Innovations in engineering: analysis of the increase effect in net present value

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Abstract. The article discusses the construction of mathematical models for assessing economic conditions under which a positive effect of using loan capital in the implementation of innovative and investment projects in engineering is possible, leading to an increase in net present value (NPV). Based on the constructed models, the authors obtained economic and mathematical relations (linking the parameters of innovation and investment projects: investor profitability standard, loan capital rate, time it was entered into the financial and temporal scheme of the project, the time it began to pay off financial obligations and its duration), which determine the increase effect of NPV due to the corresponding structure of investment capital. In the form of functions of the project parameters, analytical expressions are obtained to determine the critical value of the loan rate, the time of its input, as well as the rate of return on the investor and at which the effect of an increase in the net present value of the project becomes possible. The mathematical relations and the economic conclusions drawn on their basis are backed by practical results, given in a graphic form.

1. Introduction

Engineering is a strategic industry, without which a stable, stable, dynamically developing economy is impossible. However, the solution of the task set by the President of Russia to create a “smart” economy is constrained by the fact that modern engineering remains largely in the position of the 4th technological structure, while advanced countries are already actively mastering level 6. Such a technological breakthrough can be realized with the help of appropriate innovative projects, the content of which fully complies with the strategic program [1] to ensure national economic security and strengthen the competitiveness of our country in foreign markets.

From the point of view of achieving the final result, innovative activity can be considered as a process of implementing an investment project [2, 3], the peculiarity of which is the presence of a R&D stage in the investment part of the project and an increased level of risk during its implementation. In Russia, domestic R&D expenditures do not exceed 1.1% of GDP, and among the BRICS countries, Russia is significantly inferior to China (2.1% of GDP) [4], at that time, as the share of R&D expenses in the total revenue of companies from the USA, Germany, Japan and Switzerland increased in 2017-2019 by 4.5% [5]. The data presented indicate that the financing of investment projects related to the development and implementation of innovative technologies needs to be increased. That is why in modern conditions, along with the importance of implementing innovative investment projects, the solution to the question of assessing the effectiveness of such projects becomes equally relevant.

In modern approaches, the effectiveness of innovations is assessed, first of all, by the indicator of net present value, however, the standard algorithm for its calculation does not take into account the structure of the investment capital of the project. In real innovative projects, very often, with a lack of
equity, loan capital is attracted, which, on the one hand, makes it possible to realize the investment part of the project, but, on the other hand, reduces its profitable payments by paying off financial obligations. That is why the assessment of the impact, first of all, of loan capital, taking into account its cost and the time it takes to enter the financial and temporal scheme of the project, becomes especially relevant when solving the issue of assessing the effectiveness of innovations.

2. Problem statement

It is necessary to assess the impact that the use of loan capital (LC), as well as equity capital (EC), makes on the indicator of the net present value (NPV) of the innovation investment project (IIP). Obviously, a quantitative assessment of such an impact will be determined by the financial-time pattern of the implementation of IIP. From the point of view of the structure of investment capital, it is considered economically feasible to use the phased financing method [2, 3], the essence of which is that the necessary finances are allocated only at the beginning of the next stage of the project so that by the beginning of the next one decide on whether to continue the project or close it. This allows reducing the risk level of a potential investor in the implementation of IIP to a certain extent.

The financial-time diagram of the fundamental features of the implementation of IIP using the method of phased financing is shown in Figure 1. The specifics of the implementation of specific capital-intensive projects will differ from the above diagram in detail: the amount of capital, the duration of individual stages, but the general structure of capital and the dynamics of its use will correspond to the diagram in Figure 1.

![Financial-time diagram for the implementation of IIP](image)

At the beginning of the 1st stage of R&D \((t = 0)\), financing \(x_1^{(1)}\) \((t_1 = 0, 1, \ldots, t_1)\) is carried out at the expense of the investor’s equity \(EC_0\); at the beginning of the 2nd stage \((t = t_1)\) expenses for marketing research \(x_1^{(2)}\) \((t_2 = t_1 + 1, \ldots, t_2)\) due to \(EC_1\). If at the 3rd stage \((t_3 = t_2 + 1, \ldots, t_3)\) - production of an innovative product - own funds are not enough, loan capital \(LC_2\) is introduced at the moment \(t = t_3\) for example, in the form of a loan at a rate of \(r\%\) per annum.

At the moment \(t = t_3\), the investment part of the project ends and with some lag \(t_{lag}\), which corresponds to the main features of the IIP, its revenue part begins. From income from the sale of an innovative product \(y_1\) \((t = t_3 + t_u, \ldots, t_u)\), payments are made \(u_1\) \((t = t_4, \ldots, t_7)\) to owners, as well as repayment of a loan \(z_1\) \((t = t_4, \ldots, t_9)\).

To solve the problem of determining the influence of LC and EC on the NPV indicator, it is necessary to perform the following economic and mathematical calculations:

1) the definition of the analytical expression of the NPV indicator as a function of LC, EC, the rate of return on the investor, the cost of credit and time parameters of the project;
the definition of analytical expressions of economic conditions for the rate of return and loan rate, in which the effect of the increase in NPV will be positive.

3. Theoretical analysis
In accordance with the rules of financial mathematics, based on a systematic approach to the analysis of investment processes [6], the net present value of an innovative project, the financial-time diagram of which is presented in Figure 1 will be determined by the expression:

\[ NPV = \left( P_0 y_i + P_0 EC_1 + P_0 LC_2 \right) \left( P_0 y_i + P_0 x_i + P_0 z_i + P_0 u_i \right) \],

where \( P_0(y_i) = \sum_{i=1}^{n} \frac{y_i}{(1+i_0)^t} \) and \( P_0(x_i) = \sum_{i=1}^{n} \frac{x_i^{(1)}}{(1+i_0)^t} + \sum_{i=1}^{n} \frac{x_i^{(2)}}{(1+i_0)^t} + \sum_{i=1}^{n} \frac{x_i^{(3)}}{(1+i_0)^t} \) are the values of its inflows \( x_i \) and outflows \( y_i \) discounted to the beginning of the project, respectively;

\( P_0(EC_1) = \frac{EC_1}{(1+i_0)^t} \) -- discounted value of equity \( EC_1 \) introduced at the time \( t_1 \); \( P_0(3K_1) = \frac{3K_2}{(1+i_0)^t} \) -- discounted value of the loan capital \( LC_2 \) introduced at the time \( t_2 \); \( P_0(u_i) = \sum_{i=1}^{n} \frac{u_i}{(1+i_0)^t} \) -- discounted value of repayment payments \( z_i \) and payments \( u_i \) to owners and the respective; \( i_0 \) - investor profitability ratio taking into account innovative risk. The size of payments \( u_i \) is determined by the conditions and the cost of formation of IIP's own capital, and the size of repayment payments \( z_i \) is determined by the conditions of full repayment of the loan \( LC_2 \) by the time \( t_{t0} \). If you write (1) as follows:

\[ NPV = \left( \left( P_0 y_i - P_0 x_i \right) + \left( P_0 EC_1 - P_0 u_i \right) + \left( P_0 LC_2 - P_0 z_i \right) \right) \],

it \( P_0 y_i - P_0 x_i = NPV_0 \) can be considered as the basic net present value, determined on the basis of the values of inflows and outflows in the business plan of the project; \( P_0(EC_1) - P_0(u_i) = \Delta NPV_1(EC_1) \) -- as an increase in net present value due to the introduction at the time \( t_1 \) of equity \( EC_1 \) (taking into account its cost); \( P_0 LC_2 - P_0 z_i = NPV_1(LC_2) \) -- as an increase in net present value due to the introduction at the time \( t_2 \) of loan capital \( LC_2 \) (taking into account its value). Then

\[ \Delta NPV_i = \Delta NPV_1(EC_1) + \Delta NPV_1 LC_2 = \left( P_0 EC_1 - P_0 u_i \right) + \left( P_0 LC_2 - P_0 z_i \right) \]

(2)

there is a general increase in net present value of IIP due to the use of both own and loan capital. From (2) it obviously follows that the increase effect will be positive if the following conditions are met:

1) \( P_0 EC_1 > P_0 u_i \) and \( P_0 LC_2 > P_0 z_i \);

2) \( P_0 EC_1 > P_0 u_i \) and \( P_0 LC_2 < P_0 z_i \), but \( P_0 EC_1 - P_0 u_i > P_0 LC_2 - P_0 z_i \);

3) \( P_0 EC_1 < P_0 u_i \) and \( P_0 LC_2 > P_0 z_i \), but \( P_0 EC_1 - P_0 u_i < P_0 LC_2 - P_0 z_i \).

In practice, the repayment flow is usually annuity \( LC_2 \), and for the vast majority of cases, it is in the form of annuities with annual interest accrual at the rate \( r \) and annual payments of \( z_i = \text{const} \), which according to the rules of financial mathematics [7] for the diagram in Figure 1
\[ z_t = \frac{LC_2 \cdot r \cdot (1 + r)^{t_2 - t_1}}{1 - (1 + r)^{t_2 - t_1}}. \] 
Then, by the same rules, we get:

\[
P_0(z_t) = z_t \cdot \frac{1 - (1 + i_0)^{t_2 - t_1}}{i_0} \cdot \frac{1}{1 - (1 + i_0)^{t_2 - t_1}} = \frac{LC_2 \cdot r \cdot (1 + r)^{t_2 - t_1}}{1 - (1 + r)^{t_2 - t_1}} \cdot \frac{1}{1 - (1 + i_0)^{t_2 - t_1}} \cdot \frac{1}{1 - (1 + i_0)^{t_1}}.
\]

And the equitation \( P_0(LC_2) - P_0(z_t) > 0 \) is written in the form:

\[
\frac{LC_2}{(1 + i_0)^{t_2}} - \frac{LC_2 \cdot r \cdot (1 + r)^{t_2 - t_1}}{1 - (1 + r)^{t_2 - t_1}} \cdot \frac{1}{1 - (1 + i_0)^{t_2 - t_1}} \cdot \frac{1}{1 - (1 + i_0)^{t_1}} > 0. \quad (3)
\]

Algebraic transformations (3) we obtain the condition

\[
\frac{LC_2}{(1 + i_0)^{t_2}} \cdot \left\{ i_0 \cdot (1 + i_0)^{t_2 - t_1} - \left[ 1 - (1 + r)^{t_2 - t_1} \right] - r \cdot (1 + r)^{t_2 - t_1} \cdot \left[ 1 - (1 + i_0)^{t_2 - t_1} \right] \right\} > 0,
\]
which will be executed if

\[
\delta = i_0 \cdot (1 + i_0)^{t_2 - t_1} - \left[ 1 - (1 + r)^{t_2 - t_1} \right] - r \cdot (1 + r)^{t_2 - t_1} \cdot \left[ 1 - (1 + i_0)^{t_2 - t_1} \right] > 0.
\]

By writing the last expression as

\[
\delta = \left[ i_0 \cdot (1 + i_0)^{t_2} - r \cdot (1 + r)^{t_2} \right] + \left[ r \cdot (1 + r)^{t_2} - i_0 \cdot (1 + i_0)^{t_2} \right] > 0 \quad (4)
\]
when \( \Delta t_1 = t_4 - t_2 \) and \( \Delta t_2 = t_3 - t_1 \), we can consider various options for determining the effect of increase \( \Delta NPV_t(LC_2) \), depending on the ratio \( i_0 \) of the rate of return of the investor and the loan rate \( r \):

1) If \( i_0 = r \), then, as follows from (4), \( \delta = 0 \) and, moreover, as in the case \( \Delta t_1 = \Delta t_2 \), so in the case \( \Delta t_1 > \Delta t_2 \) and in the case \( \Delta t_1 < \Delta t_2 \). Then

\[
\Delta NPV_t(LC_2) = 0; \quad (5)
\]

2) If \( i_0 > r \), then, as follows from (4), \( \delta > 0 \) and \( \delta_2 < 0 \). Therefore, under the condition

\[
i_0 \cdot (1 + i_0)^{t_2} - r \cdot (1 + r)^{t_2} > \left[ r \cdot (1 + r)^{t_2} - i_0 \cdot (1 + i_0)^{t_2} \right],
\]

\[
\delta > 0, \text{ moreover, as in the case } \Delta t_1 = \Delta t_2, \text{ so in the case } \Delta t_1 > \Delta t_2 \text{ and in the case } \Delta t_1 < \Delta t_2; \quad (6)
\]

3) If \( i_0 < r \), then, as follows from (4), \( \delta < 0 \) and \( \delta_2 > 0 \). Therefore, under the condition

\[
r \cdot (1 + r)^{t_2} - i_0 \cdot (1 + i_0)^{t_2} > \left[ i_0 \cdot (1 + i_0)^{t_2} - r \cdot (1 + r)^{t_2} \right],
\]

\[
\delta > 0, \text{ moreover, as in the case } \Delta t_1 = \Delta t_2, \text{ so in the case } \Delta t_1 > \Delta t_2 \text{ and in the case } \Delta t_1 < \Delta t_2. \quad (7)
\]

In the general case, the analytical formula for determining the increase effect in the net present value of an innovative project will depend on the type of payment flows \( z_t \) of loan \( LC_2 \) repayments, as well as payments \( u_t \) to owners \( EC_0 \) and \( EC_1 \).
\[
\Delta \text{NPV}_i = \left[ \frac{EC_1}{(1+i_0)^i} - \sum_{i=1}^{t_i} u_i \left( \frac{1}{1+i_0} \right)^i \right] + \left[ \frac{LC_2}{(1+i_0)^2} - \sum_{i=1}^{t_i} z_i \left( \frac{1}{1+i_0} \right)^i \right].
\]

(8)

If the stream \( u_i \) also represents the annual annuity rent, then, based on (3) and (8), we obtain

\[
\Delta \text{NPV}_i = EC_1 - u_i \cdot \frac{1-(1+i_0)^{-(t_2-t_1)}}{i_0 \cdot (1+i_0)^{t_1}} + \frac{LC_2}{(1+i_0)^2} - \frac{LC_2 \cdot r \cdot (1+r)^{(t_4-t_2)}}{[1-(1+r)^{(t_4-t_2)}]} \cdot \frac{1-(1+i_0)^{-(t_6-t_4)}}{i_0 \cdot (1+i_0)^{t_4}}.
\]

(9)

4. Experimental part

Equation (9) allows visualizing the effect of individual project parameters on the increase in net present value. The data for an illustrative example are shown in Table 1.

| \(<i_0\) | CK_1 , million rubles | 3K_2 , million rubles | u_1 , million rubles | t_1 , years | t_2 , years | t_3 , years | t_4 , years | t_5 , years | t_6 , years |
|------|-----------------|-----------------|-----------------|-----------|-----------|-----------|-----------|-----------|-----------|
| 10 | 50 | 100 | 5 | 3 | 5 | 7 | 8 | 9 | 10 |

Table 1. Data of IIP parameters

Functional dependence \( \Delta \text{NPV}_i = f(i_0) \) built according to the table 1 is presented in Figure 2. It schematically displays the general tendency for the increase effect of the project’s net present value to change: with an increase in the rate of return, the net present value increases, at a certain value it reaches a maximum and then begins to decrease, which corresponds to the well-known dependence of NPV the decrease with the growth of the rate of return. Moreover, in numerical value, conditions (5), (6) and (7) of clause 3 of this work are fulfilled.

![Figure 2](image_url)

Figure 2. Impact of the rate of return \( i_0 \) on increase \( \Delta \text{NPV}_i \) for IIP

The critical value of the rate of return \( i_0 \), in which the increase effect decreases to zero and then becomes negative, can obviously be found using a numerical solution of the nonlinear equation

\[
\frac{EC_1}{(1+i_0)^i} - u_i \cdot \frac{1-(1+i_0)^{-(t_2-t_1)}}{i_0 \cdot (1+i_0)^{t_1}} + \frac{LC_2}{(1+i_0)^2} - \frac{LC_2 \cdot r \cdot (1+r)^{(t_4-t_2)}}{[1-(1+r)^{(t_4-t_2)}]} \cdot \frac{1-(1+i_0)^{-(t_6-t_4)}}{i_0 \cdot (1+i_0)^{t_4}} = 0
\]

regarding \( i_0 \), for example, using the MS Excel module “Parameter Selection”.

5
The influence of the loan rate $r$ (with $i_0 = 15\%$ and the data of Table 1) on the increase of the NPV indicator is shown schematically in the graph $\Delta NPV_i = f(r)$ shown in Figure 3.

With an growth in the loan capital (ceteris paribus), the positive effect of the increase begins to decline, as payments to repay the loan grow, and the contribution $\Delta NPV_i(\text{EC})$ to the increase of the net present value of the project, as follows from (9), does not change. Moreover, in numerical value, conditions (5), (6) and (7) of clause 3 of the present work are also satisfied.

The critical value of the loan rate $r_{\text{crit.}}$, at which the increase effect decreases to zero and then becomes negative, can be found by numerically solving equation (9) relative to using the MS Excel module “Parameter Selection”. For the IIP data given in Table 1 and $i_0 = 15\%$, the solution of such an equation gives a result $r_{\text{crit.}} = 33.24\ldots\%$ that fully corresponds to the result obtained in Figure 3.

The influence of the time $t_2$ of introducing loan capital $\text{LC}_2$ into the financial-time diagram for the implementation of IIP (with $i_0 = 15\%$ the data of Table 1) on the increase of the NPV indicator is displayed on the graph $\Delta NPV_i = f(t_2)$ shown in Figure 4. The later the capital $\text{LC}_2$ is introduced into the IIP implementation scheme, the less, as follows from (9), its positive contribution $\Delta NPV_i(\text{LC}_2)$ to the project $NPV$ increase. The contribution $\Delta NPV_i(\text{EC})$ to the increase of the project’s net present value does not depend on time $t_2$, therefore (ceteris paribus) the positive increase effect begins to decline.

The critical value of loan capital entry time $t_{\text{2 crit.}}$, at which the increase effect decreases to zero and then becomes negative, can be found by numerically solving equation (9) with respect to using the MS Excel module “Parameter Selection”.

5. Conclusion
The use of loan capital in the economy in general and in the implementation of innovative projects in particular is both an urgent task in terms of its theoretical significance and contradictory in terms of its practical implementation. On the one hand, attracting borrowed capital enables investors to implement promising innovative projects in the event of a shortage (or lack of own funds). On the other hand, the
need to repay debts reduces the positive effect of obtaining a project's net present value and, thereby, reduces its financial stability. The latter circumstance is especially important to consider in the context of inflation and unstable market conditions.

The way out, in our opinion, is the construction of mathematical models of performance indicators in the form of functions of project parameters that will allow accurate determination of the conditions for obtaining the effect of the increase in net present value of the project when using both loan and equity in the form of mathematical relationships between the individual parameters of the project. In this work, this was done for the net present value indicator. The results obtained demonstrate the possibilities of mathematical modeling for studying the dynamics of investment processes with a view to their further application in practice.

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