

Research

Evaluating multilevel resilience of Russian urban economies 2010–2019

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ABSTRACT. In this paper we examine the coevolution of individual cities and the city networks to which they belong, during an economic shock. We take an individual city and its city network to be the meso and macro levels, respectively, of a social-economic system. Focusing on the economic shocks felt by Russian cities in 2014 following the Ukrainian conflict, we demonstrate that the same shock had different effects at the meso level (a city's employment structure) and macro level (a city's interfirm linkages to other cities, both national and international). To explain our findings, we draw on panarchy theory to propose a multilevel perspective of resilience through the coevolution of adaptive cycles at the meso and macro levels of urban economies. To evaluate resilience at each level, we first operationalize the panarchy concept of connectedness using a previously developed metric called “tightness,” which quantifies the interdependencies among economic activities. We next operationalize the panarchy concept of potential by measuring a city's degree of economic specialization. At the meso level, we find that larger cities suffered less employment loss than smaller cities during the shock and that by 2019 the structure of the meso level had largely returned to its 2010 structure. On the other hand, at the macro level, we found that the 2019 macro level structure changed considerably from 2010. Thus, we show that the meso level was disturbed but returned to a previous state (engineering resilience) while the macro level transitioned to a new state (ecological resilience). Results suggest that policy makers would benefit from distinguishing between the meso and macro levels, enabling the development of multilevel urban policies to address future shocks.

Key Words: *cities; employment; multilevel; multinational firms; panarchy; resilience; Russia; system of cities*

INTRODUCTION

Global climate change in the Anthropocene is increasingly inducing exogenous shocks in human social-ecological systems, such as sea-level rise, biodiversity loss, and extreme weather events (Folke et al. 2021). Responding to climate change, countries may instigate intentional shocks such as transitions to low-carbon energy systems. Although self-induced shocks such as energy transitions are expected to have net long-term benefits for humanity, they can be highly disruptive to both cities and systems of cities on near-term time scales (Cha 2020, Villamor et al. 2020). To better prepare for impending energy transitions and other climate-related shocks, policy makers require improved knowledge of how large-scale disruptions affect the resilience and adaptability of urban systems. To contribute to that understanding, we examine how recent economic disruptions affected Russian cities and its system of cities.

Within the last 20 years, Russian cities have faced at least three significant crises: the world financial crisis of 2008–2009, the economic crisis of 2014–2016 related to international sanctions imposed on Russia following its annexation of Crimea, and the economic disruption caused by Russia's military invasion of Ukraine in 2022. The latter is ongoing and, although it is difficult to anticipate its consequences at the time of writing this paper, it is plausible that this shock will have not only the strongest short-term negative effects but may also initiate a long-term transformation of how the Russian city system is organized and how cities within that system are connected to the rest of the world.

In this study we focus on the impacts of the crisis of 2014–2016 on Russia's urban economies. This crisis was neither global nor cyclical as was the financial crisis of 2008–2009, but was national and structural (Klepach 2015, Lyakin and Rogov 2017, Lyakin

2018). The drivers of the 2014–2016 crisis were twofold. First, it was facilitated by top-down triggers, such as international economic sanctions imposed on Russia and a decline in exports of key Russian goods, which resulted in a devaluation of Russia's currency. Each of these triggers inevitably influence global connectedness of cities (Rogov and Rozenblat 2022). Second, structural problems of the Russian economy, such as its low efficiency, institutional barriers, and technological inadequacies, represent bottom-up local processes leading to urban economic decline. The cities' systems theory suggests considering cities as systems within systems of cities (Berry 1964) with an emphasis on two levels. The first of these, the meso level, is the level at which different local parts and dimensions of a city create a holistic system able to function and evolve by keeping some structural parts of its history. The second, the macro level, is also strongly embedded in history and is the level at which a city changes its situation within a larger system of cities to which it is strongly connected (e.g., nearby cities, a national system of cities, or the global system of cities).

In this paper we explore how these top-down (macro) and bottom-up (meso) crisis-related processes evolved in different Russian cities and to what extent they were similar among different types of cities. Examining the coevolution of these two levels, we seek to evaluate how local economic adaptation of cities corresponds to the evolution of a city's position in global economic networks. We further seek to understand how local economic specialization and relatedness (meso level) relate to an urban economy's ability to resist a general shrinkage of global economic networks (macro level; Rogov and Rozenblat 2022). Conversely, we ask whether there are aspects of specialization or relatedness of cities' positions in global networks (macro level) that prevent local (meso level) employment from experiencing large declines. Based on the evolution of macro level activities of multinational firms and

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meso level local employment during the period 2010–2019, we evaluate urban economic resilience of Russian cities, which, we argue, are shaped by the dynamic interplay between the evolution of a city's economic employment structure (meso level) and the evolution of its network of globally-connected firms (macro level).

The primary contribution of this study is to test a theory of urban economic resilience in a multilevel perspective and to understand the factors contributing to urban resilience so that cities may better respond to future shocks. By linking macro and meso levels, we initiate a dialog regarding top-down and bottom-up resilience processes that have not previously been studied from such perspectives for cities. With this multilevel approach, we define resilience as an emergent property of urban systems that can exist in different configurations or regimes (Allen et al. 2019). Social-ecological resilience is an overarching approach to explain the dynamics of social and ecological systems, encompassing adaptation, transformation, and panarchies (scale and cross-scale interactions). A panarchy approach considers “nature's rules,” including hierarchy and dynamism, and accounts for the interconnectedness of social-ecological resilience and vulnerability on multiple spatial and temporal scales.

Here, we bound our cities as evolving sets of interacting economic activities and entities. The response of these components to an economic shock is strong enough to be observed without needing to consider effects on a city's natural environment. Even so, this environment is implicitly considered when analyzing the economic resources of cities. Thus, although panarchy is typically applied to coupled social-ecological systems, we take panarchy to be a framework for complex adaptive systems more generally, that allow users “to understand the source and role of change in systems - particularly the kinds of changes that are transforming, in systems that are adaptive” (Gunderson and Holling 2002:5).

The originality of this paper is to advance a panarchy-inspired methodology partly tested by Shutter et al. on U.S. metropolitan areas (2015) and German labor market regions (2022), but which considered only the meso level of regional employment structures. By adding inter-city connectedness to this method (macro level), we make a critical contribution to understanding the multilevel resilience of cities, advancing not only theory but providing recommendations to city governments for further policy elaboration.

LOCAL AND GLOBAL: DEFINING LEVELS IN URBAN ECONOMIC RESILIENCE

To examine the macro level of the Russian city system, we analyze the network of interconnected multinational firms within Russian cities, where nodes are cities and links represent ownership linkages between firms within those cities. A recent study of these multinational networks (Rogov and Rozenblat 2022) found that between 2010 and 2019 the number of inter-city linkages in Russia decreased substantially. During the same period the average number of other cities to which a city is linked through firm ownership increased, especially with foreign cities, meaning that globalization continued to advance among Russian cities, despite the shock of 2014. Furthermore, since the collapse of the Soviet Union in 1991, many Russian cities have experienced a shrinking population (Cottineau 2013, Batunova and Gunko 2018), which

creates additional obstacles for urban resilience. Along with the highly diverse economic structures of Russian cities, their uneven spatial distribution, and high levels of spatial inequality, these processes lead to different economic trajectories of cities during large economic fluctuations and challenge their ability to be resilient.

Features of the crisis 2014–2016 in Russia: the urban dimension

The economic crisis of 2014–2016 had several features that distinguished it from the global financial crisis of 2008–2009 including the following:

1. “Demographic shrinkage,” meaning that Russia's economically active population decreased faster than total population, primarily because of aging (Zubarevich 2017);
2. A smaller decrease in industrial production among Russian cities and no increase in unemployment (Lyakin 2018);
3. A growth in shadow employment as a way to avoid paying taxes (Zubarevich 2017);
4. Increased regional inequality caused by the confluence of three trends in 2014–2016 (Alexeev and Chernyavskiy 2018):
 - Revenues of the poorest Russian regions declined more than those of richer regions;
 - Federal subsidies to regions were reduced in 2014–2015 relative to previous years whereas they were increased in 2009 (thus exacerbating impacts on poorer regions);
 - Unlike in 2009, the largest federal subsidies did not go to regions that experienced the largest drops in revenues.

Collectively these features caused similar transformations of all urban economies in Russia during the crisis of 2014–2016 and not only those that specialized in sectors targeted by economic sanctions as one might expect (Rogov 2021). This suggests that urban or regional economic resilience may not be shock specific, but rather system specific (Wang and Wei 2021), impacting the entire Russian system of cities. Because each Russian city interacts with the national system of cities and with foreign global cities, dimensions of urban resilience such as persistence, adaptability, and transformability (Folke et al. 2010), depend on different levels of economic organization.

Urban resilience in a multilevel perspective

Despite a rapidly growing interest in urban resilience, both in academic communities and among policy makers, there are still many ongoing conceptual debates regarding the term: is it an urban property or a manageable process? Is urban resilience about a system returning to an initial state or about the system finding a new equilibrium? Is urban resilience defined on one level or through multiple levels of city interactions? From these debates have emerged two principal approaches to defining general resilience: engineering resilience and social-ecological resilience (Meerow and Newell 2015). Engineering resilience reflects the idea that a disturbed system returns to its initial state, which is the system's single possible equilibrium state. In contrast, social-ecological resilience implies that social-ecological systems (e.g., cities) can exist in different configurations at different times (Allen et al. 2019).

Although these two approaches explain changes of a system within a stable landscape, the concept of social-ecological or adaptive resilience asserts that a shock changes both a system and its environment (Laboy and Fannon 2016). The two concepts of social-ecological and adaptive resilience are largely synonymous. However, in the terms of Laboy and Fannon (2016), the concept of adaptive resilience emphasizes specifically the influence of a shock both on the system (a city) and on its fitness landscape (the wider systems in which the city is embedded), recognizing that the fitness landscape evolves as well. Thus, it is more suitable for the multilevel approach that we advocate.

The evolutionary theory of cities' systems (Pumain 2018) stipulates that "evolution of cities is mainly driven by their specific relative situation, in terms of location, size, and functions, within systems of cities" (Pumain 2018:3). In fact, the system of cities (macro level), representing the fitness landscape or environment of individual cities, also adapts to changing economic conditions during an economic crisis. Based on this theory, which followed Berry's 1964 seminal paper, we consider that the meso level (the city's local system including its center and all its surrounding areas) and the macro level (the position of this city in the system of cities in which it is embedded) are crucial levels at which a city functions as a collective system. Moreover, not only do the meso and macro levels of cities change because of shocks, they also may change in response to each other, which requires us to further redefine what it means to be an urban resilient system (Elmqvist et al. 2019). Thus, we argue that to assess urban economic resilience it is crucial to study not only internal economic dynamics of individual cities (meso level), but also the evolution of a city's relative position in a global economic network as its principal economic context (macro level). Processes taking place at this macro level differentially affect the dynamics of individual cities depending on each city's relative position at this level (Bettencourt 2021). These levels must be carefully defined conceptually and delineated methodologically.

Levels of urban economic resilience

Cities not only support spatial proximities at the local scale they are also access points to proximities at the global scale. This access permits interactions with far-away cities or places, through long distance infrastructures and socioeconomic and financial channels. In this sense, cities support the densification and the complexification of social and economic networks both locally and globally. Thus, intra-cities' proximities and global accessibilities combine in the formation and continuation of a range of network dynamics, providing local and global conditions that constitute multilevel urban systems (Pumain 2006).

According to Pumain, "the first level is made up of elementary entities, like individual persons, firms or institutions which can make decisions in terms of locating and organizing activities, building housing, offices, or monuments, travelling on foot or by car ..." (Pumain 2006:171). These elementary micro-entities (or actors) maintain dense interactions between each other, but also with the environment on a daily basis, which contributes to structuring the city at the meso level. At the macro level, the system of cities emerges from the exchange of people, goods, or information between cities. The macro level is an emergent entity and thus more than the sum of individual cities, just as an individual city is different from the sum of its individuals. As with

all complex systems, the boundary between levels of organization is difficult to determine and to delineate, as they are intertwined and highly interdependent. Of course, we can identify many other intertwined levels or organization within a city (such as neighborhoods, communities, specialized areas, etc.) and between cities (regional cities, specialized cities in certain industries linked to the same value chains, port cities, etc.). The individual city as a whole and the system of cities are important levels encompassing the dynamics of a city (Batty 2018), and are thus the levels we examine in this study.

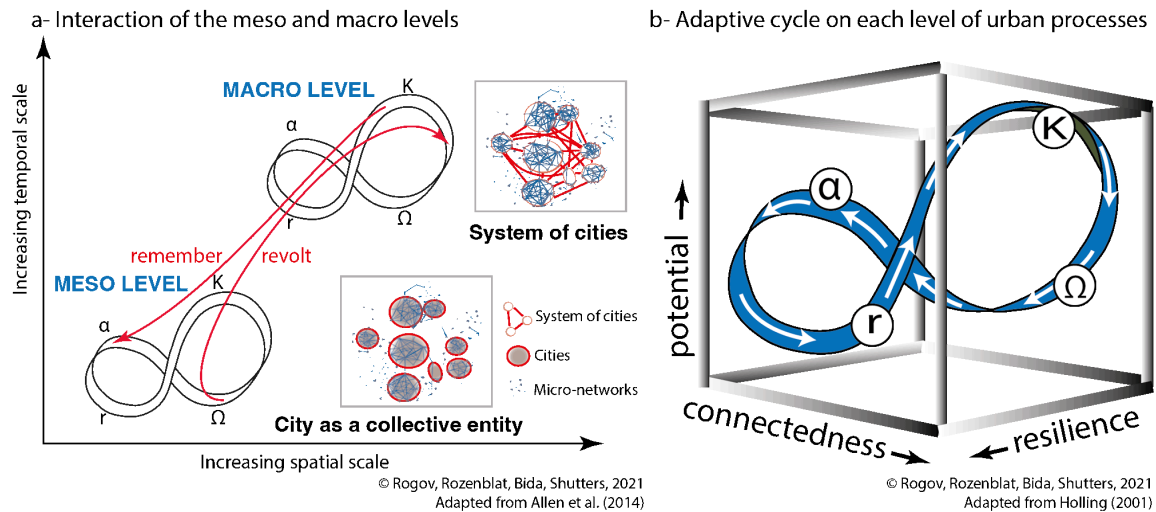
(a) Meso level: local economic specification

The meso level of a city corresponds to different delineations depending on the criteria, methods, and interests of those making the delineations (Parr 2007, Batty 2018, Rozenblat 2020). For instance, if one's interest is in the architecture of technical, water, or gas networks, one should consider the built-up areas of an urban area. On the other hand, if one's interest is in urban policies, one should consider localities or the perimeters of authority of urban councils. Despite ongoing debates on "planetary urbanization" and a definition of the footprint of cities (Harrison and Hoyler 2018), the growth of cities is generally defined as the expansion of urban agglomerations where people live, work, move, interact, and participate to common goals. Following Storper and Scott (2016), we agree that "cities are everywhere characterized by agglomeration involving the gravitational pull of people, economic activities and other related into interlocking, high-density, nodal blocks of land use" (p. 1116). Although this definition corresponds to the functional area around a city-core, encompassing most of a city's assets, we argue that meso level resilience alone is not enough to capture the properties of urban economic resilience. It rather must be contextualized in the changing landscape of the macro level of cities, thus necessitating a multilevel perspective.

(b) Macro level: cities' global connectedness

All cities of the world, being directly or indirectly linked with each other (Rozenblat 2018), are constantly in relations of exchange and competition for resources, thus forming a global network of cities. The evolution of an individual city's position in this network is always relative to other cities of the same network. As a city integrates into global and national inter-city networks its position influences its urban properties through competition for socio-spatial influence and a dependence of economic specialization in the interurban division of labor (Pumain 2006). Within these global networks, national urban systems typically create natural clusters because cities of the same country tend to interact more with each other than with foreign cities (Rozenblat 2018). National cities' systems create hierarchies in which some attributes of cities are a function of city size. Thus, cities do not always grow or decline randomly, following the Gibrat's law (1957), but some "discrete sizes" emerge (Garmestani et al. 2007, 2009) representing "available scales of opportunities" in some specific cities' system contexts. In addition, the activities in which a city specializes determines its specific position in an international division of labor. A lack of economic renewal due to small city size or over-specialization in obsolete activities often results in low global attractiveness and ultimately to a shrinking city (Martinez-Fernandez et al. 2012, Herrmann et al. 2016). Thus, we argue that the evolution of the entire city system as well as the evolution of individual cities' positions in this system under

Fig. 1. Cities in a panarchy perspective.



the crisis, could be illustrated in an adaptive resilience approach, revealing the transformation of individual cities in an evolving system of cities landscape. Although the importance of advancing knowledge of urban resilience in a multilevel perspective is recognized, empirical research using these two levels to examine urban resilience remains poorly developed (Pumain 2006, Rogov and Rozenblat 2018, West 2018, Bettencourt 2021).

COEVOLUTION OF MACRO AND MESO LEVELS THROUGH THE PANARCHY PERSPECTIVE

Searching for the conceptual framework to address multilevel interactions of cities, we believe the panarchy perspective deserves particular attention. After bringing the concept of resilience into scientific discourse in 1973, 30 years later Holling (2001) added the panarchy framework describing resilience as a set of evolving properties related to the interactions between fast and slow multilevel processes.

The panarchy framework

The panarchy framework has received considerable attention from ecologists (Allen et al. 2014), as well as from economists and economic geographers (e.g., Simmie and Martin 2010). More importantly, it has been used to advance understanding of resilience in cities' systems (e.g., Bures and Kanapaux 2011, Shutters et al. 2015, De Balanzó and Rodríguez-Planas 2018). Though the panarchy framework may be highly suggestive, its value rests in "its ability to suggest new hypotheses about regional economic resilience that can be tested by empirical case studies" (Simmie and Martin 2010:35). Indeed, the metaphor of the adaptive cycle, which is fundamental to the panarchy perspective, has generated new thinking on the dynamics of urban and regional development during a crisis (Gotts 2007, Simmie and Martin 2010, Shutters et al. 2015, van Aswegen et al. 2020). The adaptive cycle is defined as a trajectory through different stages (Fig. 1b). R is a brief initial stage of the cycle consisting of rapid exploitation of resources. The following K stage is of a longer duration and consists of an accumulation of capital and rigidity in the system, inducing an increased risk of system collapse. The release stage (ω) is a rapid phase following a collapse in which the

reserves accumulated during the conservation phase are unleashed (i.e., "creative destruction"). This is followed by a reorganization phase (α), a relatively rapid period of reassembly of the system during which opportunities for novel recombinations arise.

However, multilevel interactions of slow and large, and small and fast adaptive cycles remain a black box despite the numerous attempts to define scale mismatches (Lee 1993, Cumming et al. 2006). For the current research, this framework sheds light on two particular processes:

(a) Time scale and space scales

The processes unfolding on the macro level (system of cities or "fitness landscape") should take place on longer time scales and encompass larger geographical areas (international and transnational), whereas the meso level processes are localized within individual cities and are expected to be quicker and more reactive to disturbances. However, in the case of the Russian crisis, the shock comes from the macro level and thus is quite quick. We can wonder on the speed of the reactivity of the meso level (individual cities), and thus in this case the temporalities between the two levels could be inverted.

(b) Multilevel interactions

Conceptualizing processes at each level as occurring within adaptive cycles, panarchy describes the interactions between adaptive cycles of different hierarchical levels: when systems at one hierarchical level experience a shock or a resistance (large and slow macro cycles), lower level systems (faster and smaller micro or meso cycles) are subject to collapse or are otherwise affected, and their tightness and bound resources are released.

Evaluating resilience through potential and connectedness

Once levels of organization are defined, the question arises of how to operationalize and measure resilience within their respective adaptive cycles. Holling (2001) suggested an adaptive cycle as a system's trajectory in three dimensions: potential, connectedness, and resilience (Fig. 1b). Thus, Holling (2001) made resilience dependent on high potential and low

connectedness: “The conditions that occasionally foster novelty and experiment occur during periods in the back loop of the cycle, when connectedness, or controllability, is low and resilience is high (that is, during the α phase)” (p. 395). In the α phase of reorganization, low connectedness allows unexpected combinations of innovations that can generate new opportunities. As a system moves toward K, the conservation phase of the cycle, resilience decreases while connectedness increases. To determine resilience at each level, we first evaluate connectedness and potential, as resilience depends on these two dimensions.

Our evaluation of potential must capture an essential controlling factor of the dynamics of an urban adaptive cycle. Potential “can be thought of, loosely, as the “wealth” of a system” and it “sets limits for what is possible, it determines the number of alternative options for the future” (Holling 2001:394). Holling further specifies that “for an economic or social system, the accumulating potential could as well derive from the skills, networks of human relationships, and mutual trust that are developed incrementally and integrated during the progression from r to K. They also represent a potential that was developed and used in one setting but could be available in transformed ones” (Holling 2001:394).

In the context of cities, “agglomeration economies” create such accumulation by strong local interactions between enterprises, workers, consumers, governments, and shared infrastructures. Agglomeration economies typically comprise three main processes (Ohlin 1933, Hoover 1937, 1948, Camagni 1996):

1. Economies of scale at the firm level, exhibiting mass production for large markets, which leads to lower prices (Krugman 1993);
2. Localization economies, exhibiting concentration in specific industry sectors, which leads to high productivity;
3. Urbanization economies, exhibiting shared infrastructure and services because of city size and density, which benefits all sectors (e.g., airports, high level services, etc.).

Of these, the localization economy is the preferred viewpoint from which to evaluate potential because it displays high productivity of labor in industries that are concentrated in a city or region. Localization economies reflect the process of specialization in local economies, also called Marshall-Arrow-Romer externalities (Glaeser et al. 1992). The high productivity arising from specialization generates a high potential of wealth creation that accumulates and creates a positive feed-back loop of development, which is at the root of urban economies (Marshall 1919). Each specialized local system contributes to the spatial division of labor at the national or global scale, complementing or competing with other localities. These specializations result in accumulated local wealth and often create strong path dependencies as human (or sometimes natural) resource exploitation is already organized in strong social, economic, and financial systems, which further attracts firms seeking to benefit from these advantages. The archetype exhibiting these specialization processes is a city like Detroit, where many large firms in the auto manufacturing industry are present. On the other hand, the over-specialization of Detroit is also a weakness, as global change in the auto industry and the lock-in of Detroit’s economic system led to its bankruptcy. Yet, this is only part of the story because many other firms moved to this Renaissance

region and the Detroit metropolitan area continues to grow and flourish today beyond the downtown, and thus Detroit is still accumulating new innovations in the auto industry.

Following portfolio theory (Montgomery 1994), a variety of independent sectors reduces economic risk because it “implies that a negative shock in demand for any of these sectors will only have mild negative effects on growth and employment” (Frenken et al. 2007:686). In urbanization economies, the variety of sectors present in a city could be considered as an advantage per se, particularly when the industry sectors are related, permitting spillovers between sectors (Jacobs 1969). A certain level of economic relatedness could facilitate radical innovation by the recombination of knowledge and technologies from the related sectors, enabling the system to evolve and adapt to new external conditions. However, high levels of relatedness (or “connectedness”) might also facilitate a cascading failure between sectors, implying to lower resilience.

Jaffe (1986) initiated the use of the relatedness concept for technology fields to build “technologic spaces” using the correlation between patents of firms. The concept of related variety of economies was first applied at the global scale among countries by Hidalgo et al. (2007) and at the regional scale in the Netherlands by Frenken et al. (2007). The latter demonstrated that related variety had positive effects on the maintenance and growth of regional employment.

The evolution of specialization or connectedness of urban economies serves as an important indicator of economic resilience of cities (Frenken et al. 2007, Content and Frenken 2016, Farinha et al. 2019). Specialization is complementary to the interdependence (“relatedness” or “connectedness”) of labor occupations present in a city’s economy, which has been used to assess urban resilience (Shutters et al. 2015). Among numerous proposed measures of relatedness (see de Groot et al. [2015] for a complete review), Shutters et al. (2015) proposed “tightness” as “the degree of connectedness, integration or interdependence of the components of a system” (p. 2). The conceptualization of tightness builds on the thinking of Janssen et al. (2006), who suggested that the key to operationalizing the Panarchy notion of connectedness is through defining systems as networks of interacting system components. Representing systems as complex networks of connectivity makes them amenable to a suite of quantitative methods, including measures of connectivity among its internal components. Thus, this tightness measure is based on the network of interacting economic specializations present in a city and how strongly these specializations are related.

In summary, we may estimate potential using a specialization index and connectedness using a tightness index. Doing so allows us to test to what extent the combination of specialization and tightness facilitates the resilience of cities against shocks such as the 2014–2016 economic crisis experienced by Russian cities. These measures may be combined at the meso level of economic organization using the aggregate employment of cities, and at the macro level of cities using the industry sectors of global firms present in a city. A shock would then be evaluated at the meso level through changes in employment rates and at the macro level through changes in the total number of establishments of global firms.

These observations have been previously treated separately at the macro level in the evolutionary theory of systems of cities developed by Pumain (2006), and at the meso level in Shutters et al. (2018) and in the evolutionary economic geography frameworks used by Frenken et al. (2007), Boschma and Martin (2010), and Farinha et al. (2019). By integrating the two properties of specialization and interdependence of cities' economic activities at the meso and macro levels, we may assess and better understand their roles within the panarchy approach.

QUESTIONING THE MUTUAL INFLUENCES BETWEEN THE TWO LEVELS

To better understand resilience we assess whether the economic crisis of 2014–2016 in Russia resulted in different impacts on individual economies of Russian cities (meso level) versus their global specialization in international economic networks (macro level). Although linkages between cities within Russia declined more than linkages between Russian cities and international cities from 2010 to 2019 (Rogov and Rozenblat 2022), local businesses were additionally affected during the economic crisis of 2014–2016 by a dramatic decrease in the purchasing power of consumers.

H1: Given these simultaneous effects, we expect that positions of Russian cities in global economic networks (macro level) were more sensitive to international sanctions of 2014, and that this will manifest as a larger change in cities' activity spaces than in cities' specific sectors (meso level).

Using the proxies of connectedness and potential at both levels, we analyze the similarity between the meso and macro level trajectories of relatedness and specialization. We expect that multinational firms in a sector in which a city is specialized will tend to remain in that city, unlike firms in non-specialized sectors.

H2.1: Following H1, we expect that, at the macro level, the specialization of Russian cities increased, while at the meso level, local firms remained to meet reduced market demand, and thus, specialization of cities at the meso level changed little.

Concerning tightness, cities with lower tightness have both higher resilience and higher economic performance following a shock (Shutters et al. 2015). Because most Russian cities lost multinational firms between 2014 and 2016 and declined in terms of economic output (Zubarevich 2019), we expect that during the crisis, economic activities that disappeared in a city were less related to the main specialization of the city (Farinha et al. 2019).

H2.2: Thus, we expect that city tightness increased both at meso and macro levels, and then decreased after 2016 to better adapt to the new general economic situation.

Furthermore, we seek to understand similarities in the positions of Russian cities within the adaptive cycles of the macro and meso levels.

H3: We expect that during the crisis of 2014–2016 most Russian cities were in the adaptive cycle's K-phase (conservation) characterized by high tightness and specialization, and that after the crisis in 2019 cities had generally moved to the ω -phase (release).

The principal question of this paper concerns mutual effects between macro and meso level dynamics on their respective

performance. To understand this, we measure the correlation of employment growth (meso level) and growth in the presence of global firms (macro level) with the indices of specialization and tightness of the other level at the starting date for three periods of time between 2010 and 2019.

H4.1: We expect that growth at the two levels is negatively correlated with tightness/specialization of the other level during the economic crisis, especially for growth at the macro level, and,

H4.2: we expect they are positively correlated after 2016, by which time the most turbulent period of the crisis had passed.

DATA AND METHODS

Data

Data were collected on the macro and meso levels using the delineations of Russian large urban regions (LUR). An LUR is defined as a large functional urban area around a core city that typically includes several local administrative units surrounding the city (Rogov and Rozenblat 2020). In total we delineated 120 Russian LURs. For macro level data we used the ORBIS database from Bureau van Dijk (for 2010, 2013, 2016, 2019) on direct and indirect subsidiaries of the world's 3000 largest firms based on annual revenues. For Russia this represents approximately 40,000 establishments in 2010 and 37,200 in 2019, around 85% of which are located within Russia's LURs. For the meso level we used data on economically active population by economic activities and total population provided by the Russian Federal State Statistics Service (Rosstat 2010a, b, 2013a, b, 2016a, b, 2019a, b). Section 1 of Appendix 1 presents a detailed description of the data collected on the macro and meso levels, LUR delineations, as well as the harmonized nomenclature of economic activities for meso and macro levels in 15 industry sectors.

Methods

We discuss here the choice of indices we use to quantify the specialization and tightness of cities. We use the Chi^2 index to compute the specialization of cities and adapt the method of Muneeppeerakul et al. (2013) to compute their tightness.

Economic specialization of cities as a proxy for potential

The economic specialization of a city reflects the extent to which a city's economic activity is dominated by one or a few activities. Several measures have been used in the literature to quantify the degree of economic specialization of a city. Among the most commonly used are the Hirschman-Herfindahl index (Henderson 1997), the Isard index (Isard 1966) and the Chi^2 index. The Hirschman-Herfindahl index has a minimum value when all activities have the same importance in the city and maximum when only one activity is present in the city. Of course, economic activities are expected to differ in sizes because of variations in market structure, consumer preferences, productivities, etc. The two other indices better address the differences between activities' importance in a space of reference (generally the mean of all cities of a country or a region). Thus, the specialization index is high when some activities are over-represented in a city in comparison to the average of the set of cities to which it belongs. In choosing between the Isard index and the Chi^2 index, we favor the latter because it mitigates the influence of large size activities and the influence of large cities. By noting C the set of all cities in a system, and A the set of all economic activities, the specialization of a city c is:

$$SPEC_c = \left[\sum_{a \in A} \frac{S_{*,*}}{S_{*,a}} \left(\frac{S_{c,a}}{S_{c,*}} - \frac{S_{*,a}}{S_{*,*}} \right)^2 \right]^{\frac{1}{2}} \quad (1)$$

where

$$\begin{aligned} S_{c,*} &= \sum_{a \in A} S_{c,a} \\ S_{*,a} &= \sum_{c \in C} S_{c,a} \\ S_{*,*} &= \sum_{c \in C} \sum_{a \in A} S_{c,a} \end{aligned} \quad (2)$$

Here, $S_{c,a}$ denotes the size of activity a in city c . At the meso level, $S_{c,a}$ is measured as the share of population employed in activity a in city c , whereas at the meso level it is measured as the number of establishments engaged in activity a in city c (see Appendix 1.1 for exact definition).

A high value of economic specialization of a city (relative to other cities) implies a higher potential to resist economic crises. However, if the magnitude of specialization is too high, this potential can diminish a city's resilience properties because the city lacks diversity that might mitigate the failure of its specialized activities.

Economic tightness of cities as a proxy for connectedness

The tightness of a city (Shutters et al. 2015) and the analogous cohesion indices (e.g., Frenken et al. 2007, Essletzbichler 2015, Rigby 2015) quantify the degree to which the economic activities of a city or region are interdependent. The aspect of interdependence captured by tightness depends on what aspect of independence is considered: input-output interdependence (Essletzbichler 2015), the dependence on similar knowledge base (Rigby 2015), the dependence on similar set of skills (Farinha et al. 2019), etc. We choose here a typical indirect approach of measuring the interdependence between two economic activities as the extent to which they are co-located in the same place (Russian LURs). Behind this choice is the idea that two activities benefiting from local knowledge exchanges (Carlino and Kerr 2015), sharing resources or input-output connections (Ellison et al. 2010), or having the potential of developing local synergies (Farinha et al. 2019) are more likely to be found in geographical proximity to each other.

Interdependence between activities for the whole system of cities

Several indices have been developed to capture the intensity of interdependence, or proximity, between activities. The cosine index is an example of a widely used index for this purpose (Jaffe 1986, Yan and Luo 2017). Using the same notation as in Equation 1, the cosine index of two of activities a and b is measured as:

$$COS_{a,b} = \frac{\sum_{c \in C} S_{c,a} S_{c,b}}{\sqrt{\left(\sum_{c \in C} S_{c,a}^2 \right) \left(\sum_{c \in C} S_{c,b}^2 \right)}} \in [0, 1] \quad (3)$$

In the context of this study, the cosine index has the disadvantage of being independent from the economic landscape. Indeed, the proximity between two activities will always be maximal if their

shares in cities are perfect covariates. This property is undesirable because it implies that even similarly spread local services that are not specializations of the city will have a strong proximity without necessarily being strongly interdependent. For example, using our data, we find the proximity of the economic activities "Health and Social Services" and "Arts, Recreation and Other" at the meso level to be above 0.95 for all the considered years when measured by the cosine index. Given that both activities are essential services, they are ubiquitous, and their copresence in cities is not unexpected. Therefore, the high value of the index does not indicate any mutual economic interdependence between the two activities.

More recently, measures of interdependence based on the location quotient (or the equivalent revealed comparative advantage) have been proposed (Hidalgo et al. 2007, Muneepeerakul et al. 2013, Petralia et al. 2017). Specifically, a measure of interdependence proposed by Muneepeerakul et al. (2013) was used to study the economic trajectory of cities. The location quotient (LQ)

$$LQ_{c,a} = (S_{c,a}/S_{c,*}) / (S_{*,a}/S_{*,*}) \quad (4)$$

is the share of an activity in a city divided by the share of the same activity in the reference space. Given the location quotient, interdependence is calculated as:

$$\xi_{a,b} = \frac{P(LQ_a > 1, LQ_b > 1)}{P(LQ_a > 1)P(LQ_b > 1)} - 1 \quad (5)$$

Thus, interdependence measures the extent to which two activities are over-represented in the same cities with respect to this happening randomly if the two activities were independent. Because of its structure, interdependence has three undesired properties:

1. It is not normalized: its maximum value depends on the size of the considered activities. This can be seen by considering the limiting case of the interdependence of an activity with itself, or equivalently, the interdependence of two activities for which the exact same cities have a LQ above 1. In this case, we have

$$\xi_{a,b} = P(LQ_a > 1)^{-1} - 1 = P(LQ_b > 1)^{-1} - 1 \quad (6)$$

which depends on the size of the set of cities specialized in both activities. Because it is not normalized, this interdependence measure penalizes activities for which location quotient is higher than 1 in a larger number of cities.

2. It can be negative, leading to potentially ambiguous values of interdependence. Indeed, an interdependence value close to 0 can result when a city hosts only unrelated activities or when simultaneously hosting positively and negatively interdependent activities. This is particularly problematic because negative values of interdependence can be difficult to interpret. For example, we found that the activity "Human Health and Social Work" was negatively interdependent with the activities "Real Estate" and "Construction." In this case, we could find no clear economic argument that would explain the spatial incongruity of these activities.

3. Third, the index suffers from a resolution problem, in the sense that if the set of cities C_a having LQ above 1 for activity a is a subset of the set of cities C_b having LQ above 1 for activity b , then

$$\xi_{a,b} = P(C_b)^{-1} - 1 \quad (7)$$

is independent of the size of a . This is problematic because we expect this index to grow with the number of cities that are specialized in both activities under reasonably general conditions.

Therefore, we propose a new measure π , based on the same idea of interdependence, but that does not have the three previous inconveniences, i.e., the new measure is independent from the activity size, it is non-negative, and it does not have the resolution problem:

$$\pi_{a,b} = \max \left(\frac{P(LQ_a > 1, LQ_b > 1) - P(LQ_a > 1)P(LQ_b > 1)}{\sqrt{P(LQ_a > 1)(1 - P(LQ_b > 1))P(LQ_b > 1)(1 - P(LQ_a > 1))}}, 0 \right) \quad (8)$$

The measure can be viewed as interdependence with a different normalization that addresses the issues 1 and 2 while having a minimum at 0 to avoid negative values that could cancel out some positive ones.

Tightness of cities' activities

Given this modified measure of interdependence π between activities, tightness is used to quantify the extent to which cities host activities that are interdependent. We use here the measure proposed by Shutters et al. (2015):

$$T_c = \frac{1}{n_c(n_c - 1)} \sum_{a \in A} \sum_{b \in A \setminus \{a\}} \frac{(S_{c,a} + S_{c,b})\pi_{a,b}}{2S_{c,*}} \quad (9)$$

where n_c is the number of activities present in city c , and A the set of all the considered activities in the economy. The tightness of a city is thus the average of the proximities of the activities present in a city weighted by the sum of their sizes. The measure is analogous to the Los index (Los 2000, Frenken et al. 2007), which is a weighted average of the proximities over all pairs of activities where each pair of activity is weighted by the product of the sizes of the activities forming each pair in the city c .

Thus, the high tightness values of some cities will reveal the high connectedness of their activities compared to the average in the cities' system. This implies a quite low faculty of adaptability to a crisis because this higher connectedness between activities prevents their rapid reconfiguration. It could also lead to cascading failures between activities, as seen in London during the 2008 crisis, where banks, finance, and all related services failed in rapid succession.

EVOLUTION OF RUSSIAN CITIES' MACRO AND MESO STRUCTURES

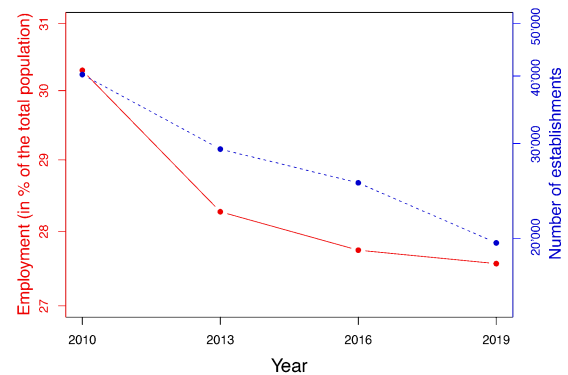
To test our hypotheses, we first explored the effect of the 2014–2016 crisis on the evolution of tightness and specialization of Russian cities during the 2010–2019 period. We then positioned cities within the adaptive cycle according to their values of tightness and specialization, and we applied panarchy theory by contrasting the theoretical resilience of a city to its empirical counterpart.

Evolution of employment rates and number of multinational firms' establishments of Russian cities

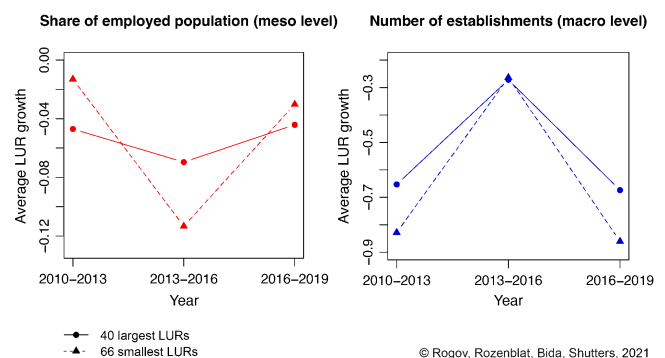
The general context is a shrinkage of economic activities: Both the level of employment (EMP at the meso level) and the number of establishments of multinational firms (MNF at the macro level) continuously decreased in Russian cities during the entire period 2010–2019. However, we must consider this decrease of EMP in the context of overall population shrinkage that was experienced by most Russian cities during the same period. Thus, we measure the decrease of the share of EMP in the total population (S-EMP; Fig. 2).

Fig. 2. Evolution of employment and multinational firms in Russian large urban regions (2010–2019).

a. Evolution of employment (% total population) (S-EMP) and the multinational firms' establishments (MNF) of Russian cities (2010–2019)



b. Average growth of the employment (S-EMP) and multinational firms (MNF) in the whole Russian LURs (2010–2019)



© Rogov, Rozenblat, Bida, Shutters, 2021
Source Macro: Orbis Bvd 2010, 2013, 2016, 2019, UNIL 2021
Source Meso: Rostat 2010, 2013, 2016, 2019, Rogov, 2021

As Figure 2 illustrates, S-EMP decreased continuously throughout the whole period, while MNF decreased less in the early part of the period but more quickly after 2016.

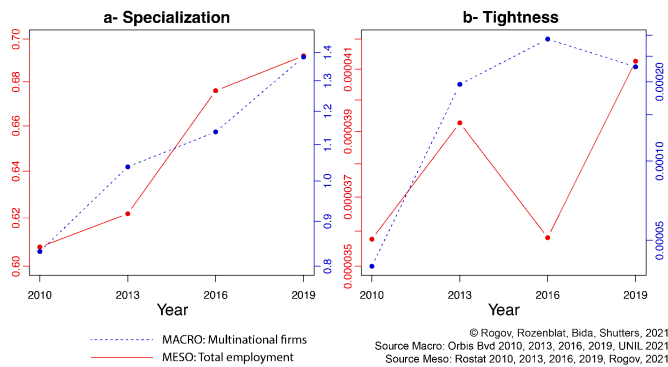
Evolution of mean specialization and tightness of Russian cities

The mean specialization and tightness values of all Russian cities over time indicate how generally the activities' proximities of the two levels evolved (Fig. 3).

For specialization of cities, while both levels' indices increased during the whole period, the crisis period 2013–2016 accelerated the growth of S-EMP (meso) specialization, but inhibited the

growth of MNF (macro) specialization. Furthermore, tightness indices for the two levels exhibited very different trajectories. For the macro level, mean tightness grew until 2016 and then decreased in the final period. On the other hand, mean tightness of S-EMP (meso) increased in the first period, fell between 2013 and 2016, and then increased again after 2016. This partially confirms Hypothesis 1 with the two levels exhibiting quite different evolutionary trajectories. These differences are further elaborated below.

Fig. 3. Evolution of Russian cities' specialization and tightness from 2010 to 2019 for the macro and the meso levels.



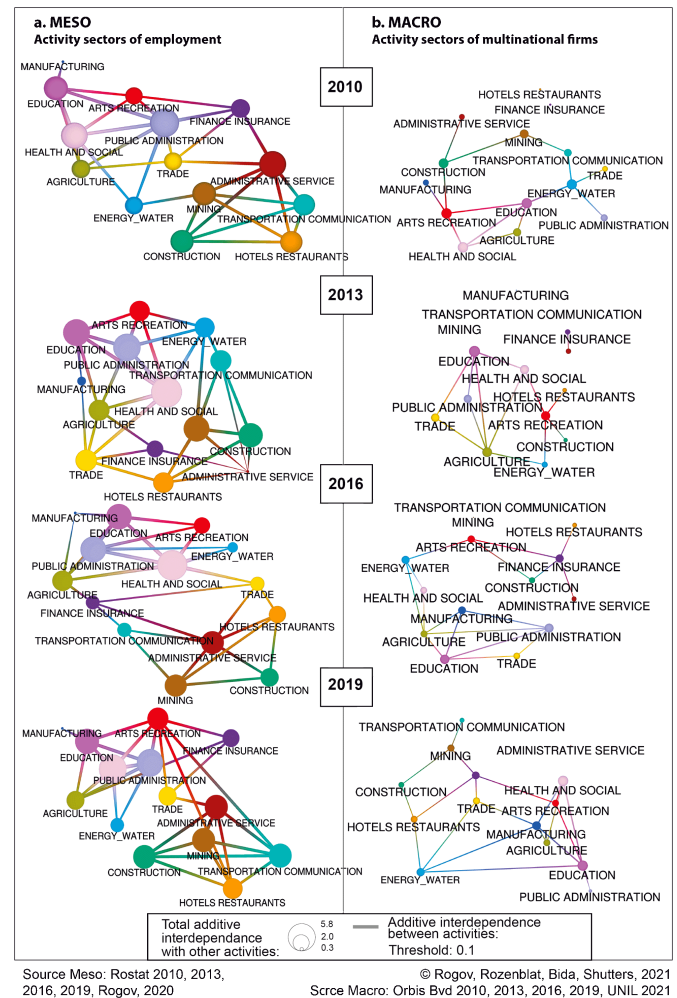
The continuous decrease of the share of S-EMP and MNF between 2010 and 2019 corresponded with an increasing specialization of cities, suggesting a conservation of the specialized complexes that were more and more related until 2016, after which their relatedness decreased. This confirms Hypothesis 2.1, revealing that along the adaptive cycle of the macro level, Russian cities are in a stage between exploitation and conservation and are exhibiting consolidation of their resources. For S-EMP at the meso level, the increasing specialization of cities accompanied by the drop in employment during the crisis, reveals a substantial reorganization of sectoral employment. The meso level evolution of mean tightness is more difficult to interpret in terms of panarchy theory. The decrease of mean tightness during the 2014–2016 crisis appears to have lessened the interdependencies between activities allowing cities to better adapt their economic structures. This contradicts Hypothesis 2.2 because, rather than leading cities to concentrate on their specializations, the crisis seems to have had the effect of disentangling economic activities.

Evolving spaces of activities

To analyze these evolving levels more deeply, we constructed networks (or spaces) of activities for the years 2010, 2013, 2016, and 2019 using NACE 15 (the European taxonomy of economic activities) categories for both EMP (meso level; Fig. 4a) and for MNF (macro level; Fig. 4b). A link between two economic activities means that they are often specializations of the same city. Activities not linked with any other above the threshold link index are isolated.

We find the proximities π are generally much higher at the meso level than at the macro level (explaining the size difference of the nodes representation). The evolution of the activity space for EMP (meso level) shows considerable reorganization in the

Fig. 4. Spaces of activities for the Russian cities' macro and the meso levels (2010–2019).



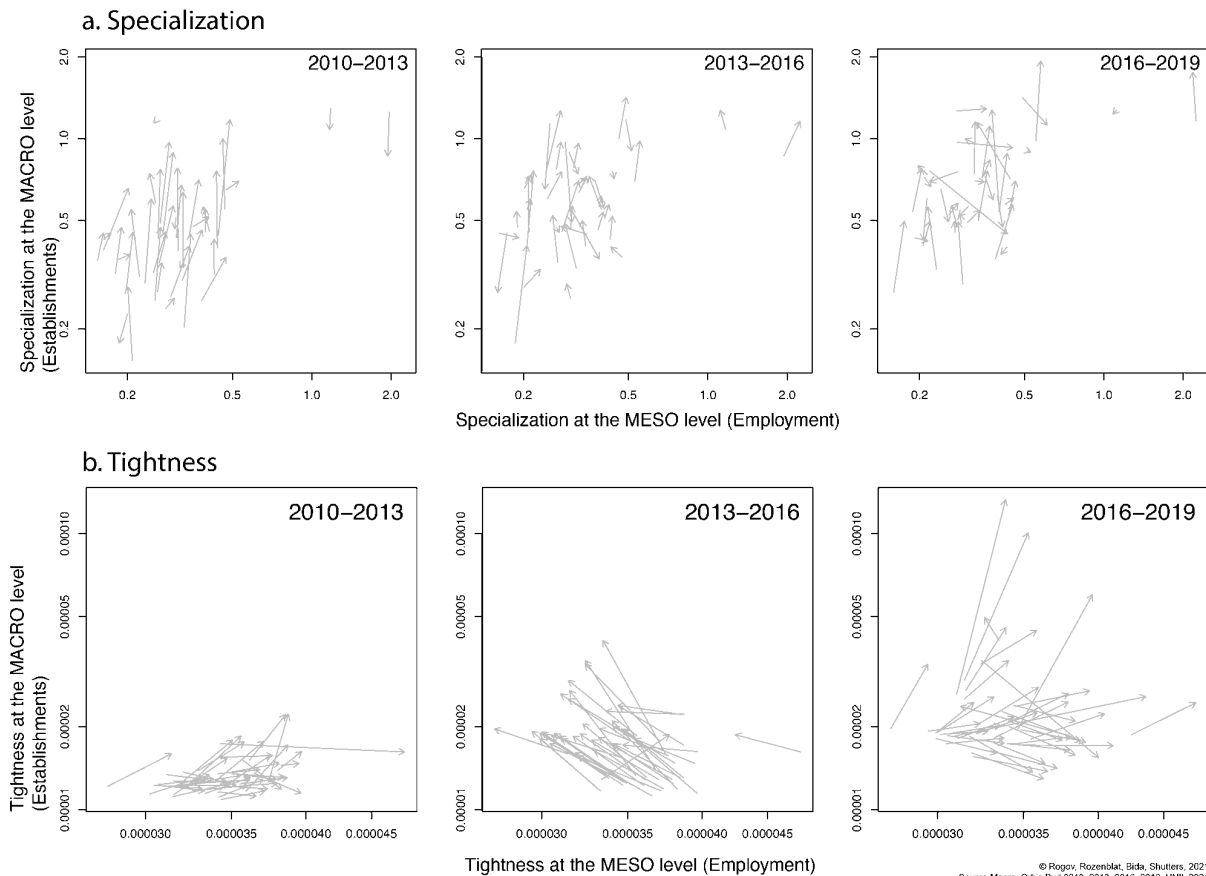
periods 2013 and 2016, returning in 2019 to a configuration quite similar to the one in 2010. By contrast, the evolution of the activity space for MNF reveals a gradual reorganization of proximities between activities during the period and includes progressively more and more activities.

Thus, assuming that activity space of the macro level changed to a larger extent than activity space at the meso level, Hypothesis 1 is confirmed. Furthermore, we observe a qualitative transformation: the meso level returned to its initial state while the macro level transformed to a qualitatively different system.

TRAJECTORIES OF RUSSIAN CITIES FOR 2010–2019 BASED ON SPECIALIZATION AND TIGHTNESS AT THE MESO AND THE MACRO LEVELS

We take transformations of Russian cities, at both the meso and macro levels, to be the combined product of changes in specialization and tightness.

Fig. 5. Trajectories of the 40 largest Russian cities (large urban regions) in 2019 according to their specialization and tightness at the meso and macro levels (2010–2019).



Trajectories of specialization for individual cities at meso and macro levels

We analyzed these factors separately, period by period to better understand the underlying dynamics of these transformations. We examined in more detail the trajectories of the 40 largest LURs in 2019 in terms of employment. These LURs include more than 80% of total employment and more than 86% of total establishments among LURs in 2019.

Decomposing specialization trajectories into smaller time periods, we found a consistent relationship between specialization at the two levels (Fig. 5a). Although macro specialization increases in most cities for MNF between 2010 and 2013, subsequent periods are characterized by a less definite common direction, suggesting a negative effect of the 2014–2016 crisis on macro specialization of cities (MNF), which lasted until 2019. The trajectories of meso specialization (EMP) appear rather static during the entire period. The difference in evolution of specialization at the two levels suggests that international firms might have been acquired by domestic actors, preserving the structure of employment but not the international connections of firms. Thus, Hypothesis 2.1 is again partially supported as some cities became more specialized during and after the crisis of 2014–2016 on the macro level, while specialization at the meso level was much less affected.

Trajectories of tightness for individual cities at meso and macro levels

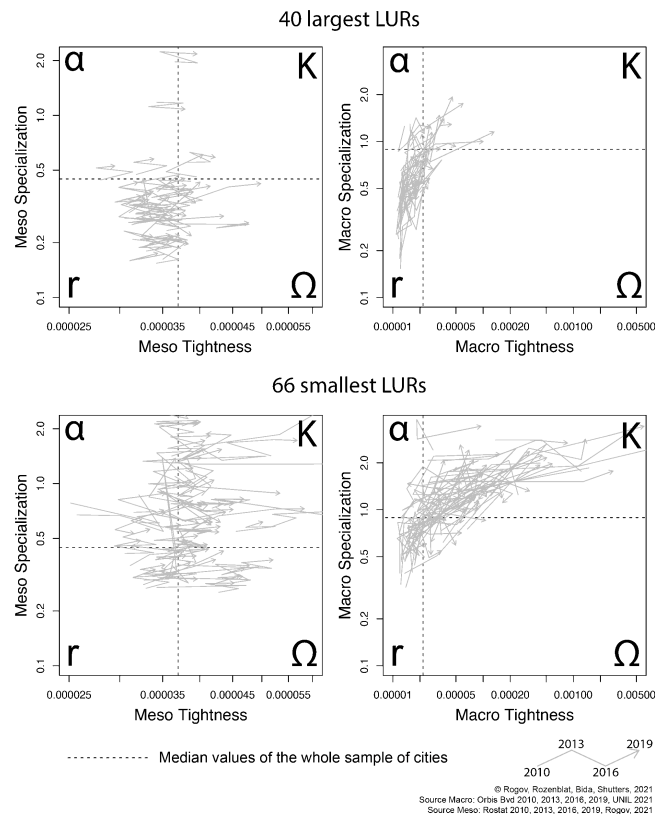
Decomposition of trajectories for tightness at the two levels reveals two effects associated with the 2014–2016 crisis, depending on the level at which we observe the economy (Fig. 5b). The most obvious effect at the meso level is a reversal of the trend of cities' tightness during the 2013–2016 period. Trajectories display a clear decrease in contrast to the remaining periods during which tightness increases for almost all 40 cities examined. Thus, Hypothesis 2.2 is contradicted noticeably at the meso level where tightness decreased during the crisis (period of 2013–2016). Because cities with lower tightness have higher resilience (Shutters et al. 2015), we can conclude that during the crisis, Russian cities demonstrated increased resilience capacities particularly at the meso level.

The second observed effect is a coordination of tightness trajectories at the macro level. A smaller variation and increasing value are observed in the trajectories of cities during 2013–2016, in contrast to the other periods. At this macro level, the reaction to the economic shock was opposite of that at the meso level, and this continuous reinforcement of activities' structure of MNF in cities confirms Hypothesis 2.2 specifically during the crisis period 2013–2016.

Cities' stages in the adaptive cycle

The trajectories of cities within the two dimensions of specialization and tightness indicate the way cities transformed their economic structures toward more or less resilience as the panarchy framework defines it (Fig. 6). In Fig. 6, we distinguished the 40 largest LURs based on total population from the 66 smallest LURs for better clarity. Dashed lines represent the median for each variable for the whole period. The bottom-left quadrant (r) represents a resilient stage defined by a low tightness (connectedness) and a low specialization (potential), corresponding to an exploitation stage. Thus, most of the cities spent the early periods in this stage, which can be largely explained by the 2008–2009 crisis that caused a reorganization of the Russian economy, positioning Russian cities in the r-phase of the adaptive cycle. The cities then shift to the right or top right (K) during the last period, meaning a re-consolidation of their activities' proximities and specialization leading to a conservation stage. Interestingly, the smallest cities transitioned much more quickly to the conservation stage than larger ones.

Fig. 6. Large urban regions' stage in the adaptive cycle (2010–2019).



The smallest cities are more specialized and have higher tightness. Many of these cities are mining cities situated in the Nordic part of the country and specialized in gas, petrol extraction, and mining of other natural resources. Economies of these cities are highly export-oriented and vulnerable to world prices of the goods they export. Thus, these cities were even more affected by the drop in petroleum prices in 2014, which likely moved them more quickly to stage K (conservation) or ω (release stage after a collapse).

For the meso level, two cities are on the top left of the graphic: the higher one is Surgut (see location in the Appendix 2), the “petroleum capital” of Siberia, and the other one is Novokuznetsk, also in Siberia, which is highly specialized in metallurgy.

For the macro level, cities shifting more rapidly to stage K (top right) and tending to have higher specialization, are Belgorod (specialized in nuclear equipment) and again Surgut. The two cities that shift most right to a high tightness are Cheboksary (specialized in mechanical engineering) and Smolensk (specialized in electronics and agriculture machinery).

The positioning of cities in the adaptive cycle indicates the resilience of cities in the Russian economy: the most resilient cities should be in the bottom left quadrant and should thus have their share of employed population and number of establishments experience a relatively smaller decrease during the crisis. Because the 40 largest cities correspond more closely to this position than the smallest cities, we compared the average growth for both groups of cities to verify whether the resilience-related predictions of panarchy theory are consistent (Fig. 2).

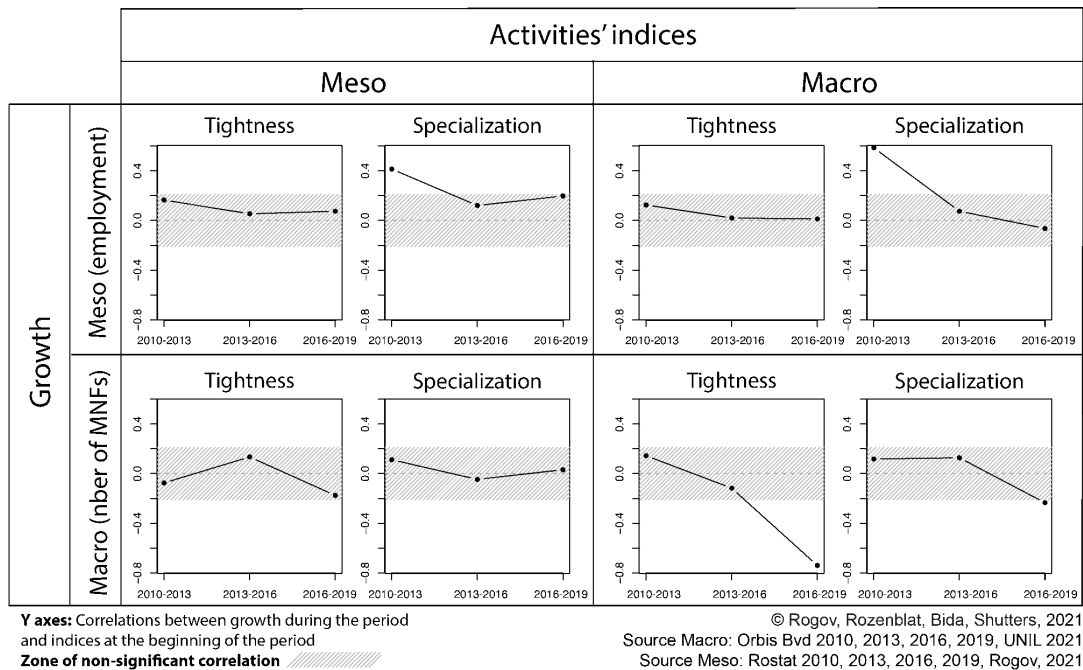
The meso level seemingly confirms predictions of panarchy theory, as the two groups of cities see their S-EMP growth flip during the crisis period, indicating that the 40 largest cities are more resilient during the crisis but with S-EMP decreases faster before and after the crisis. At the macro level, the decline in MNF is more complicated to interpret, as both growth groups saw their MNF decrease less during the crisis than before and after it. These intriguing trajectories are at odds with panarchy theory, first because we observe that the smallest cities constantly see their MNF decrease more than the largest cities, including during the periods before and after the crisis; and second, because the difference in the growth of MNF between the two groups is minimal during the crisis.

Being in a state of economic stagnation before the crisis of 2014–2016 began, we assumed in Hypothesis 3 that Russian cities would be positioned in stage K (conservation) and that the crisis would induce “creative disruption” moving cities to the ω stage and inducing a release of the system. However, results contradict H3, revealing that most cities, at both meso and macro levels, were in transition from the r stage (exploitation) to the K stage (conservation) after the crisis. However, some cities at the meso level moved directly from the r stage (exploitation) to the ω stage (release), which is somewhat inconsistent with the panarchy viewpoint.

INTERACTIONS BETWEEN THE MESO AND MACRO LEVELS

These radical changes in 2016 also manifest in the cross-effects between the meso and macro levels. Correlations were calculated between the growth of S-EMP compared to MNF between the years Y and Y-3, with the values of the indices at each level in year Y-3. Using this delay, which considers the structural indices at the beginning of the period and subsequent changes in employment and MNFs, we assume that lower values of tightness and specialization of the cities' activities are associated with less employment and MNFs losses (Fig. 7).

Fig. 7. Correlations of the Russian cities' meso and macro levels (2010–2019).



Most correlation values are not significant, especially between 2013 and 2016, and neither Hypothesis 4.1 nor 4.2 are confirmed. However, two key results appear from these correlations:

1. At the meso level: Before the crisis, the correlation is high with specialization at the meso and macro levels meaning that higher specialization supports the growth of employment (like a potential).
2. At the macro level: After the crisis, tightness is negatively correlated with the growth of multinational firms, meaning that higher tightness indicates a high level of conservation of resources (like accumulation of capital), which decreases the capacity for resilience. Future research should seek to determine if this is due to some lasting effects of the crisis.

DISCUSSION

Organizational levels and the crisis of 2014–2016

Results illuminate a key point of this study, which is that the meso and macro levels changed differently in response to the 2014 shock. The specialization and tightness trajectories of cities display different dynamics at both meso and macro levels before, during, and after the crisis. Results at the meso level are in line with Shatters et al. (2015) who found that U.S. meso level tightness decreased following the 2007–2009 global recession, before increasing afterward. Despite similar trajectories from 2010 to 2013, the shock of 2014 caused the meso and macro trajectories to be uncoupled at the city level.

By 2019 the structure of the meso level had largely returned to its 2010 structure, whereas the 2019 macro level structure changed considerably from 2010 (Fig. 4). Thus, one could speculate that the meso level was disturbed and returned to a previous state

(engineering resilience) while the macro level moved to a new state (ecological resilience). In such cases, the previous state of the meso level may no longer be well-adapted to the macro level state. However, policy makers may have intuitively pushed their cities to return to a prior state without being aware of broader changes at the macro level. This illustrates the difficulties faced by policy makers within a multilevel dynamic system.

Collectively, these results have important implications for policy makers that seek to manage the resilience of their cities. Managers simultaneously face different dynamics at multiple scales and levels, making it difficult to manage their systems for resilience. This study demonstrates a need to identify and consider multiple levels simultaneously as a single system and further implies that coordination between policy makers at the meso and macro levels may lead to improved policies and outcomes at both levels of decision making. However, by observing the behavior of these two levels, it is not easy to elaborate a “model” of interaction between the two levels. This is where the micro level (the level of individual and collective urban actors) intervenes, revealing how actors react and to what extent they can affect the dynamics at higher levels of organization. Incorporating this micro level would allow us to further make assumptions regarding the interactions between meso/macro levels in terms of possible mutual acceleration/inertia.

It is also important to understand that, while we have examined two levels of organization, other levels exist. For instance, macro levels are generally embedded in regional systems, such as international agreements, and in global systems, such as the World Trade Organization. Similarly, the meso level of cities is composed of interacting firms and individuals, which have their own dynamics, governance, and requirements for resilience. Thus,

future work should seek to understand the impacts of these other levels within a comprehensive framework of multilevel resilience.

City size and the crisis 2014–2016

This research reveals that the economies of the largest Russian cities remained more diversified than smaller cities during the crisis (or stated differently, they increased their economic specialization more slowly following the crisis), and they remained in the resilience stage of the adaptive cycle (Fig. 6). This supports the idea that diversification is a source of adaptive capacity, and a diverse regional economic structure often provides greater resistance to shocks than does a more specialized structure (Eraydin 2016, Wang and Wei 2021). However, it seems problematic to make a generalization regarding the relationship between high resilience and high diversification. As shown previously (Rogov and Rozenblat 2022), cities with highly specialized economies can also show much resistance to economic recessions if the industries in which they are specialized are not directly affected by the shock (for example, if it is not specialized in an industry with downward demand). Deeper analyses seem necessary to explain why some specialized centers resisted better than others in the context of their regional institutions and corporate and local economic attributes.

Policy making toward more sustainable urban economies in Russia

Differential impacts of the economic crisis of 2014–2016 on urban structures at the macro and meso levels requires specific policies aimed at enhancing urban resilience and sustainability of cities long term. The principal challenge to building resilient cities in Russia is the demographic shrinkage and increasing regional inequality that make the entire Russian economy more vulnerable to any economic shock. Another critical challenge is instability of Russia's foreign policy. This instability can create dramatic socioeconomic consequences for urban development inside Russia, inducing migration to larger cities and increasing interregional inequalities. It can also induce de-globalization of Russian cities, further disconnecting them from global markets.

In the framework of the Sustainable Development Goals concerning urban development (SDG 11), one of the key tasks of the Russian Federation is the mitigation and further elimination of disparities in socioeconomic development, quality of urban environment, and the level of human capital development in Russian cities. The principal document addressing this task is “the Strategy of spatial development of Russia until 2025,” adopted after the crisis in 2019, in which the government identifies the mentioned problems and proclaims that implementing an effective redistributive policy should be a national priority.

Although management of meso level urban economic structures depends largely on local and regional authorities, macro level processes are driven more by the federal government. Thus, a federal-level inter-regional redistributive policy should also focus on investments in human capital in poorer regions by increasing funding for healthcare and education. By improving quality of life and standards of living, these cities will be more attractive to multinational firms that, in turn, could contribute to the economic prosperity of these cities. Such a scenario is dependent on meaningful coordination between different levels of the Russian governance, including local, regional, and federal levels (Lebel et al. 2006, Ostrom 2010). This multilevel governance coordination

should lead the Russian urban system toward desired resilience and avoid lock-in by cities that are then unable to adapt both in the global system of cities and in their respective regional environments (Elmqvist et al. 2019). For example, several Russian cities are highly specialized in gas extraction, which cannot only be detrimental for their local ecosystems, but that can also lead to long-term economic failure. This example shows the limit of a purely economic approach to resilience that ignores other dimensions that appear on longer time scales.

Time scale of cities' resilience

Understanding time scale is essential to determining the processes that are important for managing the resilience of a city. Despite the quite short period of time we considered, we managed to show evidence of rapid transformations. Indeed, despite the fact that city systems' economies evolve quite slowly, the shock was felt so strongly by the whole Russian cities' system economy that both urban economic levels reacted immediately.

It also important to consider longer time scales because cities not only face economic crises but are also impacted by climate change. In addition, the repetition of different crises, like the recent Russian military invasion of Ukraine in February 2022, will have profound consequences in a long-term perspective on the development of Russian cities and its resilience capacities on both macro and meso levels. However, because of the unprecedented international sanctions on Russia, some changes, especially at the macro level, can already be observed. For example, closure of airspace for Russian planes in Europe and North America and closure of Russian airspace for Western air companies, caused a large change in logistics and a redistribution of supply flows. During the 2014–2016 crisis, multinational firms did not leave Russia, and in fact their number increased. In the ongoing crisis, many multinational companies have exited because of both strong public pressure and international sanctions. Almost 1000 multinationals from various industries have curtailed operations in Russia, including such large companies as Siemens, Deloitte, Shell, and many others that left the Russian market completely (<https://som.yale.edu/story/2022/over-1000-companies-have-curtailed-operations-russia-some-remain>). Thus, based on our study of the 2014–2016 crisis, we anticipate that Russia's macro level will be strongly affected by this shrinkage of companies. Depending on the relatedness of the exiting activities to others, this shrinkage could initiate cascading processes of failure of other co-located multinational companies at the macro level. Such cascades could also strongly affect the entire system of urban economies at the meso level.

At the meso level among the most affected cities are those that are specialized in automobile production such as Kaluga, Togliatti, Naberezhnye Chelny, and others. Because of international sanctions, plants that produce cars in Russia now lack production components and have largely halted all operations and manufacturing. On the other hand, sanctions of 2014 targeted the Russian military industrial complex and not manufacturing of private goods. Thus, the new sanctions of 2022 create an arguably new type of a shock for Russian industries and the cities where they are concentrated, and it will likely take years for cities to adapt to this new reality.

International sanctions will also affect service sectors. Since the start of the military invasion, many foreign firms either reduced their services to the Russian market or exited it completely. This

has reduced the number of jobs and increased unemployment, particularly in large cities that were previously less affected than the smaller ones. Perhaps the most symbolic departure from Russia was that of McDonald's, a large chain consisting of more than 750 restaurants and employing more than 60,000 people. Service activities are mostly present in large cities and constitute a large part of urban economies. Thus, following the departure of many international chains (for example, L'Occitane, OBI, Nike, and many others), this new crisis will strongly impact large cities because their services represent a substantial portion of their employment. However, to evaluate the resilience of Russian cities to this new crisis and to understand the transformation of their economies, more time and data is required, and the situation thus presents an excellent topic for future studies.

CONCLUSION

In this paper we present the first attempt, to our knowledge, to empirically examine the multilevel reaction of cities to external economic shocks. We introduce here, also for the first time, the global system of cities (macro level) as a crucial aspect of the economic trajectories of cities interacting with the local development of human resources (meso level of cities). This macro level is rarely introduced in urban comparisons largely because of the difficulty of gathering data. In many contexts of social-ecological systems, it would be worth reaching this global level because of the high dependence of many local systems to global economic and social environments.

The Russian case was chosen because the crisis that Russian cities faced between 2014 and 2016 offers an unparalleled opportunity to study a largely isolated national system of cities during an international shock. Our results revealed that, in several dimensions of performance and structural change, the impacts of the shock on Russian cities manifested quickly but differently at the meso and macro levels of organization. An important finding of our study is that the macro level was not a static landscape in which individual cities changed, but that the macro level also underwent significant structural change. A second important finding is that changes within cities (meso level) were quite different from the global (macro) level, meaning that localized impacts of the shock could not be attributed to just one level of organization but was a result of interactions between multiple levels. This implies that understanding and navigating shocks at the city (meso) level requires a more sophisticated, multilevel model of resilience, such as we have outlined in the study.

Finally, we believe that this study can strongly influence future work meant to inform policy makers that manage urban resilience. Further development of this type of multilevel approach to cities may help policy makers be better informed regarding the potential impact of their policies. Thus, a better coordination between local and national policy makers is likely to enhance desired outcomes for urban resilience.

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Data Availability:

The data/code that support the findings of this study are openly available in

- Russian Federal State Statistics Service: <https://rosstat.gov.ru/>

- Zenodo: <https://zenodo.org/record/3354436#.YcGWMhNBxpQ>

Ethical approval for this research study is not needed.

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Appendix 1

Homogenization of the different databases

1.1 Multilevel data on Russian cities

Macro level

To construct the global network of Russian cities we used the multinational firms' networks provided by the ORBIS database from Bureau van Dijk (for 2010, 2013, 2016, 2019) on the direct and indirect subsidiaries of the 3,000 largest firms of the world according to their turnover at each year. These four years were chosen to observe the evolution of Russian cities in these networks before, during and after the economic sanctions imposed on Russia that directly affected activity of international business. The deep analyses of this single macro level are presented in Rogov & Rozenblat (2021). The data is based on Bureau van Dijk individual firm's information of all the direct and indirect subsidiaries of the 3,000 largest corporations of the world according to their turnover at each date. The BvD-ORBIS-UNIL database includes all over the world about 700,000 firms in 2010 (900,000 ownership linkages), 1,4 million firms (2,4 million linkages) in 2019. For Russia it represents about 40,000 enterprises in 2010 and 37,200 in 2019 (respectively 46,000 and 21,600 ownership linkages). We only used the main establishments of enterprises here, because it is an information only available from 2016. The sample includes all the largest firms but also numerous small and medium size enterprises, as soon as they raised funds linking them to the global firms. By selecting the top ranked groups at each date, the advantage is to integrate the changes in the predominance of major firms in the world. The limit is that some firms are removed from the sample, but not disappear. However, this removal from the sample means the loss of competitiveness of the firms, decay that weakens the cities supporting these firms. Sometimes the groups are integrated in more powerful ones, thus remaining in the sample but in different networks.

Meso level

For the meso level, data on local active population by economic activities¹ and total local population provided by the Russian Federal State Statistics Service (Rosstat, 2019) were used. There is no better available data on economic activities at the municipal level that was used to build the comparable cities. The limit of the employment data (active population) is that it includes only "employees of organizations" (excluding small businesses with less than 15 employees). In total we estimated that it considers around 50% of the total employees, excluding independents and small business services. Despite the lack of its comprehensiveness, the available data is still a valuable source of information as we can consider that most of the economic base activities (opposed to non-tradable services) are included in this statistical sample.

Besides, as the Russian cities faced a general shrinkage of population (Batunova & Gunko, 2018), we removed this effect by considering the share of active population (with respect to the city total population) as the measure of the meso level city size, in order to, at least partially, compensate the changes in employment that are due to purely demographic factors.

1.2 Large Urban Regions (LURs) as a harmonized multilevel urban definition

Multinational firms from the ORBIS database are located within *Large Urban Regions* (LURs) delineated for Russian cities (Rogov, 2020) in a comparative way with other cities of the world (Rozenblat, 2020). LURs are an aggregation of continuous statistical units around a core that are economically dependent on this core and linked to it by economic amenities and strong social interdependences. An important objective of this delimitation is to encompass areas likely to be home to multinational companies and their branches and subsidiaries, which are by basic presumption the

¹ The variable provided by Rosstat: Average number of employees of organizations by types of economic activity for municipalities (in Russian: *Среднесписочная численность работников организаций по видам экономической деятельности (на муниципальном уровне)*)

most dependent on location near an airport (Rogov & Rozenblat, 2020). In total we identified 120 LURs in Russia and more than 85 per cent of all the multinational firms located in Russia belonged to these LURs (Rogov & Rozenblat, 2020). We considered the delineations identified in 2019 and we used the same delineation during the whole period 2010-2019, making comparable the territories that are considered as LURs all along the period of time.

The data from Rosstat on the meso level both for total population and employment were collected for every municipality included in LUR (see Rogov, 2020 for the composition of LURs) and then aggregated by LUR. We operated similarly for the macro level data from BvD-ORBIS-UNIL. In the following sections we use the terms “cities” and “LURs” as synonymous.

1.3. Harmonized nomenclature of economic activities for meso and macro levels

In order to compare employment activities and establishment activities, the two different sources were based on different nomenclatures. Employment information comes from Rosstat using a specific activity nomenclature, and information on establishments of multinational firms comes from ORBIS produced by the Bureau van Dijk (BvD) using the NACE classification (Statistical Classification of Economic Activities in the European Community).

Another difficulty to create a harmonized nomenclature was the fact that Rosstat changed the list of economic activities starting with 2017. Thus, before 2016 there were 16 economic activities, and starting in 2017, Rosstat switched to the NACE classification extending the list of letters (level 1) up to 21 economic activities. Based on the corresponding analysis of subcategories of activities (level 2) in two nomenclatures (before 2016 and starting with 2017), we managed to create 15 harmonized activities, which are continuous from 2010 to 2019 and are similar for the Rosstat (meso level) and the ORBIS (macro level) database (Table S1).

Literature cited:

Rogov M, (2020) *DATABASE: RUSSIAN LARGE URBAN REGIONS 2020* (Version 4) [Data set]. Zenodo.

Rogov M, Rozenblat C (2020) Delineating Russian cities in the perspective of corporate globalization: towards Large Urban Regions. *Cybergeo: European Journal of Geography* n°949.

Rogov M, Rozenblat C (2022) Intercity economic networks under recession: Counter-intuitive results on the evolution of Russian cities in multinational firm networks from 2010–2019. *Journal of Urban Affairs* (forthcoming)

Rozenblat C (2020) Extending the concept of city for delineating large urban regions (LUR) for the cities of the world. *Cybergeo : European Journal of Geography*, n°954.

Table A1.1. Harmonized nomenclature of economic activities for the Russian national data from ROSSTAT and BvD-ORBIS-UNIL (NACE) (2010-2019)

For the ROSSTAT nomenclature until 2016: All-Russian Classes of Economic Activities (OKBЭД) available for municipal level

For the ROSSTAT nomenclature in place from 2017: All-Russian Classes of Economic Activities-2 (OKBЭД-2) available for municipal level

Correspondence of ROSSTAT nomenclatures		Homogenised nomenclature between ROSSTAT and BvD-ORBIS-UNIL (NACE) (2010-2019)
Nomenclature ROSSTAT until 2016	Nomenclature ROSSTAT from 2017	
A: Agriculture, hunting and forestry	A: Agriculture, forestry, hunting, fishing and fish farming	AGRICULTURE AND FISHING
B: Fishing, fish farming	A: Agriculture, forestry, hunting, fishing and fish farming	
C: Mining	B: Mining	MINING
D: Manufacturing	C: Manufacturing	MANUFACTURING
E: Production and distribution of electricity, gas and water	D: Electricity, Gas, Steam and Air Conditioning Supply	ENERGY AND WATER
E: Production and distribution of electricity, gas and water	E: Water Supply; Sewerage, Waste Management and Remediation Activities	
F: Construction	F: Construction	CONSTRUCTION
G: Wholesale and retail trade; repair of motor vehicles, motorcycles, household goods and personal items	G: Wholesale and retail trade; repair of motor vehicles and motorcycles	TRADE
H: Hotels and restaurants	I: Accommodation and Food Service Activities	
I: Transport and communications	H: Transportation and storage	TRANSPORTATION AND COMMUNICATION
I: Transport and communications	J: Information and Communication	
J: Financial activities	K: Financial and insurance activities	FINANCE AND INSURANCE
K: Real estate transactions, rental and provision of services	L: Real Estate Activities	REAL ESTATE AND SERVICE ACTIVITIES
K: Real estate transactions, rental and provision of services	M: Professional, scientific and technical activities	
K: Real estate transactions, rental and provision of services	N: Administrative and Support Service Activities	
L: Public administration and military security; social insurance	O: Public Administration and Defence; Compulsory Social Security	PUBLIC ADMINISTRATION
M: Education	P: Education	EDUCATION
N: Public health service and social services	Q: Human Health and Social Work Activities	HEALTH AND SOCIAL SERVICES
O: Provision of other public, social and personal services	S: Other Service Activities	ARTS, RECREATION AND OTHER ACTIVITIES
O: Provision of other public, social and personal services	R: Arts, Entertainment and Recreation	

Appendix 2

Map of Russian cities cited in the text

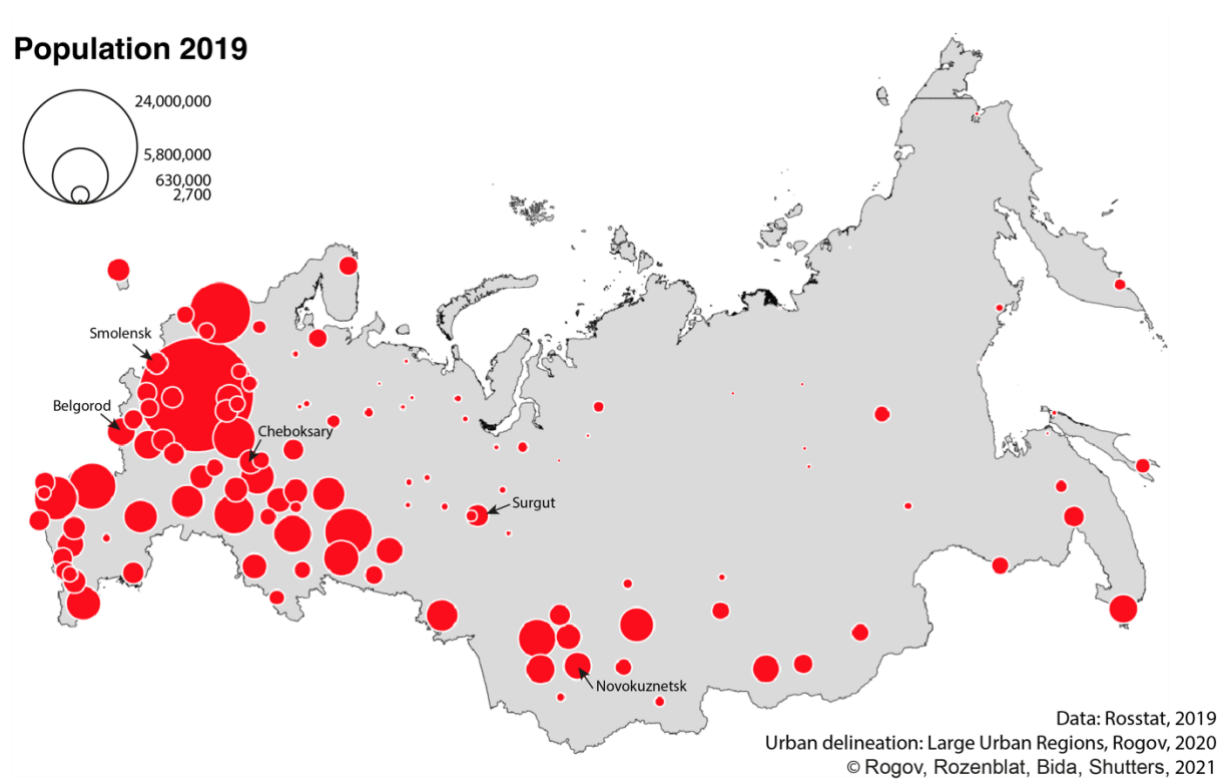


Figure A2.1: Map of Russian cities cited in the text