

# Optimization of High-Tech Products Export Program in Terms of Resource and Time Constraints

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## Abstract

**Background/Objectives:** The article discusses the conflict between the satisfaction of domestic demands and the export product supply in conditions of limited production capacities of high-technology enterprises. **Methods/Statistical Analysis:** Economic and mathematical modeling has been applied to objectively determine the conditions of the proposed dynamic strategy application and assess its effectiveness. The optimality criterion is considered to be the total volume of high-tech products supply to the domestic market for the planned period. **Findings:** The authors have built a dynamic model of a high-tech enterprise or industry, the production of which is distributed between the export and the domestic market supply. The dynamic problem of optimal production distribution between the internal and external markets has been solved. The authors have substantiated the structure of the optimal dynamic export strategy: first of all, the priority shall be given to the product export in order to increase capacity, and at a certain point it is necessary to focus the attention on the preferential satisfaction of the domestic market. The conditions for the effective implementation of this strategy have been determined; the authors have proposed the method of assessing benefit from its use ensuring a potentially attainable growth in high-tech products supply for domestic customers for the planned period. The dependence of the benefit from exchange rate changes, duration of the planning period and from the minimum acceptable volume of supplies to the domestic and foreign markets has been studied. **Application/Improvements:** In conditions of investment resources deficit and depreciation of the domestic currency, it is expedient to give preference to export supplies, which will quickly increase the production capacity of enterprises.

**Keywords:** Domestic Market, Export, High-Tech Industry

## 1. Introduction

### 1.1 Introduction to the Problem

Export of Russian high-tech industry competitive products brings a significant portion of income that is spent not only for the maintenance of the current activity of enterprises, but also for their development, and is invested in research and development and technical re-equipment of production. At the same time, it is also critically impor-

tant to satisfy the domestic market demand for the modern products of high-tech industries, such as: aerospace, shipbuilding, transport and power engineering, machine tools, etc. There is a quite high demand in the world market for the production of some sub-sectors of the Russian instrument making industry, including science, even some types of medical equipment, which is at the same time critically demandable within the country. Supply of many kinds of such products is currently

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needed for the large-scale renovation of fixed assets in a number of sectors of the Russian economy and social sphere, which, in turn, becomes a key element to national security assurance. Thus, there has been a conflict arisen in some industries between satisfying domestic market demand and export of deficit high-tech products.

## 1.2 Urgency of the Issue

The worsening of the international situation leads to a deepening of the contradiction between the satisfaction of the domestic market demands and export of high-tech products. At first glance, the only way to solve this problem is to expedite supplies for domestic customers. However, some authors<sup>1</sup> express the following thesis. Since the satisfaction of the domestic market needs, especially in the medium and long terms requires a significant expansion of production capacity, modernization of enterprises and the necessary equipment and technology are mostly imported, the export reduction will lead to a reduction in foreign exchange earnings and the investment potential of companies. This jeopardizes plans to expand and upgrade production facilities. Additionally, this threat is exacerbated by the reduction in Russian state budget capabilities (resulting in sequestration of the budget expenditures for the purchase of high-tech products for the state needs and for the support of enterprises modernization programs) and weakening of the ruble against foreign currencies. The last factor reduces the purchasing power of enterprises on the markets of modern production equipment and technology. However, there are some already non-economic restrictions in this area initiated by foreign countries, which make the issue of intensification of enterprises modernization and purchase of critically needed equipment and components even more urgent.

The described practical problem requires a scientifically grounded solution, which requires the development of appropriate modeling tools.

## 2. Literature Review

Problems of development of optimum export strategies of countries and companies have been the focus of attention of economic science since the epoch of mercantilist school. As a rule, it is considered necessary to increase exports when possible. Export restrictions imposed by the exporting country itself are discussed in a few papers, and in general in relation to specific markets, for example, the arms market<sup>2</sup>.

Basically, the contemporary world economic literature considers the problems of exchange rate influence on exports and imports of goods and services, notably at the macro-level, even if for this purpose the strategies of benchmark companies are modeled<sup>3</sup>. But even if in this context the changes in exchange rates (to be more exact, their volatility) are taken into account, usually the attention is focused on the stationary processes, including those of exchange rates and stationary strategies of firms. It is proposed here to examine the optimal dynamic strategy for an enterprise or an industry that uses changes in currency exchange rate to implement a sequence of actions (boosted export of goods, import of equipment and capacity expansion, expeditious satisfaction of the domestic market demands) within the limited time interval. The article<sup>4</sup> is one of the few works that considers the short-term export strategies of companies (in the article referred to as “hit and run”) and they are considered as quite rational, not as deviations from the norm and manifestations of bounded rationality of entrepreneurs. However, in this work, the other motives of short-term export strategies are considered, and the authors do not apply the developed mathematical apparatus, but confine themselves to qualitative reasoning.

Concerning the application of optimal control theory to business economics, it has been successfully developed over the decades to the present day<sup>5,6</sup>. But the statements of problems of optimal management of the development of enterprises described in the literature are usually general, the specific issues studied in this paper are not considered there, though they are now extremely relevant for many sectors of the Russian high-tech industry. The paper<sup>7</sup> solves the problem of the development of the production potential of the enterprise in conditions of limited resources. But at the same time, the open economy, the possibility of production export and the need to import equipment are not considered.

In recent years, there have been published many works devoted to various issues related to the problem of optimization of high-tech products export program in terms of resource and time constraints, among which we would like to mention some presented below.

The problem of the impact of changes in exports under the influence of changing external factors on the volumes of enterprise's supply to the domestic market with the possibility of forecasting production volumes based on the analysis of a wide variety of potential risks in foreign markets has been studied in<sup>8</sup>.

Problems associated with the identification and evaluation of the relationship between the degree of exported products diversification and the efficiency of enterprises in the domestic market, as well as the volume of costs and the level of profitability of enterprises that bring their products to international markets (in both the short and long term) have been studied by<sup>9</sup>.

Issues of mutual influence of such factors as the production capacity of the company, volume of domestic demand and export dynamics have been studied in<sup>10</sup>, where the authors analyze the impact of the reduction in domestic demand on the export policy of enterprises, nonlinear dependence between changes in domestic demand, volume of imports and production facilities of enterprises.

The works of<sup>11</sup> are dedicated to an assessment of the impact of a sharp decline in domestic demand for the company's products during the crisis on the efficiency of its export activities, as well as to the possibility of maintaining sustainable development through the expansion of exports in conditions of declining domestic market demand.

In general, the analysis shows that despite a wide range of works dedicated to certain aspects of the problem of optimization of high-tech products export program in terms of resource and time constraints, none of them has quite carefully studied the problem of the existing contradictions between the satisfaction of the domestic market demand and export supply of products in conditions of the limited production capacities of high-tech industry enterprises. None of the works has studied the problem taking into account the analysis of dependence of profit from the exchange rate changes, the duration of the planning period, as well as from the minimum acceptable volume of supplies to the domestic and foreign markets of the types of production, which are competitive in foreign markets, and at the same time are critically important for the satisfaction of needs of the national economy.

### 3. Methods

#### 3.1 Hypotheses and Prospective Research Plan

There is the following hypothesis: perhaps in order to speed up the domestic market saturation and the satisfaction of needs of the national economy in the high-tech products, it is appropriate to ensure in the short term the

priority of their export supply to obtain larger amounts of foreign currency assets and invest them in a prompt modernization of enterprises, expanding their production capacities. After all, this will allow faster implementing the program of deliveries of production for domestic customers. The discussion on the admissibility of such a strategy in the face of the deteriorating international situation becomes meaningless, because it is evident that the "shift to the right" of supplies to domestic consumers of strategically important products by a number of sectors of the Russian high-tech industry has become already inevitable.

Of course, the proposed dynamic strategy may not be universally applicable, but used only under certain conditions, taken into account many limitations. Therefore, it is advisable to objectively determine the conditions of its application and assess its effectiveness with the help of economic and mathematical modeling. And the model should allow for a specification at the level of individual production and type of product, as well as for an aggregation at the level of an individual enterprise or an integrated structure, sub-sector or sector of high-technology industry. In connection with this requirement, only the indicators that can be measured or at least assessed by experts should be used in the model.

It is supposed that it will be possible to consider the problem of optimal control of released products distribution between exports and supply to the domestic market, given the fact that in conditions of a decline in the national currency value, the export allows faster receiving investment resources to increase the production capacity and eventually for a faster saturation of the domestic market.

#### 3.2 Economic and Mathematical Model of High-Tech Production Development Taking into Account the Equipment Exports and Imports

Let us consider the production of a certain type of product in the amount of  $q(t)$  (in value units and in constant prices, in national currency), where  $t = t_0; t_0 + 1; \dots; t_0 + T$  is a year of the planning period lasting  $T$  years. Suppose the production capacity is fully utilized (this assumption is justified in terms of production capacity deficit of the Russian high-tech industries discussed here):

$$q(t) = V(t), \quad t = t_0; t_0 + 1; \dots; t_0 + T \quad (1)$$

(Production capacities are also measured in value units and in constant prices).

Manufactured products are partially exported in a volume of  $q_{EXPORT}(t)$ , and partially supplied to domestic customers in a volume of  $q_{DOMESTIC}(t)$ . These are the only supplies:

$$q_{DOMESTIC}(t) + q_{EXPORT}(t) = q(t), \quad t = t_0; t_0 + 1; \dots; t_0 + T \quad (2)$$

So, for a given volume of exports, volumes of supplies to the domestic market are determined using the following formula:

$$q_{DOMESTIC}(t) = V(t) - q_{EXPORT}(t), \quad t = t_0; t_0 + 1; \dots; t_0 + T \quad (3)$$

For simplicity, we assume that the production technology is unique and all the available production facilities can be used for both the production of products for the needs of domestic customers and for the export production. In fact, it is not far from the truth, because the production of modern products meeting the requirements of both a key client and external customers is usually only possible on modern production facilities introduced in the framework of technical re-equipment of the Russian high-tech industry. Since the greater part of such equipment has been acquired and put into operation during the past few years, for the sake of simplicity of the model, it is also expected not to consider within the planning period the disposal and upgrading of modern production equipment. Then the dynamics of the production facilities is determined by the following equation:

$$V(t+1) = V(t) + \frac{1}{b(t)} \cdot I(t), \quad t = t_0; \dots; t_0 + T - 1 \quad (4)$$

where  $I(t)$  - the volume of investment in the development of production capacity per year, measured in constant prices (for simplicity, lags related to creating and putting into operation production facilities have not been taken into account, but if necessary they may be easily entered into the proposed model);

$b(t)$  - full capital intensity of production (i.e. the cost of creation of a unit capacity) per year  $t$ , also measured in constant prices in national currency.

On the one hand, technology and material composition of fund-creating goods and services required for the unit capacity increase can be considered constant throughout the whole planning period. But, on the other hand, the cost of imported fund-creating products in national currency depends on the exchange rate, which can vary

during the planning period. As noted above, changes in exchange rates are one of the most important risk factors that affect the processes of development of the productive potential of enterprises of the Russian high-tech industry. We will express the importance of capital intensity in the year  $t$  as follows:

$$b(t) = b_{LOCAL} + b_{IMPORT} \cdot e(t) \quad (5)$$

where  $e(t)$  - the exchange rate of the year  $t$ , RUB/foreign currency unit;

$b_{LOCAL}$  - "local capital intensity", i.e. the cost of creation of a unit capacity required for the purchase of domestic equipment and other fund-creating goods expressed in national currency units in constant prices;

$b_{IMPORT}$  - import capital intensity, i.e. the cost of creation of a unit capacity required for the purchase of imported equipment and other fund-creating goods expressed in foreign currency units in constant prices.

Revenues from sales of products, expressed in constant prices in the national currency will also depend on the exchange rate. Its value in the year  $t$  can be expressed in the following way:

$$R(t) = R_{DOMESTIC}(t) + R_{EXPORT}(t) = q_{DOMESTIC}(t) + q_{EXPORT}(t) \cdot x(t) \cdot e(t) \quad (6)$$

$$t = t_0; t_0 + 1; \dots; t_0 + T$$

where  $x(t)$  - the indicator of the relative attractiveness of exports per year  $t$ .

Its dimension is inversely proportional to the dimension of the exchange rate, i.e. of units of foreign currency per unit of domestic. Strictly speaking, the exchange rate that appears in the formulas for revenue and profit and in the formulas for the equipment acquisition costs can vary quite substantially. In both cases, the subject of interest is not so much the exchange rate or the rate officially set by the Central Bank, as parity rate, for example, The Central Bank website<sup>12</sup> directly calculated for this "basket" of goods and services respectively, for the production and production equipment for this "basket" of goods and services respectively, for the products and production equipment. If  $x(t) = \frac{1}{e(t)}$  in the given year,

the ruble revenue from the export of a unit of production is equal to the revenue from the supply for domestic consumers. If for example  $x(t) > \frac{1}{e(t)}$ , then the export

revenues after conversion into rubles at the current rate will exceed the revenues from the sale of the same volume of production to domestic customers.

Of course, not all the funds received from the sale of products can be invested in the development of productive capacities: enterprises have operating expenses, and only the net profit and depreciation expenses can be considered as liquid assets. For the purpose of approximate earnings estimate, it can be assumed that the prices of products supplied to the domestic market are determined under the “cost plus” principle with fixed standard of expenses profitability  $r_{DOMESTIC}$ . In this case, the cost of production of products that cost  $q_{DOMESTIC}(t)$  is:

$$C_{DOMESTIC}(t) = \frac{q_{DOMESTIC}(t)}{1 + r_{DOMESTIC}} \quad (7)$$

and the profit from their sale is respectively:

$$P_{DOMESTIC}(t) = R_{DOMESTIC}(t) - C_{DOMESTIC}(t) = q_{DOMESTIC}(t) - \frac{q_{DOMESTIC}(t)}{1 + r_{DOMESTIC}} = \frac{r_{DOMESTIC}}{1 + r_{DOMESTIC}} \cdot q_{DOMESTIC}(t) \quad (8)$$

As the value of export production of goods  $q_{EXPORT}(t)$  in this model is also calculated in the prices established for domestic customers, the cost of production of these products is:

$$C_{EXPORT}(t) = \frac{q_{EXPORT}(t)}{1 + r_{EXPORT}}, \quad (9)$$

and the revenue according to the previously introduced data is:

$$R_{EXPORT}(t) = q_{EXPORT}(t) \cdot x(t) \cdot e(t) \quad (10)$$

profits from the sale of exports per year measured in constant prices in national currency will be:

$$P_{EXPORT}(t) = R_{EXPORT}(t) - C_{EXPORT}(t) = q_{EXPORT}(t) \cdot x(t) \cdot e(t) - \frac{q_{EXPORT}(t)}{1 + r_{DOMESTIC}} = \left( x(t) \cdot e(t) - \frac{1}{1 + r_{DOMESTIC}} \right) \cdot q_{EXPORT}(t), \quad t = t_0; t_0 + 1; \dots; t_0 + T \quad (11)$$

So, the total profit (obtained from both the export sales and from the supplies to the domestic market) of

the enterprise in the year  $t$  calculated in constant prices in national currency will be:

$$P(t) = P_{DOMESTIC}(t) + P_{EXPORT}(t) = \frac{r_{DOMESTIC}}{1 + r_{DOMESTIC}} \cdot q_{DOMESTIC}(t) + \left( x(t) \cdot e(t) - \frac{1}{1 + r_{DOMESTIC}} \right) \cdot q_{EXPORT}(t), \quad t = t_0; t_0 + 1; \dots; t_0 + T \quad (12)$$

Within the framework of this work, it is assumed that the main advantage of exports (in terms of the Russian high-tech industry enterprises) is their profitability which is higher comparing to supplies to the domestic market, calculated in local currencies in constant prices, due to almost double increase of the exchange rate at the cusp between 2014 and 2015. Of course, after such a significant change in the relative attractiveness of export and domestic supply, there should be some “adjustments” related to both the domestic prices - up (largely due to the presence of imported components in the composition of products, which requires a revision of contract prices) and export prices - down, as enterprises of the Russian high-tech industry incur expenses primarily in rubles, and a decrease in foreign currency expenses makes it possible to expect a reduction in prices in foreign currency under the influence of competition on the markets of high-tech products. However, these “adjustments” are not considered here, although they can be easily taken into account by reducing the parameter of relative attractiveness of exports  $x$ . As shown in<sup>13</sup>, the price system can never be completely adjusted to the exchange rate changes. Thus, it is assumed that a slight increase in the export supply of products will provide additional inflow of foreign currency needed to import production equipment and technology, which became proportionally more expensive in rubles after their rate drop.

In addition, not all available funds of companies are invested in the development of productive capacity, as the high-tech industry companies also need funds for the research and development activity to create advanced products and upgrade the modern ones, for the human resource development, i.e. specialist trainings, etc. Statistics also confirms that not 100% of available funds are invested in the development of material and technical base of the high-tech industry enterprises, though the amount of investments is pretty high. Then, if for the

investments in productive capacity development the company spends a  $i < 1$  share of its profits, the amount of investments in the year  $t$  calculated in constant prices in the national currency can be expressed as follows:

$$I(t) = i \cdot P(t) + I_{GOV}(t), \quad t = t_0; t_0 + 1; \dots; t_0 + T \quad (13)$$

where  $I_{GOV}(t)$  - the amount of state budget investments in the development of the production potential of the enterprise in the year  $t$ . In reality, we have in mind, first of all, the funds allocated in the framework of the State program of the Russian Federation "Development of the aviation industry in the years 2013-2025",<sup>14</sup> "Development of shipbuilding in the years 2013-2030", etc<sup>15</sup>.

### 3.3 Method of Searching for an Optimal Dynamic Strategy of Export of Deficit High-Technology Products

Thus, the above equations represent a model of the dynamics of production and sales of high-tech products, and the development of the productive capacity of high-tech industry enterprises. From a mathematical point of view, they represent a system of finite-difference equations that can be successively solved for all the years of the planning period, given the following:

- All the constant coefficients of the model: profitability of supplies to the domestic market  $r_{DOMESTIC}$ , rate of investment in capacity development  $i$ , capital intensity  $b_{LOCAL}$  and  $b_{IMPORT}$ ;
- The initial value of the level of production capacity  $V(t_0)$
- Expected dynamics of exchange rates  $\{e(t)\}$  and the attractiveness of export supplies  $\{x(t)\}$ ,  $t = t_0; t_0 + 1; \dots; t_0 + T$ ;
- Expected dynamics of public investments in the development of the productive capacity of enterprises  $\{I_{GOV}(t)\}$ ,  $t = t_0; t_0 + 1; \dots; t_0 + T$  (which in this model is considered as exogenous);
- Planned dynamics of export production supplies  $\{q_{EXPORT}(t)\}$ ,  $t = t_0; t_0 + 1; \dots; t_0 + T$ , which is a command variable in the model.

Calculation procedure is the following. By means of the equation for volume of production supplies to the

domestic market when  $t = t_0$ , using the known initial production capacity level value  $V(t_0)$ , with the given planned level of export products supplies  $q_{EXPORT}(t_0)$  we express the possible volume of supplies to domestic consumers:

$$q_{DOMESTIC}(t_0) = V(t_0) - q_{EXPORT}(t_0) \quad (14)$$

After that, using the corresponding equations and forecasted value of the exchange rate  $e(t_0)$ , we estimate revenues (in local currency)  $R(t_0)$ , income  $P(t_0)$  and eventually  $I(t_0)$  - the volume of investments in the development of productive capacities in the year  $t_0$ . Then the equation of the dynamics of the production facilities allows assessing the level of these production facilities in the coming year  $t_0 + 1$ :

$$V(t_0 + 1) = V(t_0) + \frac{1}{b(t_0)} \cdot I(t_0) \quad (15)$$

where for the assessment of the capital intensity  $b(t_0)$  using the above-proposed capital intensity formula in the case of imports of equipment, we have to use the predictive value of the exchange rate  $e(t_0)$  as well.

Upon obtaining the value of the level of production capacity in the year  $t_0 + 1$ , we repeat the calculation cycle from the beginning, and so on up to  $t_0 + T$ . At the same time, we should also determine the number of values of the volume of production supplies to the domestic market  $\{q_{DOMESTIC}(t)\}$ ,  $t = t_0; t_0 + 1; \dots; t_0 + T$ . Within the given research, these supplies are eventually an optimality criterion of the program of enterprises development and program of exports, which are considered here only as a means of obtaining the necessary revenues for the development of the productive capacity of high-tech industry.

Suppose that during the planning period, the high-tech products supplied to the domestic market are practically not withdrawn, and the cost functional can be considered as the total volume of their supplies for the planned period. Thus, the optimal control problem is as follows:

$$J(T) = \sum_{t=t_0}^{t=t_0+T} q_{DOMESTIC}(t) \rightarrow \max_{\{q_{EXPORT}(t)\}, t=t_0; t_0+1; \dots; t_0+T} \quad (16)$$

We assume that in conditions of the deficit of resources, there cannot be "excessive" financial and time supplies of

products to the domestic market, and the more high-tech products will be supplied to domestic customers for the planning period the better. It is useful to highlight that in this case we have used the integral objective functional, i.e. the amount of supply volumes for the entire planning period, not terminal: for example, the level of production capacities of the company by the end of the planning period  $V(t_0 + T)$ . Such optimization problems are widespread in economic science. For example, such form is taken by the problems of the income distribution between the accumulation and the consumption (at all levels: from the household to the national economy), the problems of distribution of profit of joint stock companies between dividends and reinvestment of undistributed profits in the company's development. From the optimal control theory<sup>16</sup> we know about the overall structure of optimal solutions of both the terminal and integrated optimal control problems of the type described. The optimal trajectory for the terminal criterion is trivial and intuitively obvious: in order to maximize the level of production facilities at the end of the period, it is necessary to develop them as fast as possible ("to accumulate without consuming"). Taking into account the assumptions that are made here in relation to the profitability of export and domestic supplies, this means a complete reorientation of the high-tech industry toward the export until the end of the planning period. If we consider the integral objective functional, the structure of the optimal control program will be as follows: up to a certain point of "switching"  $t_0 + t'$ , there is again the most intensive development of production capacities, which corresponds to the priority of export supplies. From this point, the industry gets completely reoriented toward the supply of high-tech products to domestic customers. So, in fact, instead of finding the optimal planning trajectory of export supplies of products  $\{q_{EXPORT}(t)\}$ ,  $t = t_0; t_0 + 1; \dots; t_0 + T$ , we solve the problem of optimizing a single scalar parameter: the moment of "switching"  $t'$ .

In reality, the optimal control problem may contain limitations, primarily regarding the minimum acceptable volume of supply to the domestic market for each year of the planning period:  $q_{DOMESTIC}(t) \geq q_{DOMESTIC MIN}(t)$ ,  $t = t_0; t_0 + 1; \dots; t_0 + T$  in order to ensure supply of appropriate strategic sectors of the national economy (energy, transport, etc.). In conditions of production capacity shortage, they will be most probably implemented as equities at the beginning of the planning

period, but starting from a certain point  $t'$  the priority will be given to supplies to domestic customers. At the same time, export supplies most likely neither can really fall to zero, because of the existing contracts, to maintain the country's position in the world markets of high-tech products. In this regard, there are similar export volumes lower limitations  $q_{EXPORT}(t) \geq q_{EXPORT MIN}(t)$ ,  $t = t_0; t_0 + 1; \dots; t_0 + T$  (and after the "switching", already these limitations will be performed as strict equalities). Of course, all these restrictions narrow the "corridor" of admissible control  $\{q_{EXPORT}(t)\}$ ,  $t = t_0; t_0 + 1; \dots; t_0 + T$  and first of all it is necessary to make sure that all these trajectories are not vain. In reality, this problem can contain limitations which are incompatible with each other or unrealistic in principle, which means that they should be adjusted with due account of the importance of certain losses, the possibility of involvement of certain additional resources, etc.

So, based on the known properties of optimal solutions and possible limitations, the problem of optimal planning of export supplies looks as follows:

$$J(T) = \sum_{t=t_0}^{t=t_0+T} q_{DOMESTIC}(t) \rightarrow \max_{t'} \begin{cases} q_{DOMESTIC}(t) \geq q_{DOMESTIC MIN}(t); \\ q_{EXPORT}(t) \geq q_{EXPORT MIN}(t); \end{cases} \quad t = t_0; t_0 + 1; \dots; t_0 + T \quad (17)$$

If the above system of finite-difference equations of the dynamics of the production of high-technology products and development of production facilities of enterprises is solved numerically in the simulation mode, the optimal time of "switching"  $t'_*$  can be found by sequential search from  $t_0$  to  $t_0 + T$  which has an acceptable computational complexity.

## 4. Results

### 4.1 Creation of an Input Data Set for Model Calculations

Let us consider the following conditional, but realistic example, following the order of values of coefficients corresponding to the aviation industry. This is one of the leading sectors of the Russian high-tech industry. According to the analysis of foreign statistics,<sup>17-19</sup> in case

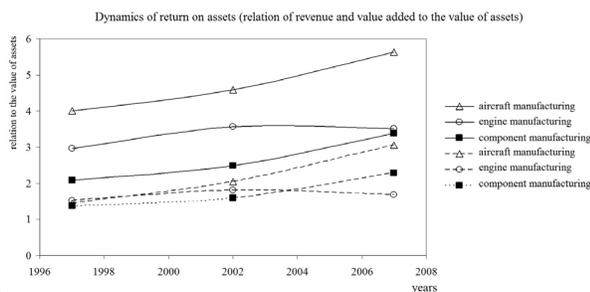
of introduction of modern technologies and organization of production, as well as at full capacity of production, the following typical values of return on assets of the main sub-sectors are achieved in the aircraft industry:

- Aircraft and helicopter manufacturing – 5-5.5;
- Aircraft engine manufacturing – 3-3.5;
- Plant and instrument making industry (combined into “component manufacturing” in the foreign statistics) – 3.0,

see graphics built on the basis of the US aviation industry official statements in Figure 1.

Similar values of return on assets are given in the Russian aircraft industry development programs<sup>13</sup> by the end of the planning period, but at the moment the actual return on assets of the Russian aviation industry is several times lower: in some sub-sectors it is of about 1. This is partly due to an objective reason: there is a great learning curve in the industry<sup>20</sup>, that allows employees showing the higher productivity of labor according to their skill acquisition. However, at the beginning of a period of new products production (which is typical for many enterprises of the industry at the moment), the formation of necessary skills is still in progress, although workers have already been equipped with the necessary modern equipment in full measure (which is why there is a low return per unit of value of fixed assets). Thus, it is possible to use in calculation the value of the average capital intensity of investments at the level of 2.5 (prior to the drop of the ruble rate).

Though the proposed model makes it possible to take into account the complex projected trajectories of changes in exchange rates  $\{e(t)\}$ ,  $t = t_0; t_0 + 1; \dots; t_0 + T$ , the development of reliable forecasts of this kind goes beyond the scope of this study, if at all possible. Therefore it is



**Figure 1.** Changes in return on assets of the main sub-sectors of the aviation industry in the United States in 1997-2007.

sufficient to confine ourselves here only to scenarios of keeping the exchange rate at a constant level  $e = Const$  throughout the planning period, except for the initial year. Suppose the duration of the planning period is  $T = 10$  years, which corresponds to the typical duration of the planning period in considered sectors. First, we will assume that the exchange rate is equal to  $e(t_0) = 30$  RUB/USD. Then it rose nearly twice, and in this illustrative calculation, we assume that the exchange rate does not change throughout the planning period and is  $e(t) = 60$  RUB/USD,  $t = t_0 + 1; \dots; t_0 + T$ .

As shown by the experience of the modernization of Russian aircraft manufacturing enterprises, the value share of imported equipment, technology, software and other fund-creating products reached 70-85%<sup>21,22</sup>, and this was before the double decrease of the ruble rate in the currency markets. If we take into account the occurred exchange rate changes, it would be reasonable to assume that in the beginning of the planning period the values of “domestic” and “import” capital intensity were equal to, respectively,  $b_{LOCAL} = 0.1$  RUB/(RUB/year) and  $b_{IMPORT} = 0.01$  USD/(USD/year). Given the initial value of the ruble rate, this meant that to create a unit capacity it was necessary to import fund-creating goods for the amount of  $b_{IMPORT} \cdot e(t_0) = 0.3$  RUB/(RUB/year), and the total capital intensity was  $b(t_0) = 0.4$  RUB/(RUB/year), which corresponds to the level of return on assets of 2.5.

Suppose the rate of investment in the development of productive capacities is equal to 50% of the company’s net profit, which is consistent with the experience of real enterprises of the Russian aviation industry being part of the integrated structures: United Aircraft Corporation, “Russian Helicopters” Corporation etc. At the same time, the net profit in this industry is usually not more than 70-80% of the gross profit, which, strictly speaking, is determined using the previously obtained formula. So, we can assume that the investment rate (relatively to the gross profit) is equal to  $i = 35\%$ .

Suppose the profitability of high-tech products supplies to the domestic market is equal to 10%. As for the profitability of exports, we can assume that prior to sudden changes in the exchange rate, the attractiveness of the export supply and the domestic market supply was equal,

$$\text{i.e. } x(t_0) = \frac{1}{e(t_0)}$$

However, after the double decrease of the ruble rate comparing to foreign currencies, it can be assumed that under the influence of global competition, there has been an “adjustment” of prices in the markets of high-tech products, so that the ruble revenue from the export sale of products could be bigger than the revenue from domestic sales not twice, but for example only 1.5 times. So

$$x(t) = \frac{1}{40}, t = t_0 + 1; \dots; t_0 + T \quad (18)$$

Let us assume that the planned investments from the state budget to the development of the productive capacity of high-tech industry companies initially allowed financing the increase in production capacity by 25% over the year. We emphasize that the proposed model allows using the dimensionless variables, taking the original level of production capacity to be 1 (or 100%), and referring to it all the volumes of production and sales, revenues, costs, profits and investment. Suppose  $V(t_0) = 100$ , then  $I_{GOV}(t_0) = 10$ . Industry development programs usually include a gradual reduction in the volume of state financial support to enterprises, especially in the medium term (5-7 years or more), expecting the enterprises to become self-financing and able to finance their development from their own funds. Specific public investment programs can also include the state budget financing growth in the short term (2-3 years), but under the circumstances, they have been subjected to sequestering, and this process can be continued. In this illustrative calculation we confine ourselves to a linear reduction of public financing of industrial development up to 0 over 5 years - although, of course, it is possible to use realistic data in the presence of real programs. After the first 5 years of the planning period, the companies carry out all investments from their own funds derived from the sale of products in the domestic and foreign markets.

## 4.2 Illustrative Example of Model Calculations

First, let us consider the problem of optimal control of the product supply distribution between the external and internal markets without taking into account the restrictions on the minimum supply volumes. Figures 2 and 3 show diagram of time-based changes during the planning period calculated in accordance with the proposed model

- Level of production capacity;

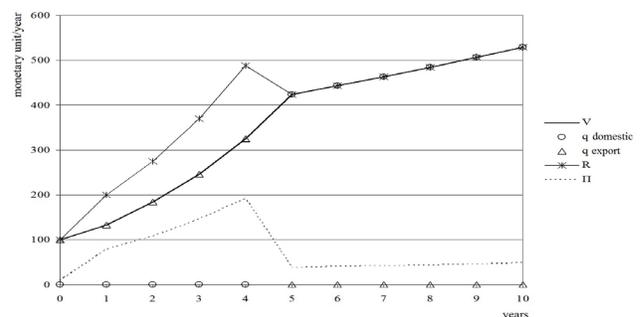
- Volume of supplies to the domestic and foreign markets;
- Revenue and profits (in the national currency, in constant prices);
- Investments into the development of production capacities.

In the present example, the time of “switching” is assumed to be  $t' = t_0 + 4$  years. At the same time, the total amount of product supplies for domestic customers for the planned period amounted to

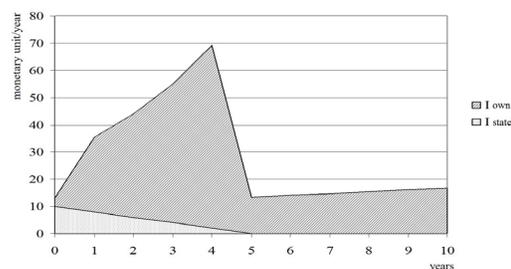
$$J(T) = \sum_{t=t_0}^{t=t_0+T} q_{DOMESTIC}(t) = 2851. \text{ Optimization of}$$

the “switching” time showed that the maximum amount of supplies for the needs of the national economy consists of 3046 monetary units and is achieved when  $t' = t_0 + 6$  years. This can be clearly seen in the following Figure 4, which shows the dependence of the achievable objective functional value from a control variable  $J(t')$  in the framework of the original example.

It is important to emphasize that this diagram provides visual imagery of the benefit obtained in comparison with the “naive” strategy of immediate refusal from export



**Figure 2.** Dynamics of changes in production capacity, supply to the domestic and foreign markets, revenues and profits (example).



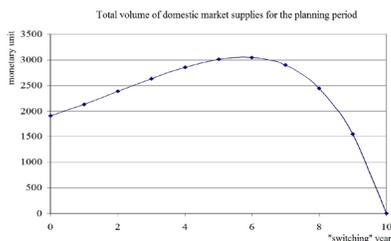
**Figure 3.** Dynamics of changes in investment flows from companies' own funds and the state budget (example).

supply in favor of supplies exclusively to the domestic customers. Technically, this naive strategy is characterized by the following  $t' = t_0$ , i.e. right from the beginning of the planning period; the products are supplied only to the domestic market. In Figure 4, the benefit is almost 60% - it is possible to that extend to finally increase the product supply for domestic customers, if in the first 6 years of the planning period the priority is given to export sales, getting deficit foreign currency resources to import the necessary production equipment. Thus, the effectiveness of the considered strategy is evident when comparing the initial point of the chart  $J(t_0)$  and its highest point  $J(t'_*)$ .

After that, it is advisable to carry out a parametric analysis of the characteristics of solution of control problem examined here in the same form as they are presented in Figure 4, i.e. in the form of dependency diagrams  $J(t')$ . It is possible to present on one picture a set of such diagrams for different values of key parameters that allows showing the influence on the optimal "switching" time, as well as on the maximum amount of high-tech products supply for domestic customers achieved in this case.

### 4.3 Analysis of the Exchange Rate Influence on the Optimal Export Strategy

First of all, it is interested to consider the influence of the exchange rate studied in this paper, because it was his double growth that led to a sharpening of the contradictions between the export supplies and the satisfaction of the Russian market demands. The Figure 5, in addition to the diagram shown in the previous Figure 4 and obtained when  $e(t) = 60$  RUB/USD,  $t = t_0 + 1; \dots; t_0 + T$ , also shows similar diagrams obtained in conditions when  $e(t) = 50$  RUB/USD and  $e(t) = 70$  RUB/USD all other conditions being equal.

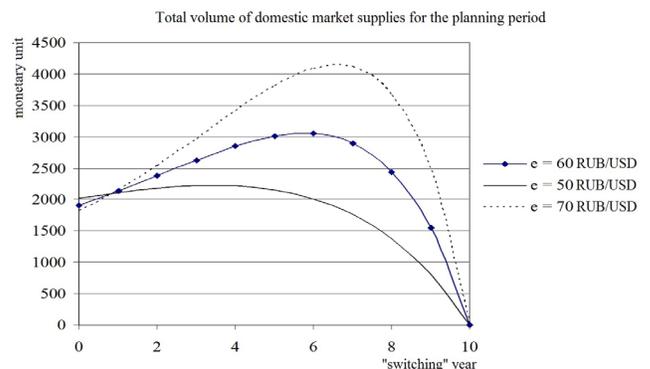


**Figure 4.** Dependence of the total volume of product supplies to the domestic market from the time of "switching" from preferential export to the domestic market supplies (example).

Comparison of these diagrams shows that the optimal time of "switching" between the export supplies and satisfaction of the needs of internal customers in case of increase in the exchange rate (i.e. depreciation of the ruble) is shifted to the right (which means that it is advisable to work longer mainly for export), and the maximum attainable volumes of production supplies to the domestic market get increased, as well as relative benefit comparing to the "naive" strategy. In this case, this is due to the fact that in case of such values of model parameters which are specific to the aviation industry, the depreciation of the ruble is profitable for it, despite the extreme vulnerability associated with the fact that most of the equipment is imported. However, high capital productivity makes it possible to quickly return the investment made in the imported equipment even at the increased prices. In other sectors of high-tech industry characterized by different values of the capital-output ratio, the situation may be different. In addition, it is assumed in this context that there is no limited demand in export markets, whereas in reality Russian companies, including aircraft manufacturers, have long been facing them.

### 4.4 Analysis of the Planning Period Duration Impact on the Optimal Export Strategy

The optimum solutions depend also from the duration of the planned period, that is, in fact, from the date by which domestic consumers should be, if possible, equipped with modern high-tech products. The real planning of industrial development is carried out in conditions when



**Figure 5.** Dependence of the total volume of product supplies to the domestic market from the time of "switching" from preferential export to the domestic market supplies (analysis of the exchange rate influence).

this deadline is unknown. In Figure 6, in addition to the diagram shown in Figure 5 and obtained when the duration of the planning period  $T = 10$  years, we can see the diagrams obtained with other factors being equal (including the exchange rate  $e(t) = 60$  RUB/USD,  $t = t_0 + 1; \dots; t_0 + T$ ), but when  $T = 8$  years and  $T = 6$  years.

Thus, the shortening of the planning period leads to a shift of the optimum moment of “shift” to the left, and the achieved value of the volume of domestic market supply (as well as the gain on the “naive” strategy) is declining rapidly, which is intuitively expected due to tightening of the conditions.

#### 4.5 Analysis of the Influence of the Highest Attainable Benefit from the Restrictions Imposed on the Minimum Proportion of Supplies to the Foreign and Domestic Markets

This is a general property of solutions of optimization problems: from the point of view of decision-makers, the tougher restrictions, the worse achievable results are, even the optimal ones (because the tightening of restrictions narrows the field of possible options, and, if some control actions are permitted after restrictions tightening, they were already acceptable before that and, therefore, it was possible to achieve at least the same result). Therefore, it is reasonably expected that the taking into account of restrictions on the minimum supply volumes will influence the optimal solution. Suppose, for example, throughout the planning period the supply of high-tech products to

domestic consumers makes at least a half of the volume of

$$\text{production: } q_{DOMESTIC}(t) \geq q_{DOMESTIC MIN}(t) = \frac{1}{2}q(t),$$

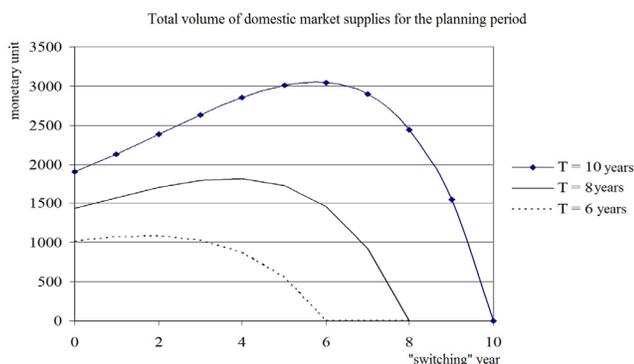
$t = t_0; t_0 + 1; \dots; t_0 + T$ , and export supply makes at least 25% of the volume of production, even after the moment of

$$\text{“switching”, i.e. } q_{EXPORT}(t) \geq q_{EXPORT MIN}(t) = \frac{1}{4}q(t),$$

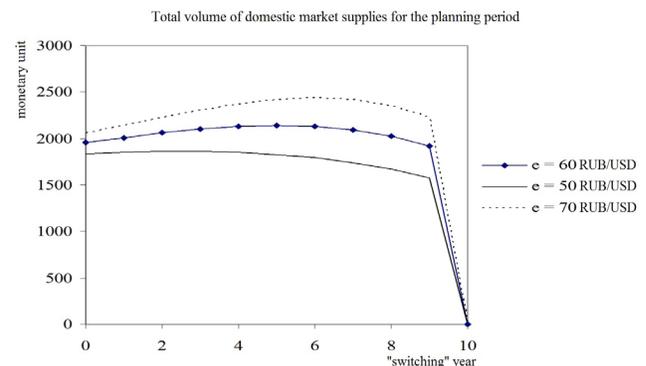
$t = t_0; t_0 + 1; \dots; t_0 + T$ . The following figures 7 and 8 represent diagrams, similar to those in the above Figures 5 and 6 showing the influence of the exchange rate and the duration of the planning period, but received with account to restrictions on the distribution of sales between the domestic and foreign markets.

As can be seen from these graphs, the relatively important benefit comparing to the “naive” strategy (which now includes not complete refusal from export, but only its restriction by 25% from the total production output from the very beginning of the planning period) is achieved only when  $e(t) = 70$  RUB/USD,  $t = t_0 + 1; \dots; t_0 + T$ , and makes about 19%, when “shifting” to the 6th year of the planning period.

Figure 8 shows that even in case of the longest planning period  $T = 10$  years, the maximum benefit achieved is below 10% comparing to the “naive” strategy (when “shifting” to the 5th year of the planning period). These results are understandable, as examples in Figure 7 and 8 correspond to a very narrow “corridor” of possible control trajectories: in fact, the share of exports in total production output was allowed to be varied from 25% to 50%.



**Figure 6.** Dependence of the total volume of product supplies to the domestic market from the time of “switching” from preferential export to the domestic market supplies (analysis of the planned period duration influence).

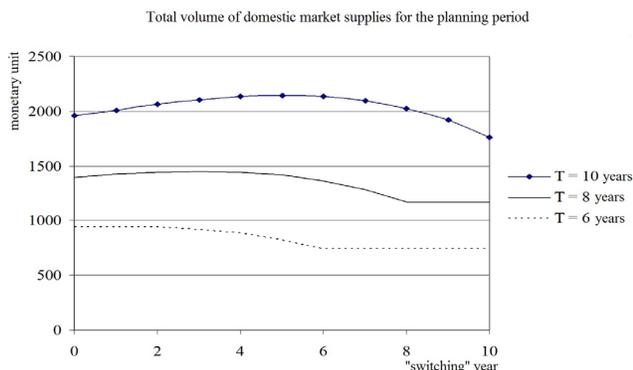


**Figure 7.** Dependence of the total volumes of supply of products to the domestic market from the time of “switching” from preferential export supplies to the domestic market supplies (analysis of the influence of exchange rates; restrictions on the supply structure).

## 5. Discussion

Thus, with the help of built economic and mathematical models the authors have shown that the initial hypothesis regarding the reasonability of a temporary increase in the share of exports does not contradict the results of the calculations under a wide range of conditions. This hypothesis has not been considered previously in famous works devoted to the export policy. The optimal control tools have been also used for the first time for the development of optimal export strategy in the context of limited production capacities and exchange rate changes. Of course, the practical application of optimal export strategy discussed here requires the availability of a comprehensive long-term plan (for a period of about 10 years), the implementation of which would be guaranteed regardless of any short-term changes, including the ones significant for the industry.

At the same time, it is important to study the issue of the optimal dynamic strategy with due account of current changes in the parameters of the model proposed here. What actions should be taken if, for example, in the course of implementation of an elaborated optimal strategy the exchange rate (or, at least, the forecast of its dynamics) gets changed, or, it turns out that the planning period is reduced, and it is necessary to satisfy the domestic market demand in deficit products within a more compressed time frame? In a first approximation, we can say that at each time step, based on new forecasts regarding the main parameters of the model, it is necessary to rebuild the export strategy using the tools offered here. In other words, the developed methods and models shall be used



**Figure 8.** Dependence of the total volumes of supply of products to the domestic market from the time of “switching” from preferential export supplies to the domestic market supplies (analysis of the influence of planning period duration; restrictions on the supply structure).

in rolling forecast mode, flexibly responding to changes in actual conditions and prognosis of their dynamics.

## 6. Conclusion

Despite the urgent need to meet the demand of the Russian economy and social sphere in the modern high-tech products, it may be appropriate for the first few years of the medium-term period (5-10 years for the aviation industry) to give priority to export sales, which will allow faster obtaining the necessary currency for production equipment import and increasing production capacity. The implementation of such a strategy makes it possible to increase the total volume of supplies of high-tech products for the needs of the national economy and social sphere of the country (compared to immediate maximization of supplies for domestic customers) by 20-60% depending on the exchange rate increase, the duration of the planning period and the minimum permissible level of the product supply to the domestic market and for export. Parametric analysis of optimal solutions has shown the following:

- In the case of increase in the exchange rate (i.e. depreciation of the ruble), the optimal time of “switching” between the export deliveries and supplies for the needs of internal customers is shifted to the right (so, it is advisable to work longer mainly for export), and the maximum attainable production volumes of supplies to the domestic market become increased.
- When the duration of the planning period is increased, the best time of “switching” between the export deliveries and supplies for the needs of internal customers is shifted to the left, and the maximum attainable production volumes of supplies to the domestic market become reduced.
- If the minimum acceptable percentage of supply of products to the domestic market during the planning period is 50%, and export supplies make 25%, the maximum achievable benefit for a 10-year period is of no more than 10-19% when the exchange rate increases 2-2.5 times relative to the initial level.

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