determine the distribution law the statistical information on the amounts of appropriate resources for a certain period of time is collected. On the basis of this information the statistical parameters are calculated: the mathematical expectation and the average quadratic deviation. The set amount of the reserve comprises the percents  $\{\delta_1, \delta_2, \delta_3, \delta_4\}$  from the costs of the appropriate resource for the project implementation. The matrix of the average expense rates of the resource on each project of the program is set in the table 1.

Table 1

The matrix of the average expense rates

The type of the resource	The mathematic expectation of the average expense rates			
	Project № 1	Project № 2	Project № 3	Project № 4
The labour (the number of workers)	$a_{11}$	$a_{12}$	$a_{13}$	$a_{14}$
The physical and natural capitals	$a_{21}$	$a_{22}$	$a_{23}$	$a_{24}$
The human capital	$a_{31}$	$a_{32}$	$a_{33}$	$a_{34}$
The innovations	$a_{41}$	$a_{42}$	$a_{43}$	$a_{44}$

It is necessary to find such a number of implementations of each type of the project which will provide a minimal cost of the program under the preceding hypothesis of the restrictions for the resources imposed by the probability vector  $P = \{\alpha_1, \alpha_2, \alpha_3, \alpha_4\}$ .

Let us assume that  $x_1, x_2, x_3, x_4$  is the unknown number of the appropriate projects realization which will provide the minimal cost-in-process of the program delivery under the preceding hypothesis of the desired conditions.

Table 2

The amounts of the additional outlay for a resource caused by its probabilistic nature

The type of the resource	Resource № 1	Resource № 2	Resource № 3	Resource № 4
Additional amount of recourses considering the probabilistic character of allowance	$\frac{1}{\ln \frac{1}{\alpha_1}}$	$\frac{1}{\ln \frac{1}{\alpha_2}}$	$\frac{1}{\ln \frac{1}{\alpha_3}}$	$\frac{1}{\ln \frac{1}{\alpha_4}}$

The maximum allowable determined number of project implementations:

$$d_j \leq x_j \leq D_j, j = 1, 4.$$

The determined version of the economic-mathematical model:

$$E = \sum_{j=1}^4 \bar{c}_j x_j \rightarrow \min$$

$$(1 + 0,01\delta_1) \cdot \sum_{j=1}^4 \bar{a}_{1j} x_j \geq \bar{r}_1 + 1 - \frac{1}{\ln \frac{1}{\alpha_1}}; \quad (1 + 0,01\delta_2) \cdot \sum_{j=1}^4 \bar{a}_{2j} x_j \geq \bar{r}_2 + 1 - \frac{1}{\ln \frac{1}{\alpha_2}}$$

$$(1 + 0,01\delta_3) \cdot \sum_{j=1}^4 \bar{a}_{3j} x_j \geq \bar{r}_3 + 1 - \frac{1}{\ln \frac{1}{\alpha_3}}; \quad (1 + 0,01\delta_4) \cdot \sum_{j=1}^4 \bar{a}_{4j} x_j \geq \bar{r}_4 + 1 - \frac{1}{\ln \frac{1}{\alpha_4}}$$

$$d_1 \leq x_1 \leq D_1; d_2 \leq x_2 \leq D_2; d_3 \leq x_3 \leq D_3; d_4 \leq x_4 \leq D_4$$

The approbation of the task is performed on the following basic data:

✓ The vector of the resource of probabilistic nature  $P = \{0,78; 0,85; 0,78; 0,66\}$ ;

✓ The vector of the prime cost of the project realization  $\bar{C} = \{5,2; 5,5; 5,85; 4,75\}$ ;

✓ The mean vector (mathematic expectations) of each type of the resource –  $R = \{15; 20; 25; 30\}$ ;

- ✓ the allowance amount vector  $\delta = \{1,5; 1,2; 1,4; 1,1\}$ ;
- ✓ the restrictions for the number of project implementations:  
 $d_1 = 5; \quad D_1 = 8, \quad d_2 = 6; \quad D_1 = 10, \quad d_3 = 4; \quad D_3 = 7, \quad d_4 = 7; \quad D_4 = 10.$

Table 3

The matrix of the average expense rates of a resource on each project of the program

The type of the resource	The mathematic expectation of the average expense rate			
	Project № 1	Project № 2	Project № 3	Project № 4
Labour (the number of workers)	1,3	1,5	2	1,2
Physical and natural capitals	1,3	1,5	1,6	1,1
Human capital	1,5	1,2	1,25	1,35
Innovations	1,1	1,3	1	1,1

Thus, the received results completely confirm our conclusions and calculations performed in the previous works – there is a low pay and a high unemployment in Ukraine). For this reason it is necessary to create new workplaces and to provide favorable conditions for the development and high-quality expanded reproduction of the human capital as the dominating factor of the economic growth, for the purpose of increase of its efficiency and preventing emigration [14]. Actually, it will partially compensate rather smaller financing of the other factors.

**Conclusions.** So, we created the stochastic optimization model that allowed to develop debt investment program in which the implementation of the projects takes place using four kinds of resource – work (number of employees), the physical and natural capital (the factors of land and capital), human capital (the mental and physical abilities and professional skills of employees) and innovation. Based on this information the following parameters have been calculated: the expectation, the average quadratic deviation, matrix of average norms of resource costs for each project and the minimum amount of debt investments. Furthermore strengthenings of economy based on a highly skilled human capital with the minimum number of intellectual and youth emigration and the unemployed people will allow to direct large volumes of the state investments, including debt, to innovations, the ground and the capital. At the same time the effective policy of the state investment will create a good incentive and a favorable investment environment for private and international capital investments in the economy of Ukraine.

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