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Demographic Strategies of the Russian Rural Population: Intersubjective Nonlinearity Versus Economic Viability

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ABSTRACT

The intersubjective demographic strategies of modern families and settlements appear to be nonlinear, negatively affecting traditional solutions' efficiency in spurring demographic growth. This study seeks to determine how external circumstances influenced the formation and changes of fundamental collective ideas. The authors present the results from a model of demographic strategies that analyzed 1,544 rural settlements in Central Russia from 1959 to 1989, which was a period of accelerated urbanization and demographic transition. A fractal model was used to reconstruct social intentions. Control factors for each settlement were estimated based on indicators that reflect rural settlements' material and technical conditions, economic, medical, and social service development levels, and the availability of attractive migration goals. More archaic communities responded to natural growth stimulation in a linear and relatively predictable fashion, but new competencies, needs, and opportunities appeared as communities developed socially and economically. Many counterintuitive effects influenced the evolution of modernized communities. In particular, the migration aspirations of rural youth led to a postponement in births and a drop in the birth rate despite an increased quality of life. An intense migratory influx into hub settlements also contributed to a decrease in the birth rate among the local population.

Keywords: Historical demography, rural population, social simulation

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INTRODUCTION

In many countries, attempts to spur population growth usually result in counterintuitive behavior. Financial incentives to boost fertility, improved healthcare quality, social support for parenting, and education—these measures are supposed to provide strong motivation and favorable conditions for increasing fertility rates. However, hard evidence has revealed that the efficiency of such activities is exceptionally low. In modern society, the demographic strategies of households and communities have proven to be nonlinear, which poorly affects the efficacy of traditional solutions.

It is essential to consider intersubjective factors—aside from social and economic realities—to gain insight into these demographic processes: people's demographic motivation and goals, typical life projects and practices, demographic expertise, and views on living conditions. These individual factors are combined into one concept, demographic behavior strategy (Morgan, 1989; Peña & Azpilicueta, 2003; Sackmann, 2015). Such strategies were not necessarily implemented and thus featured in statistics. Nevertheless, considering them is essential for devising effective demographic policies. After all, people carry out such policies—not government agencies, institutions, or corporations.

We seek to understand how external life circumstances influenced and altered demographic behavior strategies in the recent past. Researching the historical past makes it possible to trace the genesis of the processes studied and their outcomes. We have focused on 1,544 rural settlements in the Tambov region of Russia between 1959 and 1989. In this period, the demographic transition was completed; rural life rapidly and drastically changed due to mechanized agriculture. The manufacturing sector grew in rural areas, migration occurred, and healthcare infrastructure and social services improved. We selected this period to capture society's response to a historically rapid change in living conditions.

Tambov Oblast is a typical agricultural region in Russia's Central Black Earth Region. The demographics of Tambov settlements are similar to those of most Russian settlements in the Central Black Earth Region and Volga Region (Kanishchev, 2016), which ensures that the results of this study can be extended to a large part of European Russia. Furthermore, numerous economic, social, and infrastructure factors that influenced demographic behavior can easily be identified and calculated for settlements, so these agricultural settlements are an ideal object of study for solving the posed research problem.

Many important decisions concerning demography are currently made by family members, including when to marry, when and how many children to have, when and where to migrate, and how much money and time to spend on treatment and health maintenance. However, such decisions—like many other aspects of social behavior—are strongly influenced by collective representations of what is "proper" and "normal," as well as other fundamental notions inherent to the immediate social environment. For a rural population living as relatively separate groups, this social environment has been and still is their settlement community.

To reconstruct these subtle social intentions, we applied a demofractal model, which is a variation of the general fractal transition model (Zhukov & Lyamin, 2016). The results for modeling demographic strategies for rural settlements in the Tambov

Region over several periods between the mid-1800s and 1959 have been reported in several previous publications (Zhukov & Kanishchev, 2019; Zhukov et al., 2011, 2012, 2013).

The present study's objectives are critical in understanding general demographic processes in Russia and similar countries, which until recently were predominantly agrarian. First, the period under consideration is important for demographic history. From the 1950s through the 1980s, a demographic transition was completed in Russia (and several other countries), and the modern population migration and reproduction system emerged. Second, changes in migration and reproductive strategies of the rural population have largely determined the modern demographic characteristics of Russian agrarian society (and other countries). We also hope that the methodological aspects of the present study will be useful for Russian and global historical and demographic research, especially in predominantly agrarian countries.

We have proposed a model that can be adjusted for different regions and historical periods, that is, where and when different rates of demographic transition occur. Moreover, this model can simulate nonlinear effects characteristic of human behavior in any country.

MATERIALS

Initial data for the model were extracted from a various statistical, reference, and cartographic sources and the Tambov Oblast State Archive (TOSA). In particular, the primary data from two censuses were used: 1959 (TOSA, archive P-3688) and 1989 (Kamensky, 1989).

Maps of Tambov Oblast from the 1950s through the 1980s indicated the presence of industrial facilities and a transport network near certain settlements. Specific publications on the history of education and healthcare systems provided information about schools and medical facilities (Bykova & Schukin, 2004; Muravyov, 1988). Data on the settlements' economic, infrastructural, and social and cultural conditions were derived from the Tambov Regional Committee of the Communist Party of the Soviet Union (TOSA, archive P-3443) and the Encyclopedia of Tambov Oblast (Protasov, 2004). Statistical data on the material conditions of the rural population and the technical supply of agriculture were derived from our colleagues' research (Avrech, 2015).

The raw data in systematic form are available on the Center for Fractal Modeling's website: http://ineternum.ru/demo2/. The methods of processing the raw data are described in Appendix 2. The following information was obtained for each of the 1,544 settlements: population growth between 1959 and 1989, the number of men and women, the status of the settlement (disappeared, merged, and others), the formal status of the settlement (i.e., "promising" or "not promising"), the presence of an administration, remoteness from cities, the level of production facilities' development, the level of socio-cultural infrastructure development, and the presence of medical institutions. The data allow for a comprehensive understanding of the factors that may have influenced the population's migration and demographic strategies.

LITERATURE

Many extensive studies are dedicated to the late Soviet period in modern Russian historical demography, yet they mainly consider all-Union or all-Russian processes (Polyakov, 2011; Verbitskaya, 2009; Zhiromskaya & Isupov, 2005). These studies paid little attention to multiple possibilities for populations' development at the micro-level. Factors for the demographic development of the Central Black Earth region's rural population were analyzed in several studies, which offered insight into agricultural conditions, rural material conditions, and the migration of the region's inhabitants (Avrech, 2015; Pertsev, 2013; Piskunov, 2017).

The challenge in studying intersubjective phenomena is associated with the many nonlinear effects that disrupt proportionality between causes and effects and, specifically, between the intensity of external circumstances and people's reactions. Nonlinear effects occur in simulation models based on synergetic and related concepts, including fractal geometry (Mandelbrot, 1982). An interdisciplinary approach is thus considered promising in the literature (Alekseev et al., 2007; Borodkin, 2005, 2016, 2019; Malinetskii, 2013; Smorgunov, 2012; Zhukov et al., 2017).

Modeling is a powerful tool to devise alternatives—unrealized scenarios. Alternatives are of interest because they reveal the hidden potential of a subject under investigation and generate hypotheses. The application of models in the social sciences and humanities has been advocated for by many classics of modeling (Ackoff & Emery, 1972; Axelrod, 2007; Meadows, 2008; Richmond, 1993).

METHODS

General Fractal Transition Model (GFTM)

The mathematical tool (GFTM; Appendix 1) is based on the procedures described by Benoit Mandelbrot to create algebraic fractals (Mandelbrot, 1982). Specifics of the GFTM are detailed in a publication (Zhukov & Lyamin, 2016) available online. The GFTM imitates system evolution as the trajectory of a representative point in a two-dimensional space. At any instant, a point's two coordinates are equal to the values of two key properties within the system. Each point's position (i.e., coordinates) can be interpreted depending on the labeling of the phase space. Figure 1 shows the way how the labeling was done.

Specific areas are distinguished in the GFTM phase space. According to the model conditions, these areas have certain symmetric qualities of the x- and y-axes. A combination of two gradations (sharp and soft) of two properties offers four types of system states: T, O, M, and H (see Figure 1). The ratio of the simulation scale and the usual growth/loss values are shown in Figure 7 in Appendix 3. Thus, a positive net migration rate characterizes the settlement if a point (a settlement) has an x-coordinate range from 1 to 2 model units. On the other hand, if the same point (settlement) has a y-coordinate in the range from 0 to 1 model units, this implies a natural decrease. Therefore, all such settlements will be in Area O (Figure 1A).

The trajectory or evolution of a representative point depends on the initial position and magnitude of the controlling factors A, D_c, and K_c. Fractal-generating software calculates the trajectories for the simulated system with a particular combination of controlling factors specified by the user. The software generates images of attractors, given that they are within the boundaries appropriate for the system's existence. Attractors provide insight into the final states towards which the system gravitates under the influence of controlling factors. It is something of a final stage in system evolution, in which the different scenarios for the future converge. Computer experiments with the GFTM are confined to identifying the system's final states with various changes in controlling factors.

The demofractal model is a GFTM specification. A representative point in demofractal indicates the intersubjective demographic strategy of a settlement (or community). This strategy has two key characteristics: the required negative or positive net migration rate (measured along the x-axis) and the required rate of natural increase or decrease (measured along the y-axis), which is displayed in Figure 1A.

Factor A is the degree to which the external environment is favorable or unfavorable, which is also affected by society's capacity to control the environment or resist its effects. Factor D_c represents a set of measures to control positive or negative net migration, and factor K_c is a set of measures to regulate natural increase or decrease (birth and death rates). These factors will be discussed in more detail below. By determining the value of the controlling factors for each simulated rural community, we can obtain a set of attractors for all possible initial states. In this case, the attractors specify an intersubjective strategy that each society sought to implement.

The labeling of the demofractal's phase space is shown in Figure 1. The labeling turns the model's phase space into an interpretation space so a point's trajectory can be interpreted as the system's evolution in qualitative terms. For instance, the points in the H(EpMu) area denote strategies that combine natural increase (Ep) and negative net migration (Mu). These are the strategies of migration donors.

Two diagonals divide the regions T, O, M, and H into eight types. One of the diagonals is the balance line between total population increase and total population decrease (Figure 1B). All points above this line suggest a tendency to increase the total population and those below to reduce.

The eight types presented in Figure 1B and Table 1 represent a more detailed classification of these demographic strategies. Thus, Type 1 and Type 2 belong to Area H. Therefore, all points within the framework of these types signify natural increase and negative net migration. However, any point within the framework of Type 1 means that natural increase does

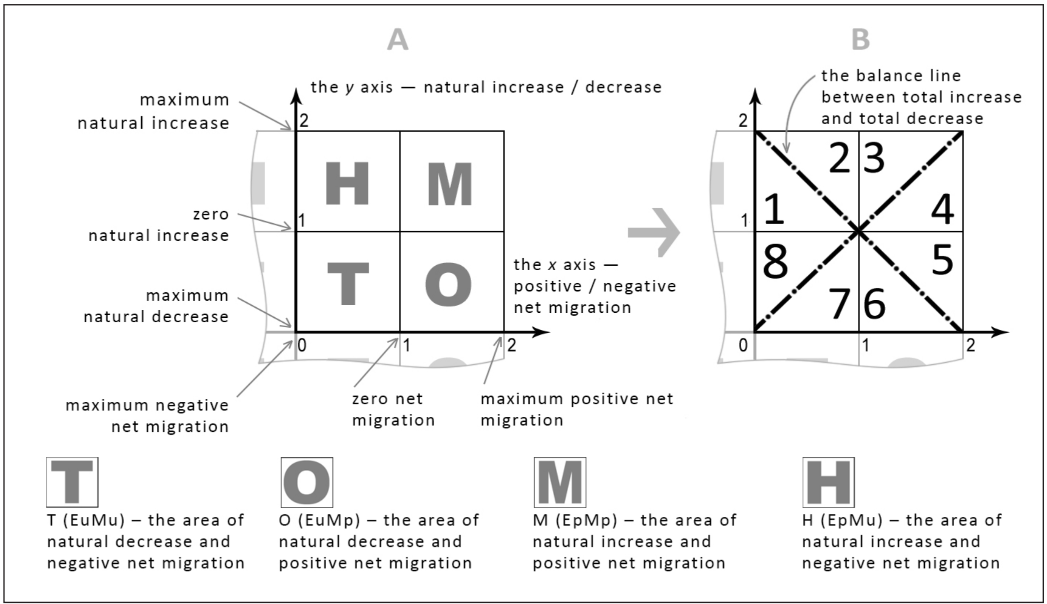

Figure 1. Demofractal phase space labeling

not compensate for negative net migration. In Type 2, natural increase is always higher than negative net migration.

During the period under consideration, many settlements disappeared. Taking this into account, we identified (Appendix 4) the desolation risk area (see Figure 2) in the phase space. The conducted experiments suggest that this area is close to the *y*-axis and is a subdivision of Type 1, which has a maximum negative net migration. Therefore, points (settlements) in this phase space area are at risk of disappearing. This effect is described in more detail in the section "Hypothetical Trajectories in the Phase Space."

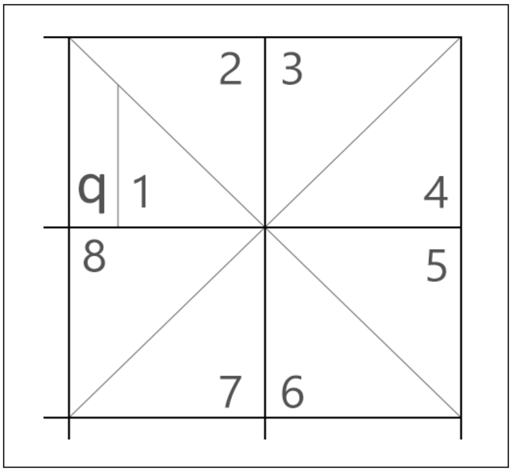

Figure 2. Desolation risk area (q)

Controlling Factors and Their Indicators

In the 1960s, a new round of agricultural mechanization had begun: agricultural machinery far superior to the tractors and combines of the previous period was introduced, thus eliminating the need for many rural workers. From the 1960s through the 1980s, rural living conditions improved significantly as hospitals and medical centers, new houses, schools, cinemas, and leisure centers, among other amenities, were built in the settlements.

Despite this, cities—which needed blue-collar workers and could provide a higher standard of living—became a preferred place to work and live for rural populations. As a result, organized resettlement from villages to cities was negligible (Piskunov, 2017). However, large-scale non-state-controlled migration flows occurred. Due to external circumstances, settlements in the countryside failed to maintain the relatively good demographic indicators present at the beginning of the 1960s (i.e., birth rate over 20‰ and death rate below 10‰).

The decline in the birth rate and increase in the death rate were a matter of concern for the state and society and required corrective measures. However, the society of that time was not sufficiently aware of the historical roots of these phenomena. In the 1960s, the demographic echo of World War II and the post-war years (i.e., the Soviet-Finnish War, the famine of 1946–1947) had begun to take effect. Moreover, the meager generation of the 1940s reached childbearing age, while the more populous generation born in the first quarter of the 20th century was passing away. Under these conditions, a natural population decline was inevitable.

The general driver of changes over the entire period was a significant increase in the value of Factor A, which is defined as the degree to which the environment is favorable. This factor is not restricted to ecological conditions but also includes society's technical and technological equipment, economic conditions, and level of medicine development, all of which fundamentally affect how deeply and in what way the environment will impact people's livelihoods.

In the period studied, K_c (a set of measures to control natural population movement) limited the "natural program" of birth rate, regulated the planned number of children, and enhanced the survival rate. On the other hand, factor D_c (a set of measures to control the population's migration movement), in general, could not prevent the outflow of people from donor settlements and encouraged their influx into large hub settlements.

Any controlling factor in a modernized society acts differently from a traditional one. In a traditional society, the impact of any factor is the blind, steady force of nature. In previous studies (Zhukov et al., 2011), we noticed that traditional societies balanced around extreme strategies, sometimes breaking into extreme scenarios (only in computational experiments), including, for example, the strategy of "populating the Universe" or "getting rid of the population."

In a modernized society, controlling factors are those forces that do not seek to impose prohibitive goals on society but rather the observance of the established norm; these are regulators. Thus, the growth of D_c requires that society focuses on regulating migration movements to solve its issues. It could mean both are encouraging a migration outflow and the efforts to contain it or even stimulate the influx, depending on how necessary it appears for a given settlement at a given time. Similarly, an increase in K_c does not imply a fight against the birth rate or the promotion of the death rate but rather an emphasis on regulating the natural population movement – that is, in a sense, reducing the range in which births and deaths are spontaneous.

Controlling factors were calculated for all 1,544 settlements studied based on the indicators. Indicators for each settlement were collected in a database available online: http://ineternum.ru/demo2/. A description of the indicators is detailed in Appendix 2.

The following indicators were used to calculate the K_c value: the degree of demographic transition completion, the ratio of men and women, the availability of medical facilities, and the development level of production capacities. Indicators for D_c included the status of a settlement, the development level of social and cultural infrastructure, the availability of a village council, proximity to a city, and the development level of production capacities. Factor *A*'s value was determined based on expert assessments (Appendix 3). The methods for calculating the controlling factors D_c, K_c, and *A* and the model calibration procedures are presented in Appendix 3.

Hypothetical Trajectories in the Phase Space

In normal development scenarios, the attractors are grouped at a single point, which means that, regardless of the initial conditions' variability, different parts of the system evolve jointly. However, when the system transcends acceptable values, it is usually accompanied by an "explosion" of attractors. During such an explosion, the attractors disperse from the same point, forming clouds of various shapes.

In demofractal, the controlling factors K_c and D_c do not independently affect the system; instead, they form a certain unity, which is not surprising: migration strategies are developed by considering natural processes—births and deaths. However, this strong feedback seems unexpected initially: natural population movement is sensitive to D_c values. Moreover, the migration situation (e.g., an influx of migrants or their mass departure) and families' migration intentions had a significant impact on the patterns of natural reproduction.

We conducted two experiments to consider such relationships between controlling factors more thoroughly. In the first series, we traced the system's trajectory (or evolution) when D_c is altered, and other parameters were set at a medium level. The resulting trajectory was denoted as *D*-evolution. Similarly, in the second series of experiments, *K*-evolution was obtained.

D-Evolution. Figure 3 shows the displacement of the same point in the phase space of the model. These images result from many experiments during which one of the control factors increased. We were able to trace how the coordinates of the point (that is, the settlement characteristics) changed in a series of experiments.

In the period under study, society was under the increasing influence of factors that regulate migration behavior, that is, under the influence of the D_c value. An increase in D_c with a constant K_c (for example, K_c = 1.77, Figure 3) leads to a two-phase evolution of the system. During phase one, negative net migration increases, and natural increase also grows (with some lag). In this phase, the model demonstrates linear behavior: society compensates for the outflow of population. Then (in the example under consideration at D_c = 0.8), an explosion occurs, followed by a minor divergence of attractors (between 0.72 and 0.91 in the D_c range). During phase two, the attractors converge again at a single point and begin to move in the opposite direction. As a result, natural growth is reduced along with the migration outflow—so much so that natural growth even becomes negative, and migration outflow is replaced by inflow. Phase two is counterintuitive.

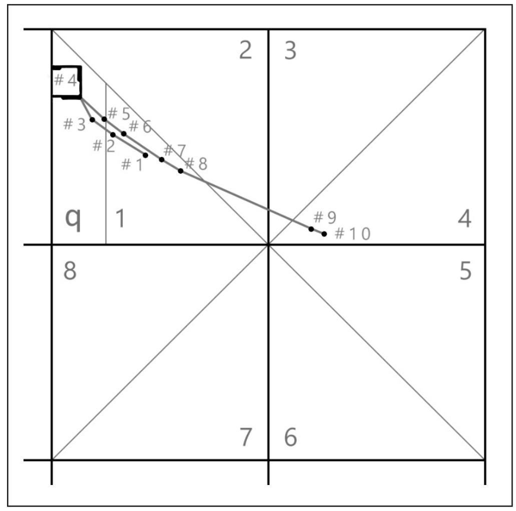

Figure 3. Trajectory of a representative point. The experiments' conditions: A = 0.3; the direction of K_c and D_c = inwards; K_c = 1.77; D_c in experiment #1 = 0.1; …#2 = 0.3; …#3 = 0.5; …#4 = 0.8; …#5 = 0.94; …#6 = 0.95; …#7 = 0.98; …#8 = 1; …#9 = 1.2; …#10 = 1.29

The growth of D_c can be interpreted as a result of the increasing role of migration motives and opportunities in the demographic strategy of people and settlements. Such growth is almost inevitable with the development of communications, production capacities, educational level, and labor competencies. In relatively archaic societies, such growth caused an outflow of the population in search of a better life and, to some extent, an increase in the birth rate. A settlement used to move towards an ideal state that was unattainable in reality—a point in the phase space where many people are born, but everyone leaves. It led to a loss of population and an increased risk of desolation.

If a settlement could survive this risk and persist in its development, then the intensification of migration factors would later turn the migration vector around. The settlement would begin to grow due to an influx of migrants but would still have a reduced birth rate. The tendency towards the opposite ideal state would emerge, wherein the birth rate was minimal, and a migratory influx supported the population.

Thus, even a smooth change in factor D_c initiates an abrupt change in the behavior of societies: they pass a certain turning point. This point is in the area with the maximum migration outflow of the population, which is the area where settlements tend to disappear. Regardless of how great the societal ambitions for natural growth are, large-scale migration would undermine local birth rates.

If the settlements manage to pass through the turning point, they further evolve within the framework of a different pattern;

they lose less population due to migration and stimulate less natural growth. Reliance on migrants and insufficient stimulation of natural growth go hand in hand and are a modernized mode of behavior. In the most extreme case, at the end of this evolution, a hub community emerges that practically does not generate natural growth but grows due to the absorption of migrants and adjoining settlements. The transition to a new mode of behavior is associated with entering the risk area. Almost all extinct settlements have attractors near the turning point. The surviving settlements have already passed this point or have not yet come close to it.

K-Evolution. Figure 4 is drawn similarly to Figure 3. Both figures show the results of a series of experiments. Again, the displacement of a point (that is, the change in the settlement characteristics) results from the growth of one of the control factors. However, in this case, a different factor was changing during the experiments, namely K_c.

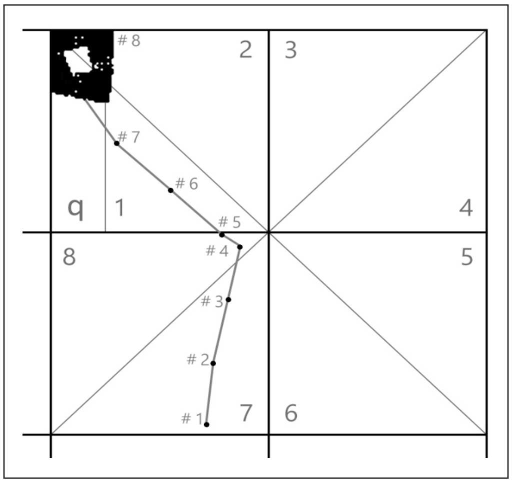

Figure 4. Trajectory of a representative point. The experiments' conditions: A = 0.3; the direction of K_c and D_c = inwards; D_c = 0.9; K_c in experiment #1 = 0.001; …#2 = 0.5; …#3 = 1; …#4 = 1.4; …#5 = 1.45; …#6 = 1.6; …#7 = 1.7; …#8 = 2

For a fixed D_c (for example, D_c = 0.9, Figure 4), an increase in K_c also generates two-phase behavior in the model. However, in this case, phase two does not cancel the consistency of phase one but only corrects this consistency. In phase one, an increase in K_c leads to a rapid decrease in natural decline. Society focuses on population growth not only due to births but also due to increased life expectancy. In contrast, the magnitude of migration outflow is almost unchanged or decreases slightly. Phase one in the presented example proceeds in the K_c range from 0.001 to 1.4. At some point (in this example, K_c = 1.45, experiment #5), the attractors reach the area of natural growth, and phase two commences. Societal behavior is substantially corrected; negative net migration begins increasing rapidly (evident that further population growth provokes a sharp migration outflow). So, it goes on until K_c = 1.77. Then, an explosion of attractors occurs in the K_c range between 1.77 and 2.

Thus, the development of measures to control survival (medicine, social security, and others) had a strong effect on the communities that, until recently, had been traditional. Communities sought to increase their population and even decrease migration outflow. With further livelihood developments, however, the migration outflow would rise sharply. The overwhelming majority of the studied settlements were in phase two: it was no longer enough for people to simply maintain their numbers, and they sought to move to other places. Thus, there was a reorientation of collective goals: it moved from the entire society's survival to a person or family searching for a better life. For archaic societies, the key to survival—both collective and individual—in maintaining their numbers by giving birth to children. Such settlements initially react strongly to material improvements in living conditions. Then, however, new needs are prioritized for progress improvement, including personal well-being (which is often associated with migration) and life extension.

In the model, phase two of *K*-evolution is associated with the continuation of natural growth. However, as it turns out, this social intention could not be fully implemented. A society's high migration aspirations were accomplished in practice, whereas aspirations for natural growth were achieved to a lesser extent. Migration largely entailed young and middle-aged people, undermining the fertile base population. A strong outflow of people changed the age and gender structure, which was a depressor for life expectancy and birth rate.

RESULTS

Simulation results for all 1,544 settlements are available on the Center for Fractal Modeling's website: http://ineternum.ru/demo2/. For almost all settlements (except for 13 cases), demographic strategy attractors converged at a single point. Figure 5 shows a combined picture of such attractors. This figure contains the results of calculations for 1531 real settlements. Each point represents the demographic strategy of a separate settlement in the simulation phase space. Such a strategy is an ideal state towards which the local community gravitates under the influence of its intersubjective ideas and objective external circumstances. In Figure 5, each point is the most comfortable state for a given settlement. Such intersubjective strategies determine the evolution of settlements in the near future. The distribution of settlements by type is presented in Table 1.

Table 1 presents the desirable strategies that could only be implemented in the most favorable circumstances. Strictly speaking, social intentions generally do not have to be realistic.

DISCUSSION

Table 1 demonstrates the logical development of trends between 1939 and 1959. The key and apparent distinction

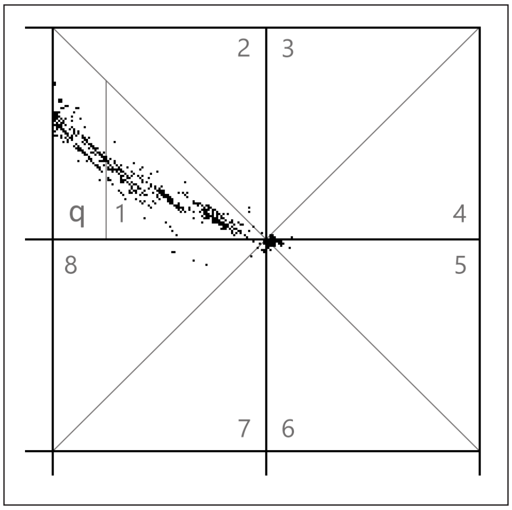

Figure 5. Particular settlements' attractors
Note. Each point denotes a single settlement

Table 1
Comparative modeling results for the periods 1939–1959 and 1959–1989

	1939–1959		**1959–1989**	
	Number of settlements	**%**	**Number of settlements**	**%**
TOTAL	561	100	1544	100
H (EpMu)/1—natural increase does not compensate for negative net migration	227	40.5	1400	90.7
including those in the risk area			975	63.1
H (EpMu)/2—natural increase is higher than negative net migration	278	49.6	5	0.3
M (EpMp)/3—natural increase is higher than positive net migration	2	0.4	5	0.3
M (EpMp)/4—positive net migration is higher than natural increase	6	1.1	36	2.3
O (EuMp)/5—positive net migration is higher than natural decrease	8	1.4	40	2.6
O (EuMp)/6—positive net migration does not compensate for a natural decrease	36	6.4	29	1.9
T (EuMu)/7—negative net migration is lower than natural decrease	0	0	12	0.8
T (EuMu)/8—negative net migration is higher than natural decrease	4	0.7	17	1.1

Note. Results for 1939–1959 were obtained from a study (Zhukov & Kanishchev, 2019) conducted according to a similar research program.

of the new results is that the settlements that once belonged to Type 2 (i.e., natural increase greater than negative net migration) have completely changed to Type 1 (i.e., natural increase does not compensate for negative net migration). Nearly half (49.6%) of the settlements between 1939 and 1959 could be considered successful demographic sources, but between 1959 and 1989, only 0.3% of such settlements remained. After the demographic transition, Type 1—endangered demographic donors—became dominant. These settlements were also focused on natural growth, which ruled out demographic collapse, but the priority for inhabitants was migration. Moreover, 63.1% of all settlements were in the risk area, where migration aspirations were so great that they could lead to settlement extinction in the foreseeable future if demographic strategies did not change. All extinct settlements and 441 existing settlements had entered the risk area.

It should be noted that the model prediction is overly pessimistic. Of the 441 settlements mentioned, relatively successful villages showed a total decrease of over 30‰. In contrast, the model indicates that these settlements were characterized by strategies that generated a minimum of 88‰ total decrease. Understandably, circumstances prevented people from leaving their homes and accomplishing their migration aspirations, but this is quite an ordinary situation. Shares of Types 3, 4, 5, 6, 7, and 8 from 1959 to 1989 remained insignificant in the previous period. However, there were some interesting adjustments. The proportion of settlements in which positive net migration was greater than natural growth doubled (from 1.1% to 2.3%). At the same time, the proportion of settlements where positive net migration did not compensate for the natural decrease dropped over three times (from 6.4% to 1.9%). Both facts indicate that settlements focusing on absorbing migrants (i.e., hub settlements) began to experience fewer problems, ensuring a migratory influx. In general, the model reproduced the situation in which masses of the rural population were in motion when rural society was experiencing accelerated disintegration. Even a significant improvement in rural living conditions could not keep most villagers in their usual place of residence.

Figure 6 shows the largest attractor clusters. Some points may have the same or close coordinates. Therefore, it is difficult to assess the number of points in clusters visually. Figure 6 shows the largest clusters in some cases.

Bipolarity is visible. Two consolidated and numerically dominant groups of settlements are distinguishable: migration donors (in Area q) and migration recipients (in Areas 2, 3, and, especially, 5 and 6). The latter two are considered hub settlements, of which there were significantly fewer than donor settlements. The main cloud of attractors is extended significantly below the balance line, which equals the total increases and decreases. In the previous period, recipient societies gravitated towards the balance line and maintained their population numbers (Zhukov & Kanishchev, 2019). Although societies were still focused on natural growth in the period under study,

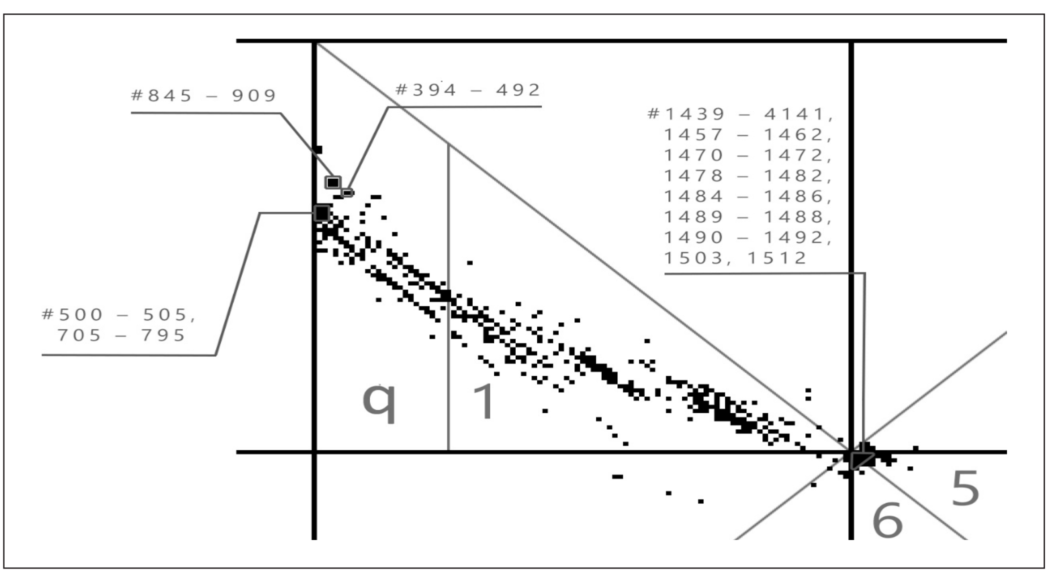

Figure 6. Attractor clusters from 1959 to 1989
Note. The callouts highlight experiment numbers that yielded attractors that are part of large clusters.

maintaining the population was not their explicit intersubjective goal.

There were no settlements where the desire for the high natural increase was coupled with a high migration influx or at least near-zero values of migration outflow. Migration limited natural growth. People waste their time on migration, which goes hand in hand with marginalization. Migration inflow reduced demand for residents of the hub settlements, and migration outflow interfered with natural reproduction in donor settlements.

The results clarify demographic patterns during the period of urbanization when the traditional peasantry began to disappear. First, the literature discusses why peasants' growing prosperity did not suppress a widespread desire to move to cities. Several researchers have drawn attention to the possibility that improvements in welfare were exaggerated by state propaganda (Avrech, 2015). Our results reveal a different picture. Living standards, medical care, and social support systems developed rapidly (Pertsev, 2013; Piskunov, 2017). However, Marshall's (1890) law of increasing needs also manifested itself in Russia in the second half of the 20th century. In rural settlements, migration intentions were unexpectedly strong when the quality of life improved.

Second, a significant finding is that migration intentions were a depressor concerning fertility. In the literature, migration and reproduction are often viewed as loosely connected. The decline in the birth rate in rural areas since the 1960s has been interpreted as the natural conclusion to the demographic transition (Zhiromskaya & Isupov, 2005). However, it is worth noting that the completion of the demographic transition and the later demographic history of Russia was significantly complicated by urbanization and the strong migratory intersubjective intentions of the rural population. It led to a decrease in the birth rate not only in cities but also in villages.

Several of the questions posed in the present study have not been previously considered. We believe it is crucial to consider objective factors of population reproduction and intersubjective demographic strategies. We have demonstrated that many methods for demographic recovery have proven to be ineffective or even counterproductive because of the nonlinear effects inherent in human behavior and the perception of external circumstances.

CONCLUSION

Modeling the demographic strategies of 1,544 settlements in the Tambov region of Russia from 1959 to 1989 revealed that most rural communities were oriented towards natural increase. However, the effects of society's desire for natural growth were neutralized by migration intentions to a certain extent. For the desired natural growth to be converted into real overall population growth, migration movements should have been halted. Unfortunately, such a policy in the specific historical conditions could never be a reality as migration was stimulated by powerful systemic factors: people's intentions, industrial growth, and state policy, which relied on the predominant development of hub settlements—promising villages, district centers, and “agro-cities”—where “the difference between the city and the country” would be erased.

The state’s reliance on hub settlements did not produce the expected results; it had directly opposite—counterproductive—effects. The hubs did not yield a significant natural increase and simultaneously “oppressed” the natural increase in the donor settlements. All hubs in the model had a minimal natural increase (or even a slight decrease), mirroring the reality of most cases. Hub communities also could not become truly attractive places to live for migrants. Hubs attracted people because they played the role of advanced airfields; they were an intermediate point on the migration path of “hamlet–village–district center–regional city–capital.” Although some people, due to life circumstances, became stuck at a point along this trajectory, this is not proof that the hubs themselves had turned into intense attraction points. Indeed, some of the official “promising” settlements turned out to be endangered. Analyzing the attractors of demographic behavior in rural settlements makes it possible to correct the seemingly obvious concepts formed by a purely linear understanding of demographic processes. The socioeconomic and living conditions created in the promising settlements of late Soviet society were at the highest levels the Russian countryside had ever experienced. However, they were still insufficient to restrain many villagers from their aspirations for a different life in a non-agricultural environment.

From 1959 to 1989, controlling factors influenced demographic strategies nonlinearly. The effect of the law of increasing needs was especially noticeable. More archaic communities responded to the stimulation of natural increase relatively predictable. However, the efficiency of such a policy would have dropped quickly: people would acquire new competencies, needs, and opportunities. The easiest way to satisfy new aspirations was migration. A disposition to migrate led to delayed births and a drop in fertility. An intense migratory influx into hub settlements also contributed to a decrease in the birth rate among the local population. The traditional link between the prosperity (and even survival) of a community and high birth rates had been severed.

In general, a modernized (as compared to traditional) society is characterized by a more complex relationship between controlling factors and the evolution of demographic strategies. Modernized society has many paradoxical regulators, and many counterintuitive effects influence the evolution of modernized micro-communities. Neither mere summation of factors nor the accentuation of any of them presents the full picture. Approaches to managing demographic behavior often remain within the framework of ordinary linear representations and, largely because of this, a demographic policy cannot achieve the required results.

ACKNOWLEDGEMENTS

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APPENDIX 1

THE GFTM MATHEMATICAL APPARATUS

Modernofractal 5.1 software was used for computer experiments with the GFTM: http://ineternum.ru/eng/software/.

The model's mathematical apparatus consists of Iterative Formula 1 and two conditions (C-symmetry and A-symmetry) that enable the identification of the geometric meaning of operations on complex numbers with the results of elementary interactions of the model's controlling factors.

$$Z_{n+1} = AZ_n^2 + C, \quad (1)$$

where $Z\ (x;\ y)$ and $C\ (D_c;\ K_c)$ are complex numbers.

Iteration imitates short- and long-term interactions of the factors considered in Formula 1. We have defined these factors in the broad sense as system reflexivity (Z_n^2), self-sufficiency (A), and external influence (D_c and K_c).

C-symmetry (see Table 2) ensures that, in each iteration, D_c and K_c are set as either positive or negative: first, set per the user's choice of the direction for D_c and K_c and, second, per the positivity or negativity of the complex numbers $F\ (D_f;\ K_f)$ in the current iteration. Thus,

$$F = AZ_n^2 \quad (2)$$

Table 2
C-symmetry

	Direction D_c				Direction K_c			
	inwards		outwards		inwards		outwards	
if D_f	−	+	−	+				
then D_c	+	−	−	+				
if K_f					−	+	−	+
then K_c					+	−	−	+

A-symmetry imitates the use of an equal amount of negative and positive values of A. The user sets the intensity of the controlling factors A, D_c, and K_c and the directions in which the factors D_c and K_c will push the system: inwards (to zero) or outwards (to infinity). The software tests a set of points on the complex plane in a specific area with a predefined increment value. The coordinates of each test point are substituted into Iterative Formula 1 as the initial value of Z_1. Iterative Formula 1 generates a series of numbers of a point's trajectory in the complex plane. The fractal-generating software, having carried out many iterations, can generate images of the system's attractors (if any are visible) and their pools.

APPENDIX 2

DESCRIPTION OF INDICATORS USED TO COMPUTE VALUES FOR CONTROLLING FACTORS

1. The indicator “place” is set as the status of a settlement at the end of the study period (Table 3).

Table 3
Indicator “place”

Marker	Description
rc	District center
p	“Incorporators” – settlements that have incorporated other settlements
ss	Surviving villages
sd	Surviving hamlets
io	“Extinct due to incorporation” – settlements that have been incorporated into other settlements
in	“Extinct due to unknown circumstances” – settlements that most likely have been incorporated into others, albeit not properly documented
i	“Extinct” – settlements that have been desolated by the end of the period but still existed for some stretch of that period; settlements with no population by the end of the period are also allocated to this group

2. The indicator “the availability of the village council in the settlement testifies to a fundamentally higher level of development in the administrative, social, and economic infrastructure.
3. The indicator “proximity to a city” (Table 4) signifies the possibility of circular labor migration. A city is considered nearby if it is within a 20 km radius.

Table 4
Indicator “proximity to a city”

Marker	Description
0	No nearby city
mg	Settlement located near a small city
sg	Settlement located near a medium city (Michurinsk)
bg	Settlement located near a large city (Tambov)

4. The indicator “development level of production capacities” indicates the availability of economic facilities of different levels and, accordingly, jobs. This indicator was established using expert estimates based on the examination results of economic facilities in each settlement. The measurement range was 0 to 1, where 1 is the maximum level (for the studied period and the group of settlements).
5. The indicator “level of social and cultural infrastructure development” presents the availability of schools, post offices, shops, and other facilities that directly affect the quality of life. The indicator was calculated using a method similar to indicator 4.
6. The indicator “degree of demographic transition completion” implies the level of development of birth control methods appropriate for the modernized settlement type. The indicator was set at the average number of children in a family: for a district center, an average of two children, while for other types of settlements (e.g., hamlet, village, small town), an average of three children.
7. The indicator “ratio of men and women” reflects the fact that fertility is limited as a result of imbalance (b), which can be evaluated for each settlement as follows:

$$b = |50 - v|, \quad (3)$$

where v = percentage of men. For extinct settlements, we assumed an imbalance of 12.5 percentage points.

8. The indicator "availability of medical facilities" indicates the level and accessibility of medical services. Examining the availability of medical facilities of one type or another, an expert evaluated the quality of medical care on a scale of 0 to 1 (Table 5).

Table 5
Indicator "availability of medical facilities"

Marker	Description	Expert evaluation of medical care quality
0	No medical facilities	0
vr. amb.	Outpatient clinic	0.4
amb.	Outpatient department	0.4
m.p.	Health post	0.5
FAP	Midwife center	0.5
ouch. b-tsa	Rural district hospital	0.6
ouch.b., d / i	Rural district hospital, nursery, and kindergarten	0.6
amb. ouch.bol.	Outpatient department, rural district hospital	0.6
CRB	Central district hospital	0.8
CRB, raySES, d / i	Central district hospital, district sanitary and epidemiological service, nursery, and kindergarten	0.8

APPENDIX 3

MODEL CALIBRATION AND COMPUTATION OF CONTROLLING FACTORS

For calibration, a limit of 142‰ (−142‰) was set for the increase and decrease values (*x* and *y*); this correlates with the boundaries of the model's phase space that were studied (see Figure 7). This limit is theoretical and can only be revealed in empirical evidence in exceptional cases. This issue is discussed elsewhere (Zhukov et al., 2011, 2012). Figure 7 shows the ratio of model and natural units adopted to measure the phenomena in question.

The indicators' values were converted to the scales adopted in the model. It was also necessary to determine and formalize the relationship between the controlling factors and their indicators and establish weighting coefficients for each indicator.

Calibration was carried out based on several well-studied settlements (Tables 6a, 6b, and 6c). For each of these settlements, we know the development results (the values of migration and natural movement of the population namely, the position of attractors in the phase space) and the experimentally established values of the controlling factors. Tables 6a, 6b, and 6c link the actual data for the calibration settlements, and the values of indicators and controlling factors.

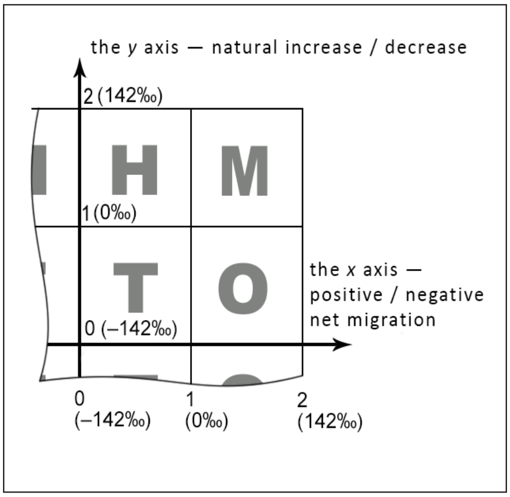

Figure 7. A sector of the demofractal phase space

Table 6a
Calibration data summary

	Iskra, Zherdevsky District (e.p. = +11‰, m.p. = −4‰) *		Sosnovka, Sosnovsky District (e.p. = 0‰, m.p. = +17‰)	
	actual data	**model data**	**actual data**	**model data**
A **=**	0.3	0.3	0.3	0.3
Direction K_c	inwards	inwards	inwards	inwards
Direction D_c	inwards	inwards	inwards	inwards
K_c **=**	**1.77**	**1.6081**	**1.69**	**1.69**
Indicator #6**	3	1.7921	2	1.85
Indicator #7	1.9	0.014	2.9	0.022
Indicator #8	0	0	0.8	0.08
Indicator #4	0.1	0.17	1	0.2179
D_c**=**	**1.06**	**0.9529**	**1.2**	**1.2**
Indicator #1	ss	0.902	rc	1.018
Indicator #5	0.3	0.15	1	0.175
Indicator #2	1	0.008	1	0.008
Indicator #3	0	0	0	0
Indicator #4	0.1	0.1072	1	0.001

* Here and in Tables 6b and 6c: e.p. – natural increase; m.p. – positive net migration.

** Here and in Tables 6b and 6c, the indicators numbering is according to Appendix 2 'Indicators'

Table 6b
Calibration data summary, follow-up 1

	Malie Pupki (Podlesnoye), Sosnovsky District (e.p.= +19‰, m.p. = −38‰)		Karpovka, Tokarevsky District (total increase = −35‰, near-extinct settlement)	
	actual data	**model data**	**actual data**	**model data**
A **=**	0.3	0.3	0.3	0.3
Direction K_c	inwards	inwards	inwards	inwards
Direction D_c	inwards	inwards	inwards	inwards
K_c **=**	**1.65**	**1.65**	**1.6**	**1.6221**
Indicator #6	3	1.7921	3	1.7921
Indicator #7	2.9	0.022	0	0
Indicator #8	0.5	0.05	0	0
Indicator #4	0.1	0.17	0.1	0.17
D_c **=**	**0.97**	**0.97**	**0.88**	**0.7368**
Indicator #1	ss	0.902	sd	0.844
Indicator #5	0.7	0.1672	0	0
Indicator #2	1	0.008	0	0
Indicator #3	0	0	0	0
Indicator #4	0.1	0.1072	0.1	0.1072

Table 6c
Calibration data summary, follow-up 2

	Pervaya Malaya Semenovka, Tokarevsky District (extinct settlement)		Belomestnaya Dvoynya, Tambovsky District (e.p. =0‰, m.p. = −4‰)	
	actual data	**model data**	**actual data**	**model data**
A **=**	0.3	0.3	0.3	0.3
Direction K_c	inwards	inwards	inwards	inwards
Direction D_c	inwards	inwards	inwards	inwards
K_c **=**	**1.7**	**1.7**	**1.62**	**1.631**
Indicator #6	3	1.7921	3	1.7921
Indicator #7	12.5	0.0921	2.4	0.0178
Indicator #8	0	0	0.4	0.04
Indicator #4	0	0	0.2	0.1832
D_c **=**	**0.7**	**0.67**	**0.99**	**0.99**
Indicator #1	i	0.67	ss	0.902
Indicator #5	0	0	0.7	0.1672
Indicator #2	0	0	1	0.008
Indicator #3	0	0	bg	0.061
Indicator #4	0	0	0.2	0.0262

Factor *A*

Factor A is the most abstract driver in the model. Based on expert estimates, it was set to 0.3 for all investigated settlements. The average value of this factor during the preceding period (i.e., the war and post-war period) was 0.1338 (Zhukov & Kanishchev, 2019).

Factor D_c

The indicator "place" is fundamental for factor D_c; other indicators should be considered correcting ones. The calibration Tables 6a, 6b, and 6c reveal that the indicator "development level of production capacities" is associated with factor D_c according to the power-law (Figure 8). Establishing industrial capacities in rural areas initially reduces the priority of migration intentions slightly. Afterward, though, the initial level of migration intentions is restored as the production develops.

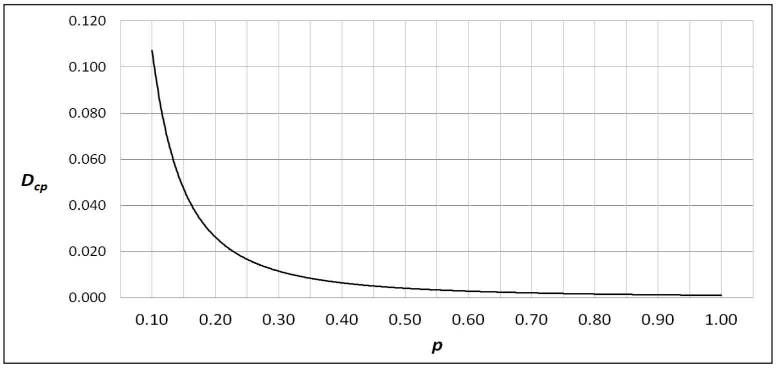

Figure 8. Relationship between indicator "development level of production capacities" and factor D_c.
Note. p – indicator value in initial units; D_{cp} – the negative contribution of the indicator to the value of D_c.

According to the power-law, the indicator "level of social and cultural infrastructure development" (s) is also associated with factor D_c (see Figure 9). Factor D_c gains after the increase in s, yet this growth slows down.

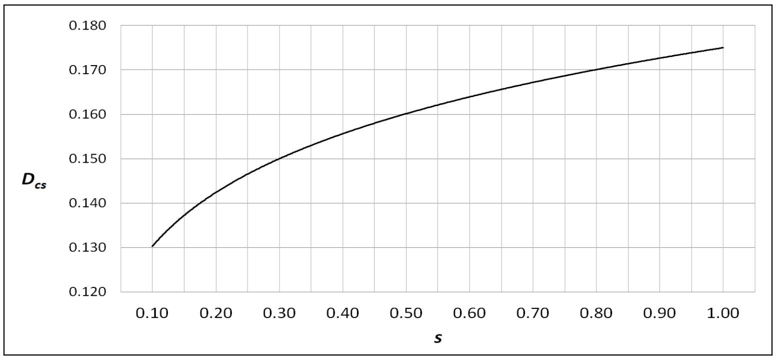

Figure 9. Relationship between indicator "level of social and cultural infrastructure development" and factor D_c.
Note. *s* – indicator value in initial units; D_{cs} – the positive contribution of the indicator to the value of D_c.

Figures 8 and 9 demonstrate the nonlinear dependence of the value of D_c on the values of p and s. The discovered power regularity is reflected in formula (4). The values for the indicators "location" (L) are shown in Table 7, "proximity to a city" (g) presented in Table 8, and "the presence of a village council in the settlement" (presence = 0.008; absence = 0) have been calculated based on calibration Tables 6a, 6b, and 6c. It should be noted that the indicator "proximity to a city," contrary to initial expectations, reduces migration intentions, as it removes the incentive for migration among people living in the area of circular labor migration.

The above considerations made it possible to obtain the following formula for calculating factor D_c:

$$D_c = L + 0.175s^{0.128} + a - g - 0.001p^{-2.03}, \tag{4}$$

where L is "place," s is "level of social and cultural infrastructure development," a is "the availability of the village council in the settlement," g is "proximity to a city," and p is "development level of production capacities."

Table 7
Conversion of the values for the indicator "place"

Indicator markers	*L*
rc	1.018
p	0.960
ss	0.902
sd	0.844
io	0.786
in	0.728
i	0.670

Table 8
Conversion of the values for the indicator "proximity to a city"

Indicator markers	g
0	0
mg	0.0203
sg	0.0407
bg	0.0610

Factor K_c

The indicator "degree of demographic transition completion" (*T*) should be considered the base for calculating factor K_c. As revealed in calibration Tables 6a, 6b, and 6c, for settlements where families had an average of three children, $T = 1.7921$, and for settlements with predominantly two-child families, $T = 1.85$.

The indicator "availability of medical facilities" also contributed to the growth of K_c through the control over the death rate and support for the birth rate.

Conversely, the indicator "development level of production capacities" significantly reduced the value of K_c because high employment (including women) alters the strategies for starting and developing a family deemed normal for the type of society being studied. A similar – negative – effect on K_c was exerted by the indicator "ratio of men and women," specifically, an imbalance of women to men.

According to the power-law, the indicator "development level of production capacities," was also associated with factor K_c (see Figure 10). Figure 10 demonstrates the nonlinear dependence of the value of K_c on the values of *s* and *p*. The discovered power regularity is reflected in formula (5).

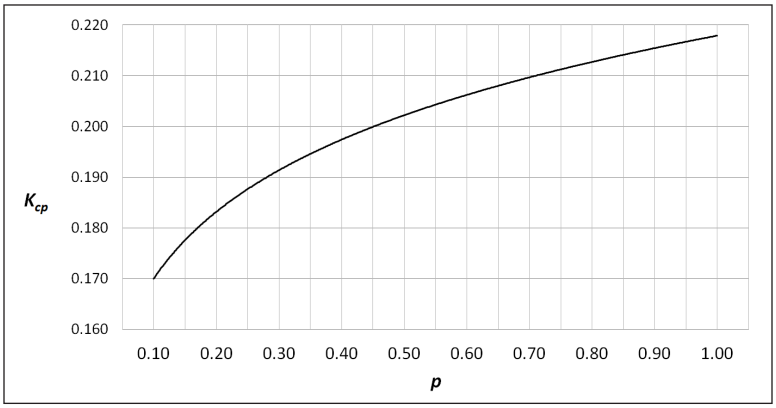

Figure 10. The relationship between the indicator "development level of production capacities" and factor K_c.
Note. p – indicator value in initial *original* units; K_{cp} – contribution of the indicator to the value of K_c.

Based on these considerations and the analysis of calibration Tables 6a, 6b, and 6c, the formula for calculating factor K_c is as follows:

$$K_c = T - 0.007367b + 0.1m - 0.2179p^{0.1078}, \quad (5)$$

where *T* is the "degree of demographic transition completion," *b* is the "ratio of men and women," *m* is the "availability of medical facilities," and *p* is the "development level of production capacities."

APPENDIX 4

DESOLATION RISK AREA

Let us determine the minimum negative net migration for area *q* (Figure 2) within the framework of Type 1. The maximum natural increase in a successful settlement (e.g., in Podlesnoye) for the study period was about 19‰. With a hypothetical negative net migration of 107‰ (three-quarters of the model maximum), the total decrease would be about 88‰. Under such conditions, a settlement would lose more than 90% of its population during the period under study. We, therefore, consider a negative net migration of 107‰ as the value distinguishing the desolation risk area.