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Simulation of Interest Coordination of Economic Subjects in Housing Construction

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ABSTRACT

In the present paper, the consequences of the introduction of project financing against the backdrop of crises in 2020 and 2022 are analyzed. The subject interactions in the course of housing construction under the conditions of project financing are considered. A multi-criteria economic-mathematical model for the interest coordination of economic subjects in housing construction has been proposed. The model permits to understand and evaluate the economic consequences of choosing the possible options from the standpoint of each of the economic subjectss. The numerical calculations of choosing two (in pairs), and all three (developer, bank and consumer) economic subjects were performed using the proposed multi-criteria model with the stated limitations. The MATLAB software was employed to solve optimization problems and plotting. The solutions acceptable to the subjects were chosen from a set of Pareto-optimal alternatives. Despite the fact that all subjects of housing construction are involved in the interaction, this interaction does not occur simultaneously, but in a complex subordinate manner: the bank took the dictating position in project financing, and the consumer pays for everything. The state should play a role of the subject, which should coordinate the interests of the developer, the bank and the population. The task of the state is to create such conditions in the housing construction market so that economic subjects are interested in coordination of their interests to find a compromise. This opens routes for further research.

Keywords: housing construction; project financing; escrow accounts; economic subjects; coordination of interests; economic-mathematical model; multi-criteria problem

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The last three years have brought a lot of chaos to the activities of actors in the residential or housing construction industry — especially to the activities of property development companies. Construction has traditionally been considered a highly fragmented industry with low profit margins and a high risk of failure due to the complex supply chain system [1].

Firstly, the introduction of project financing using escrow accounts has made it difficult to stay in the industry and has made it difficult for new participants to enter. The resulting stringent requirements on developers have contributed to the reduction and monopolisation of housing supply entities. Secondly, against the backdrop of the coronavirus crisis, accompanied by lockdowns, border closures and steep increases in building material prices, construction timelines have literally been frozen or significantly slowed down. The negative synergistic effect of these two phenomena can be summarised as follows:

- efficiency losses have been reflected in higher interest costs for bank financing of construction, higher wages due to labour shortages, and higher fixed costs due to longer construction periods;
- the disruption and recombination of the established relationships was accompanied by a dramatic change in the interaction between the developer and the home buyer, the developer and the employees, the developer and the suppliers of building materials;
- the weakening of control over the construction process was the result of the transfer of this function to the bank, while control over the use of working time was taken over by Rospotrebnadzor;
- the excessive management complexity and adaptation difficulties were caused by the bank's integration as the main actor in the construction process as well as by the increased requirements to the developer and the need to comply with "pandemic" requirements [2].

The result has been a reduction in the commissioning of housing, a sharp rise in costs and, consequently, in housing prices (from 12 to more than 20 per cent, by the end of 2020, depending on the region) [3]. State aid in the form of preferential mortgages enabled consumers to pay for them (i.e., to "swallow" the increased costs of the developers) and, thus, not to "freeze" the industry completely.

In 2021 there was a "recovery" from the coronavirus crisis with record housing commissioning due to the completion of the 2020 projects. The housing boom was stalled again in February 2022 due to a new spike in building material prices and a sharp rise in the key rate of the Central Bank of the Russian Federation. In April 2022 the annual inflation rate for the construction sector was 44% compared with the same period last year. The number of mortgage loans issued decreased by 14% in the primary market and by 43% in the secondary housing market. In terms of loan amounts (due to higher prices in the primary market), there was a 9% increase, while in the secondary market there was a 35% decrease.[1]

In spite of everything, project finance is becoming the main way of investing in housing construction year by year, replacing its archaic forms. Today, according to DOM.RF portal, there are 100.6 million m2 of flats under construction, including 87% that are built using escrow accounts (*Table 1*).

The increase in the number of developers during 2022 was about 15% and the number of commissioned square metres being built using escrow accounts — was 18.7%. At the same time, the number of developers and square metres being completed under shared construction contracts decreased by half, and the number of those being built with own funds — decreased by a quarter (*Table 2*).

[1] URL: https://www.xn — d1aqf.xn — p1ai/analytics/

Table 1

Distribution of housing under construction depending on the formation of financing for November 2022

Funding mechanism	Developers		Houses		Residential accommodation		Flats/ Apartments	
	units	%	units	%	thousand m^2	%	thousand units	%
Escrow accounts	3240	90	8252	86.8	87695	87.3	1766	87.1
DDU contract (trust agreement)	340	9.4	854	9	10177	10	206	10.2
Own (Equity) funds	92	2.6	405	4.2	2714	2.7	55	2.7
TOTAL	3672	100	9511	100	100586	100	2027	100

Source: calculated according to DOM.RF date.

Table 2

Change in share of use of housing finance in 2022

Funding mechanism	Developers, units		Houses, units		Residential accommodation, thousand m^2		Flats / Apartments, units	
	2021	growth, %	2021	growth, %	2021	growth, %	2021	growth, %
Escrow accounts	2807	+15.4	7180	+14.9	73869	+18.7	1479	+19.4
DDU contract (trust agreement)	697	–51.2	1798	–52.5	21067	–51.7	423	–51.3
Own (Equity) funds	141	–34.8	525	–22.8	3700	–26.6	73	–24.7
TOTAL	3475	+5.7	9503	+0.08	98636	+2	1975	+2.6

Source: calculated according to DOM.RF date.

Project financing in housing is a rather complex process involving the interaction of various economic actors, among which are the state, developers, banks and the public. There are many studies devoted to this topic [4–7]. The system of subject interaction in the process of housing construction under the conditions of project financing, operating in the Russian Federation, is shown in *Fig. 1*.

The relationships shown in *Fig. 1* are deciphered in *Table 3*.

In the process of interaction it is necessary to take into account the interests of each economic entity [9], which are radically different, forcing the participants to act in opposite directions. Even three years before

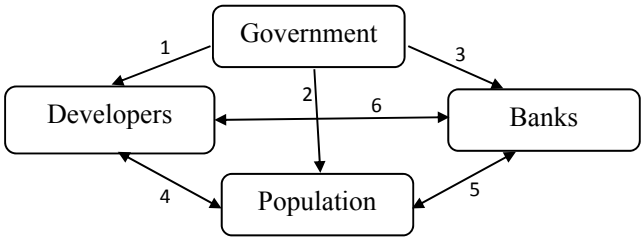

Fig. 1. **The system of subjective interactions in the process of housing construction in terms of project financing**

Source: [8].

the legitimization of escrow accounts in the Russian Federation, T. V. Svetnik and V. S. Vakhnovich noted in their article that "the following negative risks may arise for

Table 3

Interactions of economic entities in the construction process housing under project financing

Economic actors/ entities	Features of interaction
From the government's perspective	(1) The state creates a unified housing policy to regulate the activities of construction organisations, develops regulatory and legal documents with urban planning and technical content, and carries out state supervision and construction control. (2) The state enhances the opportunities for the population to purchase or build housing by offering various programmes (e.g., national project "Housing and Urban Environment"). (3) The state controls the banks and approves the list of those that can cooperate with real estate developers
From the developers' perspective	(4) Developers shape the supply of housing on the market. (6) Developers provide income as well as the repayment of the funds raised
From the banks' perspective	(5) Banks provide loans and mortgages to people to buy homes. Escrow accounts are opened at the bank for those who purchase housing under construction. (6) The banks generate cash flow for the housing project if necessary, thereby redistributing project implementation risks
From the perspective of the population	(4) The population creates the demand for housing and meets their housing needs. (5) The population pays interest to the bank for the use of borrowed money

Source: [8].

construction organizations as a result of the adoption of the bill: a sharp reduction in the number of developers who will meet the specified requirements; increase in developers' costs and higher construction costs due to the need to register changes in each contract feature with a corresponding payment of state duty". [10].

As V.V. Pukhova points out, the willingness of developers to switch to new terms of financing is determined by the ability, first, to withstand the additional credit load, and, second, to comply with all the requirements of the bank. On the contrary — unwillingness — can lead to an increase in the number of bankruptcies of construction companies and the withdrawal of some developers from the market [11]. In such circumstances, some developers openly proclaim that banks have "become the executioners" of developers. However, the banks themselves must meet certain requirements in order to be able to open and finance such projects. For example, in foreign practice an "independent engineer", who plays the role of a super-partner, is added to the classical participants of project financing, and is asked to give an opinion on the feasibility of the project, conduct a survey to evaluate it and act as a supervisor to protect the project and above all — those who put money into the financing. While the construction and engineering features of a project may be clear to the funders, this is often not the case with the lenders, who need a specialist who can assess the deal and decide whether to support and finance it or not [12].

Thus, the banking sector assessment will allow the formation of a pool of authorised banks implementing project finance using escrow accounts. Although the latter implies "conditional depositing" or escrow ("escrow" broadly refers to the suspension of not only uncertain but also certain as well as unavoidable actions and events) [13], an assessment of the possibility of phased disclosure of escrow accounts will allow conclusions to be drawn as to how the introduction of new financing conditions will affect the financial situation of developers and, consequently, potential consumers (citizens) [11].

Reconciling the multidirectional interests of the economic actors in housing is a non-trivial task. It is not just a calculation of different types of efficiency of one project [14],— it is a matter of setting an optimization problem of finding the best solution for all participants. In the works of domestic scientists there have been the attempts to reconcile the interests of economic subjects. In particular, R. I. Abdrazakov and E. G. Kravchenko built an economic and mathematical model that reconciles the interests of the population and the developer in low-rise housing construction [15]. O. I. Gorbaneva and A. D. Murzin describe a dynamic socio-environmental-economic model of synergistic development of individual economic entities, which helps to reconcile their common and private interests [16]. O. P. Smirnova, V. V. Shergin consider the sequence of solving the multi-criteria task of making investment decisions in housing construction [17]. D. A. Makarov and M. N. Yudenko systematically model economic interactions of the participants in housing construction [18]. Despite the significant number of works of theoretical and practical importance, there is a lack of a model that would allow us to understand and assess the economic consequences of choosing a combination of values of key indicators that characterize each housing project from the position of all economic actors, out of all possible options.

A number of issues related to considering the interests of economic actors in the construction of affordable housing (including the problems of introducing project financing in housing construction and its consequences for the development companies) need to be studied in detail. A distinctive feature of our model is that it specifically prescribes the optimization criteria for each economic entity and takes into account the admissible set. Solving the multi-criteria problem allows us to identify the options that arise in the interaction of entities.

MULTI-CRITERIA OPTIMISATION PROBLEM FOR THE COORDINATION OF INTERESTS OF HOUSING SUBJECTS

In the model, we consider one-, two-, three-, four- and more-bedroom flats on the primary market. We assume that each economic actor is pursuing his/her own interest. We take into account that the amount of housing to be built is limited "from below" by the difference between the need for housing and its availability in the housing stock; and is limited "from above" — by the planned indicator of housing commissioning and target housing supply. If the number of flats of a certain type available in the housing stock exceeds the need for housing of a certain type, there is no need for developers to make them. To formalize the task of coordinating the interests of the economic actors in housing construction, we introduce the following denotations.

Let us assume that $i = \overline{1,n}$ — is the number of the type of flats;

T — the construction period of apartment buildings;

t — year number in the construction timeframe, $t = \overline{1,T}$.

The values entered below will be considered in year t.

X_i — number of dwellings of type i, required to increase the housing stock (the required value in the optimisation problem) (in m^2);

V — planned housing commissioning (in m^2);

N_i — the number of type i flats available in the housing stock;

U_i — housing need of the i type by households (in flats);

S_i — the average floor area (residential accommodation) of dwellings of type i;

C — cost per m^2 of housing;

P_i — price for the consumer when buying 1 m^2 of flat of type i;

Table 4

Pareto-optimal solutions for harmonizing the interests of banks and the population

Index	Bank income, RUB.	Minimum average price of 1 m² of housing, RUB.	Residential accommodation of one-room flats, m²	Residential accommodation of two-room flats, m²	Residential accommodation of three-room flats, m²	Residential accommodation of four- and more -room flats, m²
1	–18 279 573 215	97 713	1 155 000	-	-	-
2	–17 961 166 276	94 766	763 189	-	-	391 811
3	–17 623 778 285	91 643	348 066	-	-	806 922
4	–17 341 207 005	89 025	-	-	-	1 155 000
5	–17 791 329 680	93 194	554 218	-	-	600 776
6	–17 500 977 069	90 780	232 855	-	-	920 187
7	–18 002 598 043	95 518	861 250	-	-	291 203
8	–18 216 486 152	97 130	1 077 494	-	-	77 505
9	–17 385 330 771	89 509	64 254	-	-	1 090 208
10	–17 925 773 424	94 439	719 742	-	-	435 251
11	–17 729 827 222	92 627	478 835	-	-	676 141
12	–17 884 200 521	94 054	668 512	-	-	486 484
13	–18 169 634 891	96 696	1 019 819	-	-	135 180
14	–17 870 448 289	93 927	651 722	-	-	503 266
15	–18 279 446 165	97 713	1 155 000	-	-	-
16	–17 712 571 355	92 540	467 049	-	-	687 416
17	–17 447 439 649	90 031	133 682	-	-	1 021 160
18	–18 085 718 122	95 919	916 520	-	-	238 479

Source: compiled by the authors.

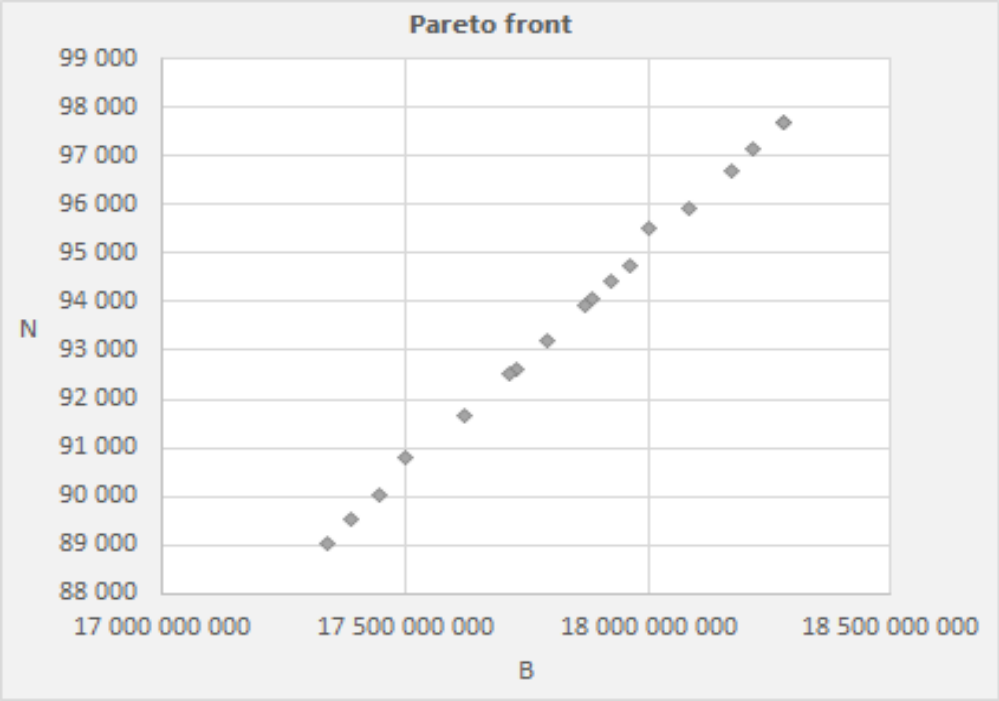

Fig. 2. **Pareto front for the problem of harmonizing the interests of the subjects "population" and "banks"**

Source: compiled by the authors.

β — the share of borrowed funds provided by the bank to the developers for the implementation of the projects;

r — interest rate for a property developer's loan;

γ — the proportion of money extended by the bank to households for the purchase of housing;

h — mortgage interest rate for private households.

In order to set up a multi-criteria economic-mathematical model, a vector of variables must be defined

$$X = (X_1, X_2, \ldots, X_n)$$

from the set of admissible solutions in which the value of the vector function of the vector argument reaches its extremum (maximum or minimum).

$$F(X) = \{B(X),\ S(X),\ N(X)\} \to exrt,$$

where $B(X), S(X), N(X)$ — are target functions that express:

maximising the banks' revenues

$$B = \sum_{i=1}^{n} r\beta X_i C + \sum_{i=1}^{n} h\gamma X_i P_i \to \max, \quad (1)$$

$$0 < \beta \le 0{,}9,\ 0 < \gamma \le 0{,}85;$$

maximising the developer's profits

$$S = \sum_{i=1}^{n} (P_i - C) X_i \to max; \quad (2)$$

minimising the average price of 1 m² for the consumer

$$N = \frac{\sum_{i=1}^{n} P_i X_i}{\sum_{i=1}^{n} X_i} \to min. \quad (3)$$

The set of acceptable solutions is given by the constraint on the number of dwellings to be built (4) and the non-negativity conditions:

Table 5

Pareto-optimal solutions to harmonize the interests of the developer and the population

Index	Bank income, RUB.	Minimum average price of 1 m² of housing, RUB.	Residential accommodation of one-room flats, m²	Residential accommodation of two-room flats, m²	Residential accommodation of three-room flats, m²	Residential accommodation of four- and more -room flats, m²
1	–55 620 187 237	97 713	1 155 000	0	0	0
2	–17 387 157 505	89 403	317	71 640	9913	354 485
3	–46 075 392 813	92 665	371 529	266 158	106 517	324 627
4	–42 659 148 314	91 845	244 090	285 042	130 713	348 927
5	–36 036 395 261	90 959	111 800	282 290	123 379	352 933
6	–34 043 996 113	90 979	108 225	275 661	85 786	352 214
7	–55 620 178 206	97 713	1 155 000	0	0	0
8	–44 809 692 705	92 581	353 425	253 283	103 523	331 282
9	–25 239 394 897	89 899	1146	235 951	35 236	353 303
10	–49 582 384 894	93 239	473 440	270 769	103 410	287 451
11	–54 684 541 565	96 972	1 034 398	71 623	29 143	18 147
12	–38 471 556 675	91 429	173 587	281 668	111 300	352 242
13	–53 493 341 707	96 026	880 852	162 811	66 247	41 252
14	–27 202 954 376	90 006	3006	280 475	36 311	352 740
15	–21 147 658 194	89 720	3129	149 362	20 776	353 284
16	–30 856 915 890	90 041	7899	280 502	120 701	353 095
17	–42 719 360 274	91 841	244 090	285 042	130 713	350 452
18	–51 528 114 377	94 272	642 444	182 098	86 611	241 203

Source: compiled by the authors.

$$\sum_{i=1}^{n}\left(U_i - N_i\right)\cdot S_i \le \sum_{i=1}^{n} X_i \le V, \quad (4)$$

$$X_i \ge 0. \quad (5)$$

Thus, we have obtained a model that allows us to see the multitude of options that arise in the interaction of economic actors in housing construction.

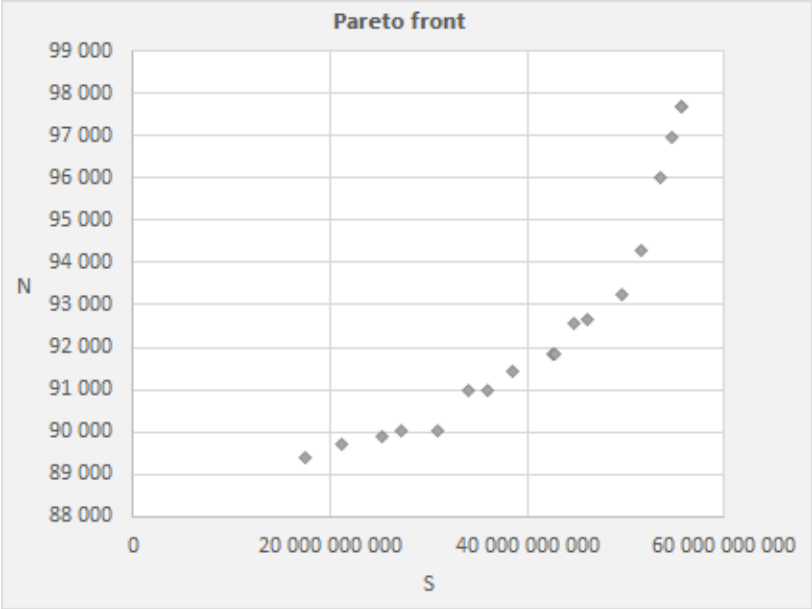

Fig. 3. **Pareto front for the problem of harmonizing the interests of the subjects "population" and "developer"**

Source: compiled by the authors.

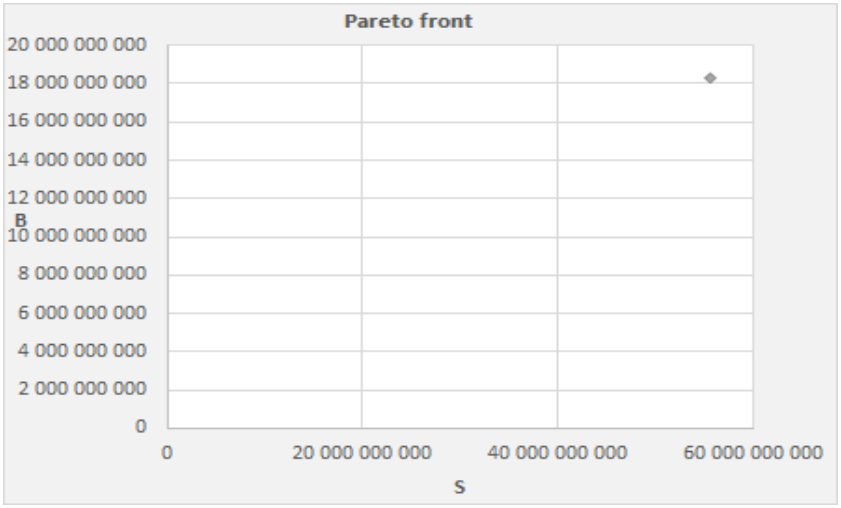

Fig. 4. **Pareto front for the task of harmonizing the interests of the subjects "banks" and "developer"**

Source: compiled by the authors.

In this problem, each of the subjects involved in the process is a decision maker.

It is shown in the theory of multi-criteria optimisation that one should look for solutions (in which the values of the target functions are acceptable for such subjects) only among the Pareto-optimal ones [19].

Let us define Pareto-optimal solutions of problem (1)—(3) with constraints (4), (5). Any set $X=(X_1,X_2,X_3,X_4)$, satisfying conditions (4), (5), will be called admissible. An admissible set X^* is Pareto-optimal if there is no other admissible set X', for which

$$B(X^*)<B(X'),\ S(X^*)<S(X'),\ N(X^*)\geq N(X')$$

or

$$B(X^*)\leq B(X'),\ S(X^*)\leq S(X'),\ N(X^*)>N(X')$$

or any other similar combinations.

Table 6

Pareto-optimal solutions for coordinating the interests of the subjects of the "bank", "developer" and "population"

Index	Bank income, RUB.	Minimum average price of 1 m² of housing, RUB.	Minimum average price for households, RUB	Residential accommodation of one-room flats, m²	Residential accommodation of two-room flats, m²	Residential accommodation of three-room flats, m²	Residential accommodation of four- and more -room flats, m²
1	–45 585 539 785	–17 341 207 454	89 025	0	0	0	1 155 000
2	–48 746 998 289	–17 636 803 876	91 762	278 742	291 751	131 964	452 543
3	–45 585 540 268	–17 341 207 321	89 025	0	0	0	1 155 000
4	–46 425 774 836	–17 419 545 071	89 753	74 078	77 822	35 323	967 757
5	–48 380 052 370	–17 601 748 111	91 447	246 374	258 827	117 478	532 255
6	–45 802 030 437	–17 361 449 180	89 212	19 088	19 979	9 037	1 106 897
7	–47 195 266 159	–17 490 857 252	90 421	141 982	149 418	67 968	795 556
8	–46 136 224 164	–17 392 111 728	89 504	48 409	51 987	23 898	1 030 654
9	–48 115 327 058	–17 576 921 212	91 218	223 100	234 286	106 338	591 203
10	–47 766 488 269	–17 544 806 185	90 914	192 416	201 282	91 042	670 233
11	–47 592 859 626	–17 528 016 700	90 766	177 074	186 020	84 480	707 349
12	–46 695 719 184	–17 444 416 342	89 988	97 921	103 049	46 876	907 103
13	–46 742 280 093	–17 419 064 968	90 120	119 113	83 570	55 955	893 687
14	–47 440 586 908	–17 514 361 746	90 632	163 485	171 775	77 888	741 826
15	–48 540 132 138	–17 614 044 433	91 594	263 037	268 092	122 982	500 586
16	–48 746 998 289	–17 636 803 876	91 762	278 742	291 751	131 964	452 543
17	–46 516 194 394	–17 428 087 130	89 831	82 108	85 891	38 849	948 140
18	–45 585 539 785	–17 341 207 454	89 025	0	0	0	1 155 000

Source: compiled by the authors.

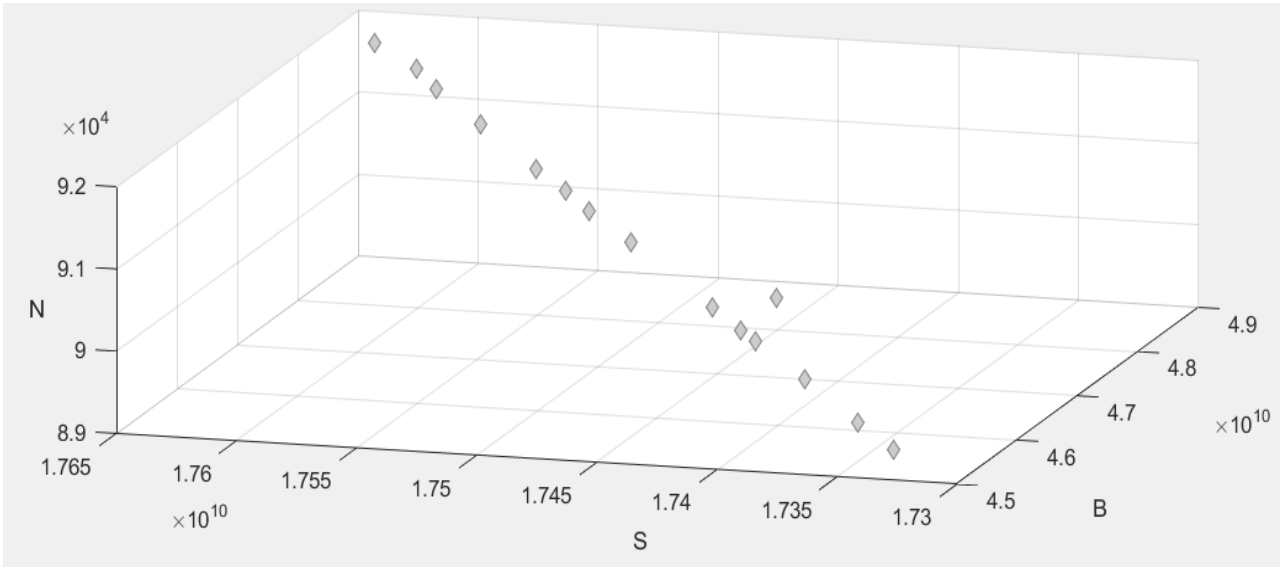

Fig. 5. **Pareto front for the task of harmonizing the interests of the subjects of the "bank", "developer" and "population"**

Source: compiled by the authors.

In other words, a solution X^* is Pareto-optimal if there is no other acceptable solution in which the value of at least one criterion was better and the others were not worse than in X^*.

To solve the problem (1)—(5) we use MATLAB application software package, which implements one of the methods of multi-criteria optimisation. The function gamultiobj is part of the Global Optimization package. It uses a supervised genetic algorithm with elitism in which there is a good compromise between computation time and the size of the desired solution [20]. The function gamultiobj generates a set of Pareto-optimal solutions by minimising the multidimensional objective function. Boundaries on the variables as well as linear inequalities and equations are allowed, but non-linear constraints are not acceptable. A controlled elitist genetic algorithm is used for minimisation.

The following data were chosen to find a numerical solution:

• Planned housing commissioning for 2021 (taken from the passport of the regional project "Housing" of the Irkutsk region).[2]

• Indicators of actual availability of flats in the housing stock of the Irkutsk region in 2021 (obtained on request from Irkutstat).

• The share of borrowed funds provided by banks to developers — for project implementation (we consider it to be 90%) and to the population — for housing purchases (mortgages) (85%).

• Loan rate for developers (consider it equal to 15%), mortgage rate (11%) — based on the Russian Federation Government Resolution No. 534 dated 31.03.2022 "On Amendments to the Resolution of the Government of the Russian Federation No. 629 dated 30 April 2020".

NUMERICAL SOLUTION TO THE PROBLEM OF HARMONISING THE INTERESTS OF HOUSING STAKEHOLDERS

Despite the fact that all the actors are involved in the interaction, it does not

[2] URL: https://irkobl.ru/sites/irkstroy/working/gilstroy/pasportj/

happen simultaneously, i.e., the consumer interacts with the bank either before choosing the object of purchase or after having already chosen it from the developer. It does not happen that all three entities meet and make a single decision — they do take into account other actors' opinions they but do not coordinate decisions with each other.

To solve the problem, we first coordinated the interests of the subjects in pairs and then — all three of them together. To do this, the three functions were created in MATLAB, which included two target functions representing the interests of the subjects involved in the problem, as well as the necessary numerical data. Using the built-in function gamultiobj, optimal solutions of these multicriteria problems were found.

The resulting solutions are presented in *Tables 4–6*. Graphical representations of the Pareto-Front for each problem are shown in *Fig. 2–5*.

The bank's income values f_1, given in *Table 4* are negative, as gamultiobj minimises the function. At the minimum average price of 89 to 97 thousand roubles per 1 m^2 the bank will receive 17 to 18 billion roubles. A compromise in the alignment of interests — is when the bank lends, and the population buys one- and four-bedroom flats. The relationship between f_1 and f_2, represented by the Pareto-front (*Fig. 2*), can be approximated by a linear function.

Table 5 shows that the developer's profit f_1 ranges from 17 to 55 billion roubles. The highest value of this indicator is achieved only in case of the sale of one-bedroom flats. If the developer has flats of all types, he loses considerably in profit. The defined eighteen Pareto-optimal points make it possible to find a compromise between the needs of the population and the developer's interest.

By reconciling the interests of the bank and the developer, a single solution is found that satisfies the interests of both entities. The bank's highest income — is 55,620,200,614 roubles and the developer's profit — is 18,279,453,191 roubles. In this situation, both the bank and the developer would prefer to build single-room flats with a total area of 1,550,000 m^2.

We coordinate the interests of all three subjects, initialise the necessary data and use the function gamultiobj as well as the function plot3 to construct a three-dimensional graph.

The results are shown in *Table 6* and *Fig. 5*.

The eighteen points represent the set of Pareto-optimal solutions for the three entities. And the bank will make a profit of f_1 between 45 and 48 billion roubles, depending on the range of types of flats sold. The developer will get a profit of f_2 about 17 billion roubles, and the minimum average price for the population f_3 will be about 90 thousand roubles per 1 m^2.

Which of the many Pareto-optimal solutions will be chosen — depends only on the decision maker.

If the actors themselves were trying to find optimal solutions to reconcile interests, it would make sense for them to go through only the Pareto optimal solutions, because in other cases the situation would be worse for some of them.

The actor whose role is to coordinate the interests of the developer, the bank and the population is the state, which must create such conditions in the housing market that the economic actors are interested in it. From our point of view, it is advisable to introduce a fourth target function into the constructed model, which would correspond to the state, for example:

$$\sum_{i=1}^{n}(U_i - X_i)^2 \to min.$$

This criterion differs in measurement units from criteria (1)—(3). An extended model with the introduction of the fourth actor is the further direction for our research.

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Authors' declared contribution:
N.N. Shelomentseva — identification of subject interactions in the process of housing construction in the conditions of project financing, development of a multi-criteria economic and mathematical model for coordinating the interests of economic entities in housing construction.
O.V. Grushina — development of the general concept of the article, analysis of the consequences of the introduction of project financing against the background of the crises of 2020 and 2022.
T.A. Krasnoshtanova — search and preparation of initial data for testing the model.

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