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THE PECULIARITY OF PLANNING THE PRODUCTION OF INNOVATIVE PRODUCTS

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A B S T R A C T

Most companies understand that the only way to ensure continuous competitive advantage is the constant creation and launch of innovative products on the market. However, when implementing the processes of creating new products, companies face problems in forecasting and strategic planning, since the markets of innovative products are characterized by various kinds of risks, many of which are uncontrollable.

The purpose of this study is to study the impact of changing consumer requirements on the technical and economic parameters of the products being created.

The authors propose a mathematical model of cascade diffusion, taking into account the above relationship, as well as the degree of consumer involvement in the development process and the rate of change in the quality requirements of the product.

The model makes allow to increase the efficiency of planning the innovation process, using a formed strategy for developing new products.

1. INTRODUCTION

The basis of modern research in the field of planning the technical and economic new products parameters is the theory of Evert Rogers. In his theory, it is proposed to differentiate consumers of innovative products into five basic groups: innovators, early adopters, early majority, late majority, and laggards, which has received a modern understanding (Rogers, 2003; Lundvall, 2010; Mahajan & Wind, 1985).

Later, this theory formed the basis of the mathematical model proposed by F. Bass. Unlike Rogers, he proposed to distinguish only two categories of consumers according to the principle of attitude to new products - innovators and imitators. Among the factors that determine the speed of bringing new products to the market, Bass attributed interpersonal communications and advertising. The Bass model (F.M. Bass, 1969) is universal in nature that is, regardless of the specifics of the product (product parameters), the sales volume versus time curve will always be «bell-shaped».

A further development of this theory (Moore, 2013, Leydesdorff, 2006;) was the introduction of the concept of a gap in the adoption and dissemination of new technologies.

According to the results of the analysis of a number of empirical data on sales of new products related to the category of electronics, the authors (Goldenberg, 2002; Mejía, 2015) found that in almost half of all cases, the sales curve shows a moment of decline in volumes up to 20% from the initial peak, which in the short term are restored again. Up to previous volumes and even exceed it. This phenomenon is called «saddle». This study confirmed the presence of two large consumer markets:

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innovators and followers, the gap between which causes a decrease in sales, and also indicated the influence of two or more developments on each other, depending on their parameters.

A fairly large number of works have been devoted to the development of mathematical models for the commercialization of new products. Many of them aim to concretize and expand the Bass mathematical model by introducing new variables into it.

Thus, in Khasanov (2016), a modified Bases mathematical model is proposed, which makes it possible to reflect the spread of new products in the regions of Russia using the example of cellular communications. The resulting model led to the conclusion that the speed of entering the market is determined by the methods of information dissemination about new products and the maximum capacity of the market. However, as the authors note, the model gives good approximation results in the analysis of disruptive innovations, but using the model it is impossible to estimate the change in speed as a result of the introduction of improving innovations to the market. The proposed model does not allow using it for strategic planning of a product portfolio.

Modern modeling tools make it possible to build simulation models for the development of new products that best meet the real conditions. For example, in Zemtsov and Baburin (2017), Günther (2016) a simulation model was built based on the Bass model in the Any Logic software environment. The main parameters that determine the speed of entry into the market are the effectiveness of advertising and the power of the buyer persuasion, who has already used the product, when communicating with another potential buyer. These parameters are set as constant values and are determined by an expert. This model allows you to explore the relationship between advertising costs and the speed of commercialization in order to optimize it further. However, this model also does not take into account the impact of entering the market of innovation modifications.

Similar problems are solved in Penkova et al. (2018), where the main goal of the study is to obtain a mathematical model for estimating the expected discounted cash flow from the implementation of innovations over the entire life cycle. At the same time, the mutual influence of the basic and improving innovations is evaluated, which makes it possible to explain the processes of leaving the goods from the market as a result of the release of the modification. The model has a fairly generalized form and does not include important parameters that quantify the factors that stimulate innovation processes.

A different approach is proposed in Tsvetkova et al. (2017), where the simulation model is based on econophysical analogies, namely, on the analogy between the processes of innovation dissemination, which is described by Fick's laws. Based on this analogy, a mathematical model for the commercialization of innovations is obtained, in which the determining factor is the diffusion coefficient. This model allows taking into account the mutual influence of basic and improving innovations when bringing them to the market, as well as planning the moment of their launch, which makes it possible to use it in the strategic management of the company's project portfolio.

2. METHOD FOR DETERMINING THE TECHNICAL AND ECONOMIC PARAMETERS OF PRODUCTS

As shown earlier, most models for predicting the volume of new products sales in the market differ in approaches that explain consumer behavior. The models where the adoption of a product by various consumers categories obeys an exponential law (the so-called S-curves) are most widely used. Evidence of such a generalized pattern is given in a significant number of publications, for example (Yakimov, 2010).

When forming a digital model of the innovation dissemination process, it is more expedient to talk about the information and diagnostic type of the model, which allows monitoring, sorting, adaptation, analysis of deviations, failures and abnormal behavior of the process, that is, the need to create a digital shadow for predictive analytics (Association «Technet», 2019). To build such models, it is required to use the methods of a systematic approach and optimization modelling (Minakov et al., 2012).

The implementation of products based on new technologies (Sokolovo Foundation, 2019) shows that there are periods of decline against the background of sales growth. This change is in the form of a «saddle», such as that shown in Figure 1, indicates that the development of any technology has a similar nature, which is associated with several factors:

- Increasing the speed of information dissemination due to the development of IT technologies;
- Reducing the cost of technology;
- Increasing the degree of automation of production;
- The size of the develops new products company;
- The level of competition in the industry;
- Growth rate of the company;
- Intercompany partnership and cooperation;
- The cost of using the technology;
- Technical and economic indicators of products formed by technology;
- Human capital.

Within the framework of the study, a method was proposed for determining the requirements for technical and economic parameters of the new products quality being developed (Moskalev & Tsygankov, 2021).

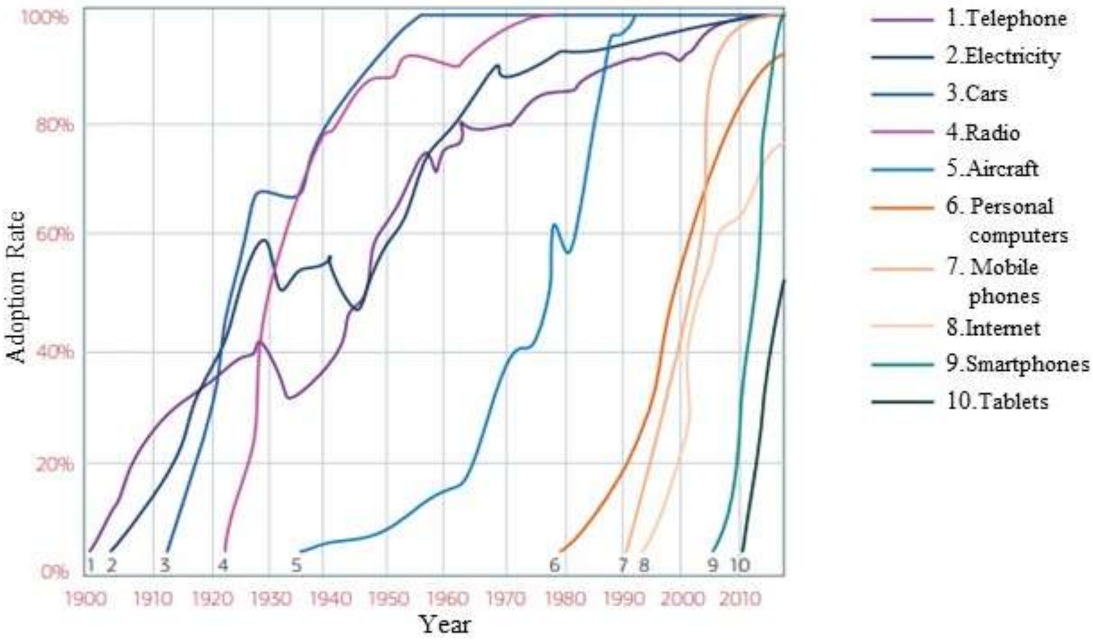

Figure 1. The degree of adoption of consumer technologies over the past 110 years

Its method is based on a mathematical model for estimating the cumulative sales volume of various modifications of new products depending on the time of their release, the announcement of the release, as well as the technical characteristics of this product.

The model has the following form:

$$Y_t = V_0 * \left(1 + \frac{e^{(p_0 - r_0 * t)}}{k_0}\right)^{-1} + \sum_{i=1}^{n} V_i * \left(1 + \frac{e^{(p_i - r_i * t)}}{k_i}\right)^{-1} \times$$

$$\times \begin{cases} (1 + h_i), & (p_{i+1} - S > p_i + R \geq t \geq p_i) \\ (1 - h_i), & (p_{i+1} - S \leq t \leq p_{i+1},) \\ 1, & (p_{i+1} - S > t > p_i + R \ \ or \ t > p_i) \end{cases}$$

where Y(t) – the cumulative sales volume of all product modifications at a certain point in time t (day, month, quarter, year),

V_i – available share, taking into account the commercial model and competition of the i-thproduct model (SOM model), mlnroubles or in kind,

p_i – time period for the start of sales of the i-th model of the product (day, month, quarter, year),

r_i – diffusion coefficient of the i-th model (derived from empirical data, in particular fromthe optimization model built in AnyLogic based on retrospective data). This indicator is a combination of the impact of advertising on product consumers and their interpersonal communication,

t – time period (day, month, quarter, year),

k_i – constant characterising the curvature of the propagation velocity of the i-th model (day, month, quarter, year),

h_i – coefficient describing the planned lag of the current product model compared to the next product model in terms of technical parameters and price. This indicator affects the declinein sales when the next model is announced,

S – date when the next product model will be announced with regard to the planned date(days, months, quarters, years),

R – period of increased demand for the product according to the price-performance ratio(days, months, quarters, years). Determined on the basis of market characteristics and the niche of the product in question.

The block diagram of the algorithm of the method is shown in Figure 2.

At the first step, we determine the analyzer model of the 3D printer and its modifications, and then set a number of initial data:

- Planned market size for each modification (Vi);
- start of sales of modifications (pi);
- Actual and planned diffusion coefficient (ri). Determined based on sales data. This indicator is a combination of the advertising impact of and interpersonal communications of product consumers;
- Actual and planned curvature of change in the growth rate of sales volume (ki).

Then, based on the analysis of the enterprise's statistical data on sales of a certain type of 3D printer in the market, an average period is established during which the products are in high demand.

At the third step, the average period between the date of the announcement of the release of a new modification of the 3D printer and the date of the actual start of sales is determined. During this period, in its first half, there is an active surge in demand for modification, which is associated with the activities of consumers from the group of «innovators» (Rogers, 2003).

The next step is the selection of key quality parameters for the analyzed type of 3D printer.

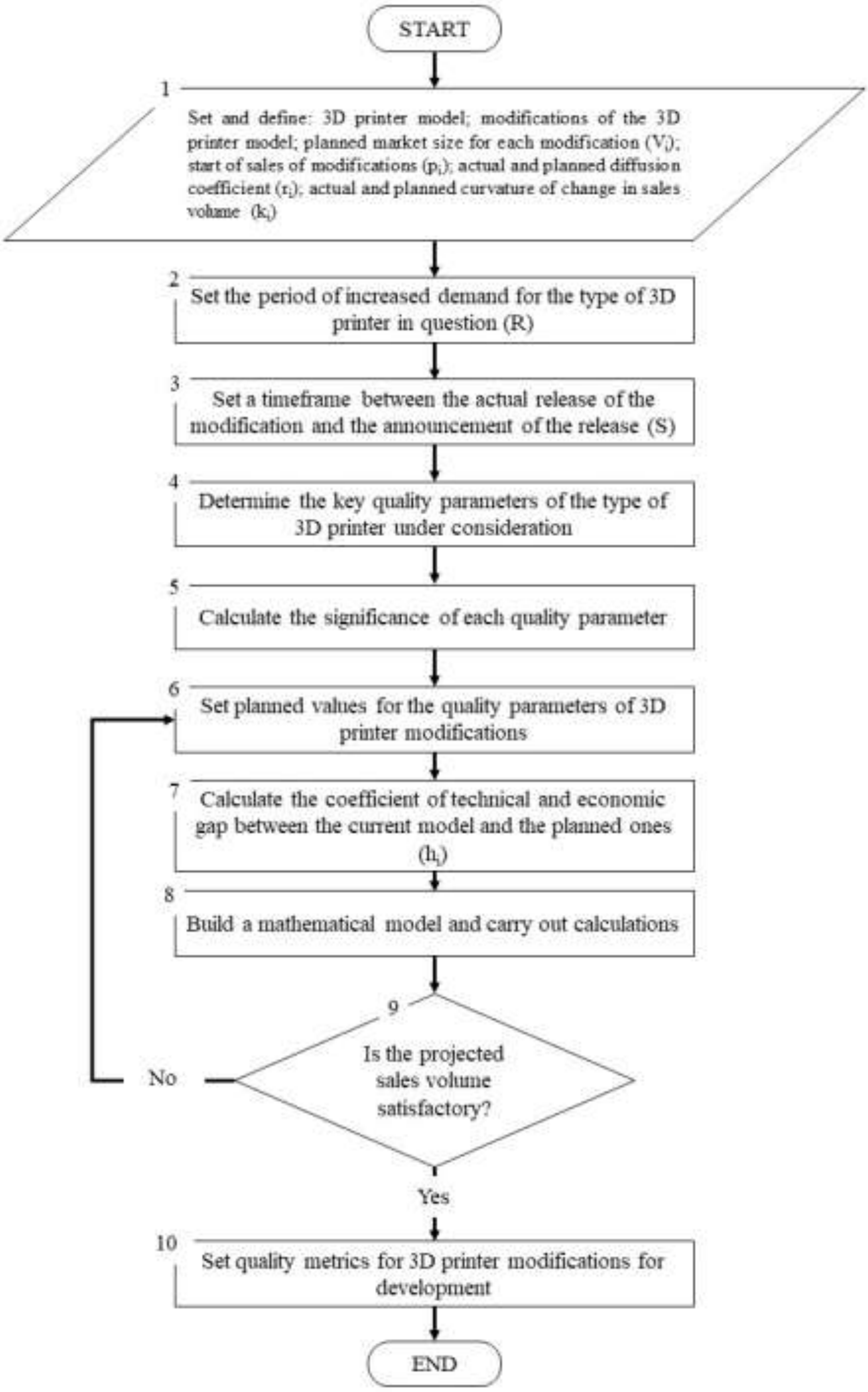

Figure 2. Diagram of the method for determining the requirements for the technical and economic parameters of the quality of 3D printers

As part of the fifth step, the significance of each of the quality parameters selected in the previous step is calculated. For this purpose, an expert approach is used in the absence of statistical data, which is typical for most innovative products. If there is enough data, then the best solution is to use the methods of neural network analysis.

Then, for each modification of the 3D printer, planned indicators are set for all key quality parameters that are expected to be achieved as a result of their development.

The sixth step, the coefficient of the technical and economic lag of the current modification of the 3D printer from the subsequent ones (hi) is calculated. This indicator affects the decrease in sales when the next model is announced.

To determine hi, it is required to evaluate the ratio of price and quality of product modification relative to previous modifications, taking into account the interval between the outputs of modifications according to the following formula:

$$h_i = \left(\frac{\sum_{j=1}^{m} \left(\frac{E_{j,i+1}}{E_{j,i}} - 1 \right) * g_j}{\left(\frac{C_{i+1}}{C_i} - 1 \right)} - 1 \right) * \frac{1}{(p_{i+1} - p_i)} * 100\%$$

where C_i is the market price of the i-th product modification, rubles;
$E_{j,i}$ – value of the j-th parameter of the i-th product modification. Each parameter is expressed in its own units of measurement. If there is a parameter that characterizes improvement when the value decreases, the inverse ratio should be used, i.e. $E_{(j,i)}/E_{(j,i+1)}$;
m – the number of parameters used to characterise the product;
g_i– weighting coefficient for the j-th parameter of the product. It is recommended to use the results of market analysis (trends, customer requirements) or the Delphi method to calculate it.

At the eighth step, calculations are carried out in accordance for the entire period under consideration using automated tools with the possibility of subsequent analysis.

Then the results obtained and their compliance with the strategy and plans of the enterprise are evaluated. If necessary, a search is made for the optimal quality parameters of the 3D printer modifications planned for development. The goal of optimization may be to reduce requirements while maintaining the potential sales volume, taking into account the company's production capacity. Another goal is to conduct a scenario analysis depending on the timing of the release of products, the price and quality of the products being developed.

At the last step, we obtain the final values of the required quality parameters of the products planned for development, as well as the required price ranges.

3. RESEARCH ON THE IMPACT OF CONSUMER REQUIREMENTS

Consider the application of the proposed mathematical model on the example of sales of Hercules 3D printers for the period from 2014 to 2023, affecting 33 quarters based on the data on the cumulative sales volume received from the IMPRINTA company.

During the period under review, the company developed and commercialized 6 models of 3D printers from one line. The analysis considered products that are designed for one category of consumers and are similar or replacing each other. An analysis of the commercialization process for each individual 3D printer model made it possible to identify the main parameters for the model, which are presented in Table 1.

Table 1. Quality parameters of extrusion 3D printers

Printer modification	Parameters						
	V_i, pcs.	P_i, quarter	r_i	k_i	h_i, %	R, quarter	S, quarter
First modification (i=1)	48	1	1	1,1	14%	3	3
Second modification (i=2)	550	7	0,74	0,72	-8%		
Third modification (i=3)	900	13	0,72	0,85	-6%		
Fourth modification (i=4)	200	22	0,79	1,3	1%		
Fifth modification (i=5)	480	30	0,88	0,7	-17%		
Sixth modification (i=6)	250	31	0,826	0,934	-7%		
Seventh modification (i=7)	100	43	0,826	0,934			

As a result of studying existing desktop and professional extrusion 3D printers, feedback from users of this equipment, as well as based on the results of a survey conducted by IMPRINTA company, it was found that the following are the main product parameters: chamber volume; print speed; minimum layer thickness; printing temperature; the presence of a heated chamber; number of extruders. In addition, their significance coefficients were determined. The results are presented in Table 2.

The results of applying the model with the identified parameters are shown in Figure 3.

The model error was 5.12%, but one can observe a deviation from the actual data when the third and fourth models of the 3D printer are released, which is associated with external market factors, namely the lack of analogues in terms of price and quality among competitors compared to the third model of the 3D printer, which positively affected the sales of the model. There were some minor technical problems at the launch of the fourth model, which led to a simultaneous increase in sales of the previous model of the 3D printer.

Consider the impact of consumer preferences when they change significantly with the release of each model. To do this, we take two extreme situations:

1) All changes in 3D printer models do not coincide with consumer preferences;

Table 2. Quality parameters of extrusion 3D printers

Parameter	Coefficient	Model №1	Model №2	Model №3	Model №4	Model №5	Model №6	Model №7
Chamber volume, liters	0,2	5,832	8	8,4	8,4	18	72	216
Print speed, cm^3/hour	0,2	40	50	50	100	162	162	162
Minimum layer thickness, microns	0,2	50	50	20	10	10	10	10
Printing temperature, degrees Celsius	0,2	260	260	260	410	420	420	420
The presence of a heated chamber (0 - no, 1 - yes)	0,1	0	0	0	0	0	1	1
Number of extruders, pcs.	0,1	1	1	1	1	1	1	1
Price, thousand rubles		60	64	104	219	289	499	1 590
Release quarter		1	7	13	22	30	31	43 (plan)

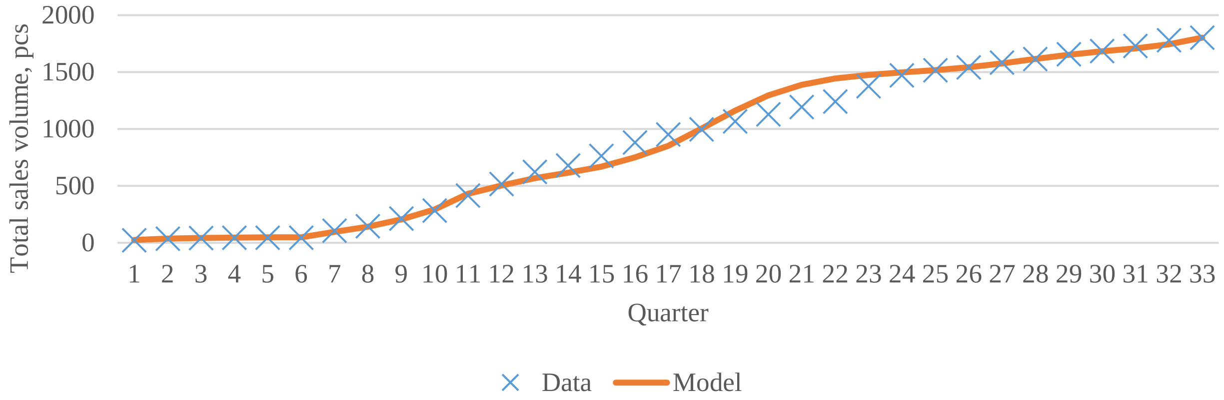

Figure 3. Results of applying the diffusion model

2) The company's products are developed in full accordance with the requirements of consumers, at least in one of the most improved parameters.

The results of the changing significance coefficients are presented in Table 3.

As a result of applying the modified coefficients for each product modification, we get 2 models, which are shown in Figure 4 together with the base model, where the base model is model №.1, the model in accordance with case 1 from table 3 is model № 2, the model in accordance with case 2 from table 3 - model №3.

As a result of the simulation, 3 areas were identified where the largest deviation is observed - with the release of 2, 3 and 5, 6 models of a 3D printer. At the same time, it can be seen that with full compliance of product improvements with consumer requirements, an accelerated diffusion process of up to 43% is observed.

However, with the release of models 5 and 6 of the 3D printer in the 30th and 31st quarter, there is a completely opposite situation associated with the almost simultaneous release of products and such a rapid change in consumer preferences. The forecast for the period of 8 quarters shows that, depending on the changing preferences of the consumer, an increase in the absolute amount of the cumulative sales volume up to 62 units of products is possible. When this event occurs, the enterprise should be able to increase production capacity to cover additional demand.

The analysis performed shows that companies, when releasing substitutes or analogues of products, the influence of consumers can have a significant impact on the rate of commercialization, even without taking into account the impact on other external factors, for example, the possible size of the market, which is also confirmed in a number of other studies (Yu et al., 2015; Antipov et al., 2020).

Table 3. The value of preferences (coefficients) at the time of release of models

Parameter	Model №1	Model №2	Model №3	Model №4	Model №5	Model №6
Case №1 - Preferences are completely out of alignment with product improvement direction						
Chamber volume, liters	0	0	1	0	0	0
Print speed, cm^3/hour	0	0	0	0	1	1
Minimum layer thickness, microns	1	0	0	1	0	0
Printing temperature, degrees Celsius	0	1	0	0	0	0
The presence of a heated chamber (0 - no, 1 - yes)	0	0	0	0	0	0
Number of extruders, pcs.	0	0	0	0	0	0
Case №2 - Preferences fully coincide with the direction of product improvement						
Chamber volume, liters	0,3	0	0	1	1	1
Print speed, cm^3/hour	0,3	0	0	0	0	0
Minimum layer thickness, microns	0,3	1	0	0	0	0
Printing temperature, degrees Celsius	0	0	1	0	0	0
The presence of a heated chamber (0 - no, 1 - yes)	0	0	0	0	0	0
Number of extruders, pcs.	0	0	0	0	0	0

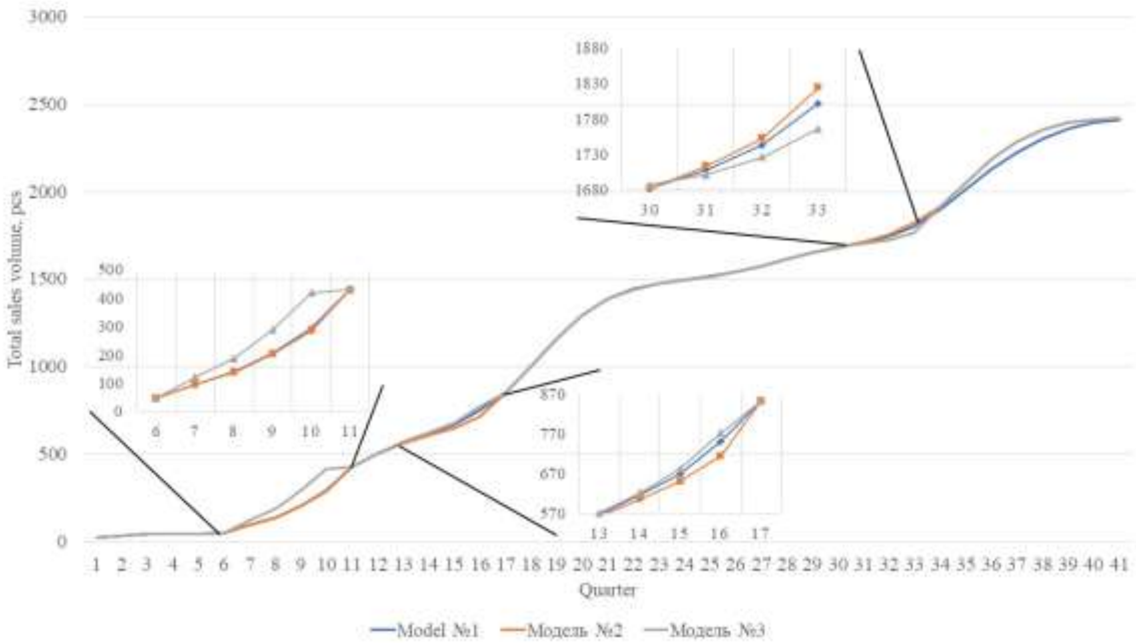

Figure 4. Changes in cumulative sales volume in extreme cases of changing consumer requirements

Which suggests that in the face of changing product requirements, enterprises should plan and organize the development process in such a way as to be able to:

- To improve all technical parameters of products to reduce the negative impact in the event of a change in preferences;
- Make changes to products at any stage of development without a significant increase in time and financial costs;
- Reduce uncertainty in understanding consumer preferences by embedding consumers in the development process (getting feedback, increasing the number of product testing stages, etc.).

4. CONCLUSION

Based on the proposed model of cascade diffusion, which takes into account the mutual influence of innovative products based on their technical and economic differences and the time between release, the authors analyzed the impact of changing consumer requirements on the diffusion process using the example of 3D printers of the IMPRINTA company. The error of the resulting model was 5.12%.

The results obtained indicate the need for enterprises to form a strategy for development and commercialization, taking into account various demand scenarios for products, depending on the susceptibility of consumer preferences to change. Depending on the degree of changes in the company, the risks of developing in-demand products and achieving sales targets for new products increase.

Further research in this area requires expanding the boundaries of the model and including in the considered contour the influence of consumer requirements on the available market volume, depending on the degree to which they correspond to the direction of changes in the product.

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