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Measuring Triple-Helix Synergy in the Russian Innovation Systems at Regional, Provincial, and National Levels

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We measure synergy for the Russian national, provincial, and regional innovation systems as reduction of uncertainty using mutual information among the 3 distributions of firm sizes, technological knowledge bases of firms, and geographical locations. Half a million units of data at firm level in 2011 were obtained from the *Orbis*™ database of Bureau Van Dijk. The firm level data were aggregated at the levels of 8 Federal Districts, the regional level of 83 Federal Subjects, and the single level of the Russian Federation. Not surprisingly, the knowledge base of the economy is concentrated in the Moscow region (22.8%) and Saint Petersburg (4.0%). Except in Moscow itself, high-tech manufacturing does not add synergy to any other unit at any of the various levels of geographical granularity; instead it disturbs regional coordination. Knowledge-intensive services (KIS; including laboratories) contribute to the synergy in all Federal Districts (except the North-Caucasian Federal District), but only in 30 of the 83 Federal Subjects. The synergy in KIS is concentrated in centers of administration. The knowledge-intensive services (which are often state affiliated) provide backbone to an emerging knowledge-based economy at the level of Federal Districts, but the economy is otherwise not knowledge based (except for the Moscow region).

Introduction

Following the demise of the Soviet Union, the Russian state apparatus and the Russian innovation system were disorganized during the 1990s. More recently, innovation policies and the construction of innovation systems are back on the agenda: Can one use the wealth from oil and gas revenues to convert the Russian economy from a resource-dependent one into a knowledge-based one? How should one stimulate innovation in such a vast country? Should this be left to the regions or be coordinated more nationally?

In the last decade, the Russian government has proposed a series of initiatives to stimulate the transition of the country from a resource-based to a knowledge-based economy. Three stages of federal involvement in the development of an innovation infrastructure can be distinguished:

1. During the years 2005–2008, the federal government established science and technology parks across Russia.
2. During 2009–2011, legislation was passed to facilitate the development of innovations.
3. In 2011 and 2012, the government provided federal grants to establish entrepreneurial universities and regional innovation clusters (Perevodchikov & Uvarov, 2012).

The government actively encourages the development of science and technology parks, technology transfer offices, innovation centers, spin-off programs, etc. Technology incubation centers were set up within local universities, and their entrepreneurial capacity and ability to generate, manage, and promote start-ups was encouraged. Skolkovo, a large

innovation and education center which is to be built in Moscow in collaboration with the Massachusetts Institute of Technology, is the most recent government initiative. In 2012–2014, the government plans to invest almost $3 billion in this development (Pakhomova, 2013).

In 2009–2010, amendments were passed to Federal Law 217 (Federal Law of Russian Federation N 217-FZ, 2009) and Federal Decrees 218–220 (Federal Decree 218, 2010; Federal Decree 219, 2010; and Federal Decree 220, 2010) were issued in order to create opportunities for effective collaborations between universities, business, and government(s). Federal Law 217 is similar to the Bayh-Dole Act in the United States (e.g., Mowery & Sampat, 2004) and has the objective to create a collaborative environment between universities and companies, by encouraging the involvement of scientific and technological institutions in the innovation process. Federal Decree 219 awarded up to $267 million during 2010–2012 to support the development of infrastructures for innovation in the higher-education sector; Federal Decree 220 awarded $400 million in 2010–2012 to support leading scientists.

The recent government priorities are directed towards facilitating trilateral collaborations in university-industry-government relations as a part of Russia's strategic economic development. A related issue remains the allocation of national government funding to stimulate innovations at the regional level. The Russian economy can nowadays be considered as a combination of free-market activities with a variety of government interventions. Abundant in natural resources, Russia remains highly dependent on the petroleum sector; the role of the state in stimulating the transition to a knowledge-based economy remains crucial given this condition.

Synergy in Three Dimensions

To what extent—in which regions and sectors—can a synergy in innovation systems be shown in Russia? The main objectives of this study are to analyze the knowledge-based economy of Russia and measure the quality of the Russian (regional) innovation systems using the indicator of synergy based on entropy statistics (Jakulin & Bratko, 2004; see also Guo, 2010; Chanda et al., 2007; Lewontin, 2000, 10–12; Yeung, 2008). A number of European studies have estimated the reduction of uncertainty at the systems level using this Triple-Helix indicator of the (latent) synergy in the knowledge base of an economy, including the Netherlands (Leydesdorff, Dolfsma, & Van der Panne, 2006), Sweden (Leydesdorff & Strand, 2013), Germany (Leydesdorff & Fritsch, 2006), Hungary (Lengyel & Leydesdorff, 2011), and Norway (Strand & Leydesdorff, 2013). Studies about China (Leydesdorff & Zhou, 2014) and Italy (Cucco & Leydesdorff, in preparation) are also forthcoming.

The Triple Helix indicator of synergy is more abstract than the Triple Helix model of university-industry-government relations; the specification of institutional relations can be considered as a first step in the operationalization of an eco-system (Etzkowitz, 2001, 2007; Storper,

1997). However, synergy among three functions such as novelty production, wealth generation, and normative control in innovation systems is based on correlations—instead of relations—among distributions in three (or more) dimensions. University-industry-government relations, for example, can be considered as an eco-system of bi- and trilateral relations in which these functions can operate on the basis of the correlations that are consequently shaped at the network level.

In this study (and following the aforementioned studies) we operationalize the function of governance in terms of the distribution of geographical addresses—regions, provinces, nation(s); the economic dynamic of wealth generation in terms of the distribution of firm sizes—small and medium sized enterprises (SMEs) versus large corporations; and the distribution of technological capacities is operationalized in terms of the NACE codes of the OECD.[1]

Firms are assumed as the units of analysis: each firm has an address and thus falls under the jurisdiction of a local, regional, and national government; each firm is attributed NACE codes and has a size in terms of numbers of employees. These three distributions are analytically independent, but they relate in terms of covariations. For example, firms can be clustered in regions or technological sectors of the economy. The research question is whether the distributions at various levels of administration and/or in sectors of the economy (e.g., knowledge-intensive services) are synergetic in terms of the fit among the distributions?

The mutual information in three (or more) dimensions follows from Shannon's (1948) information theory (e.g., McGill, 1954), but cannot be given an interpretation within this theory because its value can potentially be negative (Krippendorff, 2009a; Yeung, 2008, p. 59f.). Instead of generating uncertainty (that is, Shannon-type information), redundancy is then generated in next-order loops among the codes in different dimensions. In other words, redundancy is generated because the same instances of covariation (relation) are provided with different meanings and may therefore be counted more than once. Leydesdorff and Ivanova (2014, p. 396) argue that one measures not "mutual information," but "mutual redundancy" in three (or more) dimensions.

In the Triple Helix framework, Etzkowitz and Leydesdorff (2000) suggested that an overlay of shared meanings provided to the relational events may reduce uncertainty depending on the configuration in the total set of relations. The overlay is the result of a configuration of relations, but may begin to feedback on the further shaping of relations. Because of this (partial) sharing of meanings, a niche can be formed in which the prevailing uncertainty is reduced locally. The localization of these niches can be in terms of geography, the technological capacities, or the economic dynamics. Empirically, there is always a trade-off between forward uncertainty (variation) generation in

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[1]NACE is an abbreviation of *Nomenclature générale des Activités économiques dans les Communautés Européennes*. The NACE code can be translated into the International Standard Industrial Classificiation (ISIC).

relations, and the possible reduction of uncertainty in terms of feedback by the overlay of interacting meanings that operates selectively (Ulanowicz, 2009).

Operationalization in Terms of Shannon's Formulas

For each of the three dimensions, our data contain a proxy: Geography is indicated with the postal address; economic weight with the size of the firm in terms of number of employees (e.g., SMEs versus large corporations); and technological capacity is indicated in terms of the NACE code (Rev. 2) developed for this purpose by the Organization of Economic Co-operation and Development (OECD) in Paris.

According to Shannon (1948), probabilistic entropy provides a measure of the expected uncertainty in a probability distribution p_x of a variable x as follows: $H_x = -\sum_x p_x \log_2 p_x$. (If two is used as the base of the logarithm, uncertainty is expressed in bits of information.) Analogously, the uncertainty in two dimensions based on the joint probability distribution p_{xy} of two variables x and y, is $H_{xy} = -\sum_x \sum_y p_{xy} \log_2 p_{xy}$. However, if there is interaction between the two variables (e.g., the locations and the sizes of firms), this uncertainty is reduced with the mutual information or transmission (T_{xy}) as follows: $T_{xy} = (H_x + H_y) - H_{xy}$. (If the distributions are completely independent $H_{xy} = H_x + H_y$ and $T_{xy} = 0$.)

Likewise, the measure of uncertainty in three dimensions based on the joint probability distribution p_{xyz} of three variables x, y, and z is $H_{xyz} = -\sum_x \sum_y \sum_z p_{xyz} \log_2 p_{xyz}$. It can be shown (e.g., Abramson, 1963, p. 131 ff.) that the mutual information or transmission is specified as follows:

$$T_{xyz} = H_x + H_y + H_z - H_{xy} - H_{xz} - H_{yz} + H_{xyz} \qquad (1)$$

Depending on the relative weights of the terms in Equation (1), the resulting value of T_{xyz} can be positive or negative (Yeung, 2008, p. 59 ff.), whereas T_{xy} in two dimensions is always positive. Krippendorff (2009a) showed that Shannon-type interaction information in three dimensions can be approached differently, namely as the (positive) uncertainty added to the sum of the two-way interactions.[2] However, the *signed* information measure T_{xyz} can be considered as the result of next-order loops that may entail positive or negative redundancies (Krippendorff, 2009b, p. 676). Adding redundancy (other options) to a system adds to the maximum entropy and can thus reduce the relative uncertainty. The signing remains consistent with Shannon's (1948) information theory only if this reduction of uncertainty prevailing at the systems level is subtracted as negative information (Leydesdorff, 2010; Leydesdorff & Ivanova, 2014).

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[2]Krippendorff (1980, 2009a) suggested to write this Shannon-type information as $I_{ABC \rightarrow AB:AC:BC}$.

TABLE 1. Example of mutual information in three dimensions.

	x	y	z
Nr 1	0	1	0
Nr 2	1	0	1
Nr 3	1	1	0
Nr 4	0	1	1

Table 1 provides an example of three binary variables (x, y, and z) attributed to four cases. The uncertainty in x (H_x) is precisely one bit of information because the variable is attributed 0 in two cases and 1 in the other two cases: $p(0) = p(1) = 0.5 \rightarrow H_x = -\frac{1}{2} \log_2 (\frac{1}{2}) - \frac{1}{2} \log_2 (\frac{1}{2}) = 1$ bit. The four combinations of x, y, and z, however, are all unique and hence $H_{xyz} = 4 * [-\frac{1}{4} \log_2 (\frac{1}{4})] = 2$. Using Equation (1), it follows that in this case $T_{xyz} = 1.00 + 0.81 + 1.00 - 1.50 - 2.00 - 1.00 + 2.00 = -0.19$ bits. Leydesdorff, Park, and Lengyel (2014) provide other examples; Sun and Negishi (2010) discuss the potentially negative value of T_{xyz} in relation to partial correlations. A routine for computing mutual information in three or four dimensions is available online at http://www.leydesdorff.net/software/th4.

One advantage of information theory is that all values are based on summations and can be fully decomposed into the contributing terms. As in the decomposition of probabilistic entropy (Theil, 1972, p. 20f.), the mutual information in three dimensions can be decomposed into G groups as follows:

$$T = T_0 + \sum_G \frac{n_G}{N} T_G \qquad (2)$$

When one decomposes, for example, a country in terms of its regions (or provinces), T_0 is between-region uncertainty or a measure of the dividedness among the regions; T_G is the uncertainty at the geographical scale G; n_G the number of firms at this geographical scale G; and N the total number of firms in the data set. The values for T and T_G can be calculated from the respective distributions (using Equation [1]), if the sum values of N and n_G are known. The normalized values of the contributions of regions to the national synergy $\left(\Delta T = \frac{n_G}{N} * T_G \right)$ and the between-group synergy (T_0) can then be derived. T_0 is equal to the difference between the T-value for the whole set minus the sum of the subsets.

Note that T_0 can have positive or negative signs, and can also be expressed as a percentage contribution to the total synergy for a system of reference (e.g., at the national level). A negative value of T_0 indicates that the uncertainty at the next geographically aggregated level is reduced more than the sum of the parts, whereas a positive value indicates that the next level of integration does not add synergy to the system. Thus, one can test, for example, whether the national level adds to the systems integration more than the sum of the regional units. The relative contributions at each level can be specified after proper normalization for the number of firms.

TABLE 2. Distribution of Russian firms with valid data in the *Orbis* database by year.

Year	*N* of firms
2008	111,943
2009	116,408
2010	170,911
2011	593,987

TABLE 3. Distribution of firms by geographical region and Federal District.

Geographical region	Federal District	Number of firms	%
European part	Central	227,476	38.3
	Volga	105,699	17.8
	Northwestern	54,671	9.2
	Southern	48,843	8.2
	North Caucasian	10,876	1.8
Siberia	Siberian	80,437	13.5
	Ural	42,090	7.1
	Far Eastern	23,895	4.0
Total		593,987	100.0

Data

Almost a million records with a Russian address were harvested *at the firm level* from the *Orbis* database (available at https://orbis.bvdinfo.com) on January 20, 2013 (Table 2). *Orbis*™ is a database maintained by Bureau Van Dijk (BvD) and consists of company-level data for more than 100 million firms (including banks) collected worldwide for commercial purposes. Regardless of its numerous drawbacks and data coverage issues (Ribeiro, Menghinello, & De Backere, 2010) —this is not a complete set of governmental statistics—we used these data given a lack of alternatives. In a study of the Italian innovation system (Cucco & Leydesdorff, in preparation), an almost perfect correlation was found (Pearson's $r = 0.98$; Spearman $\rho > 0.99$) between the distributions of the synergy values based on 462,316 valid observations using *Orbis* data versus 4,480,473 firms registered by Statistics Italy in 2007. This gives us some confidence in the representativeness of the *Orbis* data and their usefulness for this purpose.

By far the most complete data at the date of the download were for 2011 (Table 2). For this year, 613,018 records were retrieved, with 593,987 (96.9%) records containing valid information in the three relevant dimensions (address, size, and NACE code). Despite the limitations of this sample, we are able to address our main research question about the synergy generated in the Russian economy in terms of combinations among geography, technology, and organization. Three variables attributed to each firm will be used as proxies for each specific combination in the geographical, technological, and organizational dimensions: (a) the zip code as indicator of the firm's geographical location; (b) size, measured by the number of employees, as a proxy of the economic dynamics—one can distinguish among small, medium (e.g., SMEs), and large firms—and (c) the NACE code (Rev. 2) of the OECD as a measure of the main technology.

A firm's geographic location is captured by the four-digit zip code. This code allows us to aggregate the data into three regional classification levels: national (the Russian Federation), district (eight Federal Districts), and regional (83 Federal Subjects or states) levels (Table 3 and Figure 1). One can also distinguish between the European and Siberian parts of the Russian Federation; but this division is not used by the administration.

More than 75% of the firms (447,565) are located in the European part of Russia as can be expected given the low population rates in the Siberian regions (Table 4). One third of the firms (179,009 or 31%) are located in Moscow, Saint Petersburg, and the Moscow region ("Moscow Region"), reflecting the highly centralized and clustered economic structure of Russia. The Novosibirsk Region has, with 19,225 (3%), the largest concentration of firms east of the Ural mountains. The normalized Gini coefficient of the distribution of firms over the eight Federal Districts is 0.49, and 0.59 over the 82 Federal Subjects.

The number of employees of a firm can be considered as a proxy of its size and industrial organization (Blau & Schoenherr, 1971). Almost half of the sample consists of medium-sized firms with between 10 and 50 employees (Table 5). According to the European Commission's (2003, 2011) classification of firms by number of employees, micro-entities have less than 10 employees, small-sized firms have less than 50 employees, and medium-sized less than 250.

Companies without employees (including sole ownership firms),[3] represent only a relatively small share of the sample (20%), which is similar to the previously reported Dutch data (19.7%), but well below that in the Norwegian (61%) or Swedish (more than 70%) case studies, respectively. However, we are uncertain about the inclusion of firms with no employees in the *Orbis* data set (Cucco & Leydesdorff, in preparation; Ribeiro, Menghinello, & De Backere, 2010).[4] We follow (in Table 5) the discretization in terms of size classes provided by Leydesdorff et al. (2006, at p. 186), except for the two largest classes, which were chosen so that they are approximately of the same magnitude and in accordance with the definitions of the European Commission (2003, 2011). Classification of the numbers in discrete classes is needed given our information-theoretical framework.

The data contain the NACE codes at the four-digit level for each firm, but we use only the first two digits. This provides us with 35 classes in use in this data. The NACE codes can be considered as a proxy of a firm's technology. Using the NACE classification of Table 6, 76,078 (12.8%) of the Russian firms can be considered as knowledge-

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[3]It is assumed that zero number of employees implies the sole ownership firm, even if it can be a missing value (Ribeiro et al., 2010).

[4]Of these 594,189 firms, 593,987 (>99.9) were included into the analysis. Some firms were removed because of missing or incomplete data in one of the other two dimensions.

FIG. 1. Administrative map of the Russian Federation: eight Federal Districts and 83 Federal Subjects. [Color figure can be viewed in the online issue, which is available at wileyonlinelibrary.com.]

TABLE 4. Administrative map of the Russian Federation: eight Federal Districts and 83 Federal Subjects.

Federal district	Area (km^2)	Population (2010 Russian Census)	Federal Subjects
Central Federal District (Europe)	652,800	38,438,600	18
Southern Federal District (Europe)	418,500	13,856,700	6
Northwestern Federal District (Europe)	1,677,900	13,583,800	11
Far Eastern Federal District (Siberia)	6,215,900	6,291,900	9
Siberian Federal District (Siberia)	5,114,800	19,254,300	12
Ural Federal District (Siberia)	1,788,900	12,082,700	6
Volga Federal District (Europe)	1,038,000	29,900,400	14
North Caucasian Federal District (Europe)	170,700	9,496,800	7

Source. President of the Russian Federation (2000).

TABLE 5. Size classes of firms in terms of numbers of employees.

Employees	Number of firms	Percentage
0	121,553	20%
1–4	74,892	13%
5–9	19,978	3%
10–19	115,853	19%
20–49	165,246	28%
50–99	44,822	8%
100–249	28,502	5%
>249	23,343	4%
Total	**594,189**	100%

Note. Of these 594,189 firms, 593,987 (>99.9) were included into the analysis. Some firms were removed because of missing or incomplete data in one of the other two dimensions.

intensive services (KIS); 2,564 (0.4%) are classified as high-tech manufacturing firms; and 15,860 (2.7%) as medium-tech manufacturing.

The Russian sample has a relatively low share of firms with knowledge-intensive services when compared with the data reported in the Norwegian, Dutch, or German case studies (44%, 51%, and 33%, respectively). High-tech manufacturing is scarce and highly centralized in Moscow itself (Gini = 0.73). Medium-tech manufacturing (2.7%) is more evenly distributed across the regions (Gini = 0.64), whereas the knowledge-intensive services (12.8%) are concentrated in Moscow and its metropolitan environment (Gini = 0.71).

A shape file for mapping the administrative organization of Russia was retrieved from http://www.diva-gis.org/datadown for the geographic mapping using SPSS v20. The database of this file distinguishes the two administrative layers within Russia: eight Federal Districts and 83 Federal Subjects (states, provinces, and republics). Our data do not contain one of the latter subjects (Kostroma Region), and thus we use 82 lowest-level regional units.

Analogous to the previous studies, we also explore whether regional differences in the configurations are determined by high- and medium-tech manufacturing. Research questions are consistent with previous case studies: (a) is the in-between group reduction of uncertainty at the regional (that is, Federal Subject) level larger than at the level of Federal Districts? and (b) is medium-tech manufacturing

TABLE 6.   NACE classifications (Rev. 2) of high- and medium-tech manufacturing, and knowledge-intensive services; according to Eurostat/OECD.

High-tech manufacturing	Knowledge-intensive sectors (KIS)
21 Manufacture of basic pharmaceutical products and pharmaceutical preparations	**50** Water transport
26 Manufacture of computer, electronic and optical products	**51** Air transport
30.3 Manufacture of air and spacecraft and related machinery	**58** Publishing activities
Medium-high-tech Manufacturing	**59** Motion picture, video and television programme production, sound recording and music publishing activities
20 Manufacture of chemicals and chemical products	**60** Programming and broadcasting activities
25.4 Manufacture of weapons and ammunition	**61** Telecommunications
27 Manufacture of electrical equipment	**62** Computer programming, consultancy and related activities
28 Manufacture of machinery and equipment n.e.c.	**63** Information service activities
29 Manufacture of motor vehicles, trailers and semi-trailers	**64 to 66** Financial and insurance activities
30 Manufacture of other transport equipment	**69** Legal and accounting activities
excluding 30.1 Building of ships and boats, and	**70** Activities of head offices; management consultancy activities
excluding 30.3 Manufacture of air and spacecraft and related machinery	**71** Architectural and engineering activities; technical testing and analysis
32.5 Manufacture of medical and dental instruments and supplies	**72** Scientific research and development
	73 Advertising and market research
	74 Other professional, scientific and technical activities
	75 Veterinary activities
	78 Employment activities
	80 Security and investigation activities
	84 Public administration and defence, compulsory social security
	85 Education
	86 to 88 Human health and social work activities
	90 to 93 Arts, entertainment and recreation
	Of these sectors, **59 to 63, and 72** are considered *high-tech services*

Sources. Eurostat (2014; cf. Laafia, 2002).

FIG. 2.   Synergies in the knowledge-based economy of Russia (in mbits) at the level of the eight Federal Districts (2011; $N = 593,987$). [Color figure can be viewed in the online issue, which is available at wileyonlinelibrary.com.]

associated with synergy more than high-tech firms? On the basis of the previous studies, knowledge-intensive services can be expected to uncouple from regional economies because they are less geographically constrained in terms of buildings, etc. However, this may be different for Russia because research laboratories are also classified as knowledge-intensive services.

Results

Figure 2 shows that synergy at the level of the eight Federal Districts is found in the European part of Russia more than in the Siberian part. This is not a surprise given the larger density of the firms and volume of government subsidies in the European part of Russia. Within the

FIG. 3. Synergies in the knowledge-based economy of Russia at the level of 83 Federal Subjects (2011; $N = 594{,}987$; mbits of information). [Color figure can be viewed in the online issue, which is available at wileyonlinelibrary.com.]

Scale:

■ $\Delta T > 0$;

■ $0 > \Delta T > -10$ mbit;

■ $-10 > \Delta T > -25$ mbit;

■ $-25 > \Delta T > -50$ mbit;

■ $-50 > \Delta T > -100$ mbit;

■ $-100 > \Delta T > -200$ mbit;

■ Moscow: -484 mbit

framework of the Triple-Helix theory, this part of the country has found a more virtuous balance among the three sub-dynamics than in the more peripheral parts of the country. However, Figure 2 shows that the pattern "the farther from Moscow, the lower the synergy" has one striking exception, the Siberian District. Most likely, it is due to large university centers such as in Novosibirsk, Tomsk, and Krasnoyarsk. Figure 3 supports this explanation, but with Omsk instead of Tomsk as the local center of synergy.

Figure 3 provides a map of Russia with the 83 Federal Subjects (states) colored according to their respective contributions to the synergy in the knowledge-based economy. Figure 4 zooms in on the European part of Russia in Figure 3. This highlights the specific positions of Moscow and Saint Petersburg. The scaling in the legend is similar as in Figure 3.

The total synergy for the nation is -2690.7 mbits of information, of which 37.9% (-1019.7 mbits) is realized at the level above Federal Subjects (Table 7 column [a]: -704.2 mbits at the level of Federal Districts and -315.5 mbits at the national level). This 37.9% reduction of the uncertainty at the above-regional level is far more than the values reported for Norway (11.7%), the Netherlands (27.1%), or Sweden (20.4%).

Table 7 concisely summarizes the results of this study decomposed both geographically and in terms of the most relevant sectorial division. First in column (a), the synergies generated at the levels of 83 Federal Subjects and eight Federal Districts, respectively, are summarized in terms of their respective contributions to the synergy at the national level. Considering firms in all sectors
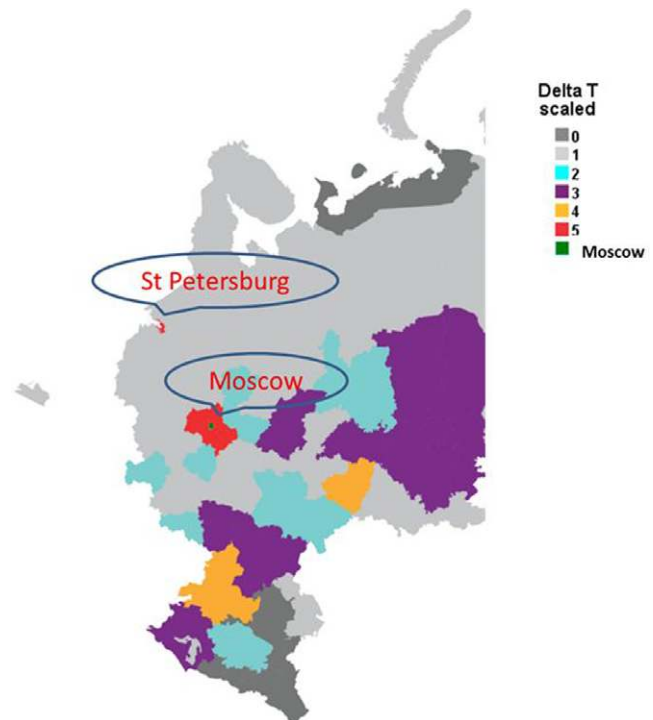

FIG. 4. Synergies in the knowledge-based economy of the European part of Russia at the Federal Subject level (2011; $N = 447{,}565$ [75.3% of the 593,987 firms in the sample]). [Color figure can be viewed in the online issue, which is available at wileyonlinelibrary.com.]

($N = 593{,}987$), 62.1% of the synergy is found at the regional level of Federal Subjects; 26.2% at the level of the eight Districts; and 11.8% on top of that at the national level of the Russian Federation. Of these firms 19.9% were

TABLE 7. Synergy in Triple Helix interactions at different levels of administration; and in knowledge-based manufacturing (high- and medium-tech), and knowledge-intensive services (KIS); in mbits and as percentages.

	All sectors $N = 593,987$ (a)	High tech $N = 2,564$ (0.4%) (b)	Medium tech $N = 15,860$ (2.7%) (c)	KIS $N = 76,078$ (12.8%) (d)
Federal Subjects (83)	−1,670.9 (62.1%)	879.3	555.6	−1,024.8 (54.9%)
Federal Districts (8)	−704.2 (26.2%)	−386.4	−986.6	−550.6 (29.5%)
National	−315.5 (11.8%)	−570.4	−716.9	−293.9 (15.7%)
Total	−2,690.7	−77.4	−1,147.3	−1,869.3
normalized nationally	−2,690.7	−0.3 (0.01%)	−30.6 (1.1%)	−239.4 (8.9%)

located in Moscow ($N = 118,072$); 33,489 (5.6%) in the surrounding Moscow Region; and 27,451 (4.6%) in Saint Petersburg (Gini = 0.59). As shown in Figure 4, these are by far the most integrated regions in terms of synergies between economics, technology, and geography.

In the second column (b) we focus on the 2,564 firms (0.4%) which are classified as "high-tech manufacturing" in terms of the classifications provided in Table 6. In this case, one third (33.3%; $N = 854$) of these firms are located in Moscow with another 7.0% in Moscow Region. Saint Petersburg follows with 220 firms (8.6%). In the other regions, the presence of high-tech manufacturing is rare, that is, fewer than 100 firms. In these sectors, the synergy is found at the national level more than at the district level. Only the Central Federal District (including Moscow) shows a synergy (−23.7 mbits; $N = 1,324$) at this next level of aggregation. At the regional level of Federal Subjects, the high-tech firms disturb the synergy considerably by generating 879.3 mbits of uncertainty in the regions. (We did not add percentages to this column because of the sign change involved.) In other words, high-tech manufacturing is not embedded at the regional level of Federal Subjects, but at the next level of Federal Districts (−386.4 mbits) and even more at the national level (−570.4 mbits).

Column (c) shows the results of focusing on the 15,860 firms (2.7%) that are classified as medium-tech manufacturing (in Table 6). In this case most of the synergy is found at the level of the eight Federal Districts, that is, above the regional level (−986.6 mbits); the national level adds another −716.9 mbits to this synergy. However, when normalized in relation to the national level, medium-tech manufacturing contributes only 1.1% (30.6 mbits) to the synergy in all sectors,[5] whereas they form 2.7% of the total number of firms.

In summary, medium-tech manufacturing does not add to the knowledge-base of the Russian economy, unlike other countries that were studied using this method hitherto. The distribution of medium-tech manufacturing across the regions is less concentrated than that of high-tech manufacturing. For example, 16.8% of them are in Moscow against 19.9% for the whole set (and 33.3% for high-tech manufacturing). In other words, medium-tech firms are distributed across the economy, but do not contribute to the synergy in the regional economies at the level of Federal Subjects.

Knowledge-intensive services (column [d]) are provided by 76,078 firms (12.8%) and contribute 8.9% to the synergy in the national economy. The coordination is both large at the level of the regions (54.9%), but heavily concentrated in Moscow as one of these regions ($N = 29,190$; $\Delta T = −738.8$ mbits, that is, 72.1% of the total of −1,024.8 mbits). We conjecture that these services are provided in state-apparatuses and establishments related to these. They are pervasively present throughout the economy and integrating the economy. At the level of Federal Districts, only the North-Caucasian Federal District fails to show synergy at this level.

Table 8 lists the 15 Federal Subjects that contribute to the sample of KIS, in decreasing order of the (normalized) contributions to the synergy (ΔT in mbits). The values of ΔT seem to be strongly correlated (with the opposite sign) to the number of establishments (N), but for all 82 Subjects, the (Spearman) rank-order correlation between these two values is −0.662 ($p < .01$). In 52 of the 82 Federal Subjects, KIS has smaller numbers ($N < 1,000$) and is not embedded regionally ($\Delta T > 0$).

In summary, high-tech manufacturing plays a role exclusively in Moscow; medium-tech manufacturing is distributed across the country, but fails to contribute to the knowledge-based economy probably because these firms are not sufficiently embedded (Cohen & Levinthal, 1990). Where present in sufficient numbers, KIS is regionally integrated in Russia more than in other countries. On the basis of our previous studies, one would expect knowledge-intensive services and high-tech manufacturing to be more volatile ("footloose"; Vernon, 1979). We conjecture that knowledge-intensive services in Russia are related to the administration in the state apparatus, and therefore not so flexible. One

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[5]One can normalize the numbers at the national level by multiplication with n_G/N, or in this case 15,860/593,987.

TABLE 8. Fifteen Federal Subjects that contribute more than 1.2% to the number of KIS at the regional level; in decreasing order of the contributions to the synergy.

Federal Subject	N	ΔT in mbits
Moscow	29,109	−738.84
Saint Petersburg	4,445	−88.58
Moscow Region	3,755	−55.71
Samara Region	1,925	−25.38
Novosibirsk Region	1,842	−22.09
Sverdlovsk Region	1,787	−21.61
Rostov Region	1,478	−17.48
Perm Region	1,352	−15.08
Krasnoyarsk Region	1,218	−10.88
Republic of Tatarstan	1,205	−9.75
Omsk Region	1,124	−8.58
Udmurt Republic	979	−8.39
Tomsk Region	951	−7.59
Krasnodar Region	1,354	−7.41
Chelyabinsk Region	1,105	−7.36

should also keep in mind that distances are large in Russia, making it difficult to offer services nationwide or across regions.

Conclusions

The analysis of the Russian economy using the Triple-Helix indicator provides us with a perspective on an economy organized very differently from the Western economies that we have studied hitherto or the Chinese economy (Leydesdorff & Zhou, 2014). It transpires that the Russian economy is not knowledge based. Synergies in the regions among existing technological and economic structures are disturbed instead of reinforced by medium-tech manufacturing and even more so by high-tech manufacturing. Knowledge-intensive services are grounded and not, as we hypothesized in the introduction (on the basis of previous studies), a mechanism that uncouples from the local economies. Both KIS and high-tech manufacturing are heavily centralized in Moscow.

Moscow, the Moscow Region, and Saint Petersburg are the regions where synergy is generated to such an extent that the scale of the operations is different from those in the other regions or Federal Districts. The Federal Districts are a relevant level of coordination, but do not function as does the provincial level in China to provide the main coordination mechanism of that economy (Leydesdorff & Zhou, 2014). The centralization resembles that of Sweden (with Stockholm, Gothenburg, and Malmö/Lund providing 48.5% of the TH synergy; Leydesdorff & Strand, 2013). For Russia, however, the aggregate percentage for the top-3 regions (Moscow, Moscow Region, and Saint Petersburg) is only 26.8% of the national synergy. In Sweden, the mechanisms of embedding high- and medium-tech manufacturing and KIS are similar to other European nations, whereas in Russia KIS is associated with governmental structures. High- and medium-tech manufacturing do not play a role in the coordination of the economy at the regional level.

It remains to be cautioned that our data are not based on official government statistics, but on a commercial database (*Orbis*™). *Orbis* data are collected by Bureau Van Dijk from numerous sources (more than 100). These sources remain otherwise unrevealed to the user of this database (Ribeiro et al., 2010). However, we are currently not aware of data that are of higher quality than *Orbis* about the Russian economy in the three relevant dimensions and at the micro-level of establishments.

Given these *caveats*, one may wish to note in terms of policy implications that the Russian system of innovations integrates the three dimensions synergetically at all three levels of Federal Subjects (62.1%), Federal Districts (26.2%), and the nation state (11.8%; Table 7, column [a]). In other words, a Russian innovation system is in place at all three levels of administration. When the sectors are decomposed in terms of knowledge intensity, however, both medium- and high-tech firms are no longer integrated at the regional level of Federal Subjects. Medium-tech manufacturing contributes to the integration at the levels of districts more than nationally, whereas high-tech contributes mainly nationally (that is, in Moscow). Different than Western Europe, knowledge-intensive services are embedded at all three levels (Table 7, column [d]), and function more or less comparably to the respective synergy for all sectors (Table 7, column [a]). Enhancing the circulation of these services and encouraging the diffusion of high-tech across the country—perhaps in the form of more competition—could be beneficial to the further development of a knowledge-based economy in Russia.

Acknowledgments

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