

# Budget optimization modelling for sustainable development of the university research: the example of US

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**Abstract.** Sustainable development is an important condition for the successful and effective development of most organizations and projects. Universities as organizations are also interested in sustainable development of their activities. In this article, one form of university activity is considered, namely R&D activities and the possibility of its sustainable development over the long term. To achieve the objective optimization model is used, which gives the most favourable option for the use of own funds of universities to smooth and increase the growth rate of the financial flow. The model uses mathematical and machine learning methods. The model has some degree of simplification and abstraction of reality. But the application of the model on real US indicators provided interesting results and conclusions.

## 1. Introduction

From an economic point of view, the further planning horizon of organization, the more it has a chance of stable growth. The ability to maneuver under adverse economic conditions is a sophisticated task that requires a carefully mature strategy, too. And in this case it is necessary to initially have sufficient resources and have the confidence that the company will survive in the current period before building long-term plans. Therefore, we can conclude that the more unstable and unpredictable the nearest economic conditions, the more attention is paid to the nearest planning.

For universities, long-term strategy is especially important, because they are engaged in scientific R&D projects that last from 2 to 6 years. Also, the usual education programs (bachelor, master, doctorate) last for an average of 2 to 5 years. Since the university does not have the ability to crucially change its activities and react to external economic shocks, universities are highly vulnerable to this problem.

The society has always striven for stability and risk reduction. Stability and security are some of the basic needs not only of man, but also of the organization for development under normal conditions. "Sustainability" was first used in a United Nations document in 1978 [1]. However, this definition has several meanings. Charles Kidd finds at least 6 different sources (or roots, as he calls them) of the interpretation of this term. They are the "no growth"/"slow growth", the carrying capacity, the resources, the ecodevelopment, the critique of technology and the biosphere roots [1]. B J Brown also considered different ways of interpreting the term stability [2]. She also mentions sustainable development and the sustainable economy. Thus, this topic is very relevant among researchers, especially in recent times.



Higher education also needs sustainable development. Typically, the authors highlight the complexity of adapting education to new global conditions, reducing quality and increasing demand, inadequate funding and the need to form long-term processes [3]. Sustainability in this article is seen as the absence of shocks and recessions in the flow of funding over the years. Accordingly, sustainable growth is a smoothed growing trend of investment in the RD, which is predictable and does not contradict expectations.

Building an optimization model is a way to more accurately plan for managing limited resources. One of the successful examples of building such a model can be found in the work of EM Modiano [4]. He builds an optimization dynamic model for the management of delectable resources and applies it on the energy industry using historical values.

One of the most important resources for research is financing. Interruptions in the flow of funds may adversely affect the development of the R&D project. Continuity and predictability of the volume of core resources should be provided for the sustainable R&D development. As we already discussed in the previous article “Impact of the macroeconomic factors on university budgeting: the US and Russia” [5], we found a correlation between macroeconomic downturns and the amount of investment in university R&D. So we continue to study this case and the goal is to build an optimization model of university budgeting. First of all, the model should provide a stable flow of financing, which will not strongly fluctuate under the influence of economic shocks.

## 2. Methodology and data

In this article we use methods of statistical analysis, logical generalization, mathematical programming and machine learning to find the optimal vector of solutions. The basis of the study is a constrained optimization problem [6].

The constrained optimization problem has some important components:

- 1) Optimization function  $F(x)$ , which has the maximization or minimization criterion of the search.
- 2) A set of vector  $x_{1...n}$  satisfying a certain set of constraints.

The solution of the problem consists in finding a vector  $x^*$  such that the function  $F(x)$  would have minimum or maximum value, depending on the criterion of the search [6]. For a simple linear function, one could use the simplex method [7]. But if the function turns out to be non-linear, then you'll have to turn to machine learning. There are many automatic ways to find a solution by enumeration of allowable values.

The verification of the model was carried out on statistics collected by the National Science Foundation's National Center for Science and Engineering Statistics [8]. The data set contains University Science & Engineering R&D Funding by Source taken in billions of 2017 US dollars. The total R&D investments are divided into federal, state and local, universities own funds, industry and other. Constant dollar conversions based on OMB's GDP deflators from the FY 2018 budget [9].

Indicators of inflation in the US over the last 20 years have also been used. Rates of inflation are calculated using the current Consumer Price Index published monthly by the Bureau of Labor Statistics (BLS) [10]. We also took S&P 500 Historical Annual Returns [11]. They are calculated as a percentage change of the last trading day of each year to the last trading day of the previous year. These two indicators are needed to calculate the possible redistribution of funds through time periods and opportunities to multiply them. All data are taken from 1997 to 2016 and do not have missing values.

## 3. Optimization model

Let's take a look at the data that we have in the context of the future model. We have indicators of the activity of funding sources by years. They are federal, state and local, universities own funds, industry and other sources. Since we act on behalf of the university, the universities own funds are the only source of investment that we can influence, and all the rest are permanent. Together they form a panel data. Each year the university allocates some own funds for R&D. The university has two options how to use its money: to invest them in the R&D in the current period or to invest

on the exchange to use in the future. As a simplification, we will assume that the decision on the allocation of funds is made at the beginning of each academic year.

The following variables are present in the model:

$t$  – time, number of years in the survey data in increments of one year.

$R_{1...t}$  – total R&D Funding, historical values.

$C_{1...t}$  – constant, includes the historical values of funds that we cannot influence: federal, state and local, industry and others.

$U_{1...t}$  – university own funds, historical values of money that the university allocates for the year from its own funds.

Where  $R_{1...t} = C_{1...t} + U_{1...t}$

The main problem consists in smoothing fluctuations of total R&D Funding ( $R$ ). So first we need to build an ideally smoothed function ( $R^*$ ) to aim for. Thus, each next value of  $R_{i+1}$  should be proportional to the previous  $R_i$ .

$R_{i+1}^* = R_i * (1 + \alpha)$ , where  $\alpha$  is the chosen growth rate.

Since we know the values of  $R_0$ , the resulting vector will be fully known and within the model will be a constant. To bring the actual values of  $R_{1...t}$  closer to the normative  $R_{1...t}^*$ , we need to reduce the deviations ( $\delta_{1...t}$ ). Since the deviations can be either positive or negative, then we will use the square deviation to avoid mutual compensation ( $\delta_{1...t}^2$ ). Thus, the objective function is

$$\min F(U_i) = \sum_{i=0}^t \delta^2 = \min \sum_{i=0}^t (R_i - R_i^*)^2$$

But the only variable we manage is our own R&D funds  $U_i$ . Thus, actual  $U_i$  consists of  $U_i^*$  that we spend in the current period and  $U'_i$  that we invest for use in future periods. So, we can rewrite objective function:

$$\min F(U_i) = \min \sum_{i=0}^t (C_i + U_i^* - R_i^*)^2$$

Now consider constraints,

1)  $U_i^* \geq 0$ , because we cannot take out foreign investments.

2)  $U_i^* \leq I_i$  where  $I_i$  is investments that constitute the amount of deferred own funds and interest accrued on them.  $I_i$  is indicator of the state of the account at the beginning of a period  $i$  at the time of making a decision on investment in R&D.

$I_{i+1} = I_i * (1 + \beta) + U'_i$  where  $\beta$  is return on investments rate.

The solution is a vector  $U_{1...t}^*$  satisfying all the constraints and for which the value of the function  $F(U_i)$  is minimal. Moreover, we get the estimated value of  $R_{1...t}'' = C_{1...t} + U_{1...t}^*$ , which was obtained after applying the optimization measures.

#### 4. Model application on real data

Let's look at a specific case for the R&D Funding in the US between 1997 and 2016.

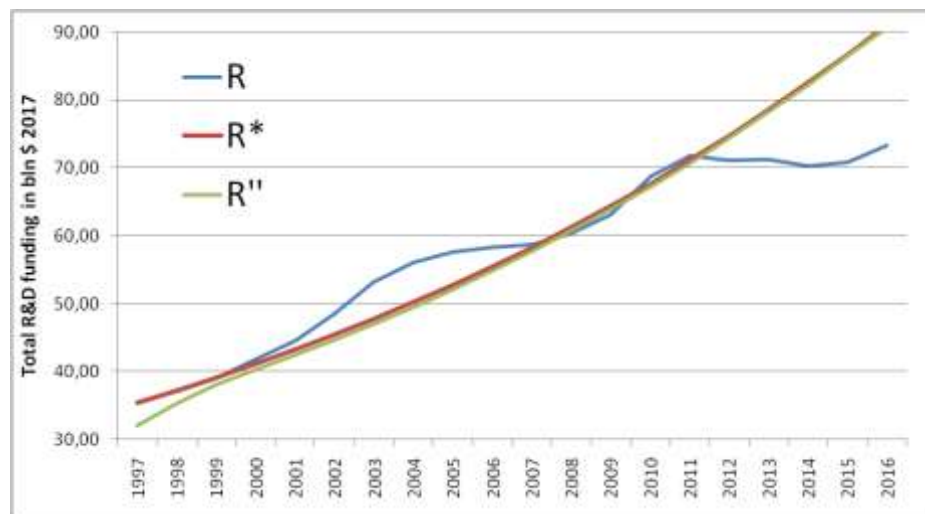
As a return on investments rate we are using the average S&P500 index returns as an indicator of the average market return:

$\beta = 7.31\%$  – S&P500 index returns, represents historical average annual profitability of S&P500 index, average for the period under study (1997–2016).

We take growth rate ( $\alpha$ ) for the second variable for the optimization model to see the best potential of the model. Use the minimax algorithm to find the optimum, since we must maximize the value of  $\alpha$ . We will have to introduce one more restriction on the non-negativity of  $\alpha$ . Following the solution algorithm based on the model, we use a method of machine learning to select the optimal vector  $U_{1...t}^*$ . Now we can compare historical  $R_{1...t}$  with model  $R_{1...t}^*$  and new estimated  $R_{1...t}''$ .

The sum of the deviations turned out to be rather small (21.50), and on the graph we see that the line of estimated  $R''$  is smoothed and has no negative shocks. Thus by managing own funds universities can make R&D funding flow smooth and more stable over the years.

The results can be seen in the graph below (fig. 1).



**Figure 1.** Comparison of the vector of historical total R&D funding ( $R$ ) with the model ( $R^*$ ) and estimated ( $R''$ ) under the condition of an optimal growth rate

The optimal value of  $\alpha$  in this case is 5.1%. Now we see that the result is much better. The lines of the modal ( $R^*$ ) and estimated ( $R''$ ) are almost completely coincides. Due to small savings in a period of abundance, it would be possible to completely compensate for the failures in recent years.

The average growth of historical total R&D findings is 4% on the background of the optimal  $\alpha = 5.1\%$ . Thus, by managing own funds universities can make R&D funding grow faster on average. For investments of this scale, 1% is a significant amount of money. If we count in absolute numbers, then the sum of all historical total investments in R&D for the last 20 years was 1151 bln dollars, but on the optimization model, they could be 1169 bln dollars and the difference is 18 bln dollars, which appeared due to returns on the investment of deferred funds.



**Figure 2.** Own funds share in total R&D funding

Another effect that can be exaggerated by comparing the model and historical investment behavior of universities is significantly larger fluctuations in investing own funds in model situation, which, nevertheless, repeat the extremes of historical values. Let's look at own funds share in total R&D funding and compare historical and estimated values (fig. 2). If universities in terms of relative

stability saved their money, now the share of own funds in general funds would be about 40% against the actual 25% in 2016.

One more argument in favor of this model. Since under the conditions of the model, universities compensate for insufficient funding from business and the government, they also depend on macroeconomic fluctuations. However, in periods of economic downturns the government and business invest less, but the universities, on the contrary, invest more to compensate this fluctuation. In this case, it is also correct in the opposite direction, the universities save and invest own funds on the stock exchange when the economy is growing, which means that it is likely to receive good interest returns.

## 5. Conclusion

Using the optimization model and machine learning, it is possible to smooth out the R&D investment flowing universities that make it more stable. Moreover, by investing surpluses in the years of abundance according to the average exchange rate coefficient and using them in future periods, it is possible to increase the average rate of investment growth. At the same time, the allocated money remained the same every year, but they were not invested instantly, but partly postponed for the future. Thus, the stability and efficiency of investments is improved. If we take into account the correlation between macroeconomic fluctuations and the investment behavior of the state and industry, we can predict future funding and optimize own funds of universities using the algorithm offered in this article. This is a challenge for future research.

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