Comparison of Soviet and post-Soviet Russian settlement systems with the US settlement system, 1959-2020

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Abstract

The lack of discernible changes in the Russian (hereinafter RF) settlement system after the transition from a centrally managed economy to a capitalist economy seems to be contrary to the established view of the exceptional character of capitalist-style settlement systems. To explain this misunderstanding, we compared the state of settlement systems in Russia and in the United States between 1959 and 2020 in this paper. The measures of shape of the Pareto curve were used to quantify the state of the settlement systems: critical exponent, asymmetry coefficient, and Gini coefficient. The study found that the system of settlement in RF territories during the Soviet and post-Soviet periods had the same order and development trend as the system of settlement in US states. The order of urban systems in regions correlates with the local average annual temperatures. The results have led us to conclude that the settlement systems were independent from the economic paradigm.

Keywords: Soviet and post-Soviet settlement systems; rank-size rule; regional urban system; local climate; Russia; USA.

Introduction

In economic geography, there is a strong opinion that in market economies, a balanced inequality in settlement systems at all levels of aggregation should be consistent with the Zipf's Law or the rank-size rule (Alperovich 1984), (Berry and Okulicz-Kozaryn 2012), (Carroll 1982). However, much of the modern settlement system of the Russian Federation (RF) was formed during the period of centralized economic policy planning (Lappo and Polyan 1999) that held back the growth of major cities and supported strongly the development of regions (Clayton and Richardson 1989), (Gang et al. 1999), (Iyer 2003), (Pumain et al. 2015), (Kumo and Shadrina 2021), (Murray and Szelenyi 1984). The "underdevelopment" of 12 cities of over one million in the RF, including Moscow and Saint Petersburg, is considered to be a negative effect of this economic policy because they are below the linear dependence of the rank-size rule on the diagram of logarithm of cities (*Ot Ekonomiki Perekhodnogo Perioda k Ekonomiki Razvitiia. Memorandum Ob Ekonomicheskom Polozhenii Rossiiskoi Federatsii* 2004) (*Russia: Reshaping Economic Geography* 2011), (Kumo and Shadrina 2021); the same is applied to an excessively large number of federal subjects (FS) which makes them small compared to subjects in other federated states (Granberg, Kistanov, and Adamesku 2003). It was expected that the transition to a market economy would liberate the resettlement systems of former socialist countries, including Russia, from socialist heritage and remove those shortcomings (Ferenčuhová and Gentile 2016). Yet three decades after the abolition of central planning, no discernible changes have occurred in the settlement system of the RF and the former republics of the Soviet Union (Iyer 2003; Becker, Mendelsohn, and Benderskaya 2012; Ubarevičienė 2018; Kolomak 2020); this is possible when and only when settlement systems are independent of economic paradigm and tend to organize themselves according to the same rule, subject to the external constraints. One such constraint is the average annual temperature in regions of Russia

The purpose of this paper is to test empirically a hypothesis for the independence of the order of settlement systems from the economic paradigm and to find a correlation between the local average annual temperature and the order of urban systems in the regions. To achieve this purpose, we have compared the state of settlement systems in territories of the RF and United States between 1959 and 2010 and analyzed the dependence of the order of urban systems in regions of the RF and United States from local temperatures.

Theoretical framework for the study

Pareto Curve

Let the system consist of *n* elements. We rank the items by descending size and introduce w_r, a fraction of a size of the element with rank *r*. Elements of such a rank distribution satisfy the inequation $w_r \le w_{r-1}$. The fraction of a system size accumulated in *k* elements with ranks 1, 2,..., *k* is $S_k = \sum_{r=1}^{k} w_r$. The graph of dependency of S_k from the fraction of the elements $p_k = k/n$ is a discrete function. We interpolate $S_k = S(p_k)$ with a non-negative non-decreasing differentiable function $S(p)$, which we call the Pareto curve (PC). From the definition of PC, the inequation $p \le S(p) \le 1$ for $p \in [0,1]$ follows, as also boundary conditions: $S(0) = 0$, $S(1) = 1$. The first derivative is $S'(p) > 0$, the second is $S''(p) < 0$. PC is definitely related to the Lorentz curve (*L*) (Lorenz 1905) by the formula: $S(p) = 1 - L(1-p)$.

Using PC, the fractions of the size of system elements can be calculated using the following formula:

$$w(p_r) = S(p_r) - S(p_{r-1}). \tag{1}$$

The abscissa of the mean size element of the system satisfies the equation: $S'(p_\mu) = 1$ (Kakwani 1980). The point $(p_\mu, S(p_\mu))$ at which the PC derivative is equal to 1 is at the maximum distance from the egalitarian line $y = x$.

Gini coefficient

To compare the concentration of inequality in settlement systems, we use the Gini coefficient (*G*) equal to the double area between the PC and the equality line $S(p) = p$

(Gini 1912). The Gini coefficient values are within the interval $0 \le G \le 1$. The greater the size inequality, the closer the *G* value is to 1.

Pareto curve asymmetry

Let us use $(p_a, S(p_a))$ to denote the point where PC intersects the diagonal $y = 1 - x$ (hereinafter the orthogonal diagonal) perpendicular to egalitarian line. By convention:

$$p_a + S(p_a) = 1. \tag{2}$$

Pareto curves are symmetric with respect to the orthogonal diagonal when the equality $p_\mu = p_a$ from which the PC symmetry condition (Kakwani 1980) follows is satisfied:

$$p_\mu + S(p_\mu) = 1. \tag{3}$$

PCs have a right-hand asymmetry when $p_\mu < p_a$, and a left-hand asymmetry when $p_\mu > p_a$. In this paper, the following coefficient was used to estimate the asymmetry of the Pareto curve:

$$\gamma = \frac{p_\mu}{p_a}. \tag{4}$$

The Pareto curve is symmetric with respect to the diagonal perpendicular to the orthogonal diagonal if $\gamma = 1$; it has a right-hand asymmetry when $\gamma < 1$, and a left-hand asymmetry when $\gamma > 1$.

Critical exponent

In the late 19th century, Vilfredo Pareto, when studying the income of the population based on income tax statistics, found that the Pareto curve in the area of large incomes can be approximated by power function:

$$S(p) \approx mp^\beta, \quad p << 1 \tag{5}$$

with an average exponent of $\beta \approx 1/3$ (Pareto 1897), *m is a* constant, which is possible if and only if there is a limit:

$$\beta = \lim_{p \to 0} \frac{\ln S(p)}{\ln p}. \qquad (6)$$

In the physics of phase transitions, the index β defined by formula (6) is called a critical exponent (Stanley 1971). The value $\beta = 1$ suggests that there is no order in the system, as the elements are of the same size. The order in the system is only when $\beta < 1$.

Since real systems almost always have a limit (6), it is not surprising that systems of different nature in the area of $p << 1$, PC have a power function, even if the true base distribution is not a Pareto distribution.

Using (5), we obtain the approximation for relative primacy coefficient λ:

$$\lambda = \frac{w_1}{w_2} = \frac{S_1}{S_2 - S_1} = \frac{1}{2^\beta - 1}, \quad 1 << n. \qquad (7)$$

When solving equation (7) with respect to β, we find:

$$\beta = \frac{\ln\left(1 + \frac{1}{\lambda}\right)}{\ln 2}. \qquad (8)$$

It follows from (8) that a primate city having size of $w_1 > 2w_2$ (Jefferson 1939) appears in settlement systems when the inequation $\beta < 0.585$ is true.

Rank-Size Rule

When we substitute the ratio (5) in (1), we have:

$$w_r = w_1 r^\beta \left[1 - \left(1 - \frac{1}{r}\right)^\beta\right], \quad \frac{r}{n} << 1. \qquad (9)$$

When we use the approximation $\left(1 - \frac{1}{r}\right)^\beta = 1 - \frac{\beta}{r} + O\left(\frac{1}{r^2}\right)$, we obtain:

$$w_r = \frac{w_1 \beta}{r^{1-\beta}}\left[1+O\left(\frac{1}{\beta r}\right)\right], \quad \frac{r}{n} << 1, \tag{10}$$

From the ratio (10), it can be seen that even though the Pareto curve in the neighborhood of zero can be approximated by power function (5), while the rank-size rule (Auerbach 1913) (also known as the Zipf's Law (Zipf 1949)), will not apply to describe the size of large and small elements of settlement systems. The result is supported by numerous empirical studies (for example, see (Cottineau 2017) and the review (Arshad, Hu and Ashraf, 2018)).

PC model

The study (Grachev 2020) showed that the PC of the USA settlement system adequately approximates the two-parameter model (Antoniou et al. 2004):

$$S(p;\alpha,\beta) = \sqrt[d]{1-(1-p)^{\alpha}}, \quad 1 \le \alpha < \infty, \quad 1 \le d < \infty. \tag{11}$$

It can be seen that when $\alpha > d$, PC has a negative asymmetry. When $\alpha = d$, PC is symmetrical relative to the orthogonal diagonal, but PC has a positive asymmetry when $\alpha < d$. In a state of stable equilibrium, all systems, regardless of their nature, have symmetrical PCs.

The Gini coefficient of the model (11) has an analytical expression:

$$G(\alpha,\beta) = \frac{2\Gamma\left(\frac{1}{\alpha}\right)\Gamma\left(\frac{1}{d}\right)}{\alpha d\,\Gamma\left(\frac{1}{\alpha}+\frac{1}{d}+1\right)} - 1. \tag{12}$$

When applying L'Hôpital's rule, we will find:

$$\beta = \lim_{p \to 0} \frac{\ln\left(1-(1-p)^{\alpha}\right)^{\beta}}{\ln p} = \frac{1}{d}. \tag{13}$$

As might be expected, in the neighborhood of zero, the two-parameter model (11) is independent of the α parameter and can be approximated by a single-parameter function (5) with a critical exponent β.

When we substitute $\alpha = 1 \text{and} 1 \le d$ in (11), we obtain the PC of the classical Pareto distribution:

$$S(p;1,\beta) = p^{\beta}, \quad \beta \le 1 . \tag{14}$$

If $\beta = 1$ and $1 \le \alpha$, then PC has the form of a power-series distribution:

$$S(p;\alpha,1) = 1 - (1-p)^{\alpha}, \quad 1 \le \alpha . \tag{15}$$

When we substitute $d = \alpha$ in (11), we obtain a single-parameter symmetric PC, which is a special case of the Burr III distribution (Burr 1942):

$$S(p;\beta) = \left[1 - (1-p)^{\frac{1}{\beta}}\right]^{\beta}, \quad 0 \le \beta \le 1. \tag{16}$$

When we substitute $p = 0.2$, $\beta = 1/3$, in (16), we obtain $S \approx 0.8$ or proportion 20-80 better known as the Pareto principle (Grachev 2009, 2010, 2011, 2020).

Data and Methods

Data

Data on the population of RF constituent territories and cities within the modern borders is downloaded from public websites: https://rosstat.gov.ru/, http://www.citypopulation.de/en/russia/. Data on the average annual temperatures in the Russian regions is downloaded from https://tehtab.ru/. For US states, we used https://www.currentresults.com/index.php. The measures of the order of the USA settlement system are taken from research (Grachev 2020).

Methods

The value of the empirical Gini coefficient was calculated using the formula (Sen 1973):

$$G = \frac{n+1}{n} - \frac{2}{n}\sum_{r=1}^{n} r w_r \ . \tag{17}$$

Model parameters (11) were estimated using the Solution Search function in Microsoft Excel. As an objective function, we have used the Kolmogorov — Smirnov statistics that is most common for abnormal data, which is equal to the maximum modulus of differences between the empirical and theoretical PCs:

$$KS = \sup_x \left| S(x_i) - S\left(x_i; \hat{\alpha}, \hat{\beta}\right) \right|, \tag{18}$$

where $S\left(x_i; \hat{\alpha}, \hat{\beta}\right)$ represents the estimated PC.

The results

RF subjects

As of 2020, the Russia's administrative structure consists of 85 federal subjects, including 3 cities of federal importance (Moscow, Saint Petersburg and Sevastopol). The largest subject of the Russian Federation is the city of Moscow (12.48 million people). Moscow Oblast is the second largest subject, Krasnodar Krai is the third largest subject, and the city of Saint Petersburg is in the fourth place. Note that Krasnodar Krai became the third largest subject, ahead of Saint Petersburg, only in 2002.

Rank change of federation subjects suggests a local (or incomplete) equilibrium of the settlement system across subjects (subsystems), which means that there is no equilibrium between the subsystems. This paper did not address the change in the ranks of the subjects of the Russian Federation over time. This means that the order of the settlement system by region was considered at the macroscopic state level.

The results of the estimation of measures of the settlement system in RF subjects within the 2020 borders between 1959 and 2020 are shown in Figure 1. Also, for comparison, the behavior of the measures of the settlement system in US states published in (Grachev 2020) is presented. The margin of error of the critical exponent is not greater than ± 0.01, while the margin of error of the asymmetry coefficient is not greater than ± 0.012.

From the graphs shown in Figure 1, it is clear that since the transition to a market economy, the development trend of the settlement system in the Russian Federation has not changed. As we compare the order of the settlement systems of the RF and the USA, we can see that both systems have the same decreasing rate of the critical exponent, which can be treated as a direct confirmation that the order of settlement systems does not depend on the economic paradigm. This result explains the lack of noticeable changes in the RF settlement system after the transition from centralized economic policy to market economy.

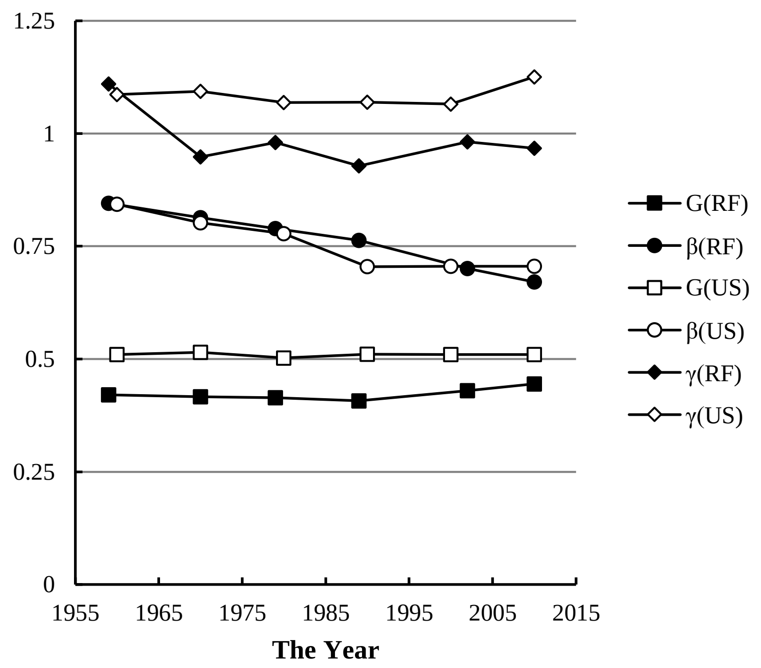

Figure 1. The behavior of Gini coefficient (*G*), critical exponent (β) and asymmetry coefficient (γ) of settlement systems by federal subjects of the Russian Federation and the United States

From the graphs shown in Figure 1, it is clear that since the transition to a market economy, the development trend of the settlement system in the Russian Federation has not changed. As we compare the order of the settlement systems of the RF and the USA, we can see that both systems have the same decreasing rate of the critical exponent, which can be treated as a direct confirmation that the order of settlement systems does not depend on the economic paradigm. This result explains the lack of noticeable changes in the RF settlement system after the transition from centralized economic policy to market economy.

From the graphs shown in Figure 1, it also follows that the main difference between the RF and US settlement systems is the asymmetry coefficient. In the US, it is larger than 1 (the left-hand asymmetry of PC), and in the RF it is smaller than 1 (the right-hand asymmetry). Note that the left-hand asymmetry of PC tends to suggest an active struggle of system elements for a place in the rankings.

Figure 2 shows the results of the approximation by model (11) of the rank distributions of settlement systems by federal subjects in the Russian Federation and the United States in 2010.

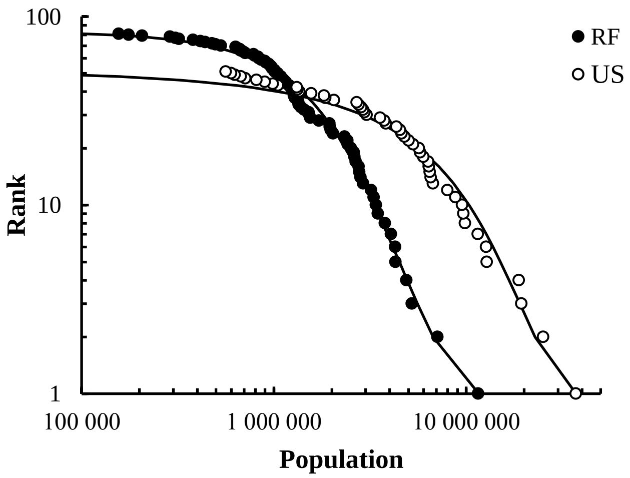

Figure 2. Rank distributions of sub-federal entities of the Russian Federation and the United States in 2010 (thin lines are simulation results)

From the rank distributions in Figure 2, it is evident that the rank-size rule is not a good approximation for describing the sizes of federal subjects. At the same time, model (11) adequately describes the distribution across federal subjects in the RF and the US in almost the entire range of ranks.

Urban systems in regions

There is currently no universal definition of what the term "urban" means. The problem is that countries adopt very different definitions of urbanization (Rozenblat, C., Pumain 2018) (Lobo et al. 2020). In the Russian Federation, inhabited localities are considered to be cities if approved by legislation as cities and urban-type settlement. According to the classification in place in Russia, cities are inhabited localities with a population of more than 12,000. According to the 2010 national census, the number of cities in Russia was 1,100, the number of urban-type settlements — 1,286, and the number of rural-type settlement — 153,124. Russia has 15 cities of over one million and 170 cities of over 100,000 people.

The USA population is 2.24 times larger than that of Russia. There are about 30,000 cities in the US (inhabited localities with a population of over 2.5 thousand), of which there are 10 cities of over one million, and 307 of over 100,000 people. The largest city in the United States, New York, is home to 8.49 million people. Comparison of big cities in the RF and the United States shows that the assumption that Russian cities "are too small" is more paradoxical than true.

The estimation of urban settlement systems in the Russian Federation was performed for 66 federal subjects (FS) comprising at least 10 cities. The average values of the order of urban systems in federal subjects of the Russian Federation and US states in 2010 are presented in Table 1.

Table 1. Average values of the order of urban systems in regions in the RF and the US

Country	G	β	γ	λ
RF	0.72±0.02	0.34±0.04	0.93±0.75	5.58±1.39
USA	0.71±0.03	0.54±0.06	1.12±0.93	3.36±1.44

From the order measures in tables 1, it can be seen that the urban systems in both countries have average values of G approximately 1.4 times greater than the settlement systems for FS. The average values of γ are close to zero. However, the average critical exponent of PC for urban systems in Russia is less than that of the United States.

Climate impact on settlement systems

The territory of the Russian Federation is located in four climatic zones (from polar to subtropical). The United States has predominantly a temperate continental climate. The distribution of relative frequencies of average annual temperatures $\overline{T}$ in the RF and US states is shown in Figure 3.

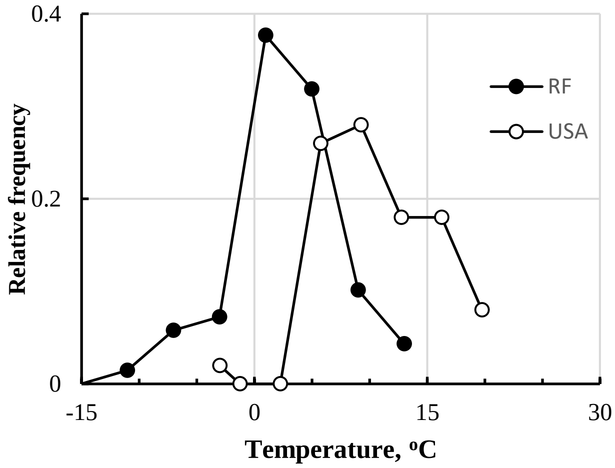

Figure 3. Distribution of relative frequencies of average annual temperatures in the RF and the USA

From the relative frequencies presented in Figure 3, we can see that the average annual temperature in RF subjects is $\overline{T} = 2.1$°C, while in the US it is $\overline{T} = 11.1$°C. In the RF, 20 regions have an average annual temperature of less than zero degrees Celsius, while in the United States — only the state of Alaska.

The relationship between average annual temperature and urbanization, annual average temperature and urban system order in regions of the RF and the USA proves the scattering graph in Figure 4 to be true.

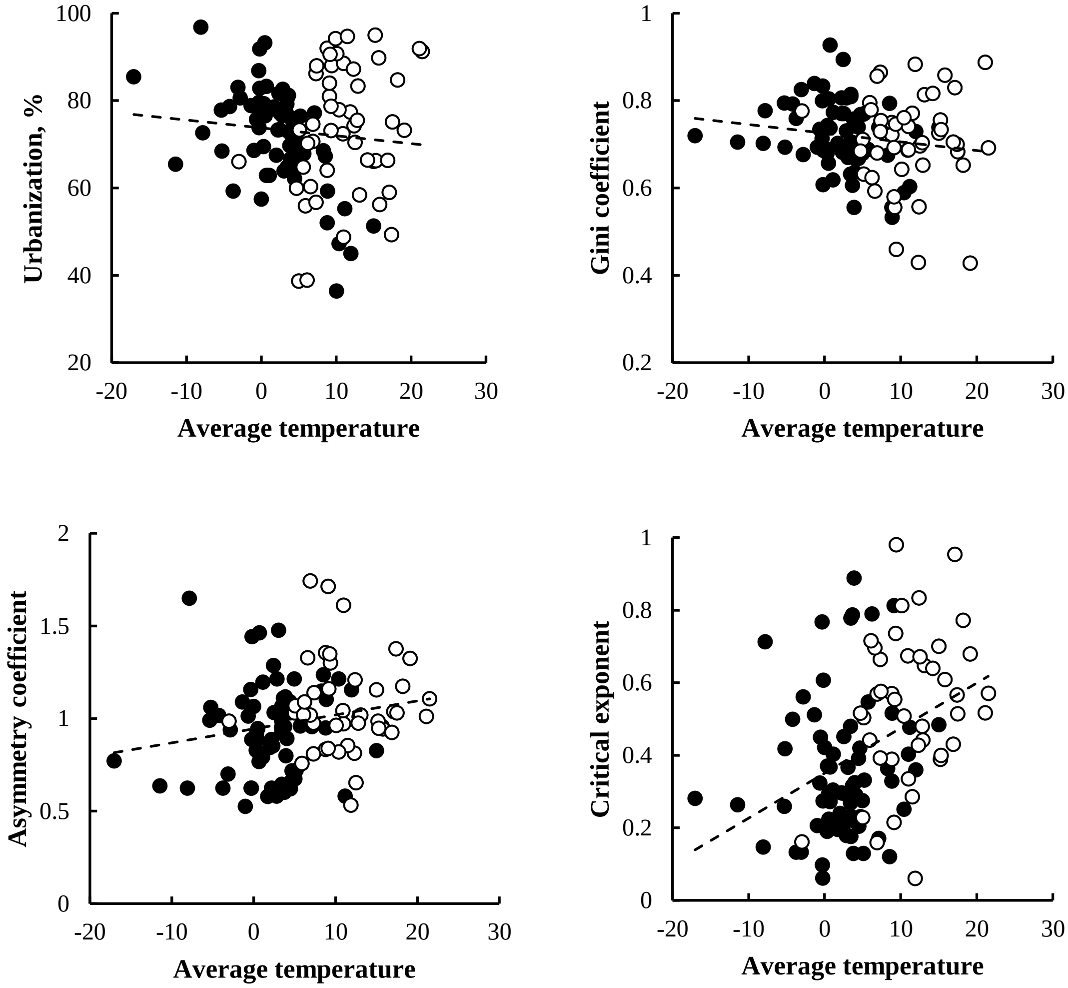

Figure 4 Scattering graphs (points — RF settlement system, circles — USA settlement system, dotted lines — regression lines)

The empirical data presented in Figure 4 shows that there is a correlation between the average annual temperature and the order of urban systems in the regions — rise in temperature results in a decrease in urbanization and the Gini coefficient, but the critical exponent increases. The asymmetry of Pareto curves changes the sign in the neighborhood of 10°C.

The bold points in Figure 5 show the rank distributions of cities in three Russian regions and three US states. The approximation of rank distributions by model (11) is represented by a thin line.

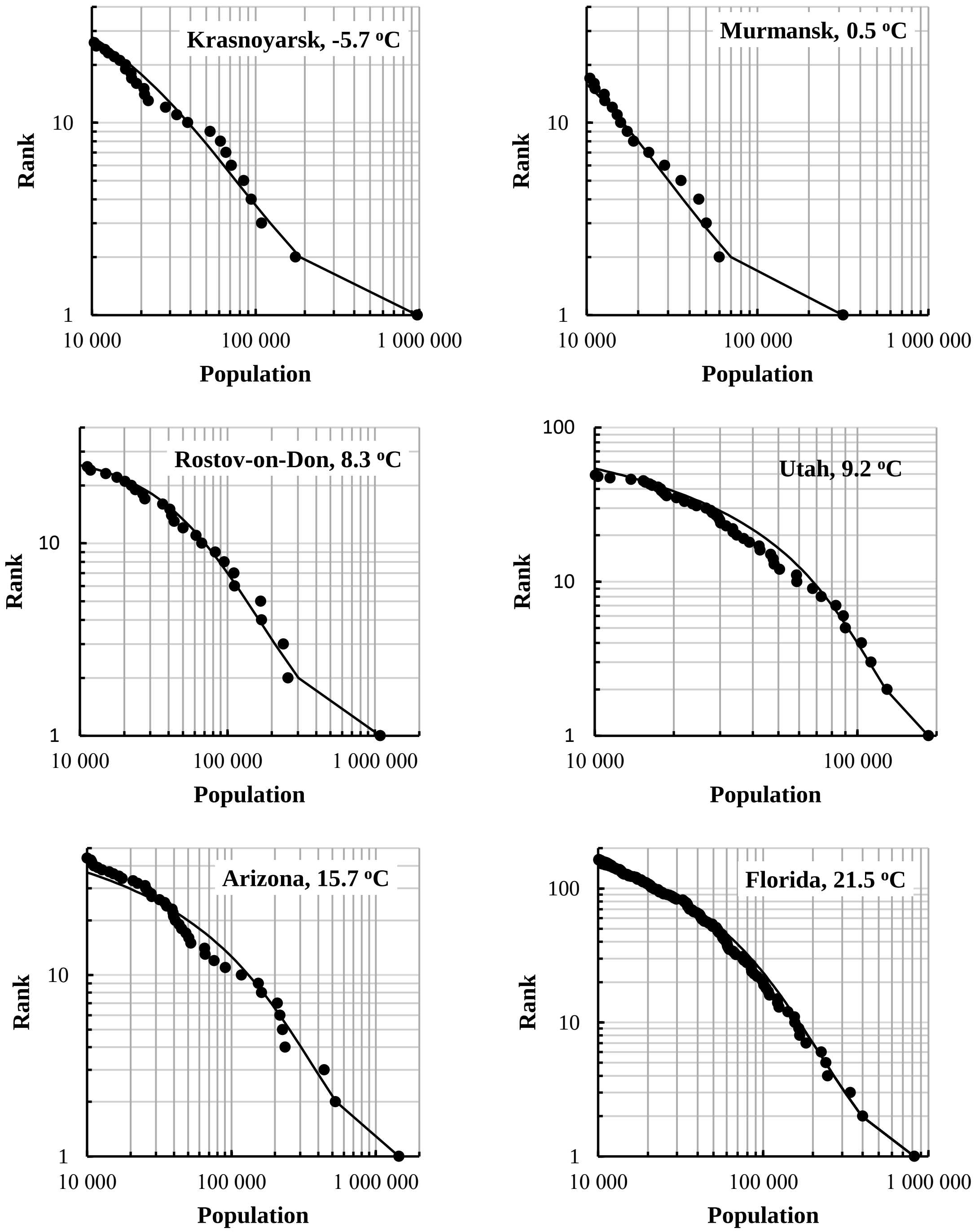

Figure 5. Rank distributions of cities in the federal subjects in the RF and the USA

From rank distributions in Figure 5, it is clear that model (12) adequately describes the rank distributions of cities across the rank range. The dependence of the order of settlement systems on the average annual temperature of the region is clearly visible, which explains the wide variety of urban structures in federal subjects of Russia.

Discussion of results and conclusions

The original assumption of this paper was the idea of independence of the order of settlement systems from the economic paradigm and existence of a correlation between the local average annual temperature and the order of urban systems in the regions.

This research found that the settlement system in RF subjects during the period of centralized economic policy planning and after the transition to market economy had the same order and development trends as the US settlement system.

A study of the correlation between local average annual temperatures and the order of urban systems in regions found that rise in average annual temperature leads to a decrease in urbanization and concentration of inequalities in urban systems. This result is in line with the findings of the work (Castells-Quintana, Krause, and McDermott 2020) that noted that worsening climatic conditions increase urbanization, and the work (Smirnov 2020) that stated that arctic regions are dominated by major cities. Thus, the cause of the wide variety of urban systems of the Russian regions is established, which makes it impossible to create a universal extensive urban policy (Kolomak 2015), (Andreev 2020).

These results have the following important implications. First, the fact of the independence of settlement systems from economic paradigm is a further support for the general systems theory whereby all systems, irrespective of their particular kind, organize themselves according to the same rule (Bertalanffy 1967). Second, the dependence of the order of urban systems in regions on the climatic conditions suggests that a sample of cities from different regions of the Russian Federation is a priori heterogeneous. Therefore, using such a sample to estimate the order of settlement systems is incorrect. Third, the study carried out explains why not only in the RF but also in other former Soviet republics after the transition from centralized economic policy planning to a capitalist economy there has been no discernible change in settlement systems (Ubarevičienė 2018).

The strong point of the study is that the state of settlement systems was estimated using empirical measures of the shape of the Pareto curve without involving settlement models.

A limitation for the application of system order measures obtained is that the study was conducted only for two federated states located in the Northern Hemisphere. Therefore, in the future, it will be reasonable, with the aid of method used in this study, to estimate the order of settlement systems not only in federated states but also in unitary states located in different geographical conditions, which will clarify the parameters of regression equations describing the dependence of the average order of regional settlement systems on average annual temperatures.

In conclusion, since the shape of the Pareto curve does not depend on the number of elements in the system, the results of this study do not depend on the number of federal subjects. At the same time, given that the consumer wants to maximize total utility, increase in the number of federal subjects will give them great opportunities to satisfy their needs. Therefore, there is no reason to believe that the two-fold reduction in the number of regions proposed by the Government of the Russian Federation in the draft Common Development Strategy could increase efficiency of the settlement system. Because of its incorrectness, the rank-size rule cannot be a reason for increase in the population of the cities of Moscow, Saint Petersburg and other cities of over one million in the RF.

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