# Optimization of the Process of Adoption of Innovations in the IT Sector: What is the Right Time to Invest in IT Equipment?

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**Abstract.** The predominant part of the innovations is the implementation of the achievements of modern information technologies in business organizations. The main problem for investors is that they cannot determine the exact moment to do so, because the industry is directly related to the technological revolution in microelectronics. New IT products are constantly coming to market, and the price of existing ones is collapsing under Moore's Law. This article answers the question, when to invest in new technology, if the price of the investment is reducing about 2 times for a period of a year and a half.

**Keywords:** Analytical Model, Innovation, Investment, Moore's Law.



## 1 Introduction

According to a study by UNCTAD [1], over the last 10 years, the industrial policies of more than 100 economics, representing more than 90% of world GDP, have adopted formal industrial development strategies. It is noteworthy that in recent years the formulation of new industrial policies and strategies has increased sharply. Over time, they become more diverse and complex, focusing on newer topics setting a growing number of goals. This development cannot be described by the classical principles of conventional industrial development but is a complete reengineering, including:

- development of the knowledge economy;
- building sectors related to sustainable development goals;
- integration and modernization of the global value chain (GVC);
- competitive positioning for the new industrial revolution (NIR).

The dynamics of this change mainly affect foreign direct investment FDI (FDI), where there are different models of industrial policies. This is a set of industrial policies, as they reflect a number of factors: development of the country, legislation, and way of investment: purchase of an enterprise or shares from it, mixed production, mergers, and acquisitions. Investment policies are investments in management restructuring, NIR technology transfer, innovation, training, and more. On the other hand, FDI can be horizontal, vertical, and platform [2].

The industrial investment policy is a package of interactive strategies and measures aimed at building a favorable industrial environment:

- construction of global transport, logistics, production, and financial infrastructure;
- development of the domestic and export markets, including reengineering procedures at company, industrial and sectoral levels.

Nowadays, the innovations are at the top of the business agenda. The main reason for this rapid development is the technological revolution, especially in information technology. Moore's Law [3] refers to Gordon Moore's 1965 view that the degree of integration of microchips (the number of transistors in them) doubles every two years, although the cost of the products is halved. In the last 20-30 years, the doubling period has been reduced from 24 to 18 months, ie. the line of growth became steeper. This growth is not only valid for microprocessors – but it also applies to memory, hard drives, communication equipment, video cards, data volume, and more. Due to different interpretations of this increase [4,5] determined by Moore's formalism, it is specified analytically by the coefficient R:

$$R = 2^{\frac{N}{2}} \quad (1)$$

where N is the number of years for the given growth period.

On the other hand, the obsolescence (default) D of IT equipment according to Moore's Law is:

$$D = Q\frac{1}{2^{\frac{N}{2}}} \quad (2)$$

where Q is the initial value of the IT equipment. Fig.1 gives a graphical interpretation of (2) for Q = 1 graphical interpretation of (2) for Q = 1 (100%)

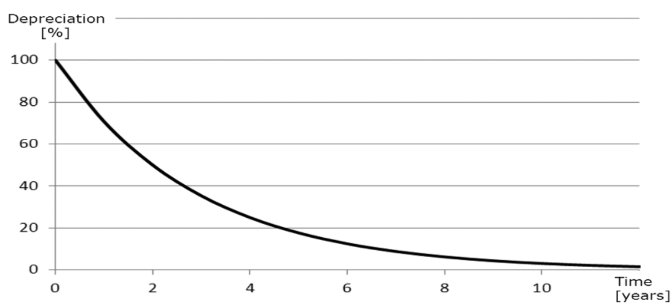


**Fig. 1.** Graphical interpretation of the depreciation of IT equipment over time.

This accelerated development leads to the following characteristics of the modern investment business:

- larger and more frequent investments in innovations in order to maintain the competitiveness of the enterprise;
- due to the rapid development of technologies and the sharp devaluation and obsolescence of investments (respectively innovations), it is especially important to specify the correct investment portfolio, as well as the moment of investment, which determines the continuous increase of investment risk;
- The biggest risk in investing is the refusal to invest, which also applies to investing in innovation.

When making investment decisions, two diametrically opposed errors are possible (Fig. 2):

- Doing something that does not work (false positive, type 1 error);
- Nothing is done that would work (false negative, type 2 error).

In practice, investors worry more about a type 1 error – accepting a false result, thinking it is real. The second type of error is also important – to reject a real result, thinking that it is false [6].

Fig. 2 shows a model based on which an assessment can be made of the correct perception of the innovation.

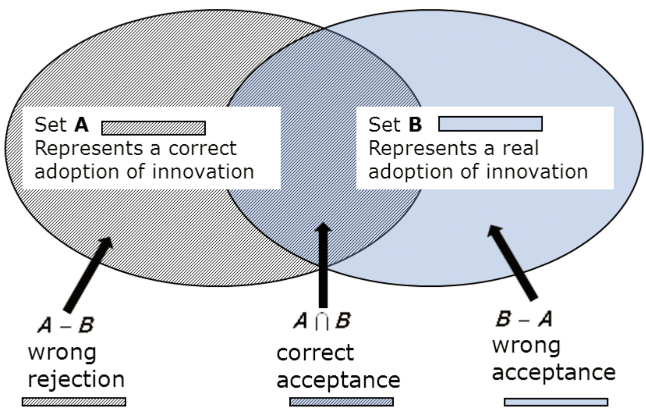


**Fig. 2.** Venn diagram illustrating the correctness of an innovation solution.

From Fig. 2 can be derived analytical dependences, giving a quantitative assessment of the correctness of the decision for the perception of innovation:

– Probability of correct adoption of innovation $P_c$:

$$P_c = \frac{|A \cap B|}{|A|} \tag{3}$$

– Probability of wrong rejection of innovation $P_{nc}$:

$$P_{nc} = \frac{|A - B|}{|A|} \tag{4}$$

– Probability of wrong adoption of an innovation $P_{ec}$:

$$P_{ec} = \frac{|B - A|}{|B|} \tag{5}$$

A very important indicator giving an integral assessment of the correctness of the adoption of the innovation is the identification coefficient $K_i$:

$$K_i = \frac{|A \cap B|}{|A \cup B|} \tag{6}$$

The identification coefficient gives a complete picture of how it is adopted, taking into account both inverse risks – wrong adoption (optimism) and abstinence (skepticism).

# 2 Existing computable models for investment and innovation

## 2.1 Analytical models of investment

The introduction of innovations in production (new technologies, organizations, products) leads to drastic improvements in quality and cost reduction. Companies invest to get more benefit. In this process, some companies succeed and others lose. As a result, there is a rapid growth of the industry. Eventually, when everyone has introduced innovation and it ceases to bring benefit as markets are saturated.

In economics, to illustrate the spread of innovation through its life cycle, the so-called logistics curve described by the so-called logistics function.

The logistic function used in economics [7] (logistic, sigmoid curve) is an S-shaped curve given by the equation:

$$L(x) = \frac{G}{1 + e^{-k(x-m)}}, \tag{7}$$

where:

- G is the maximum value of the curve, resp. the improvement of innovation;
- k is the speed of logistic growth (steepness);
- m is the mean value of the sigmoid.

It is obvious that this application of an analytical model through a logistic curve gives satisfactory accuracy only for uniform distribution (ie fashion, median and mathematical expectation coincide). In most cases [13,14] there is a deflected (asymmetric) distribution and the investment life cycle model represented by a logistic curve becomes inaccurate.

Another model that more accurately describes the process of saturation of innovation was proposed in 1962 by Rodgers [8] in his seminal book The Diffusion of Innovation. This is a theory explaining the spread of new ideas and technologies. The basic thesis is that diffusion is a process of transmitting innovation between the participants in a given system. Each new idea is adopted, with 4 main categories that adopt the innovation (Fig. 3):

- early adopted;
- early majority;
- late majority;
- lagging behind.

According to the author, the diffusion of innovations manifests itself in different ways and is highly dependent on the type of adopters and the decision-making process. The criterion for categorization of adopters is innovation, defined as the degree to which a person perceives a new idea.

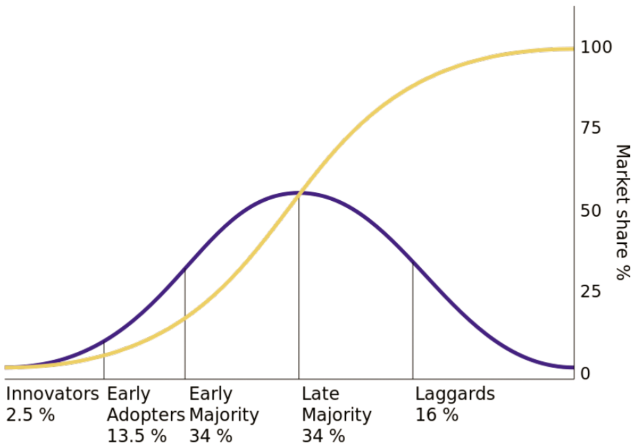


**Fig. 3.** Diffusion of Innovation DoI (Rogers Everett - Based on Rogers, E. (1962) Diffusion of innovations. Free Press, London, NY, USA).

Fig. 3 is widely distributed in various literature sources [9]. In the given example is shown so-called "skewed distribution", which in practice is more common. Of particular note is the error that the cumulative distribution function is below the probability distribution function of innovation, which is impossible because the relationship between the two functions is determined by the expression:

$$F(t) = \int_{t_1}^{t_2} f(t)dt\,, \tag{8}$$

where f (t) always has a positive value. On the other hand, two dimensions relevant to the described functions could be assigned to the ordinate.

Fig. 4 shows the correct type of the two functions obtained by simulations of MS Excel.

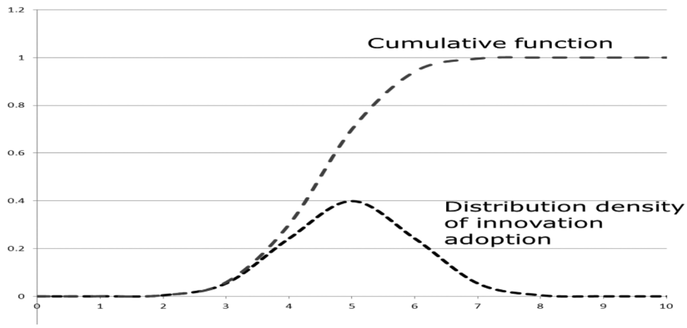


**Fig. 4.** Correct drawing of DoI curve (instead this from Fig. 3).

Greg Lowe (2012) evaluates cost-benefit considerations regarding the Rodgers product perception curve [9]. Lowe looks at investment and return separately, and believes that those who slowly adopt innovation are skeptics, bystanders, and enemies. Lowe believes that in most cases, lagging behind is counterproductive. He argues that the highest return on investment comes from the early majority and skeptics (Fig. 6).

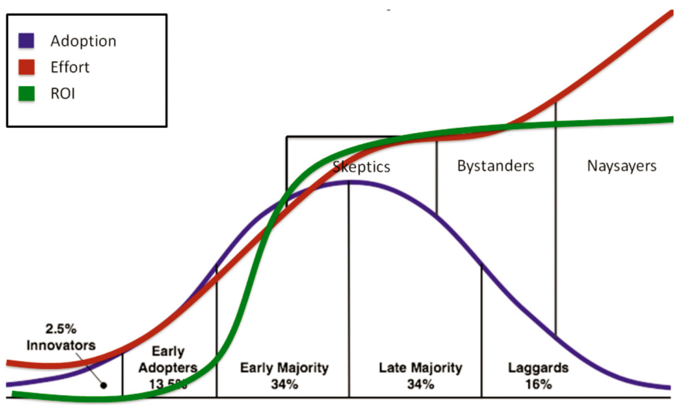


**Fig. 5.** Return on investment according to Lowe (Rogers Everett - Based on Rogers, E. (1962) Diffusion of innovations. Free Press, London, NY, USA).

## 2.2 Supposed analytical model

If needs to find a return on investment in the IT industry should be placed on a chart and the same scale, the functions of the continuous reduction in the price of a given technology (Fig. 1) and profit from it (Fig. 6).

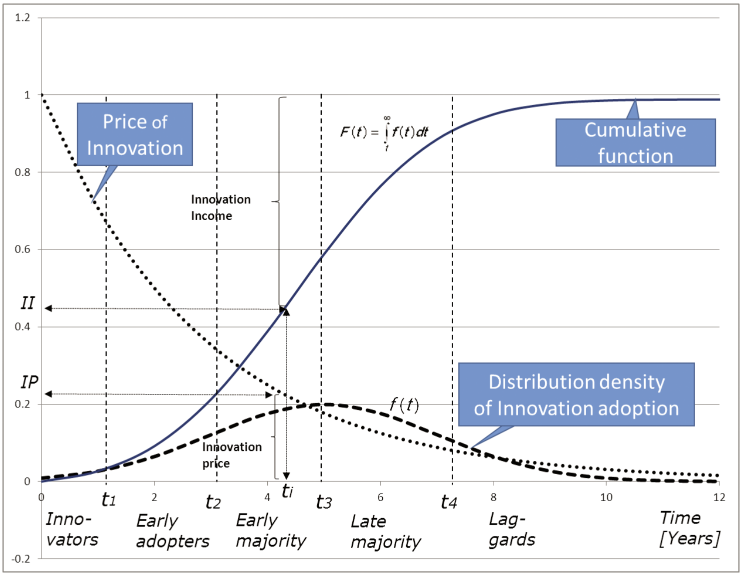


**Fig. 6.** Return on investment in IT innovation. An example of an investment is given: moment ti, value of the investment and expected added value.

If you invest at the time ti (Fig.6), the RoI will be:

$$I_i = F(t)_{[t_i \to t_{end}]} = \int_{t_i}^{t_{end}} f(t)dt \approx \int_{t_i}^{\infty} f(t)dt \tag{9}$$

The costs of the investment, started from the moment ti, are:

$$I_p = D(t) = Q\frac{1}{2^{\frac{t_i - t_0}{2}}} \quad 10)$$

At all other things being equal (variable interest rate, force majeure obstacles, etc.), the profit from the adoption of the new technology is determined:

$$V_A = I_i - I_p = F(t) - D(t) = \int_{t_i}^{t_{end}} f(t)dt - Q\frac{1}{2^{\frac{t_i - t_0}{2}}} \tag{11}$$

Due to the fact that the investment adoption density function is normalized, the following can be written:

$$\int_{t_i}^{t_\infty} f(t)dt = 1 - \int_0^{ti} f(t)dt \tag{12}$$

At distribution close to normal with sufficient accuracy instead f(t) (8) can be used the logistic function (3):

$$\int_0^{ti} f(t)dt \approx L(x) = \frac{G}{1+e^{-k(x-m)}} \quad (13)$$

This transformation allows studying the return on investment function ROI (11) in the interval [0; ti]:

$$V_A = 1 - \frac{G}{1+e^{-k(t-m)}} - Q\frac{1}{2^{\frac{t}{2}}} \quad (14)$$

The extremum of (14) is sought with aim to determine the best time to invest. The first derivative of the above is:

$$V_A^{/} = \ln(2)q\,2^{-\frac{t}{2}-1} - \frac{kG\,.e^{k(m-t)}}{\left(e^{k(m-t)}+1\right)^2} \quad (15)$$

The result of the simulation by [11] of formulas (14) and (15) is given at Fig.7, where is shown an integral idea of RoI. If the efficiency of the expected profit in relation to the invested funds is to be obtained, the so-called efficiency of the investment is obtained:

$$V_A = \frac{1 - \int_0^{ti} f(t)dt}{\frac{Q}{2^{\frac{t}{2}}}} \quad (16)$$

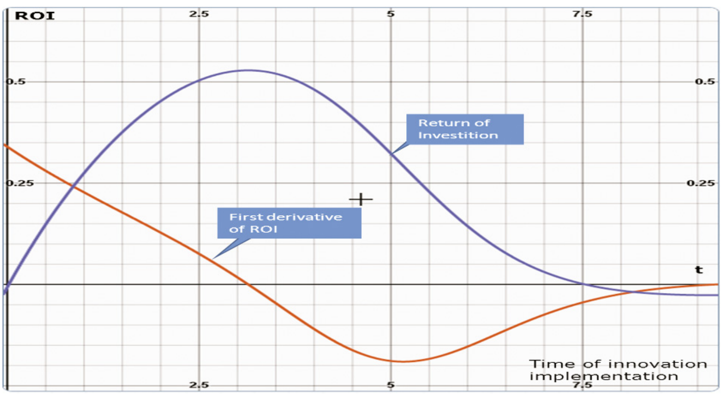


**Fig. 7.** Return on investment ROI in the implementation of IT innovations as a function of the moment of adoption, calculated by the formula (14). The values of G = Q = k = 1 and m = 5. It can be seen that late investments can lead to losses.

After the replacement of f (t) with a logistic function (16) obtains the type:

$$V_A = \frac{1 - \frac{G}{1+e^{-k(t-m)}}}{\frac{Q}{2^{\frac{t}{2}}}} = \frac{(1+e^{-k(t-m)} - G)2^{\frac{t}{2}}}{(1+e^{-k(t-m)})Q} \quad (17)$$

Fig. 8 shows the graphic form of the effectiveness of ROI (EROI), calculated according to (17).

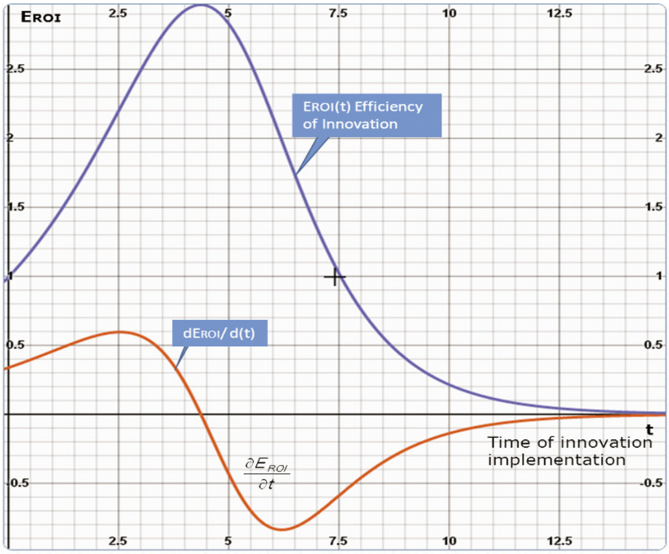


**Fig. 8.** EROI depending on the adoption time calculated by formula (17).
The values of G = Q = k = 1 and m = 5.

Fig. 8 and Fig. 9 shows that the ROI and EROI maxima diverge. The logical explanation is that investment must be made earlier in order to capture the peak of EROI.

Similar calculations (14) and (17) were made using MS Excel, based on the data in Figs. 8. ROI and EROI are calculated as the difference and ratio of the functions f (t) and D (t). The results are shown in Figs. 10 and Fig. 11.

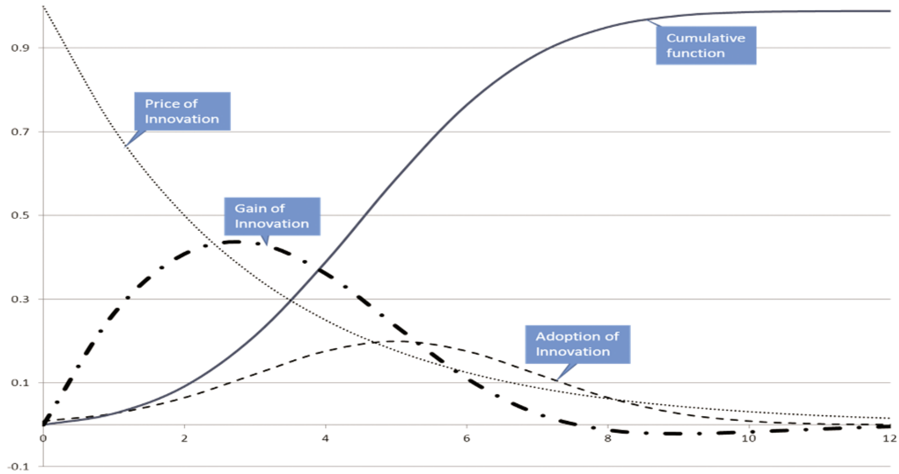


**Fig. 9.** Return on investment ROI in the implementation of IT innovations as a function of the moment of adoption, calculated using MS Excel. The values of G = Q = k = 1 and m = 5.

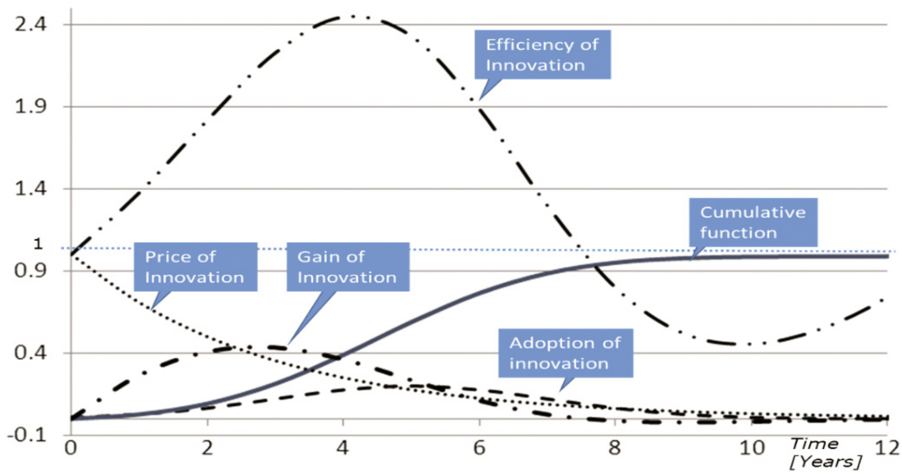


**Fig. 10.** The ROI and EROI as a function of the moment of implementation calculated using MS Excel. The values of G = Q = k = 1 and m = 5.

It can be seen that the results of the two calculation methods coincide, which confirms the calculations made. The use of MS Excel is more accurate and provides opportunities for convenient specification of various functions. For its part, the analytical approach offers a ready-made formula suitable for direct calculations.

Figures 12 and 13 show examples of investments with different initial data. The optimal time for adopting the innovation is marked with tin. Fig. 13 shows that it is possible to incur financial losses if the investment time is not chosen appropriately.

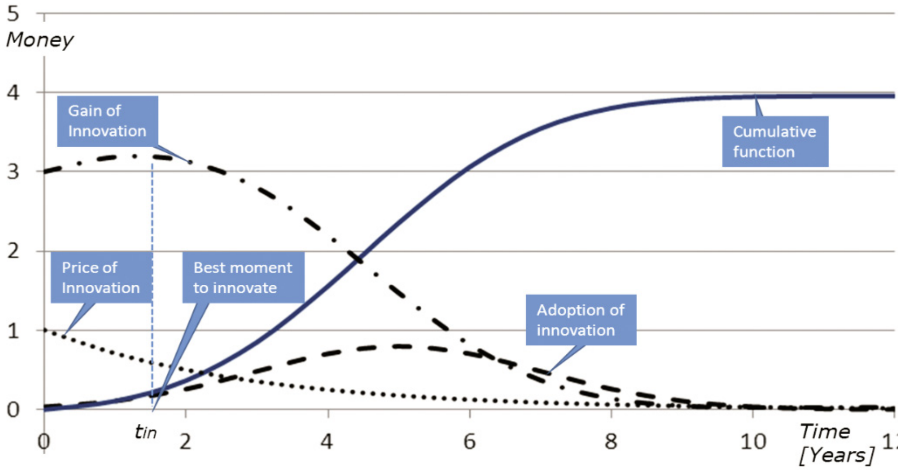


**Fig. 11.** ROI as a function of the moment of implementation. The values of G = 4, Q = k = 1 and m = 5. Maximum profit is obtained if the innovation is implemented after 18 months.

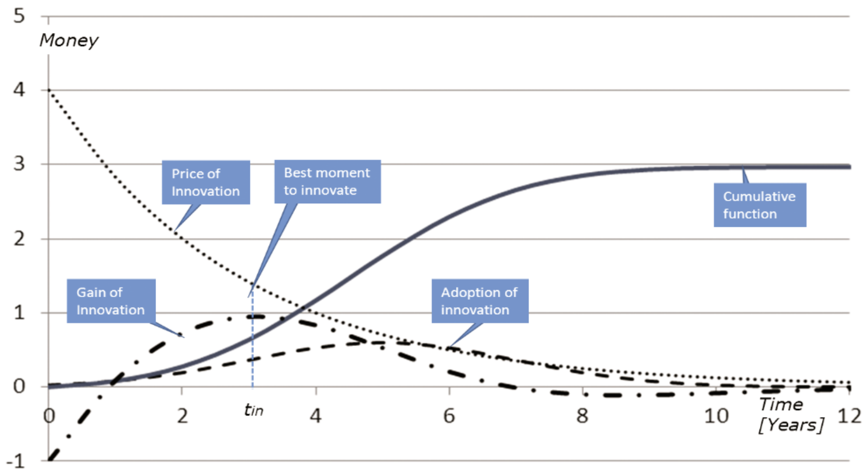


**Fig. 12.** ROI as a function of the moment of implementation for G=4, Q=3, k=1 and m=5. It can be seen that if the investment is made very early or significantly late, losses occur.

## 3 Conclusion

Proof of the accuracy of the calculations is obtained in two different ways – they coincide completely. New analytical material has been added to the theory of innovation. The proposed mathematical apparatus makes it possible to determine accurately the optimal time for the perception of innovation in fast-growing industries such as information technology [12]. The proposed formalism can be further developed and used for calculations that are more complex such as modeling of continuous simultaneous innovations in a heterogeneous investment fund.

An additional contribution is a theory of identifying the correctness for accepting investments. This makes it possible to quantify the probability of proper investment.

With a few changes, current models will be able to include additional calculations for the impact of inflation, key interest rates and market risk. In this way, based on the assessments, a detailed analytical model can be developed, allowing a quantitative assessment of the processes in the management of innovation and investment.

## 4 Acknowledgment

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