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Regional differentiation of fertility in the Russian Federation: cohort perspectives

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Abstract: This article is the first to investigate the long-term evolution of completed cohort fertility for cohorts of women born since 1935 and later at the regional level of the Russian Federation. The choice of this topic is due to the fact that timing shifts and structural changes in childbearing may cause a significant distortion of period-specific fertility indicators. Changes in the age profile of childbearing, in the distribution of births by order (parity), and in the variability of reproductive intentions and their implementation all have regional specificity and occur at different speeds across the Russian provinces.
At the same time, it is important to understand which trends in the regional differentiation of the Russian fertility model predominate once the conjunctural component of the changes has been minimized: convergent or divergent. We looked at how the completed cohort fertility rate has changed and may change in the future at the regional level of Russia. We used the approach of the International Institute for Applied Systems Analysis (IIASA), which applies a Bayesian hierarchical model in population projections.
The result of the study was both the assessment and projection of completed cohort fertility rates for 83 subjects of the Russian Federation and an analysis of the obtained data to identify the main trends of fertility change at the level of geographical macro-regions, of certain groups of provinces, including the capital region (Moscow, Moscow region, St. Petersburg, Leningrad region), of national republics and autonomous districts.

Keywords: Russia, regional differentiation of fertility, demographic projections, completed cohort fertility rate, demographic transition, theories of low fertility.

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Introduction

The Russian Federation, being a large state in terms of both territory and population, has a high level of regional differentiation in demographic processes (Arkhangelsky et al. 2020). At the same time, there are no works in Russian about the completed fertility of birth cohorts of the regions of the Russian Federation. The only authors whose works have touched on certain aspects of the issue are Sergei Vladimirovich Zakharov (Freika, Zakharov 2014; Zakharov 2019) and Vladimir Nikolaevich Arkhangelsky (Arkhangelsky 2019; 2021; 2022), and that on a small scale. There are also no similar works in the foreign literature.

The study takes for analysis 83 regions of the Russian Federation for which there are sufficiently long dynamic time series of data. The time period under consideration for the completed cohort fertility of birth cohort is female cohorts born between 1935 and 2000, inclusive, in the form of one-year indicators (with relatively high accuracy from 1937 to 1993), and female cohorts from 1935-40 to 2045-50, inclusive, in the form of five-year indicators from the middle of the first analyzed year to the middle of the sixth analyzed year according to the methodological recommendations of IIASA[1] and the UN Population Division[2].

As part of this work, an attempt was made to consider the long-term dynamics of the completed fertility of female birth cohorts in 83 regions of the Russian Federation and to assess the convergent-divergent direction of changes in the regional differentiation of these indicators.

This leads to the main questions that we are trying to answer here:

- what are the fertility dynamics in 83 regions of Russia for female cohorts born in 1935-1990? How might fertility behave in the future under the IIASA-2022 Bayesian predictive model?
- is there a convergence of indicators of the completed fertility of birth cohorts at the level of the regions of the Russian Federation? When should we expect the smallest regional dispersion in this indicator?
- what are the geographic specifics of the dynamics of fertility in Russia in birth cohorts? Are there similarities in fertility trends among neighboring regions and regions with similar levels of socio-economic development? Are there features that go beyond the specific, according to experts, geographical regions of Russia? What is the distinctive feature of demographic modernization of fertility in national republics and autonomous okrugs?

Theoretical models of low fertility: general aspects and conceptual description of fertility differentiation at the regional level

Long-term fertility trends are most often analyzed and interpreted at country and intercountry levels (the situation with mortality and migration is similar) (Gordon 2016). It is therefore not surprising that both the causes of the decline in fertility and the socio-political consequences are

[1] Speringer M. Global reconstruction of educational attainment and demographic data, 1950-2015: methodology and assessment. 2019. Vienna Institute of demography (for IIASA).
[2] United Nations, Department of Economic and Social Affairs, Population Division (2022). World Population Prospects 2022: Methodology of the United Nations population estimates and projections (UN DESA/POP/2022/TR/NO. 4).

considered exclusively in terms of states. This “methodological nationalism” (Bertram, Bujard 2012) prevails not only in the analysis of statistical data, but also in understanding the reproductive attitudes of people inhabiting certain countries.

It is quite reasonable to believe that there are several topics for which such strict “methodological nationalism” makes sense, for example, if we are talking about the global context of the demographic transition in fertility and the prospects for fertility in the world. Also, discussions about the future of social security systems and comparisons between different types of welfare states can, insofar as demographic factors are concerned, only take place at the national level (Esping-Andersen 1990, 2014), since such systems and policies are organized at the level of states (Dănuţ-Vasile, Michaela 2021).

Although most theories of fertility decline are implicitly or explicitly valid at both the micro and macro levels (Fox, Klüsener, Myrskylä 2019), the focus of their operationalization and specific empirical research for some theories lies more at the macro level, and for others, at the micro level. Thus, “methodological nationalism” is a methodological problem for theories applicable at the micro level. The knowledge we can gain from a regional perspective is particularly useful for this kind of theory and related research. The famous Princeton Project to Study the Historical Decline of Fertility in Europe (Coale and Watkins 1986) used extensive demographic and socioeconomic data collected at the European provincial level over more than a century to search for general and specific explanatory mechanisms of the demographic transition (Knodel, van de Walle 1979).

The theoretical literature has established (Bengtsson, Dribe 2014) that the features of fertility decline during the demographic transition can be considered from the point of view of a number of different conceptual approaches (Krätzig-Ahlert 2018). Among such approaches, a number of main directions can be identified that can be applied when analyzing the process of declining fertility in both conditional and female birth cohorts in the regions of the Russian Federation:

a) various versions of the neo-economic approach to the sociology of family and demography;
b) theories of modernization and human capital, including both classical options and their criticism, and the theory of the second demographic transition (at the same time and as part of the framework of the theory of demographic transition), the theory of the influence of gender equality, the theory of diffusion of innovations, the theory of the connection between the transition in fertility and reduction in child mortality;
c) models of the dynamics of regional differentiation of fertility due to historical and economic differences between countries/regions;
d) patterns of transition in fertility in heterogeneous populations.

There are a number of theories (Bengtsson and Dribe 2014) in which the demand for children plays a crucial role in explaining fertility in general and its historical decline in particular (Caldwell et al. 2006). The demand for children is determined by both the economic benefits of children and their costs. From the perspective of this neoeconomic approach, the direct productive contribution of children may have been important in agricultural and early industrial societies, where children often began working early (e.g. (Humphries 2013)), but ceases to be significant in later stages of the evolution of economic systems. Legislation restricting child labor may have affected the direct costs of children, although, at least in Russia, it seems that child labor became unprofitable long before the change in labor legislation (Vishnevsky 2006). Children could also be a benefit to their parents as a form of social security and support in old age (Caldwell et al. 2006).

As for the cost of children, two main hypotheses have appeared in economic models of fertility: the “time expenditure hypothesis” and the “quantitative-qualitative trade-off hypothesis.” The time-cost hypothesis highlights the increasing indirect costs of children resulting from women's employment outside the family (Caldwell et al. 2006). Increased participation of married women in the labor force and higher relative wages for women increase the opportunity cost of children and thus reduce the demand for them.

The quality-quantity trade-off hypothesis focuses on changes in the direct costs of children associated with increased demand for education as a result of a shift in consumption toward manufactured goods and services produced by a more educated workforce. Assuming a limited family budget, this led families to reduce fertility and invest more in each child: in other words, quality replaced quantity (Bengtsson, Dribe 2014). This trade-off is seen as an important reason for the transition from the regimes of the Malthusian trap and Malthusian stagnation to modern economic growth (Becker, Cinnirella, Woessmann 2010).

A popular theory within the community of demographic experts is that according to which economic development and fertility dynamics are described by a curvilinear relationship: the growth of society’s economic resources first leads to a decrease in fertility, and then to a slight increase in the most highly developed countries (Myrskylä, Kohler, Billari 2009). The relevance of this assumption in the context of theories of modernization and human capital is that there exists a combination of institutional factors in the economic and social spheres of society that contribute to the stabilization of fertility in birth cohorts at the level of 1.6 - 1.8 children per woman, in particular, as women’s ability to combine the roles of mother and worker in modern societies improves. Unfortunately, this analysis was carried out only at the international level, although in the case of large countries such as the United States or Russia, it would make sense to test the claims of this theory using data at the regional level.

The influential theory of the Second Demographic Transition (SDT) characterizes cultural change as the most important cause of change in both family formation and fertility. For our study, it is important to note that the SDT in its classical form focuses its attention precisely on the national level (Lesthaeghe, Neidert 2006). At the same time, both R. Lesthaeghe and D. van de Kaa contributed their own explanations that go beyond the usual cultural factors: in addition to cultural changes, van de Kaa highlights the influence of contraceptive innovations, and Lesthaeghe emphasizes structural factors such as female education, the participation of women in the labor force, differences in mainstream social value systems, and unemployment rates (Lesthaeghe and Moors 1995). For a deeper understanding of the strength of these factors, it is useful to take into account regional differentiation of both the fertility itself and the indicators of these factors (Lesthaeghe, Neidert 2006, van Bavel 2010).

Some other theories of fertility decline analyze the relationship between the dynamics of gender inequality and the fulfillment of reproductive intentions, but the theory of gender equality (McDonald 2000) is also built at the national level and, by emphasizing the inconsistency between individual-oriented and family-oriented institutions, partly deals with those same factors explaining low fertility at the national level as those used by the abovementioned authors of the SDT, although they are interpreted in different ways: as a change in the relationship between the processes of social diffusion and adaptation (Lesthaeghe, Neidert 2006) or as a growing inconsistency of gender regimes in the family and household sphere with the increasing participation of women in economic activities and non-family social relations (Lappegård 2020).

Another possible explanation is the theory of diffusion of innovations, or, more loosely, the spread of social, cultural, and value innovations (Rogers 1962). The basic premise of this theory is that people in the past were not fully prepared to limit family size, although they may have had reasons to do so, including economic and demographic ones (Bengtsson and Dribe 2014). It was necessary to change the attitude of society towards birth control, making it socially acceptable to limit births within marriage, and later to out-of-wedlock births (Coale, Watkins 1986).

Greater knowledge of contraceptive methods may also have played a role in this process. Although most researchers believe that people knew traditional methods of pregnancy and birth control, it is unclear to what extent they used them in marriage, depending, among other things, on social status and ethnocultural and religious affiliation (Caldwell et al. 2006). In any case, the distinction between willingness and ability is crucial—the fact that people were able to limit fertility does not mean that they were willing to do so. For this to happen, it was necessary to have social approval for limiting the number of children in marriage, and according to the innovation-diffusion paradigm, this basically did not happen in pre-transition societies, including in most countries of Western Europe, where in the 18^{th}-19^{th} centuries the European type of marriage was formed. Therefore, the spread of new norms, values, and attitudes toward limiting family size may have been an important part of the decline in fertility as it influenced people's willingness to adopt new behaviors (Bengtsson and Dribe 2014).

If we consider deliberate limiting of family size within marriage as an innovation (for example, (Cleland 2001)), then we can expect that we will find a clear vector of distribution of birth control from more economically developed regions to less developed ones, which is confirmed by research results. However, it is not entirely clear how to explain the innovation, i.e., why innovators suddenly decided to do things differently and limit the size of their families. One possibility, raised by Cleland, is to attribute the reasons for this innovation and its diffusion to the influence of the costs of social regulation of fertility, which may have delayed the decline in fertility because the social or emotional costs of limiting the family were too high (Bengtsson and Dribe 2014; Coale and Watkins 1986; Vollmer, Strulik 2015). However, it is still not completely clear what factors explain the time lag in the decline in fertility between different countries, regions of countries, social groups and classes, and whether this gap is expressed in years or decades (Vollset et. al 2020).

Finally, declining mortality is often seen as an important explanation for declining fertility going back at least to the earliest formulations of demographic transition theory (Poston and Trent 1982). In Poston's model, the decline in mortality has a decisive influence on the number of surviving children that a couple would have had if they had not made a conscious effort to limit family size. The decline in mortality during the first stage of the demographic transition changed this number of children, and this became one of the important factors in the decline in fertility, as stated in a report analyzing actual data and making forecasts for countries around the world (Lutz, Butz, KC 2014).

Recent studies based on microdata from actual female cohorts have confirmed the important role of childhood survival for individual reproductive decisions during the transition to low fertility (van Poppel et al. 2012; Reher et al. 2017). Mortality alone does not explain this life-changing transition, and many other factors (often ethnocultural or social) have attracted the attention of researchers, but without the impetus of improved child survival, the fertility transformation would never have occurred (Lutz 1996; Lesthaeghe and Neidert 2006).

There are also conceptual frameworks of varying degrees of sophistication that attempt to explain the transition in fertility by factors related to the supply and demand for children, as well as the degree of social acceptance of family size limits that change because of modernization processes (Hakim 2003). From a theoretical point of view, they complement each other rather than compete, contributing to the understanding of the complex mechanisms of social determination of changes in fertility (Anderson, Kohler 2015; Bengtsson, Dribe 2014).

Empirical research findings, drawing on a variety of theoretical approaches, help to explain the underlying cause of historical-economic and socio-historical inequalities in the timing of social and demographic change throughout much of the last century and how this set the stage for the eventual disappearance of mortality as a cornerstone of past demographic systems – all this became the basis for modeling historical-economic differences in fertility between countries/regions of countries during the demographic transition (Reher 2019; Pelletier 2021).

This approach also applies to the completed fertility of birth cohorts (van Bavel 2010): recent data show levels close to or greater than 1.8–1.9 children per woman in northern Europe and English-speaking non-European countries, and much lower levels (about 1.5-1.7 children per woman) in Southern Europe, Germanic Europe (Germany, Austria and Switzerland), post-Soviet countries and East Asia, with Central European countries falling in between (Myrskylä, Goldstein, Cheng 2013). Long-term differences in fertility levels, as well as common features of the process, are evident from these data (Lutz, Skirbekk, Testa 2006). A similar trend is observed in the completed fertility of birth cohorts at the level of regions of countries, although this is quite rarely the subject of study by researchers (Bertram, Bujard 2012; Fox, Klüsener, Myrskylä 2019). The remaining differences (Kohler, Mencarini 2016) highlight the need to find a new paradigm for interpreting modern demographic regimes, including, but not limited to, the standard interpretations mentioned earlier (Lutz, Scherbov, Gietel-Basten 2013; Buber-Ennser, Riederer 2020).

In the indicated theoretical approaches, the main focus is on the study of period (for conventional cohorts) and cohort (for birth cohorts) fertility indicators in light of the fact that mathematical modeling and the theory of demographic transition in fertility are widely used to analyze trends in the fertility level of an average woman with similar characteristics.

However, women in the same cohort or during the same period of time may have different indicators and characteristics of fertility (distribution of births by age, order, etc.), despite similar living conditions in the same country, while women in countries with different conditions may demonstrate very similar trajectories of fertility decline. Changes in fertility are rarely uniform across a population (Lee, Carter, Tuljapurkar 1995), and it is important to assess fertility considering both the differences in timing and size of heterogeneous groups at different reproductive ages, and the fact that socioeconomic and cultural value factors are heterogeneous within the same state (Caswell, Vindenes 2018).

The heterogeneity of the process of fertility decline as a result of the demographic transition can be determined through the presence of groups of multiple trajectories of fertility dynamics (Rosero-Bixby, Casterline 1993), be it period total fertility rates (TFRs), somewhat adjusted TFRs (see, for example, Kohler and Ortega 2004) or the completed fertility of birth cohorts. Formal analysis of fertility transitions has often overlooked the heterogeneity of society and has focused more on changes in fertility only on the average, since internal changes in the structure of fertility were of secondary importance, as was once mistakenly believed. However, the experience of Mayotte, Reunion, Israel, Fiji, French Guiana, a number of countries in the Middle East, Oceania, Central Asia and Tropical Africa shows that changes in the heterogeneous composition of the population can lead (Keskin, Çavlin 2022) first to a slowdown in the demographic transition in fertility (in period TFR in the 2000s and the first half of the 2010s), and then, vice-versa, to its significant acceleration (from the end of the 2010s in the period TFR).

Thus, when making comparative studies of fertility trends in the regions of the Russian Federation, including based on the indicators of the completed fertility of birth cohorts, it should be taken into account that the population is heterogeneous not only at the level of interregional comparisons, but also within the regions themselves; for example, this is very important when analyzing trends in national republics and autonomous okrugs.

The theoretical component of regional argumentation in the methodology raises questions about how political borders, economic and social institutions, gender policies, "high density of internal communication" (Lesthaeghe, Moors 1995), systems of public values and collective beliefs, social norms and discourses influence fertility at the regional level. As long as these factors themselves are formed mainly at the national level, regional differentiation is weak, but this does not work in countries such as Russia, Italy, Spain, Germany, Switzerland or the USA.

In Russia, most financial, tax, and welfare policies for families are organized at the national level, but child care infrastructure is organized at both the federal and regional levels. The economic structure of the population has great specificity in different regions of the same country. Fertility determinants such as labor force participation, unemployment, and employment in the service sector demonstrate diversification both between and within countries. Comparing the average values of these factors at the cross-national level is problematic for heterogeneous and large countries. Of course, in many cases these differences are relatively small, so comparisons at the national level may be warranted. But in such large heterogeneous countries as the Russian Federation, the USA, Brazil, India, China, Nigeria, etc., an analysis of regional diversity is essential.

Data, methods and primary description of results

The use of indicators characterizing the fertility of birth cohorts makes it possible to level out structural transformations in fertility models that arise in the process of demographic transition (Sobotka, Lutz 2011); however, this approach is not without its shortcomings, associated with problems of data collection.

First, there is the problem of the large time lag: it is possible to calculate the completed fertility of birth cohorts only for female cohorts that have left reproductive age, i.e., for women born at least 50-55 years ago, depending on the upper limit of reproductive age (Sobotka, Yoo 2018). To some extent, this can be smoothed out by taking not the completed fertility of birth cohorts, but the cumulative (accumulated) fertility of birth cohorts by the age of 40 or 45, since usually by these ages female birth cohorts have already given birth to the vast majority of the children they are likely to give birth to throughout their entire life. However, the expansion of the boundaries of reproductive age with the help of modern technologies and the continuing aging of the age profile of fertility in general, described within the framework of the SDT, makes the use of these indicators more problematic.

Second, to calculate the completed fertility of birth cohorts, much more demographic information is required than to calculate the period TFR, not to mention cruder fertility indicators. First of all, a sufficiently long time series of data is needed. Estimating the completed fertility of birth cohorts may require specialized information from population censuses and additional databases (for example, data for female birth cohorts that have reached the upper age limit of reproductive age can be obtained from the UN Population Division database "World Population Prospects-2022" by interpreting age-specific fertility rates in the logic of the birth cohort method). To obtain the completed fertility of birth cohorts for cohorts that have not completed their reproductive years, one must resort to a combination of demographic analysis and econometrics methods (Gordon 2016).

In our work, we used both population census data and estimates obtained using econometrics and demographic analysis tools. So for cohorts from 1935 through the early 1970s, the coefficients of cumulative (accumulated) fertility and completed fertility of birth cohorts are identical to each other, and for female cohorts born in the 1970s - 1990s who did not complete childbearing, it was necessary to calculate both cumulative (accumulated) and residual (potential) fertility.

It has become commonplace to estimate the completed fertility of birth cohorts for cohorts born before the beginning of the 1970s, and the cumulative (accumulated) fertility rates for cohorts born after the beginning of the 1970s, for the Russian Federation as a whole. The necessary data is available in the databases of the All-Union and All-Russian population censuses and in the Russian Database on Fertility and Mortality (RosBRiS[3]), but also in the international Human Fertility Database (HFD)[4], which contains initial data on the annual registration of births by age of women and birth order, as well as the most reliable estimates of derived fertility indicators for both conditional and birth cohorts (Max Planck Institute... 2023).

As the basis for our study to compare the summary data for the regions of Russia with the Russian Federation as a whole, we took HFD indicators, since they are a compilation from censuses and RosBRiS (Russian Economic School 2023) with additional correction aimed at correcting distortions arising in the process of statistical registration of the population and demographic events[5].

Data on the final, age-specific and cumulative fertility of birth cohorts in Russia for one-year female cohorts born in 1944 - 1978 were taken from the "Completed cohort fertility" and "Age-specific fertility rates" sections in the HFD database, which takes into account birth registration data from 1959 to 2018. Data for 2019-2021 were taken from the RosBRiS database, and for 2022, reporting data from Rosstat were used, handed over for analytical purposes to

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[3] Russian Database on Fertility and Mortality (RosBRiS) of the Center for Demographic Research of the Russian Economic School. See: http://demogr.nes.ru/index.php/ru/demogr_indicat/data_description

[4] The Human Fertility Database (HFD) is the leading scientific database on fertility in developed countries, maintained by the Institute of Demographic Research of the Max Planck Society (Germany) and the Vienna Demographic Institute of the Austrian Academy of Sciences. See: https://www.humanfertility.org/Home/Index

[5] Methods Protocol for the HFD. A. Jasilioniene, D.A. Jdanov, T. Sobotka, E.M. Andreev, K. Zeman, V.M. Shkolnikov; with contributions from J. Goldstein, E.J. Nash, D. Philipov, G. Rodriguez. 02.09.2015

the A.G. Vishnevsky Institute of Demography of the National Research University Higher School of Economics.

We also used data on the completed fertility of cohorts born in 1935 to 1972 in the context of the 83 subjects of the Russian Federation that we analyzed, obtained during surveys of women within the framework of population censuses: the All-Union Population Censuses of the USSR in 1979 and 1989 (Goskomstat USSR 1979; 1989) and the All-Russian population censuses of 2002 and 2010 (Rosstat 2002; 2010), while for cohorts born in 1966-1971 additional data were taken from the 2020 All-Russian Population Census (Rosstat 2021), which was actually carried out as of October 1, 2021.

Results from the 1979, 1989, 2002 and 2010 censuses in relation to the number of children ever born by age of mothers show a high level of similarity, which probably indicates their high reliability. At the same time, a big problem is that the published census data for the regions of the Russian Federation are presented by five-year age groups (Zakharov 2008), and since our study is aimed, among other things, at obtaining the completed fertility of birth cohorts from 1935 to 2000 according to one-year groups, to move from five-year to one-year age groups it was necessary to carry out interpolation by the finite difference method as the most effective and reliable (Lutz, Butz, KC 2014).

At the same time, we made an additional check by adjusting the regional data by the proportion of resident women out of the total number of women and the proportion of children out of the total number of births in the regions of the Russian Federation to the values of the country as a whole according to HFD data with simple double iteration methods (Krätzig-Ahlert 2018) using a statistical weighting procedure. The proportions of women were taken from the 1979, 1989, 2002 and 2010 censuses, but not from the 2021 census, due to problems with the quality of data on the size and age-sex composition of the population in a number of regions.

Subsequently, this method was also used to check data on the completed fertility of birth cohorts for cohorts born in 1973 to 2000 for 83 regions of the Russian Federation: first, cumulative (accumulated) fertility rates were calculated using the same census data on the number of children born by the mother’s age in 2002, 2010 and 2021, taking into account age-related fertility rates by one-year age groups and one-year time periods from 1989 to 2022. To check using simple double iteration methods, we used the distributions of the total number of women and the total number of children born in the country as a whole and for the regions of the Russian Federation based on Rosstat data from 1990 to 2022.

In addition, for female cohorts from 1972 to 2000 residual fertility rates were calculated by the Sobotka-Zeman method (Zeman et. al 2018) using model tables of T. Sobotka (Sobotka 2017): according to the value of residual fertility depending on the combination of the age model of fertility, the model of fertility by order of birth and size changes in the dispersion of the age distribution of fertility rates.

For all 83 regions of the Russian Federation we obtained:

a) TFR estimates adjusted by the Bongaarts-Feeny method for 1990-2021, smoothed by a three-year moving average for 1991-2020 and a five-year moving average for 1992-2019, as recommended by HFD experts (Bongaarts, Sobotka 2012); for this we used estimates of the distribution of the completed fertility of birth cohorts by birth order (orders) for 1, 2, 3 and 4+ children and data on the average age of the mother at the birth of children for the period from 1989 to 2021, obtained from Rosstat, and for certain periods of time, indicators previously published by other authors were taken into account (Arkhangelsky 2019; Arkhangelsky et al. 2020);
b) integrated estimates of indicators of reproductive intentions (desired and expected number of children) based on the results of sample observations of reproductive plans of the population of the Federal State Statistics Service of Russia 2017 and 2022 (Rosstat 2017; 2022) - microdata for all regions of Russia, except for the Chukotka and Nenets Autonomous Okrugs and the Jewish Autonomous Region (no data for them); for the latter we used an analogy with the regions that are most similar in terms of fertility profiles (Yakutia and Buryatia for the Chukotka Autonomous Okrug, the Yamalo-Nenets Autonomous Okrug for the Nenets Autonomous Okrug, the Amur Region for the Jewish Autonomous Region) with additional adjustments for the results of mass questionnaire surveys of the population “Man. Family. Society" for 2017 and 2020 for the Russian Federation as a whole, Moscow and the Moscow region (RANEPA 2017; 2020);
c) assessment of the possible fulfillment of reproductive intentions through a system of second-order differential equations using the Chang-Kasturits method; this system of equations allows one to link the mathematically ideal, desired, expected number of children with its real value, depending on the stage and model of the demographic transition and structural models of fertility in the context of the formal analysis of fertility (see modern modification of this method (Kocourková, Štastná 2021)).

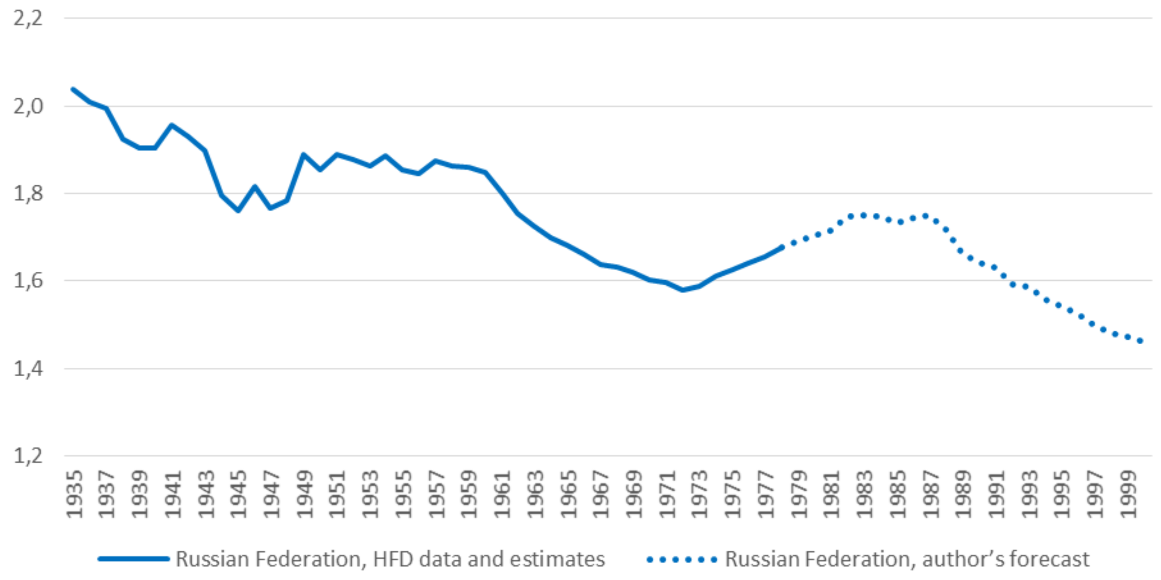
As a result, we obtained estimates of the completed fertility of birth cohorts (one-year female cohorts) for 83 regions of the Russian Federation and, accordingly, balanced estimates for Russia as a whole (Figure 1, Table A1 of the Appendix). Our estimates for Russia as a whole are practically no different from those previously obtained independently of us (Zakharov 2023); the discrepancies across one-year cohorts average ±0.6%.

We see that for the cohort born in 1935 the completed fertility rate was 2.04 births per woman and fell to 1.90-1.91 births in the 1939-1940 cohorts, and after a slight fluctuation in the cohort born in 1941 (1.96 children per woman), the decline continued to 1.76-1.77 in the 1945 and 1947 cohorts.

Next, a wave of insignificant growth begins, associated both with slightly higher values of the desired and expected number of children in the cohorts born in the 1950s, and with the fact that the period of their reproductive activity coincided with the active pronatalist policy of the 1980s in the USSR (Golod 1998; Zakharov, Churilova 2019), which additionally gave up to 0.05 children per woman (this value is slightly lower than the 0.09 obtained earlier (Zakharov 2006)). For cohorts born from 1949 to 1959 the completed fertility rate fluctuated between 1.84 and 1.89 children per woman.

However, starting with the cohorts born in the 1960s, a new, rather smooth, but monotonous wave of fertility decline begins. Its bottom was reached by the female generation born in 1972, at 1.579 children per woman. After this, the trend changes again to a slight increase, associated both with small changes in reproductive intentions for cohorts born in the second half of the 1970s and the first half of the 1980s, and with the insignificant effect of pronatalist policies in the second half of the 2000s through the first half of the 2010s, although this policy did not significantly change the general pattern of Russian fertility (Zakharov 2017, Zakharov 2023): at their peak, the completed fertility of the cohorts of 1983-1987 is 1.73-1.75 births per woman, with a nominal peak in the cohort born in 1983.

Figure 1. Completed fertility of birth cohorts for 83 regions of the Russian Federation, women born in 1935–2000, children per woman



Source: HFD data and author's calculations.

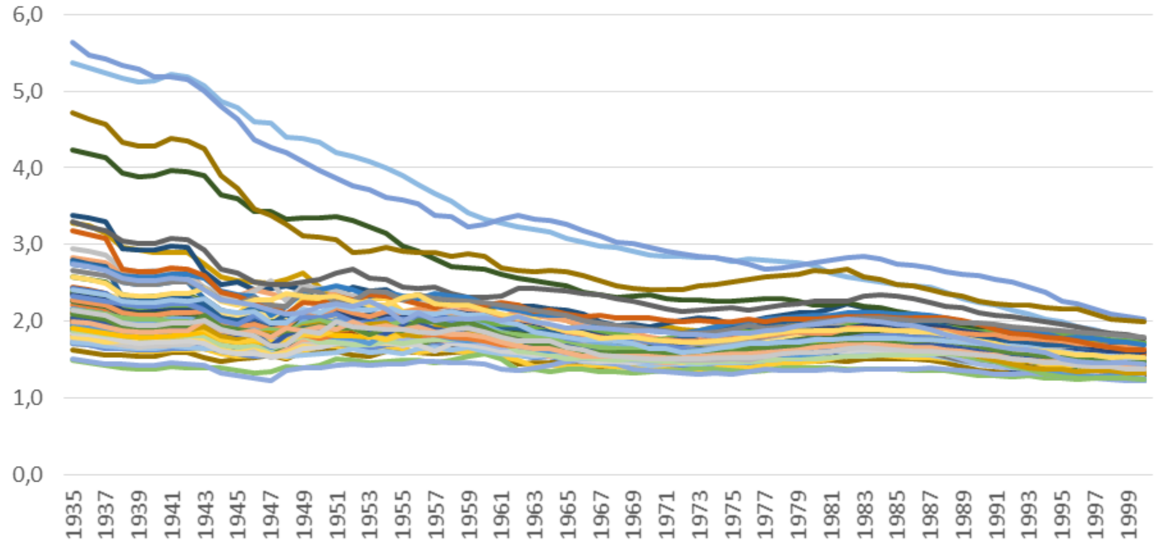
Starting with the cohort born in 1988, we see another wave of fertility decline, reminiscent in intensity and smoothness of that of the cohorts born in the 1960s through the early 1970s, and by the end of the period under review, according to the author's forecast, the completed fertility of birth cohorts in Russia falls to 1.459 children per woman (cohort born in 2000), which corresponds to long-term expectations (Zakharov 2023).

In the data for 83 regions of Russia (see Appendix Table A1), we can observe generally similar trends (Figure 2), reflecting the same alternating waves of growth and decline: a decline in cohorts born from the mid-1930s to the end of the 1940s, a slight growth in cohorts born in the 1950s, a decline for those born in the 1960s – early 1970s, growth from 1973 to 1983, a small plateau for cohorts born between 1983 and 1987, and a new wave of decline for cohorts born in 1988 and later.

Nevertheless, some regions demonstrated local minima and maxima in waves with a lag of several years from those indicated; for example, in the Vladimir region the minimum occurred not in the cohort born in 1972, but in the cohort born in 1973, and in the Nizhny Novgorod region, in the cohort born in 1969.

On average, most regions were in the range of 1.7–2.8 births per woman in the mid-1930s birth cohorts; of 1.5-2.5 in cohorts born in the late 1940s; 1.65-2.45 in cohorts born in the second half of the 1950s, 1.45-1.95 in cohorts born in the early 1970s, 1.55-2.10 in cohorts born in the first half of the 1980s, probably 1.3-1.8 in cohorts born in the first half to the mid-1990s, and 1.25-1.7 in cohorts born in the second half of the 1990s.

Figure 2. Completed fertility of birth cohorts for 83 regions of the Russian Federation, women born in 1935–2000, children per woman



Source: Author's calculations.

From this we can draw a preliminary conclusion that the decline in fertility in the cohorts of the 1930-1940s was not accompanied by increased fertility convergence between regions, unlike the wave of some growth in the female birth cohorts of the 1950s. Then the situation, on the contrary, became the opposite: the speed of convergence intensified during waves of fertility decline (cohorts born in the 1960s - early 1970s, from 1988 to 1995, and most likely further), but slowed down during the period of low growth in women born in the second half of the 1970s through the first half of the 1980s. Later on, this conclusion will be clarified within the framework of the analysis of variance.

It must be remembered that the key problem of the study is the use of a quite large number of data sources, which required significant use of both the methods of classical demographic analysis and statistical calibration of the completed fertility indicators of birth cohorts in the context of the regions of the Russian Federation by the share of the regions in the total number of women in the corresponding birth cohorts in the country and the total number of children born to the corresponding birth cohort in order to accurately match the completed fertility rates for the country as a whole.

Calibration also helped to take into account the average effects of internal migration of women between regions, since we do not have other sufficiently reliable methods for assessing the impact of internal migration on the final fertility of birth cohorts.

Some problems arose in the process of estimating cumulative fertility rates for birth cohorts whose active reproductive age fell in the period before 1989. In the absence of reliable age-specific fertility rates for regions, one has to rely only on census results. By analogy with the recommendation of the Japanese Bureau of Statistics[6], to clarify these data we used data from five censuses at once - 1979 and 1989 (data from the Russian State Archive of Economics), 2002, 2010 and 2021 (Rosstat). The use of several censuses makes it possible to partially neutralize the possible selective effects of mortality on fertility, i.e., those associated with the survival of women until the time of the next census.

Also, certain shortcomings of the study are associated with distortions in the population size and, as a consequence, age-specific fertility rates in a number of regions of the Russian Federation, which is especially important for the national republics in the east of the North Caucasus and a wide range of regions according to the 2021 census.

Another objective of the study is to estimate the completed fertility of female birth cohorts of women born from 1995-2000 to 2045-2050 at five-year intervals.

Expected completed fertility of birth cohorts for cohorts born in 2000-2050, as well as the projected completed fertility of birth cohorts for cohorts born in 1973-2000, is an estimated forecast indicator. But while for cohorts born in 1973-2000 some cumulative fertility has already accumulated (for many regions, the cohorts of the early 1990s have already achieved 50% or more of the expected value of completed fertility, since they have reached the average and median age of the mother at the birth of children), for the cohorts born in 2000- 2050 the value of the completed fertility is purely hypothetical, predictive in nature.

To obtain the expected completed fertility of birth cohorts, it is first necessary to generalize the previously obtained results of the completed fertility of birth cohorts from one-year to five-year cohorts, since the forecast of the expected completed fertility of birth cohorts will be based on a model with five-year cohorts. For this purpose, we will divide the interval of one-year cohorts from 1935 to 1995 into five-year cohorts from 1935-1940 to 1990-1995 in such a way that we will take the values from the second to the fifth year, as well as ½ the values of the first and sixth years, and from them we will obtain the arithmetic mean.

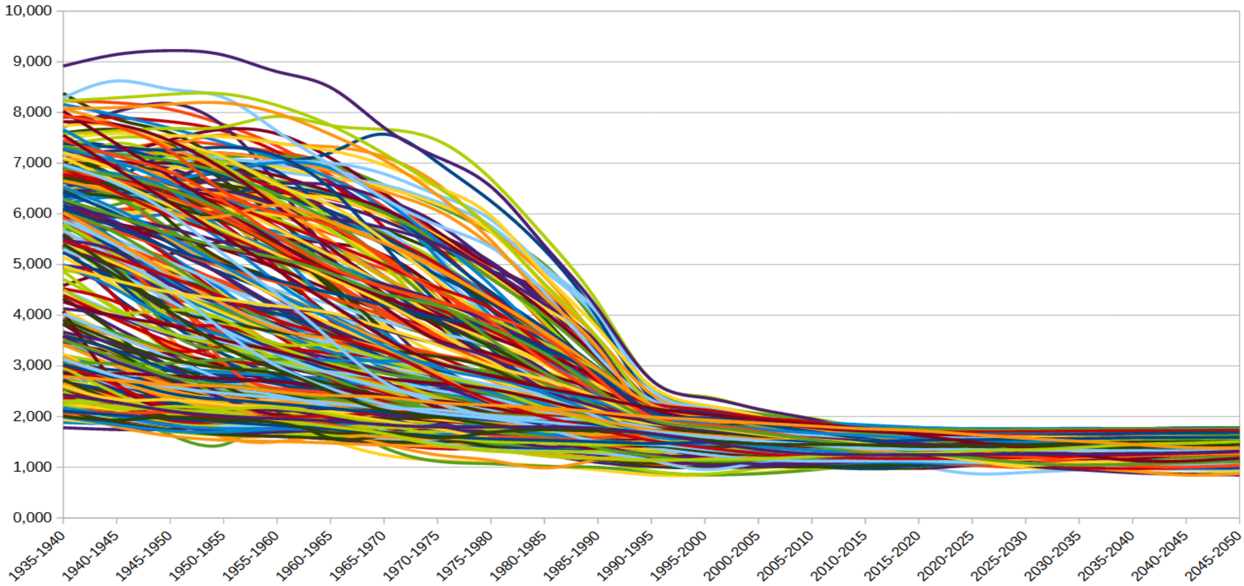
Then we can try to calculate the value of age-specific fertility rates in the coming calendar years. This can be done through multi-level hierarchical regression. Such a constructed model will statistically connect the values of age-specific fertility rates and a number of parameters of socio-economic development, which will make it possible to predict the dynamics of age-specific fertility rates in a period-wise manner (for calendar years) based on the forecast of socio-economic indicators of the regions. As a forecast for the regions of the Russian Federation, we took the forecast of socio-economic indicators of the Ministry of Finance of Russia for the purposes of the consolidated budget for 2023 (with correction for existing data) and for the period 2023-2025. For Russia as a whole, it is also advisable to adjust this forecast to project estimates of socio-economic parameters in 2023-2028 from the World Bank (in the version of August 2022) and the IMF (in the version of April 2023 - World Economic Outlook) with its approximation to the analyzed 83 regions of the Russian Federation.

The basic forecast of the expected completed fertility of birth cohorts will be based on the Bayesian hierarchical fertility model of the International Institute of Applied Systems Analysis (IIASA) as the most plausible and probable forecast model of fertility dynamics (Kishenin 2023),

[6] Ogawa N., Retherford R. D. The Resumption of Fertility Decline in Japan: 1973-92. (1993). *Population and Development Review*, 19(4), 703–741., namely, the section "Methodical recommendation by completed cohort fertility of Japan, 1926-1960" by the Statistical Bureau of Japan

in the version from July 2022 for 278 countries of the world and dependent territories (Figure 3), including former West and East Germany, former North and South Yemen, former North and South Vietnam, as well as Great Britain as a whole and separately England, Wales, Scotland and Northern Ireland (see Table A2 in the Appendix).

Figure 3. Completed fertility of birth cohorts for 278 countries of the world and dependent territories, women born in 1935-2050, children per woman



Source: Author's calculations based on age-specific fertility rates from the IIASA-2022 Bayesian hierarchical model, median version (SSP-2). Visualization in R (ggplot2 package).

In general, the most preferred source of fertility data is the count of live births by maternal age from civil registration systems with at least national coverage and a high registration rate, but as only 134 countries in the world have so far established such a system (Lutz, Butz, KC 2014), it is often necessary to resort to modeling the number of births by maternal age, based on some other data - censuses, sample surveys and observations, on estimates obtained using indirect methods, etc.

Bayesian hierarchical models are based on the same principle of modeling through a multi-level model of the available data and the values of regressor variables (Barakat 2017; Pelletier 2021), not retrospectively, but rather to forecast for the future. The basis of the methodology of such fertility models is the theory of demographic transition, highlighting the pre-transition period, the period of the first demographic transition in fertility, the period of the second demographic transition, and the post-transition period with the gradual convergence of all countries in terms of fertility in the distant future in the area of simple generation replacement or slightly lower, depending on fertility convergence models (Anderson 2014; Kishenin 2023). The process of fertility decline is described at the level of age-specific fertility rates, adjusted for the aging of fertility as a result of the second demographic transition (Schmertmann et al. 2014).

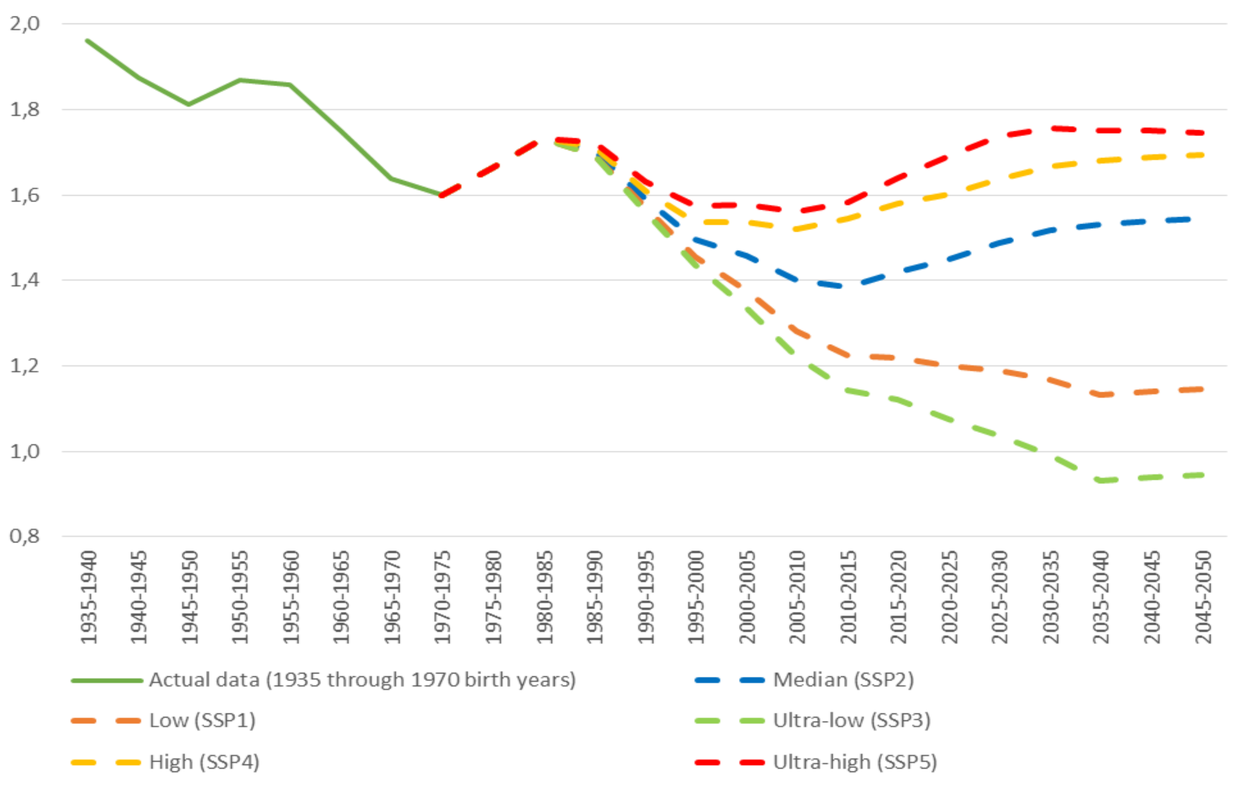
The process of fertility decline itself is not described deterministically, although there are cause-and-effect models of the dependence of fertility on socio-economic indicators and the degree of general modernization of society - for example, the prevalence and duration of female education, the level of gender equality, etc., but through the representation of a probabilistic space in a Bayesian network analysis, which reflects the historical features of the experience of each country or territory in the fertility transition.

At the moment, almost all international organizations use Bayesian hierarchical models when predicting fertility. This methodological approach has proven its effectiveness at the national level (Pelletier 2021), but only relatively recently has it been applied at the regional level to fertility rates of conditional and birth cohorts (Rafael, García-Moreno, Pérez-Priego 2022).

IIASA, in its forecast for the summer of 2022 (IIASA 2022), considers the most likely two forecast variants to be median fertility (SSP-2) and low fertility (SSP-1), followed by variants for ultra-low fertility (SSP-3) and high fertility (SSP- 4), and last but not least, the ultra-high fertility variant (SSP-5). For more details, see Table A3 of the Appendix.

The median fertility variant (Figure 4) assumes that the wave of decline in the completed fertility of birth cohorts, which began in the cohorts of females born at the end of the 1980s, will continue up to the cohorts born in the first half of the 2010s, to 1.35-1.45 children per woman, followed by a smooth recovery to 1.50-1.55 children per woman. The low-fertility variant comes from a more intense and deeper decline in fertility to 1.20-1.25 children per woman in the cohorts of the first half of the 2010s, with a further slow decrease to 1.10-1.15 children per woman in cohorts of women born in the second half of the 2030s and an increase to 1.15-1.20 children per woman in cohorts born in the mid-21st century.

Figure 4. Completed fertility of birth cohorts according to 5 IIASA forecast variants for 83 regions of the Russian Federation, women born in 1935-2050, children per woman



Source: Author's calculations based on age-specific fertility rates from the IIASA-2022 Bayesian hierarchical model.

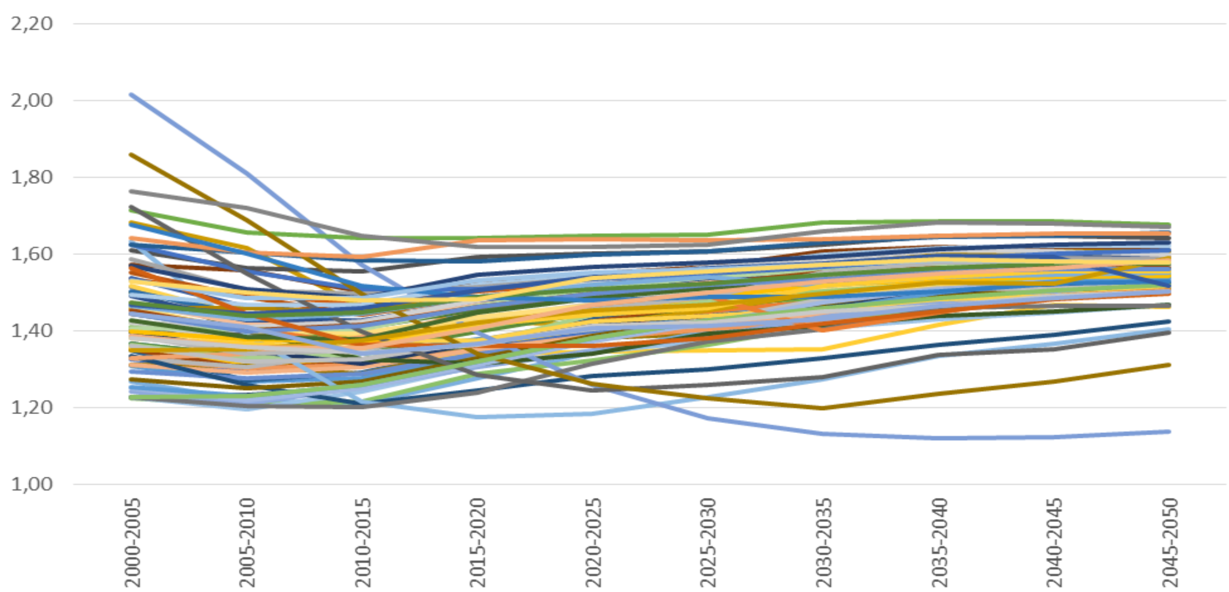
When moving from the national to the regional level, extrapolation was used as a formal technique for extending time series within the boundaries of the probability space of the Bayesian hierarchical model. Among the extrapolation methods used in our work are:

a) the finite difference method in the extrapolation interpretation of the Aitken-Neville algorithm;
b) extrapolation through the Lagrange polynomial;
c) spline function calculation done in R.

These are the most effective methods for extrapolating general demographic projections to more specific levels (Cheng, Lin 2010).

For all 83 regions, for each five-year interval of birth years of female cohorts, a forecast was obtained by all three extrapolation methods. Then the arithmetic averages were taken from the resulting values. The final results are presented in Figure 5.

Figure 5. Expected completed fertility of birth cohorts for 83 regions of the Russian Federation, women born in 2000–2050, children per woman



Source: Author's calculations by analogy with the Bayesian hierarchical model IIASA-2022, median variant (SSP-2).

In the regions of Russia, the same trends are seen (see Table A4 in the Appendix) as for Russia on the whole. While in the cohorts born in 2000-2005 there is an average spread in the completed fertility of birth cohorts from 1.2 to 1.6 births per woman, in the median fertility variant this spread will decrease by the time of the 2045-2050 cohorts to 1.49-1.67 children per woman, with the exception of Dagestan, the Altai Republic (Altai Mountains) and Ingushetia (1.39-1.42 children per woman), Tuva (1.31 children per woman) and Chechnya (1.13-1.14 children per woman).

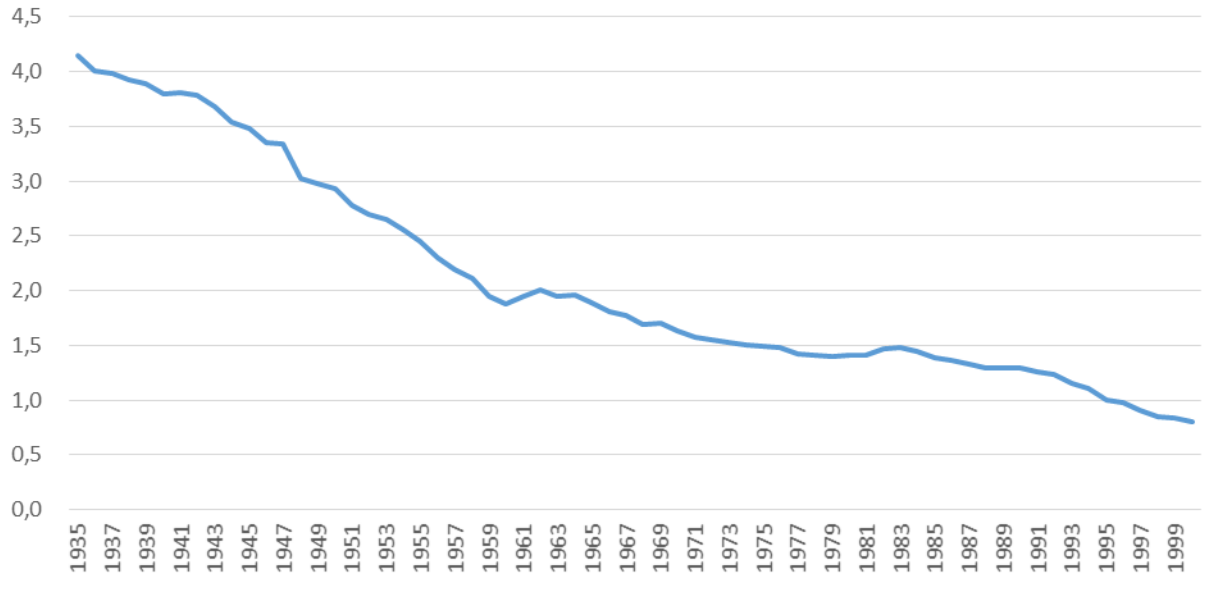
It is easy to see that these are the same national republics that in the 1995-2000 cohorts are distinguished by the highest completed fertility of birth cohorts. The reason for this mirror change in the situation should be sought in the features of the Bayesian hierarchical fertility model IIASA-2022 and the corresponding theoretical models in the framework of the theory of demographic transition: countries with more conservative gender regimes at later stages of the demographic transition reach local minima in fertility, including completed fertility for birth cohorts, due to the double burden on women's time budgets (Lappegård 2020) - a situation called the feminist paradox. It is worth noting that for the above-mentioned national republics of Russia, with lagging demographic modernization and conservative-patriarchal gender regimes, this situation is quite similar.

Analysis of the results obtained

To better understand the characteristics of regional differentiation of fertility in female birth cohorts between 83 regions of the Russian Federation, a quantitative analysis and analysis of the dynamics of fertility by groups of regions will be carried out.

A quantitative analysis of the dynamics of completed fertility of birth cohorts will consist of variation and cluster analyses. The first will include an assessment of changes in the absolute range of variation in the completed fertility of birth cohorts (the difference between regions with maximum and minimum values) and the coefficient of variation. It is worth noting that, in contrast to the relatively available data on average fertility rates in conventional or birth cohorts, much less is known about how dispersion changes as fertility declines during the demographic transition.

Figure 6. The absolute range of variation in the completed fertility of birth cohorts for 83 regions of the Russian Federation, women born in 1935–2000, children per woman

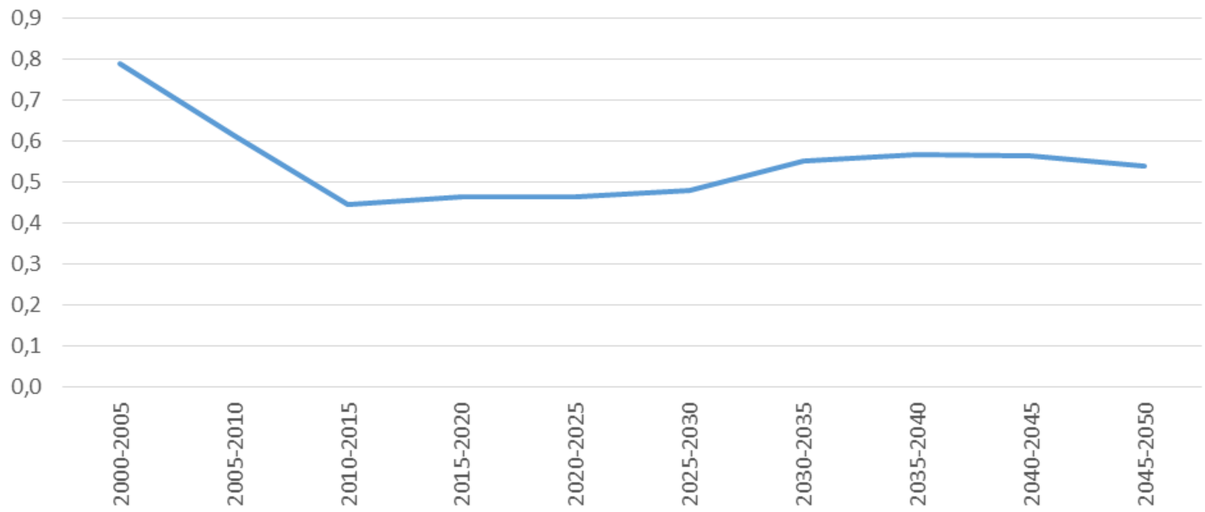


Source: Author's calculations.

Figure 6 shows a stable trend in reduction in the absolute range of variation for the completed fertility of birth cohorts for female cohorts born in 1935-2000: from 4.1 births per woman in the 1935 cohort to 0.8 births in the cohort born in 2000. Most of the time, the regions with the highest completed fertility of birth cohorts will be Chechnya or Ingushetia, i.e., national republics with a lagging demographic transition in general, including in terms of fertility modernization, while the regions with the lowest completed fertility of birth cohorts were consistently Moscow or St. Petersburg - the largest cities, with an earlier demographic transition and a consistently low fertility of birth cohorts at levels of 1.25-1.50 children per woman.

In the expected completed fertility of birth cohorts for the 2000-2050s birth cohorts, one can observe (Figure 7) a tendency for the absolute range of variation to decrease down to the cohorts born in the first half of the 2010s (the minimum of the wave of fertility decline from the late 1980s to the mid-2010s). But then it is worth noting the stabilization of the absolute range of variation and even a slight increase in cohorts born in the 2030s through the first half of the 2040s, and only from the mid-2040s does a new wave of decline begin. The source of the change in the trend in the absolute magnitude of variation should again be sought in the fact that in the Bayesian hierarchical IIASA model, territories with conservative gender regimes should reach a lower minimum in fertility rates during the transition process. It is likely that the final convergence in the completed fertility of birth cohorts between the regions of the Russian Federation, while maintaining the above trend, will occur in cohorts born in the second half of the 21st or even the beginning of the 22nd century.

Figure 7. The absolute range of variation in the completed fertility of birth cohorts for 83 regions of the Russian Federation, women born in 2000–2050, children per woman

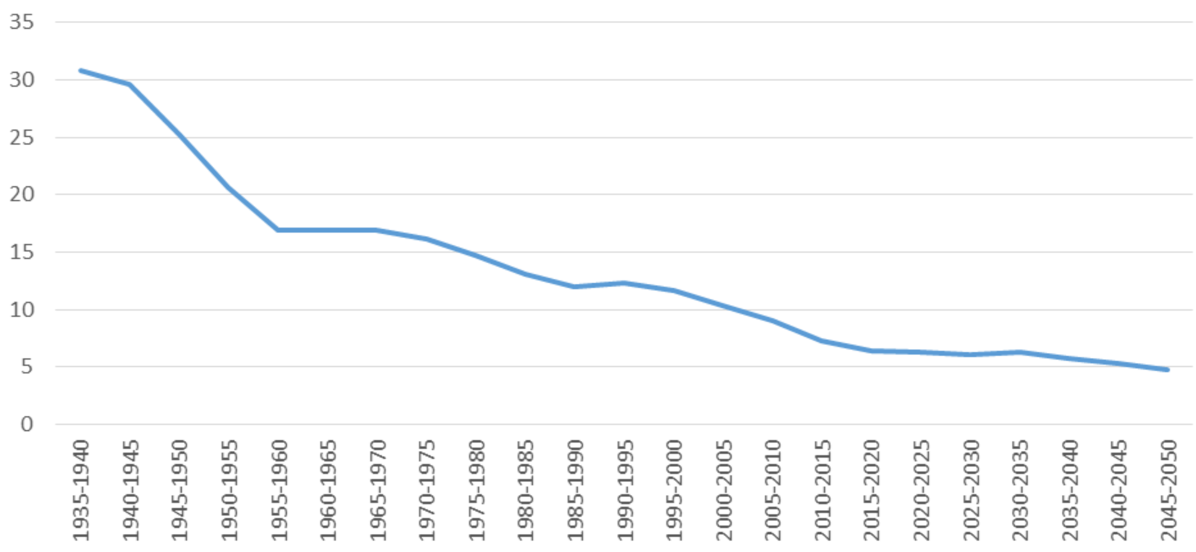


Source: Author's calculations.

The regions with the maximum value of the indicator for earlier periods are Chechnya, and then the Khanty-Mansiysk Autonomous Okrug and the Trans-Baikal Territory. The regions with minimal values are first Moscow, St. Petersburg and the Leningrad region, and then Ingushetia, Tuva and Chechnya.

Similar trends, although in a slightly smoother form, can be observed in the dynamics of the coefficient of variation (Figure 8):

Figure 8. Coefficient of variation in the expected completed fertility of birth cohorts for 83 regions of the Russian Federation, women born in 1935–2050, %



Source: Author's calculations.

In addition to variance analysis, cluster analysis was also used. Clustering of time series according to the completed fertility of birth cohorts from 1935 to 2050 was carried out using the k-means method and by partitioning the time series around medoids in the asardaes and dtwclust packages in R.

Table 1. Groups of clusters for 83 regions of the Russian Federation obtained as a result of cluster analysis, according to similar trends in the completed fertility of birth cohorts, women born in 1935-2050

Cluster number	Regions included in cluster	Number of regions
Cluster 1	Chechnya, Ingushetia, Tuva, Dagestan republics	4
Cluster 2	Kalmykia and Altai republics, Nenets AO	3
Cluster 3	Yakutia, Buryatia, KhMAO, Trans-Baikal Territory, Irkutsk and Astrakhan regions	6
Cluster 4	Khakassia, Udmurtia, YANO, Chukchi AO, Jewish AO, Tyumen and Amur regions	7
Cluster 5	Bashkortostan, North Ossetia, KBR, KCR, Chuvashia, Orenburg and Kurgan regions	7
Cluster 6	Komi, Adygea, Mari El, Krasnodar, Perm, Altai, Khabarovsk, Arkhangelsk, Vologda, Kirov, Chelyabinsk, Omsk and Kemerovo regions	13
Cluster 7	Tatarstan, Stavropol, Krasnoyarsk and Primorsky republics, Bryansk, Kostroma, Kursk, Lipetsk, Novgorod, Pskov, Nizhny Novgorod and Ulyanovsk regions	12
Cluster 8	Karelia, Mordovia, Kamchatka Krai, Belgorod, Orel, Tambov, Volgograd, Penza, Saratov, Novosibirsk, Tomsk, Magadan and Sakhalin regions	13
Cluster 9	Vladimir, Voronezh, Ivanov, Kaluga, Ryazan, Smolensk, Tver, Tula, Yaroslavl, Kaliningrad, Leningrad, Murmansk, Rostov, Samara and Sverdlovsk regions	15
Cluster 10	Moscow, St. Petersburg, Moscow Region	3

Source: Author's calculations.

As a result, it was possible to identify 10 groups among the 83 studied subjects of the Russian Federation (Table 1).

Cluster 1 includes 4 national republics - Chechnya, Ingushetia, Tuva and Dagestan, of which similar trends in the completed fertility of birth cohorts are found in Chechnya and Ingushetia, while Tuva and Dagestan differ both from them and from each other, but cannot be separated into separate clusters, since clusters should not include one single object. For cohorts born in 1930-1980s, these regions show the highest fertility among the analyzed subjects of Russia, but starting from the cohorts of the 2000s, they show, on the contrary, the lowest values in the forecast data.

Cluster 2 consists of three different regions – Kalmykia, Gorny Altai and Nenets Autonomous Okrug. Unlike the regions of the previous cluster, the completed fertility of birth cohorts in the cohorts of the 1930-1980s was lower, but at the same time, in the long term, the decline will not be as strong there, so the regions are more convergent with the rest of the regions of the Russian Federation.

Clusters 3 and 4, which contain 6 and 7 subjects respectively, characterize regions where the completed fertility of birth cohorts, although slightly lower than in the previously mentioned national regions, is more stable in the long term, which will allow the subjects of these clusters to have higher values for the expected completed fertility of birth cohorts born in 2000-2050. Moreover, the Khanty-Mansiysk Autonomous Okrug (KhMAO) and the Trans-Baikal Territory will, for female cohorts born starting from the beginning of the 2010s, become the leading regions in Russia. It is worth noting that these clusters mainly include regions, both more and less wealthy, of Eastern and Western Siberia, the Far East, and, beyond them, only the Astrakhan region.

Cluster 5 (7 subjects) also contains a number of national republics of the Volga region and the western part of the North Caucasus, as well as the Orenburg and Kurgan regions - regions where the completed fertility rate was and remains high relative to the country on average, but these regions will move to average levels of completed fertility of birth cohorts in cohorts born from the mid-1990s to the end of the 2000s.

Cluster 6, consisting of 13 subjects of the Russian Federation, includes the national republics of the European North and the Volga region, regions in the European North, the Urals, Siberia and the Far East, as well as the Krasnodar Territory and Adygea. These are regions that were in the zone of average or slightly above average completed fertility of birth cohorts relative to the country on average, and will remain there in the future.

Cluster 7, consisting of 12 regions of Russia, reflects the trend of transition from the average completed fertility of birth cohorts relative to Russia as a whole to a fertility slightly below average. It contains Tatarstan, the Stavropol Territory, some regions of the central Chernozem region and the Volga region, regions with moderate fertility in Siberia and the Far East.

Clusters 8 and 9, which include 13 and 15 subjects, respectively, are characterized by either a movement from an average fertility relative to Russia as a whole to a fertility moderately below average (cluster 8), or a stationary location in the zone of low completed fertility of birth cohorts (cluster 9). This includes most regions of central and northwestern Russia, some regions of the Far East, Tomsk region and Mordovia, as well as subjects that can periodically demonstrate significant growth in TFR, but have a low completed fertility of birth cohorts - Rostov, Samara and

Sverdlovsk regions. The Leningrad region also belongs to this cluster, although it is a border region, which under certain circumstances can be classified as cluster 10.

Cluster 10 is Moscow, the Moscow region and St. Petersburg, i.e., subjects with a very low completed fertility of birth cohorts relative to Russia over the entire chronological interval of analysis in our study. It will be discussed in more detail below when talking about metropolitan regions.

In addition to quantitative analysis, to illustrate the regional differentiation of fertility in the Russian Federation in birth cohorts it is necessary to analyze the completed fertility of birth cohorts by regional groups. These groups of regions themselves are not identical to clusters, but may have some overlap with them in theory.

The following were taken for analysis:

a) the capital regions of Russia;
b) national republics and autonomous okrugs with a greater degree of demographic modernization (the republics of the Volga region and the European North, Khakassia, Khanty-Mansi Autonomous Okrug, Yamal-Nenets Autonomous Okrug, the republics of the western North Caucasus - Kabardino-Balkaria, Karachay-Cherkessia, North Ossetia);
c) national republics and autonomous okrugs with a lesser degree of demographic modernization (all other national entities, except those indicated above);
d) geographic macroregions of Russia classically distinguished in socio-economic geography and demography (Arkhangelsky et al. 2020): central non-chernozem Russia, central chernozem Russia, the Northwest, European North, European South, North Caucasus, upper Volga region, middle and lower Volga region, Urals, Western Siberia, Eastern Siberia, Far East.

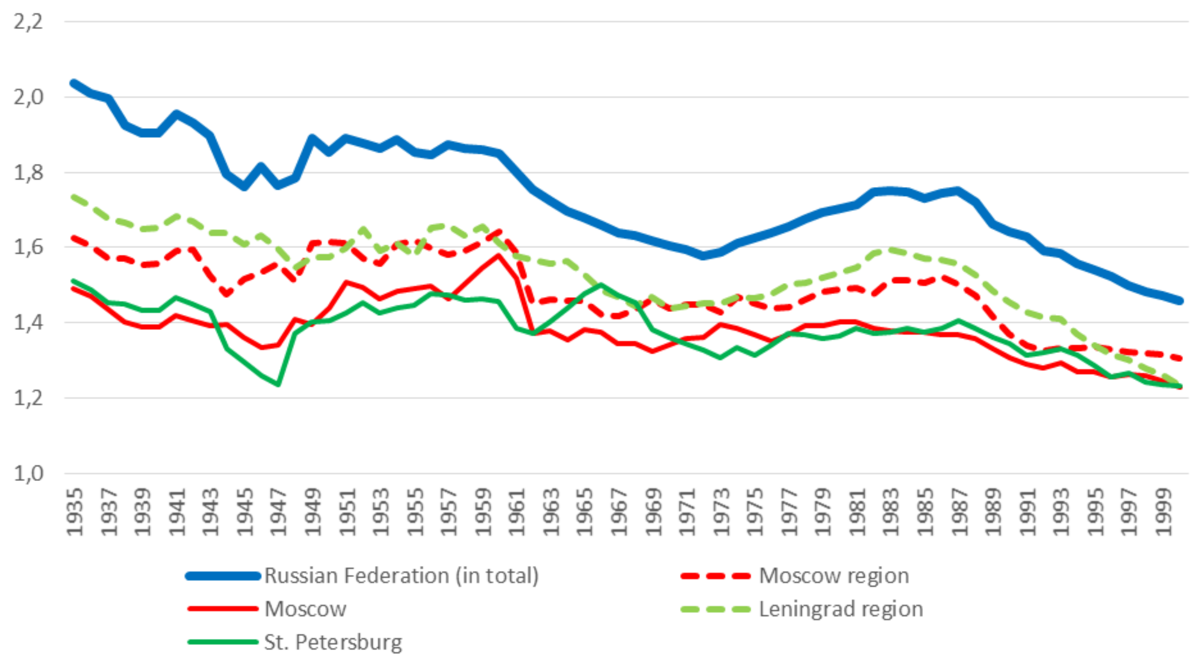
The capital regions include the two largest cities in Russia - Moscow and St. Petersburg - and the surrounding Moscow and Leningrad regions.

This group of regions is characterized (Figure 9) by low or very low completed fertility of birth cohorts (1.25-1.45/1.50 children per woman), and we can indicate a number of important features of fertility in these subjects:

1. Moscow and St. Petersburg have historically demonstrated lower fertility than the Moscow and Leningrad regions: convergence with the Moscow region occurs in cohorts born in the mid-to-late 1980s, and with the Leningrad region in cohorts born in the mid-1990s. This can be explained within the framework of the neo-economic approach to low fertility and SDT;
2. Moscow and the Moscow region show a fairly similar pattern of fertility dynamics – a slight increase in cohorts born in the late 1950s and a sharp decline in cohorts born in the early 1960s, plateauing for cohorts from the mid-1960s until the end of the 1970s, a slight rise in the cohorts of the first half of the 1980s, a decline in the cohorts of the late 1980s – early 1990s (albeit a little more pronounced in the Moscow region).
3. There is no such synchronicity between St. Petersburg and the Leningrad region, which is also explained by the de facto dual structure of the Leningrad region - the suburbs of St. Petersburg in the west of the region and the periphery of the central and eastern Leningrad region are more similar to the Novgorod or Pskov regions;

4. St. Petersburg in some years shows even lower completed fertility of birth cohorts than Moscow: in cohorts of the mid-1940s, the 1950s and the early 1970s;
5. despite the fact that the completed fertility of birth cohorts as an indicator should reflect smoother and calmer movements in fertility, there are also relatively sharp fluctuations in Moscow, the Moscow region and St. Petersburg - in the cohort of the mid-1940s in St. Petersburg and in the cohort of the early 1960s in Moscow and Moscow region. This is probably caused by large migration waves in these regions for the corresponding cohorts;
6. in the expected completed fertility of birth cohorts, as the regions of Russia converge, there will likely be a transition of the capital regions from low to medium-low fertility, although the absolute increase will not be very significant - from 1.20-1.25 births per woman in the 2010s cohorts to approximately 1.45 births in the 2040s cohorts.

Figure 9. Completed fertility of birth cohorts in the capital's regions and 83 regions of the Russian Federation, women born in 1935-2000, children per woman

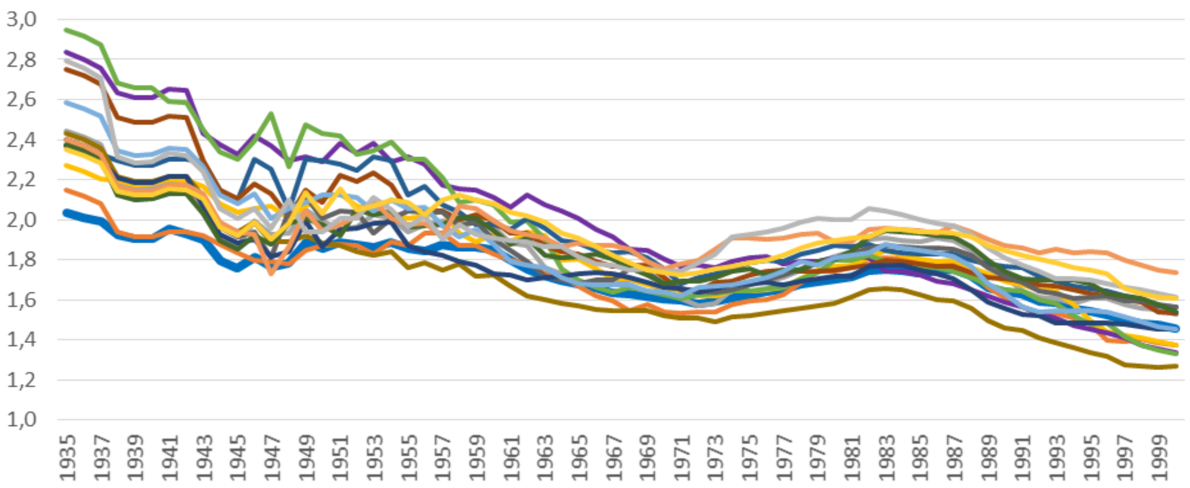


Source: Author's calculations.

Among national administrative-territorial entities (republics and autonomous okrugs), two different groups of regions can be distinguished: with earlier and later demographic modernization.

The first (Figure 10) includes the republics of the Volga region, the western part of the North Caucasus and Adygea, Karelia and Komi, Khanty-Mansi Autonomous Okrug and Yamal-Nenets Autonomous Okrug, Khakassia.

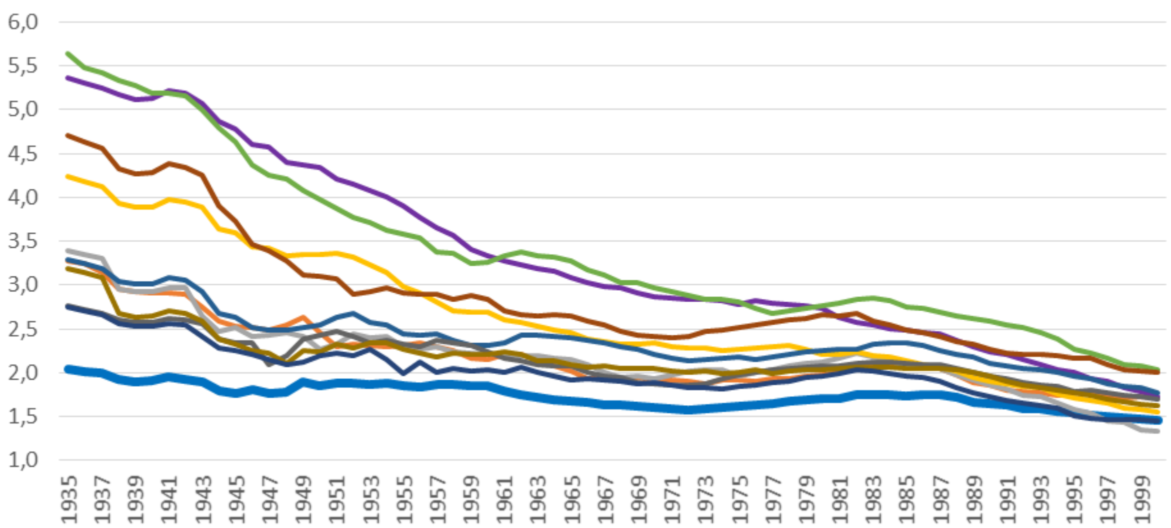
Figure 10. Completed fertility of birth cohorts for demographically modernized national regions and 83 regions of the Russian Federation, women born in 1935-2000, children per woman



Source: Author's calculations.

The second group (Figure 11) includes the eastern regions of the North Caucasus, Kalmykia, the Nenets Autonomous Okrug, the remaining republics of Siberia, and the Chukotka Autonomous Okrug.

Figure 11. Completed fertility of birth cohorts for less demographically modernized national regions and 83 regions of the Russian Federation, women born in 1935-2000, children per woman



Source: Author's calculations.

Several features can be identified in the dynamics of the completed fertility of birth cohorts in the national republics and autonomous okrugs of these two groups.

1. National regions with lagging demographic modernization are characterized not only by a more rapid decline in fertility, but also generally by sharper fluctuations in the fertility (with the exception of Karachay-Cherkessia and North Ossetia).

2. National regions with a greater degree of demographic modernization are characterized by a faster convergence of completed fertility of birth cohorts (with the exception of Mordovia and the Khanty-Mansiysk Autonomous Okrug in the first group and the Chukotka Autonomous Okrug in the second).
3. The more patriarchal-conservative the gender regime and the less urbanized the national region, the more delayed, but also the faster, on average, is the demographic transition in fertility. At the same time, it is also important to note that the farther will be the future fall in the expected completed fertility of birth cohorts.

It is worth dwelling separately on the connection between the dynamics of the completed fertility of birth cohorts in the main 12 macroregions of Russia and the 10 clusters (Table 2) obtained by us in the process of clustering time series by the completed fertility of birth cohorts.

Table 2. Geographic macro-regions for 83 regions of the Russian Federation, trends in the completed fertility of birth cohorts, women born in 1935-2050

Macroregion	Number of regions	Leaders (highest value)	Anti-leaders (lowest value)	Trend and clusters
Central non-chernozem Russia	11	Tver Oblast, then Vladimir Oblast, then Kaluga Oblast	Moscow, then Moscow and Moscow region	Clusters 9 and 10, transition from low and very low to medium-low
Central chernozem Russia	7	Bryansk region, then Lipetsk region	Voronezh region, then Orel region	Clusters 7, 8 and 9, stable fertility
Northwest	6	Vologda region	Saint Petersburg, then Leningrad region	Clusters 6, 7, 9 and 10, stable fertility
European North	6	Nenets AO, then Arkhangelsk region and Komi	Murmansk region	Clusters 2, 6, 8, 9, transition from high, medium-high to medium-high and medium fertility
European South	5	Kalmykia, then Adygea and Krasnodar region	Rostov region, then Volgograd region	Clusters 2, 6, 8, 9, transition from high, medium-high and medium fertility to medium-high, medium-low and low
North Caucasus	6	Chechnya, then North Ossetia	North Ossetia, then KBR, then KCR, Dagestan, Ingushetia and, last but not least, Chechnya	Clusters 1 and 5, transition from high and very high fertility to medium-low and very low
Upper Volga region	6	Udmurtia	Nizhny Novgorod region, then Tatarstan	Clusters 4, 5, 6, 7, transition from medium- high and medium fertility to medium and medium-low
Middle and Lower Volga region	7	Mordovia, then Astrakhan region	Samara region, then Saratov region and Mordovia	Clusters 3, 7, 8 and 9, transition from medium-high and medium fertility to medium-low and low
Urals	6	Bashkortostan, then Orenburg and Kurgan regions	Sverdlovsk oblast	Clusters 5,6,9, fertility state stable
Western Siberia	9	Mountain Altai, then KhMAO	Novosibirsk and Kemerovo regions, then Novosibirsk and Tomsk regions	Clusters 2, 3, 4, 6, 8, transition from medium-high and medium fertility

Macroregion	Number of regions	Leaders (highest value)	Anti-leaders (lowest value)	Trend and clusters
				to medium, medium-low and low
Eastern Siberia	7	Tuva, then Buryatia and Trans-Baikal Territory	Krasnoyarsk Krai, then Khakassia and Tyva	Clusters 1, 3, 4, 7, fertility state stable
Far East	7	Chukchi AO, then Amur region and Jewish AO	Primorsky Krai, then Kamchatka Krai and Sakhalin Region	Clusters 4, 6, 7, 8, transition from high, medium-high and medium fertility to medium, medium-low and low

Source: Author's calculations.

Conclusion

In this study, we were able to describe the long-term dynamics of fertility at the level of 83 regions of the Russian Federation through the optics of the birth cohort method for female cohorts born from 1935 to 1972, and also highly likely for 1973-2000 cohorts and hypothetically according to variants for cohorts born in 2000-2050.

We have solved a number of research problems.

First, the theoretical framework of regional differentiation of fertility for both conditional and birth cohorts is described. Then, this framework is applied to Russia in the context of the neo-economic approach, the framework of the theory of demographic transition in fertility, theories of modernization and human capital, the David Reher model and various models of the fertility transition in heterogeneous populations.

Second, estimates are given of the completed fertility of birth cohorts for the analyzed 83 subjects of the Russian Federation: for the completed fertility of birth cohorts of women born between 1935 and 2000 by one-year cohorts, and for the expected completed fertility of birth cohorts born in 2000-2050 by five-year cohorts.

Third, for a better understanding of the diversity of trajectories of decline and subsequent stabilization of the completed fertility of birth cohorts in different regions of Russia, statistical analysis was performed within the framework of variation analysis (absolute range of variation and coefficient of variation) and cluster analysis using the k-means method and by dividing the time series by medoids using the R programming language. 10 main clusters of the regions of the Russian Federation were identified, the most concentrated of which were clusters 6 to 9.

Variation and cluster analysis made it possible to understand that already within the framework of the completed fertility of female birth cohorts of 1935-1972 among the regions of Russia, the same convergence trends are occurring as in the whole world between countries, which indirectly indicates the adequacy of the selected Bayesian hierarchical model for predicting the final fertility for female cohorts of 1973-2050. Within the framework of the resulting formal model, it can be argued that a significant convergence of fertility between regions will already occur for cohorts born in the mid-2000s, when the minimum absolute range of variation will be recorded, although the coefficient of variation will decrease up to the cohorts of 2045-2050. Complete and, apparently, final convergence of fertility between the subjects of Russia should be expected if current trends continue among cohorts born in the second half of the 21st century or even at the beginning of the 22nd century.

A comparative analysis of the dynamics of fertility in birth cohorts was also carried out by groups of regions - capital regions, national regions with accelerated demographic modernization, and national regions with lagging demographic modernization. A comparison of 12 geographic macroregions of Russia with the resulting 10 clusters of regions according to trends in changes in the completed fertility of birth cohorts showed that clusters and geographic macroregions do not coincide along its geographical boundaries.

Despite the fact that the study achieved its goal, we must remember the limitations of the work we have done - by overcoming them in the future, it is possible to improve the results obtained. These include the large number of original data sources, to which new ones may be added over time, and problems with the quality of statistics in a number of Russian regions. A particular problem is the data from the latest All-Russian Population Census 2020 (2021), the reliability of whose results is questionable. In addition, mention should be made of the need to level out the impact of mortality and especially internal and external migration on estimates of the completed fertility of cohorts obtained both on the basis of census statistics and on current birth registration data. The creation of a high-quality population register could significantly reduce the significance of the above problems, even if this does not affect the earliest cohorts (born in the 1930s-1950s).

The work has potential for future development of the study of regional features of the evolution of age profiles of fertility and fertility taking into account birth order.

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