The object of this study is the process of analyzing the volume of product sales in the retail market, where producers and consumers with different levels of social responsibility operate. Advancements are aimed at solving the problem of insufficient consideration of the social responsibility of economic entities in modern economic and mathematical models. In the work, the improvement of the linear programming model, intended for the evaluation of sales of alternative variants of goods with different social utility to consumers with different social responsibility, by taking into account some real conditions of making purchases, was carried out. As a result of the study, a modification of the model was proposed that makes it possible to take into account the behavior of buyers who choose a product randomly. Also, with the help of additional restrictions, the model takes into account the fact that consumers with different social responsibility make purchases in parallel in time. In addition, the approach to identifying a set of consumer groups in the aspect of social responsibility using the method of questionnaires of the ranking type and building a decision tree of consumers is described.

The proposed modification of the model was tested on the example of evaluating the sales volumes of environmentally-friendly and non-environmentally-friendly varieties of goods in the office paper market. It is shown that not taking into account the added restrictions in the model could significantly affect the estimates of sales volumes.

The proposed improvements to the model make it possible to obtain more realistic estimates of the volume of sales of goods, taking into account the social responsibility of consumers, as well as quantitative and qualitative characteristics of competitors' offers. This contributes to better decision-making support for manufacturing socially useful products, in particular, environmentally-friendly ones

Keywords: environmentally-conscious consumption, environmentally-friendly products, sales structure in the market, linear programming

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IMPROVING LINEAR PROGRAMMING MODEL FOR ASSESSING PRODUCT SALES TAKING INTO ACCOUNT SOCIAL RESPONSIBILITY OF CONSUMERS

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1. Introduction

The spread of the ideas of sustainable development, Triple Bottom Line principles, and the concept of corporate social responsibility led to the fact that the decisions of many economic entities began to be influenced by the requirements for social responsibility, in particular environmental friendliness [1]. Therefore, the factor of social responsibility should be taken into account in modern mathematical models for decisions and behavior of economic entities.

The social responsibility of the subject has two main aspects [2, 3]:

a) social responsibility as social accountability, which causes sanctions for actions of the subject that are contrary to the interests of society (normative aspect of social responsibility);

b) social responsibility as a personal property associated with the subject's awareness of his/her influence on society and intentions to take this influence into account (internal aspect of social responsibility).

Social responsibility as a property of an individual is manifested in the preferences of this individual and affects his/her choice among alternatives that differ in their social usefulness, i.e., compliance with the interests of society. The subject's preferences can be formalized using a utility function, a set of criteria for evaluating alternatives, or a vector of priorities for a set of alternatives. The higher the social responsibility of the subject, the greater the positive influence on his/her choice exerted by the socially significant characteristics of alternatives.

The task of identifying and formalizing the social responsibility of economic entities is important not so much in itself but for the purposes of modeling the decisions of these subjects. At the same time, the models must take into account both the social responsibility of decision-makers (DMs) and the social responsibility of their counterparties. The consequences of socially responsible behavior of DMs often depend on the social responsibility of counterparties. Regarding enterprises, this means that their ability to fulfill the requirements of corporate social responsibility depends to some extent on competitors and buyers [4]. Buyers can support or not support the company's social activities with their consumer choice. They may or may not buy an environmentally friendly product. And competitors can attract consumers from «responsible» or «irresponsible» segments.

At the same time, numerous studies, in particular [5–7], show that consumers differ significantly in their social responsibility, which depends on many personal and external factors. The behavior of producers and sellers also differs in terms of social responsibility [8]. As a result, consumers with different levels of social responsibility and goods with different social utility appear in the market. These characteristics of buyers and goods affect sales and therefore must be taken into account in the process of market analysis. This requires a suitable mathematical tool – models for estimating the volume of sales of products with different social utility to buyers with different social responsibility, taking into account the limited supply of products in the market. The construction of such models is an urgent task as it will provide support for decision-making regarding the production of socially beneficial products, in particular environmentally-friendly ones, taking into account the behavior of competitors and consumers in the market in terms of social responsibility.

2. Literature review and problem statement

In accordance with their purpose, models for evaluating the volume of sales of products with different social utility to consumers with different social responsibility should take into account the following factors:

1) preferences on the analyzed set of goods by consumers with different social responsibility;

2) volumes of demand from consumers with different social responsibilities;

3) volumes of supply in the market of product variants with different social utility.

The first of these factors – preferences and social responsibility of buyers and customers – is actively taken into account in modern scientific research in normative decision-making models. To take this factor into account, the models use a set of criteria that describe not only the economic but also the social and environmental consequences of the choice made. That is, the buyer is considered as a socially responsible subject who wants to take into account the interests of society, applying social and environmental criteria to evaluate alternatives. Normative models of decision-making taking into account social responsibility are used, for example, in works [9, 10]. In these works, issues of evaluation of alternatives (specifically, materials and technologies of building renovation) from the point of view of environmental friendliness are deeply investigated. The models built, according to their purpose, formalize the behavior of the buyer who is ideal from the point of view of social responsibility in the studied market. And although these advancements can be modified in such a way that they take into account the real, and not the ideal, preferences of buyers, this is not enough to solve the task of estimating product sales volumes. Of the above necessary three groups of factors, normative decision-making models partially take into account only the first point. The reason for this is that these models are designed to support the decision-making of buyers, not manufacturers.

In contrast to normative models of decision-making, descriptive models of consumer choice are designed to reveal the actual preferences of consumers and their further consideration for the purposes of calculating demand volumes. Two main groups of consumer choice models can be distinguished:

1) discrete choice models, which are based on the theory of random utility and are designed to determine the choice of buyers for multiple product options;

2) models of continuous choice, which are based on the ordinal theory of utility and are designed to determine the optimal vector for the buyer of the purchase volume of goods from the consumer basket within the budget.

Discrete choice models, which are based on the theory of random utility [11], make it possible to determine the probability of buyers choosing one or another product option from a given set of alternative products, which are described by a set of characteristics. Calculations are carried out by means of regression analysis based on sample data on the preferences or choices of buyers on a set of alternative product options. Discrete choice models are widely used to analyze consumer preferences for goods that differ in their social utility and environmental friendliness. Thus, study [12] demonstrated the willingness of consumers to buy apples grown without the use of chemical pesticides and agrivoltaics. Factors that determine consumers' intentions to purchase eggs from free-range chickens were investigated in [13]. In [14], the factors influencing the demand for organic food products were studied. In particular, it was found that the probability of buying organic food products is influenced by economic, and not influenced by socio-demographic characteristics of consumers. Paper [15] identified consumer segments in the market of fish grown in natural reservoirs and taking into account other important aspects of sustainable production. All of these studies revealed the factors that influence consumer intentions, but the calculations of the demand for the studied products were not carried out in these works since such a task was not set.

At the same time, discrete choice models make it possible not only to analyze the factors of consumer choice but also to assess the demand for alternative types of products. Estimates of probabilities of consumer choice obtained by the discrete choice model characterize the structure of demand by types of goods. Thus, calculations of demand volumes and analysis of their dynamics were carried out in work [16] to forecast the demand for hybrid and electric cars. It is important that this work takes into account the diversity of consumer preferences. But no restrictions on the supply of goods or the ability of consumers to purchase them were taken into account. These questions cannot be investigated by means of discrete choice models. They require the use of other methods of analysis.

In part, the limitations on the ability of consumers to purchase goods are taken into account in models of continuous choice, which are based on the ordinalist theory of utility. In such models, the demand function is built by solving the problem of consumer choice, which consists in maximizing the utility function of the consumer basket, the arguments of which are the quantity of interchangeable goods, taking into account budget restrictions on purchases. The problem is solved analytically using the method of Lagrange multipliers based on the Karush-Kuhn-Tucker theorem (for example, in [17]). The influence of social responsibility on the consumer choice of buyers is implicitly taken into account in those cases when the problem of consumer choice considers goods that differ in their social usefulness and environmental friendliness. This approach is used, for example, in work [18] to analyze visits to national parks in Japan. The paper analyzes the quantity of park visitors for different values of the visit fee. In the proposed model, unlike normative models, the utility function is built on the basis of statistical data and reflects the real preferences of individuals (depending on their individual characteristics, such as, for example, gender and age). But restrictions on consumer choice are imposed only by the budget.

Limitations on the volume of product (service) supply are not taken into account. Other types of models are needed to take into account the competition of consumers for the desired goods under the conditions of a limited supply of products.

Thus, the described descriptive models can be applied to obtain estimates of demand for products taking into account the social responsibility of buyers. But they do not take into account the presence of restrictions on the volume of supply of various types of goods and the competition of consumers with different social responsibilities for the goods they like.

Descriptive models of consumer choice should be supplemented with other models to determine the volume of product sales taking into account restrictions on the supply of goods (and other factors). As a result of the literature review, examples of the use of consumer choice models together with optimization planning models were found. Work [19] presents a system of models that combines an improved model of consumer choice (generalized product attractiveness model) and an optimization model of linear programming designed to calculate optimal sales volumes. The variables of the model are the volumes of sales of products (services) in terms of types of products and market segments. The objective function is sales revenue. Consumer preferences, demand volumes, and product supply are taken into account in the model constraints. The proposed system of models is intended for use in the field of revenue management. In [20], a similar system of models is proposed to optimize the sales of a multi-channel retailer that sells a number of interchangeable products from which customers choose no more than one option. The variables of the linear programming model are the volume of product sales through different channels. The objective function is the maximum profit from sales. Consumer preferences are also factored into the model's constraints. Works [19, 20] are an example of combining the model of consumer choice with the optimization model of linear programming. But in these works, the activity of an individual company is considered, and the models are designed to calculate the optimal sales structure of the company. There were no examples of similar works designed for market analysis taking into account the social usefulness of competitors' goods.

Study [21] proposed an approach based on the construction of a linear programming problem in which the total utility function of consumers' choices in the market is maximized to solve the task of evaluating the structure of sales volumes in the market, taking into account the aspect of social responsibility. At the same time, limitations on the volume of demand from different groups of consumers and limitations on the volume of supply of alternative product options are taken into account. Solving this problem makes it possible to determine the option of distributing the volume of goods between buyers, which is optimal according to the criterion of maximum total utility for the totality of buyers in the market under conditions of limited supply. But the disadvantage of this approach is that it describes reality in a very simplified way and does not take into account the actual conditions of making purchases, as a result of which the sales structure obtained as a result of calculations turns out to be too ideal for the real world. In particular, the approach does not take into account the fact that the sales process takes place over time, and a specific unit of the product is bought by the one who previously chose it, and not by the one who needs it more.

Therefore, according to the results of the literature review, it was found that the approach proposed in [21] is the most suitable among others for solving the task of modeling sales in the market, taking into account the aspect of social responsibility. But in order for this approach to be applied in practice, it needs to be improved by taking into account the real conditions for making purchases.

3. The aim and objectives of the study

The purpose of this study is to improve the linear programming model, designed for evaluating sales of product variants with different social utility to consumers with different social responsibility, by taking into account the real conditions for making purchases. This will make it possible to obtain more realistic estimates of future sales of socially beneficial products.

To achieve the goal, the following tasks were set:

– in the considered linear programming model, formalize the set of consumer groups with different preferences for the set of analyzed goods;

– formalize in the model certain aspects of shopping by consumers with different social responsibility (in particular, devise a way to take into account in the model a realistic sequence of purchases over time, as well as the behavior of buyers who equally evaluate the usefulness of several product options);

– test the improved model on the example of the office paper market.

4. The study materials and methods

The object of the study is the process of analyzing the volume of product sales in the retail market, where producers and consumers with different levels of social responsibility operate.

The initial hypothesis of the study assumes that consumers in the market act in an optimal way, maximizing the total market utility of purchases, so for the purposes of determining the structure of sales in the market, a linear programming model could be applied.

The following assumptions were adopted regarding consumer behavior:

– consumers in the market act optimally so that their choices maximize the overall utility of purchases in the market;

– the choice made by the consumer on a set of goods can be unambiguously described by the vector of the ranking of the goods in the order of their preference for the consumer;

– buyers who equally evaluate the usefulness of several product options choose one of the equivalent options randomly, with the same probability for each option.

As noted above, this work builds on the approach proposed in [21]. This approach is as follows.

Let a certain product market includes:

1. A set of interchangeable product options that differ in their social usefulness, for example, environmental friendliness: $A=\{a_i \mid i=\overline{1,n}\}$, where a_i is a vector of characteristics of product option i. Denote the supply volume of product variant i in the market as v_i.

2. A set of consumer groups united by their preferences regarding the characteristics of product options. The preferences of each consumer on a set of product options are described by a vector of priorities (a vector of utility): $(u_i)_{i=\overline{1,n}}=(u_1,u_2,...,u_n)$. Consumers who have the same vector of utility values of goods are united in one group. The vector that describes the utility of goods from the point of view of consumers united in group j will be denoted as $(u_i^j)_{i=\overline{1,n}}=(u_1^j,u_2^j,...,u_n^j),\ j=\overline{1,m}$.

Denote the volume of demand for the analyzed product by consumers of group j as d_j. It is believed that the utility vector $(u_i^j)_{i=\overline{1,n}}$ implicitly characterizes the social responsibility of consumers of group j. The higher the social responsibility of consumers, the higher the value of priority for socially beneficial goods.

Then the distribution of volumes of product options between buyers, which is optimal according to the criterion of the maximum total utility of purchases in the market, can be determined using a linear programming model:

$$\begin{cases} \sum_i \sum_j u_i^j \cdot x_i^j \to \max, \\ \sum_j x_i^j \le v_i, i = \overline{1,n}, \\ \sum_i x_i^j \le d_j, j = \overline{1,m}, \\ x_i^j \ge 0, \end{cases} \quad (1)$$

where x_i^j is the volume of sales of the i-th variety of products to buyers of the j-th group; u_i^j – ordinalistic evaluation of the utility of the i-th variety of goods from the point of view of buyers of the j-th group; v_i – volume of supply of the i-th variety of products; d_j is the volume of demand for the analyzed type of products from buyers of the jth group.

To verify the modification of the linear programming model (1) proposed in this study, calculations were performed using an example of the office paper market. Information on consumer preferences was collected through a ranking-type pilot survey. The applied ranking method corresponds to the above assumption that the consumer's choice of a set of products in the model could be described by a vector of product ranks. Information on types of products in the office paper market was obtained based on the analysis of relevant products at the «Rozetka» marketplace.

The proposed linear programming problem was solved using Python tools, for which a script was written using the linprog function from the SciPy library.

5. Results of investigating the improvement of the linear programming model intended for the estimation of sales volumes

5. 1. Formalization in the model of the set of consumer groups with different preferences for the set of analyzed goods

This advancement is based on the assumption that the choice made by the consumer on a set of goods can be uniquely described by the vector of product ranks $(r_1, r_2, ..., r_n)$, where $r_i \in \{1, 2, ..., n\}$ is the rank that the consumer assigns to the product i on the set of analyzed products. The rank vector actually specifies the procedure for choosing a product by the consumer: among the set of alternative products, the consumer chooses the product with rank 1; in the absence of a product with rank 1, chooses a product with rank 2, etc. The vector of ranks of goods for each consumer can be determined by means of a questionnaire of the type of ranking. Consumers who have the same rank vector on a given set of goods are combined into one group.

The vectors of utility values of goods $(u_1^j, u_2^j, ..., u_n^j)$, $j = \overline{1,m}$, which characterize group j in model (1) can be calculated on the basis of the corresponding vectors of the ranks of goods according to the formula:

$$u_i^j = f\left(r_i^j\right) / \sum_{i=1}^{n} f\left(r_i^j\right),$$

where f is a strictly decreasing function. For example:

$$u_i^j = \left(n + 1 - r_i^j\right) / \sum_{i=1}^{n} r_i^j.$$

Under the adopted assumptions, the total set of consumer groups can be determined by sorting through all possible variants of the product rank vector. But there are too many groups selected in this way, and far from all of them exist in reality. For example, for a problem with 4 alternative goods, there are only $4! = 24$ variants of the vector of ranks without repeated ranks (Table 1) and a set of variants of the vector of ranks with repeated ranks.

To reduce the number of consumer groups under consideration, it is recommended to limit to those groups in which the rank vectors correspond to the rules of consumer logic.

5. 2. Formalization in the model of certain aspects of shopping by consumers with different social responsibilities

5. 2. 1. Formalization in the model of the behavior of buyers who equally evaluate the usefulness of several product options

This advancement is based on the assumption that buyers who equally evaluate the usefulness of several product options choose one of the equivalent product options randomly, with the same probability for each option.

Since in the linear programming problem (1) consumer choice is not determined by means of probability theory but by means of utility theory, I propose to describe random consumer choice by the same means. To formalize random selection, I suggest using fictitious groups of buyers.

Table 1

Variants of the rank vector and corresponding groups of consumers for the case of four types of goods, excluding rank vectors with repeated ranks

Product rank	Group of consumers																							
	g_1	g_2	g_3	g_4	g_5	g_6	g_7	g_8	g_9	g_{10}	g_{11}	g_{12}	g_{13}	g_{14}	g_{15}	g_{16}	g_{17}	g_{18}	g_{19}	g_{20}	g_{21}	g_{22}	g_{23}	g_{24}
r_{1j}	1	2	3	4	1	2	3	4	1	1	1	1	2	4	3	4	4	2	3	4	3	3	2	2
r_{2j}	2	1	4	3	3	4	1	2	2	4	3	4	1	1	1	1	3	3	2	2	4	2	4	3
r_{3j}	3	4	1	2	2	1	4	3	4	2	4	3	3	3	2	2	1	1	1	1	2	4	3	4
r_{4j}	4	3	2	1	4	3	2	1	3	3	2	2	4	2	4	3	2	4	4	3	1	1	1	1

For example, if buyers from group k with a quantity of d equally evaluate g product variants a_1, a_2, ..., a_g, then it can be assumed that as a result of random selection, buyers in the quantity of d/g will buy product variant a_1, the same quantity of other buyers will buy product a_2 and etc. More precisely, the quantity of buyers of each product will approach the value of d/g as the quantity of the group increases. Therefore, to simulate a random choice, it is advisable to divide the consumer group k into g fictitious groups, in each of which one of the product options is preferred. But this is not enough. In the considered model, for each consumer group, not only the preferred product is specified but a full vector of ranks, which specifies the procedure for choosing a product by the consumer in the absence of some products. If there is no product with rank 1, consumers will buy the product with rank 2; if this is not there, then they will buy a product with rank 3, etc. Therefore, an additional assumption was introduced: each buyer from the consumer group k, which corresponds to a vector of ranks with the same evaluations of products a_1, a_2, ..., a_g, chooses one in the process of purchase of g items at random. At the same time, s/he demonstrates behavior that is described by one of the possible options for strict ranking of these goods. There is a total of $g!$ such options. Based on this, to simulate random selection, it is advisable to divide the members of the group k into $g!$ subgroups, the number of each of which approaches $d/g!$ where d is the quantity of group k. For example, among consumers from a group characterized by the rank vector (1 2 3.5 3.5), half of the consumers will demonstrate behavior corresponding to the vector (1 2 3 4), and the other half will behave according to the vector (1 2 4 3). That is, in the absence of the first two products, half of the consumers from this group will choose product No. 3, and half will choose product No. 4. Therefore, to simulate a random choice, it is necessary that model (1), instead of a group of consumers with a rank vector (1 2 3.5 3.5), should include 2 groups – with the rank vector (1 2 3 4) and the rank vector (1 2 4 3).

5. 2. 2. Taking into account the sequence of purchases over time in the model

In order to take into account in the model a realistic sequence of sales over time, the assumption is accepted that purchases are made with a constant intensity during the entire time period T, which is considered, and consumers from different groups make purchases in parallel in time. It is also assumed that consumers from different groups receive goods from the same sources, and therefore, if a product runs out, it will run out simultaneously for all groups of buyers.

The following follows from this assumption. If the total volume V of the supply of the product is less than the total volume D of demand for it and is equal to $\alpha \cdot D$, then the supply of this product will be exhausted in the period $\alpha \cdot T$. Then the demand from each group of buyers will be satisfied by this product at level α:

$$\frac{\sum_{i=1}^{n} x_i^j}{d_j} = \alpha,\ j = \overline{1,m}, \tag{2}$$

where

$$\alpha = \begin{cases} \dfrac{V}{D} = \dfrac{\sum_{i=1}^{n} v_i}{\sum_{j=1}^{m} d_j}, & \text{if } V < D, \\ 1, & \text{if } V \geq D. \end{cases}$$

This assumption implies restrictions not only on the total volume of purchases but also on the volume of purchases of each product.

If the volume of supply of the product i variant is less than the demand from consumer groups $j \in J_i$ that prefer this particular variant (i.e., $v_i = \beta_i \cdot \sum_{j \in J_i} d_j$, where $\beta_i \in (0; 1)$), then the demand from each specified group of buyers $j \in J_i$ will be satisfied by these goods for a share of β_i:

$$x_i^j = \beta_i \cdot d_j,\ j \in J_i,\ i = \overline{1,n}, \tag{3}$$

where

$$\beta_i = \begin{cases} \dfrac{v_i}{\sum_{j \in J_i} d_j}, & \text{if } v_i < \sum_{j \in J_i} d_j, \\ 1, & \text{if } v_i \geq \sum_{j \in J_i} d_j. \end{cases}$$

Equalities (3) set values for m variables that characterize the volume of purchases by each group of consumers of their preferred product.

To take into account the real conditions of purchase of goods, constraints in the form of equalities (2) and (3) should be added to model (1).

5. 3. Testing the improved model using an example of the office paper market

Model (1) with constraints (2) and (3) was tested on the example of modeling the structure of sales in the office paper market taking into account the environmental responsibility of consumers.

In the office paper market, there are two interchangeable versions of the product – «ordinary paper» and «environmentally-friendly paper». These product options differ in price and environmental friendliness. According to the price criterion, the usual version of the product is better for buyers. According to the criterion of sustainable development, the environmentally-friendly option is the best. According to the quality criterion, there are no significant differences between the options if they belong to the same class of paper (class A, B, or C). An analysis of the B-class office paper offer on the Rozetka marketplace revealed that 60 % of the office paper brands have an FSC or PEFC certificate, as well as the Ecolabel marking, that is, they can be categorized as eco-goods.

To test the model, a case was considered when the new company A plans to enter the equilibrium market of office paper, in which the volume of supply equals the volume of demand. Company A plans to offer eco-paper and ordinary paper in the market, each product in the amount of 10 % of the total supply of goods by other companies.

Thus, the analyzed market includes the following product variants: product 1 – eco-paper from company A; product 2 – eco-paper from other enterprises; product 3 – ordinary paper from enterprise A; product 4 – ordinary paper from other enterprises.

If all volumes of goods are evaluated as a percentage of the volume of demand, then, based on the initial data and taking into account the results of the «Rozetka» analysis, I have the following volumes of supply of goods in the market: $v_1 = 10.0$; $v_2 = 60.0$; $v_3 = 10.0$; $v_4 = 40.0$.

The task was to build a model that would make it possible to estimate the volume of products that consumers

would buy from the analyzed company A, considering the given market characteristics and buyer preferences close to actual ones.

To determine the volumes of demand from different groups of consumers, a set of such groups was first identified. This was done by analyzing the decision-making procedure of consumers of the analyzed goods. The decision tree, which describes the consumer choice according to the rules of logic on the set of the analyzed four goods, is shown in Fig. 1. Each path along the branches of this tree describes the logic of the consumer choice of one group of paper consumers. For example, representatives of group 1 choose paper, first of all, on the grounds of environmental friendliness, and among the environmentally-friendly options of the product, they prefer the paper from company A. That is, group 1 unites responsible consumers loyal to enterprise A. Group 2 unites responsible consumers loyal to enterprise B. Group 3 unites consumers who prefer cheap paper and are also loyal to enterprise A. Group 4 unites consumers who prefer cheap paper and are also loyal to enterprise B, and so on.

The given decision tree makes it possible to form groups of consumers based on three characteristics:

1) environmental responsibility.

According to this feature, buyers are divided into the following segments:

– environmentally responsible buyers (they prefer environmentally-friendly paper);

– thrifty buyers (prefer cheap paper);

– indifferent buyers (do not prefer environmentally-friendly or economic modification of the product);

2) loyalty to the manufacturer.

According to this feature, buyers are divided into the following segments:

– buyers loyal to company A (let's clarify that in the example under consideration, company A is a newcomer to the analyzed paper market and therefore does not yet have loyal customers);

– buyers loyal to other enterprises (they prefer the products of some other enterprises);

– non-loyal customers (do not prefer any company).

3) signs of a more significant characteristic of the product.

According to this feature, buyers are divided into two segments:

– buyers who choose a product, first of all, by its manufacturer;

– buyers who choose a product, first of all, based on its characteristics of «environmental friendliness and cheapness».

The set of consumer groups, built on the basis of the decision tree, contains groups g_1–g_8, listed in Table 1. At the same time in Table 1, there are variants of the vector of ranks g_9–g_{24}, which do not correspond to the logic of the given decision tree. For example, an individual puts the eco-paper from one company in the first place, and the cheap paper from another company in the second place. I believe that such variants of the rank vector describe only a random selection of the product.

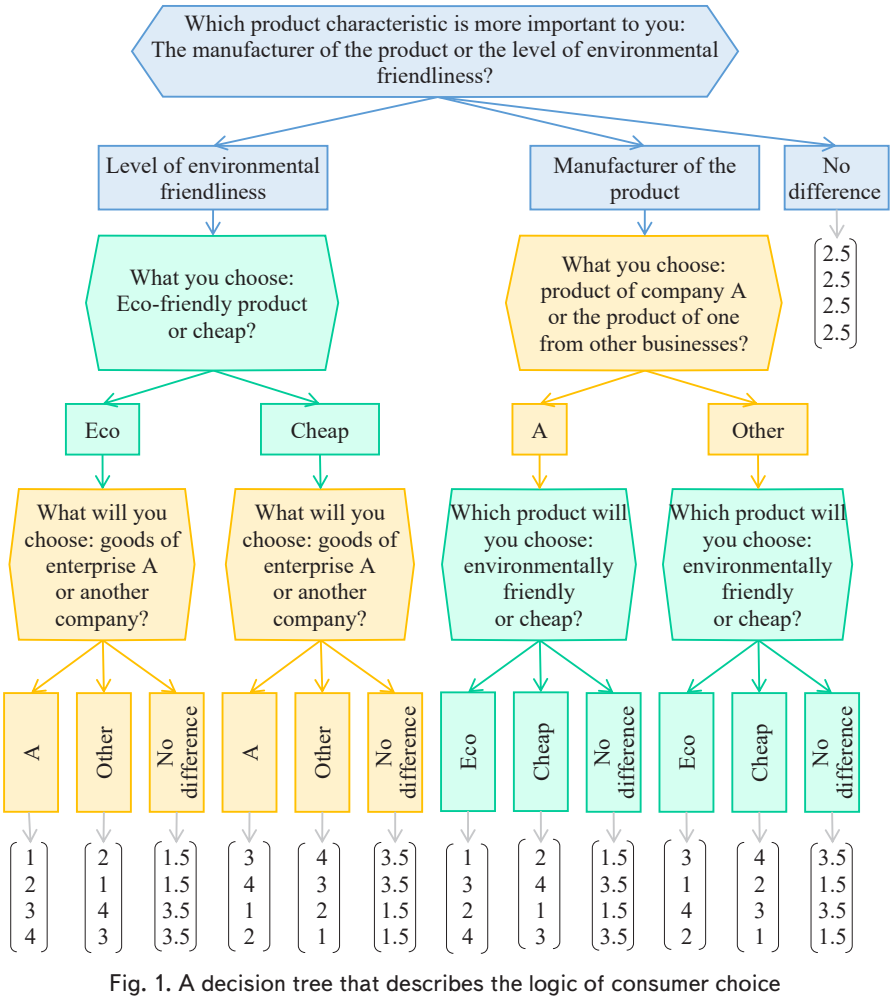


Fig. 1. A decision tree that describes the logic of consumer choice for multiple options of office paper, as well as corresponding groups of consumers with the same preferences

After identifying a number of consumer groups, their quantity was determined. In the example under consideration, the quantity of consumer groups was determined by surveying a «convenient» sample of paper consumers from among the students of KhNEU named after S. Kuznets (45 people). Respondents were asked questions about the presence of their favorite brands of paper and then, depending on their answer, they were asked to rank the paper options. The data obtained as a result of the questionnaire are given in Table 2. The groups marked «*» in Fig. 1 were not considered during the survey since company A does not have loyal consumers according to the conditions of the task.

Based on the given input data, the initial (unmodified) linear programming model designed to evaluate the structure of sales of the analyzed goods with different social utility takes the following form:

$$\begin{cases} \sum_i \sum_j u_i^j \cdot x_i^j \to \max, \\ \sum_j x_1^j \le 10.0, \sum_j x_2^j \le 60.0, \\ \sum_j x_3^j \le 10.0, \ \sum_j x_4^j \le 40.0, \\ \sum_i x_i^1 \le 6.5, \ \sum_i x_i^2 \le 0, \\ \sum_i x_i^3 \le 8.8, \ \sum_i x_i^4 \le 4.3, \\ \sum_i x_i^5 \le 43.5, \ \sum_i x_i^6 \le 13.0, \\ \sum_i x_i^7 \le 2.2, \ \sum_i x_i^8 \le 21.7, \\ x_i^j \ge 0, \\ i = \overline{1,4}, \ j = \overline{1,8}. \end{cases} \quad (4)$$

But it is necessary to take into account that the set of groups of consumers created on the basis of the decision tree contains groups of consumers whose preferences are described by vectors with repeating ranks. Equal rank values in the product rank vector appear when consumers treat several or all product variants equally. The assumption was adopted above that buyers who equally evaluate the usefulness of several product options choose one of the equivalent product options randomly, with the same probability for each option. To take into account this assumption, it was suggested to use fictitious groups of buyers: the consumer group with «indifferent» consumers should be divided into several fictitious groups, each of which will correspond to its own version of the rank vector. Let's consider this approach using the example of group b_8, which corresponds to the product rank vector (2.5 2.5 2.5 2.5). Members of this group don't care which version of the product to buy. Therefore, to simulate a random consumer choice, it is necessary to distribute the members of this group among the 24 groups from Table 1, each of which corresponds to one of the variants of the rank vector. Since I believe that all options are equally likely, the quantity of each group g_1–g_{24} will increase by 1/24 of the quantity of group b_8. Similarly, the members of groups b_5, b_6, b_7 must also be distributed among several groups from the set of groups g_1–g_{24}. Thus, to «simulate» a random choice, consumers who equally evaluated several product options were distributed among several relevant consumer groups from Table 1. As a result, 24 groups of consumers were obtained, taking into account fictitious groups. The demand volumes of each group of consumers are shown in the first row from Table 3.

The modified model of linear programming taking into account fictitious groups of consumers takes the form (5) to (9). The values of the coefficients u_i^j, d_j, $\beta_i \cdot d_j$ are given in Table 3. Utility vectors were calculated on the basis of rank vectors according to the formula $u_i^j = \left(1/r_i^j\right) / \sum_{i=1}^{4} \left(1/r_i^j\right)$. Based on this formula, the rank vector r=(1 2 3 4) corresponds to the utility vector u=(0.48 0.24 0.16 0.12):

$$\sum_i \sum_j u_i^j \cdot x_i^j \to \max, \quad (5)$$

$$\sum_j x_1^j \le 10.0, \sum_j x_2^j \le 60.0, \sum_j x_3^j \le 10.0, \sum_j x_4^j \le 40.0, \quad (6)$$

$$\sum_i x_i^j = \alpha \cdot d_j, j = \overline{1,24}, \text{ where } \alpha = \frac{\sum_{i=1}^{n} v_i}{\sum_{j=1}^{m} d_j} = 1, \quad (7)$$

$$x_i^j = \beta_i \cdot d_j, j \in J_i, \text{ where } \beta_i = \frac{v_i}{\sum_{j \in J_i} d_j}, \ i = \overline{1,4}, \quad (8)$$

$$x_i^j \ge 0. \quad (9)$$

Table 2

Structure of the division of respondents into consumer groups revealed by questionnaires

Group	Rank vector	Description	Percentage of respondents
b_1	(2 1 4 3)	Consumers of this group choose paper, first of all, on the grounds of environmental friendliness; in addition, they show loyalty to one of the paper manufacturers	6.5
b_2	(4 3 2 1)	Consumers of this group choose paper, first of all, on the basis of cheapness; in addition, they show loyalty to one of the paper manufacturers	0
b_3	(3 1 4 2)	Consumers of this group choose, first of all, paper of a specific manufacturer; among paper options from your favorite manufacturer, choose an ecological option	8.8
b_4	(4 2 3 1)	Consumers of this group choose, first of all, paper of a specific manufacturer; choose a cheap option among paper options from your favorite manufacturer	4.3
b_5	(1.5 1.5 3.5 3.5)	Consumers of this group choose paper based on environmental friendliness; the manufacturer is not important for them	43.5
b_6	(3.5 3.5 1.5 1.5)	Consumers of this group choose cheap paper; the manufacturer is not important for them	13.0
b_7	(3.5 1.5 3.5 1.5)	Consumers of this group choose paper of a specific manufacturer; «environmental-price» characteristics are not important for them	2.2
b_8	(2.5 2.5 2.5 2.5)	Consumers of this group choose paper randomly, without paying attention to price and environmental characteristics	21.7

Table 3

The value of coefficients in the linear programming problem (5) to (9)

C-s	j=1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	1	17	18	19	20	21	22	23	24
d_j	11.8	18.3	4.2	4.2	0.9	0.9	10.3	5.8	11.8	0.9	0.9	0.9	11.8	1.5	0.9	0.9	4.2	0.9	0.9	0,9	4,2	1,5	0,9	0,9
$\beta_1 \cdot d_j, j \in J_1$	4.3	–	–	–	0.3	–	–	–	4.3	0.3	0.3	0.3	–	–	–	–	–	–	–	–	–	–	–	–
$\beta_2 \cdot d_j, j \in J_2$	–	18.3	–	–	–	–	10.2	–	–	–	–	–	11.8	1.5	0.9	0.9	–	–	–	–	–	–	–	–
$\beta_3 \cdot d_j, j \in J_3$	–	–	3.5	–	–	0.8	–	–	–	–	–	–	–	–	–	–	3.5	0.8	0.8	0.8	–	–	–	–
$\beta_4 \cdot d_j, j \in J_4$	–	–	–	4.2	–	–	–	5.8	–	–	–	–	–	–	–	–	–	–	–	–	4.2	1.5	0.9	0.9
u_1^j	0.48	0.24	0.16	0.12	0.48	0.24	0.16	0.12	0.48	0.48	0.48	0.48	0.24	0.12	0.16	0.12	0.12	0.24	0.16	0.12	0.16	0.16	0.24	0.24
u_2^j	0.24	0.48	0.12	0.16	0.16	0.12	0.48	0.24	0.24	0.12	0.16	0.12	0.48	0.48	0.48	0.48	0.16	0.16	0.24	0.24	0.12	0.24	0.12	0.16
u_3^j	0.16	0.12	0.48	0.24	0.24	0.48	0.12	0.16	0.12	0.24	0.12	0.16	0.16	0.16	0.24	0.24	0.48	0.48	0.48	0.48	0.24	0.12	0.16	0.12
u_4^j	0.12	0.16	0.24	0.48	0.12	0.16	0.24	0.48	0.16	0.16	0.24	0.24	0.12	0.24	0.12	0.16	0.24	0.12	0.12	0.16	0.48	0.48	0.48	0.48

Problem (5) to (9) has 96 variables and 48 constraints in the form of equations. Problem (5) to (9) was solved by the simplex method implemented by Python tools. The solution to the problem with fictitious groups is given in Table 4.

In Table 4, it can be seen that the volumes of purchases of goods with rank 1 (the ranks of goods for different consumer groups are given in Table 1) are determined from equalities (8). At the same time, since $v_1 \le \sum_{j \in J_1} d_j$ and $v_2 \le \sum_{j \in J_2} d_j$, goods of company A are completely sold out to those consumer groups that put these goods on the 1st place (this also follows from formula (8)). And as a result of this, the sales of all goods of enterprise A with ranks below 1 are equal to 0. And the sales volumes of all goods of other enterprises with rank 2 are equal to the difference between the demand from the corresponding group and the sales volumes of this group of goods with rank 1. Only in four groups (b_5, b_6, b_{10}, b_{18}) goods with rank 3 were consumed, as there were not enough goods with higher ranks (as a result of the fact that in these groups the goods of company A, which were bought up by other consumer groups, have rank 2). Sales of products with a rank of 4 are equal to 0.

After the reverse transition from fictitious consumer groups to real ones, a solution to the initial problem with 4 producers and 13 consumer groups was obtained (Fig. 2). The vector of total sales of four types of paper is equal to (10.0 59.0 10.0 20.5).

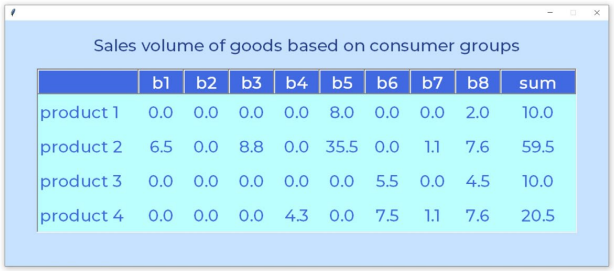
In order to analyze the sensitivity of the solution, the optimal (from the point of view of optimizing the overall utility of purchases) variants of the sales structure for other values of the coefficients of the utility function were also calculated. 3 variants of the utility vector with coefficients close to those analyzed were used: (0.5 0.25 0.15 0.1). (0.5 0.3 0.15 0.05). (0.51 0.3 0.15 0.04). In all three problems, the optimal sales structure coincided with the solution shown in Fig. 2. Thus, problem (5) to (9) has a unique solution (otherwise a change in the coefficients of the objective function would lead to a change in this solution), which can be considered as an estimate of the optimal structure of sales distribution in the analyzed market. It can be seen that in the modeled ideal option (from the point of view of optimizing the overall utility of purchases), the new enterprise sells out all its goods. This happens, firstly, at the expense of environmentally responsible consumers from group b_5, and secondly, at the expense of «indifferent» consumers from group b_8, who choose the product randomly.

A similar problem was also considered for another variant of the quantity of consumer groups. An example with a larger number of environmentally responsible consumers was taken: for example, group b_6 is empty, and the quantity of group b_5 is 56.5 %. In this case, according to the results of calculations, the vector of total sales of four types of paper is equal to (10.0 60.0 7.3 22.7). That is, for the second variant of the quantity of consumer groups, the sales plan for product 3 will be fulfilled by only 73 %. For comparison, the same problem of linear programming (with the second variant of the quantity of consumer groups) was considered without taking into account equalities (7), (8). It turned out that the specified problem has many solutions, among which there is a solution that corresponds to the vector of total sales (10.0 60.0 10.0 20.0), which predicts the implementation of the sales plan for product 3. In a certain sense, it can be said that in the given example, disregarding equalities (7), (8), which describe the actual conditions of making purchases, leads to an overestimation of the implementation of the sales plan of goods 3.

Table 4

Solutions to the given problem of linear programming with fictitious groups

Sales volume	g_1	g_2	g_3	g_4	g_5	g_6	g_7	g_8	g_9	g_{10}	g_{11}	g_{12}	g_{13}	g_{14}	g_{15}	g_{16}	g_{17}	g_{18}	g_{19}	g_{20}	g_{21}	g_{22}	g_{23}	g_{24}
x_{1j}	4.3	0.0	0.0	0.0	0.3	0.0	0.0	0.0	4.3	0.3	0.3	0.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
x_{2j}	7.4	18.3	0.0	0.0	0.6	0.0	10.3	0.0	7.4	0.0	0.0	0.0	11.8	1.5	0.9	0.9	0.0	0.1	0.1	0.1	0.0	0.0	0.0	0.0
x_{3j}	0.0	0.0	3.5	0.0	0.0	0.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	3.5	0.8	0.8	0.8	0.0	0.0	0.0	0.0
x_{4j}	0.0	0.0	0.7	4.2	0.0	0.1	0.0	5.8	0.0	0.6	0.6	0.6	0.0	0.0	0.0	0.0	0.7	0.0	0.0	0.0	4.2	1.5	0.9	0.9



Sales volume of goods based on consumer groups

	b1	b2	b3	b4	b5	b6	b7	b8	sum
product 1	0.0	0.0	0.0	0.0	8.0	0.0	0.0	2.0	10.0
product 2	6.5	0.0	8.8	0.0	35.5	0.0	1.1	7.6	59.5
product 3	0.0	0.0	0.0	0.0	0.0	5.5	0.0	4.5	10.0
product 4	0.0	0.0	0.0	4.3	0.0	7.5	1.1	7.6	20.5

Fig. 2. Results of calculations: distribution of volumes of goods among buyers, which is optimal according to the criterion of maximum total utility for the totality of buyers in the market

In general, the calculations based on the model built make it possible to assess the prospects for the sale of goods for various variants of the structure of consumers in the aspect of social responsibility.

6. Discussion of results based on improving the analyzed model of linear programming

This study has demonstrated the possibility of building a model designed to evaluate the sale of alternative goods with different social utility to consumers with different social responsibility, by means of linear programming, taking into account certain purchasing conditions.

In the work, an approach to the formalization of consumer groups used in the linear programming model was devised, based on the results of consumers' ranking of the analyzed product varieties. This approach is an alternative to both the application of point evaluations of goods and the construction of utility functions of goods for each consumer. The proposed approach is simpler and makes it possible to identify more overlaps in consumer preferences, which facilitates the process of forming groups of consumers with close preferences. To reduce the total number of consumer groups under consideration, it is recommended to be limited to those groups in which the rank vectors of goods correspond to the rules of consumer logic. Such groups can be distinguished by building a decision tree that describes consumer choice according to the rules of logic for a set of analyzed goods. The decision tree, which describes the logic of consumer choice on multiple options of office paper, is shown in Fig. 1.

A feature of the improvement of the linear programming model proposed in this work is taking into account the fact that there are consumers in the market who choose a product randomly and at the same time make purchases at the same time as others, not giving up products to those buyers for whom these products are preferred. In order to take into account the random choice of such consumers, their groups are divided into subgroups, each of which implements one of the possible options for consumer behavior in choosing products. Each variant of consumer behavior is described by one of the product rank vectors. The total set of such vectors for the problem with four types of goods is given in Table 1. In this work, all variants of random behavior of consumers are considered to be equally likely but the proposed approach using fictitious subgroups makes it possible to take into account other types of distribution of probabilities for multiple variants of consumer behavior.

In addition, the model, with the help of additional constraints in the form of equations (2) and (3), takes into account the fact that consumers from different groups make purchases in parallel in time and each product expires simultaneously for all groups of consumers. These restrictions reduce the optimal value of the objective function of the model in comparison with [21] but reflect the actual conditions of making purchases in the market.

In the process of testing the improved model of linear programming on the example of the office paper market, the structure of consumer groups was determined based on environmental responsibility and loyalty to producers. According to the results of the pilot survey, the group of consumers who intend to choose environmentally-friendly office paper without paying attention to its manufacturer became the first in terms of quantity (Table 2). The second largest was the group of consumers who equally evaluate all the offered options of office paper. That is, the conducted survey confirmed the importance of taking into account in the model the presence of consumers who choose a product randomly. The results of modeling the structure of sales on the office paper market in the problem under consideration are shown in Fig. 2. According to the simulation results, a comparison of the model solution with additional constraints (2) and (3) was performed with the model solution without these constraints (for one of the hypothetical examples of the quantity of consumer groups). In the considered example, the differences between the specified solutions turned out to be significant: the sales volumes of one of the products differed in these two models by 27 %. This confirms the importance of considering constraints (2) and (3) in the analyzed model.

Therefore, the advantage of the implemented improvements of the model is that they make it possible to obtain more realistic estimates of sales volumes of product variants to consumers with different social responsibility in comparison with the approach outlined in [21]. Owing to the improvements made, the model can be applied to solve practical problems of evaluating sales in the market for different options for the supply of goods with different social utility and different social responsibility of consumers.

The advantage of the linear programming toolkit used in the research compared to the models of discrete choice [12–16] and continuous choice [18] is that it makes taking into account significantly more factors in the models. In particular, it makes it possible to take into account the volume of supply of goods, the volume of demand of consumer groups, as well as the above-mentioned conditions of sale of goods.

In contrast to works [19, 20], the proposed model of linear programming determines the structure of product sales in the market, which is optimal according to the criterion of the maximum total utility of purchases for the totality of buyers.

The advantage of linear programming tools in comparison with multi-agent modeling is the simplicity of practical implementation of the developed models.

Based on the above advantages, the proposed improved model of linear programming may prove useful as a means of substantiating practical decisions regarding the production and sales of socially beneficial goods.

The advancements outlined in the paper partially resolve the specified problem, which concerns a simplified description of reality in linear programming models. The proposed improvements make it possible to take into account in the models the separate conditions for making purchases in the market described above. But the real sequence of purchases in time cannot be fully taken into account by means of linear programming.

The application of the proposed model is limited to the introduced assumptions. In particular, it is assumed that buyers who equally evaluate the utility of several product options choose one of the equivalent product options at random, with the same probability for each option. That is, the probability of choosing a product in the proposed model does not depend on the volume of its offer. This formalization of choice is suitable, for example, for describing online purchases.

Another important limitation is that the model is suitable for analyzing only a small number of products. Increasing the number of products in the model leads to a sharp increase in the quantity of consumer groups with different preferences, which will complicate data collection. Therefore, the model is not suitable for the analysis of the sales structure of different brands of goods, but rather for the analysis of generalizing groups of these brands, such as «environmentally-friendly» and «non-environmentally-friendly» products.

The disadvantage of the advancements is that the proposed additional inequalities, designed to take into account the real sequence of purchases in time, take into account the volume of demand for each product only by those consumers for whom it is preferred. This is a simplification of reality.

The disadvantage of using product rank vectors to describe consumer preferences is that, in the event of a change in the set of analyzed products, a new questionnaire must be introduced to identify new rank vectors.

It is advisable to conduct further research in the area of developing a specialized application designed to automate the proposed approach with a convenient user interface.

7. Conclusions

1. A set of consumer groups with different preferences has been formalized in the linear programming model designed to estimate sales volumes in the market taking into account the aspect of social responsibility. It is proposed to distinguish consumer groups on the basis of product rank vectors, which characterize the preferences of each consumer on the set of analyzed products and are revealed by questionnaires. Consumers who have the same product rank vector are united into one group. The coefficients of the total sales utility function are also calculated based on the values of the rank vectors. The total set of consumer groups in a specific market is recommended to be formed on the basis of a consumer decision tree.

2. The formalization of certain aspects of shopping by consumers with different social responsibilities has been carried out in the considered model. First, the behavior of buyers who treat several goods with different social utility and choose a product randomly is formalized. To take into account in the model the random choice of such consumers, their groups are divided into subgroups, each of which corresponds to one of the possible options for the consumer's behavior regarding the choice of products.

Secondly, the model takes into account a realistic sequence of purchases in time, according to which a specific unit of the product is bought by the buyer who previously chose it, and not by the one who values it higher. This is done with the help of additional constraints in the form of equations that describe the fact that each product will run out simultaneously for all groups of consumers.

3. The improved model was tested on the example of simulation of sales in the office paper market, which includes two general types of goods – environmentally-friendly paper and paper that does not meet modern environmental requirements. Information about the preferences of office paper consumers for the built model was collected through a pilot questionnaire. According to the results of the survey, it turned out that the majority of respondents (43.5 %) prefer environmentally-friendly paper, equally evaluating paper from different manufacturers. And 21.7 % of respondents equally evaluate all the proposed paper options. This confirmed the importance of taking into account in the model the presence of consumers who choose a product randomly. In addition, for one of the hypothetical variants of the number of consumer groups, a comparison was made of the solution of the proposed model, which contains additional restrictions, with the solution of the primary model, which does not contain these restrictions. The difference between the compared solutions turned out to be significant: the calculated sales volumes of one of the products differed in the specified models by 27 %. This confirmed the importance of introducing the proposed constraints into the model.

Conflicts of interest

The author declares that she has no conflicts of interest in relation to the current study, including financial, personal, authorship, or any other, that could affect the study, as well as the results reported in this paper.

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Data availability

This work is a continuation of study [21].

Use of artificial intelligence

The author confirms that she did not use artificial intelligence technologies when creating the current work.

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