Papers in Evolutionary Economic Geography

15.09

Innovation in Russia: the territorial dimension

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April 15 2015

Abstract

The debate on Russia's innovation performance has paid little attention to the role of geography. This paper addresses this gap by applying an 'augmented' regional knowledge function approach to examine the territorial dynamics of innovation in Russia. The empirical results suggest that regional R&D investments are strong predictors of local innovative performance. However, R&D activities are inadequately connected to regional human capital resources. The activities of foreign firms play a fundamental role as 'global knowledge pipelines'. Different territorial dynamics of innovation are observed in the European and the Asian part of Russia, with regions to the East of the Urals less likely to benefit from interregional knowledge spillovers. The historical legacy from the Soviet era still emerges as a strong predictor of current innovative performance, shedding light on the importance of long-term path dependency in the Russian geography of innovation.

Keywords: Innovation, R&D, geography, regions, Russia

JEL classifications: R11, R12, O32, O33

1. Introduction

Despite its relatively strong position in science after the collapse of the Union of Soviet Socialist Republics (USSR) and substantial investments in Research and Development (R&D), Russia's innovative performance remains astonishingly low. The debate about this "Russian innovation paradox" (Gianella and Tompson, 2007) has focussed on national-level historical and institutional factors. The latter include weak linkages between production and R&D (Klochikhin, 2012), inadequate protection of intellectual property rights (Aleksashenko, 2012), insufficient evaluation of public R&D spending (Graham and Dezhina, 2008), degradation of the human capital stock (Cooper, 2008; Gaddy and Ickes, 2013a) as well as adverse effects of natural resource abundance (EBRD, 2012). Several authors compare Russia's performance with that of other countries, especially China and India (Gianella and Tompson, 2007; Klochikhin, 2013). However, notwithstanding the country's unique spatial configuration, the existing literature has paid very little attention to the geographical aspects of the genesis of knowledge and innovation in Russia.

Russia is the world's largest country by land area. Low density and large distances between population centres (especially in the East) interact with a unique historical legacy, shaping the production and diffusion of new knowledge. As a consequence, space and subnational heterogeneity appear particularly important in the case of Russia. In contrast to the cross-country approach adopted by large part of the existing literature, this paper focuses on differences in innovative performance across Russia's regions in order to unveil the underlying territorial dynamics of innovation. The analysis sheds new light on potential spatial mismatches that might contribute to explaining the long-debated 'innovation paradox' from a geographical perspective.

By focussing on the sub-national drivers of innovation performance this paper addresses the scarcity of systematic, quantitative research about Russia's geography of innovation. This study contributes to the small but growing body of literature in economic geography that examines the territorial dynamics of innovation in emerging countries (Crescenzi et al., 2012; Fu, 2008; Llisteri et al., 2011), building upon the broader geography of innovation literature (Feldman, 1994; Storper, 1997; O'hUallachain and Leslie 2007; Feldman and Kogler, 2010; Carlino and Kerr, 2014). In addition, Russia's recent history adds a rich evolutionary perspective to the analysis of geographical processes (Martin and Sunley, 2007; Neffke et al., 2011): the country's starting position in science after the USSR's breakup sets it apart from most emerging countries. It inherited a large-scale science system in 1991. Legacies of the Soviet science infrastructure are likely to influence the present-day geography of innovation of Russia, linking history and geography in a unique fashion.

This paper explores the territorial dynamics of innovation in Russia by adopting an 'integrated approach' that 'augments' the traditional regional knowledge production function (O'hUallachain and Leslie, 2007; Charlot et al., 2015) by taking into account local innovative efforts and inter-regional knowledge flows, 'global' knowledge pipelines in the form of Foreign Direct Investments (FDI) as well as long-term 'historical' geographies from the Soviet era. Although constraints in terms of data availability force us to rely on patent intensity as a measure for regional innovation performance (the limitations of this choice are extensively discussed in the following section), a number of interesting insights emerge from the empirical analysis.

Our analysis reveals a strong and robust connection between local R&D efforts and regional innovation performance. However, it also suggests that R&D activities in Russian regions are inadequately aligned to regional human capital, shedding light on a fundamental spatial mismatch between the two key inputs of the innovation process. If regions' indigenous innovation efforts suffer from this potential misalignment their possibility to access external knowledge is highly differentiated. On the one hand, multinational enterprises seem to play a pivotal role, forming global knowledge pipelines and 'channelling' new knowledge into the Russian regions capable of attracting them. On the other hand inter-regional localised knowledge flows seem to benefit only regions in 'European' Russia – regions to the East of the Urals are less likely to benefit from this knowledge source. This suggests that international tensions that tend to isolate Russia from the rest of the world might substantially hamper the innovation performance of all Russian regions, but adverse effects are likely to be particularly pronounced in Eastern regions that cannot rely on localised knowledge flows as an at least temporary compensatory mechanism. The empirical analysis also shows that the legacy of Soviet-founded science cities remains a strong predictor of contemporary regional innovation performance: recent attempts to develop new innovation centres, such as Skolkovo (Radošević and Wade, 2014), have to take into account simultaneously the geographical misalignments discussed above as well as the strong path-dependency.

2. Some stylised facts on the Geography of Innovation in Russia

Capturing innovation in developing and emerging economies is an empirical challenge, exacerbated in the case of Russia by the scarcity and limited accessibility of regional-level data. In developing and emerging countries innovations tend to be mostly new to the firm, whereas a larger proportion of innovations in advanced economies is new to the world as a whole (Bell, 2007). As technological gaps between Russia and leading countries have accumulated in several sectors, imitation strategies are prevalent among firms (Gokhberg and Roud, 2012). As a consequence, in order to fully capture the complexity of firms' innovation strategies, it would be ideal to rely on firm-level innovation data (such as for example Community Innovation Survey data for Europe or Pintec for Brazil). However, the regional-level coverage of such data is still very limited in Russia, and PCT patent data (counted according to inventor's region of residence) therefore remain the best available measure of regional innovation.

For the purpose of spatial analyses patents can be considered as a "fairly good, although not perfect, representation of innovative activity" (Acs et al., 2002: 1080). We will be unable to capture all types of innovation (Brenner and Broekel, 2011; Smith, 2005). Not all forms of innovation are equally likely to be patented (Griliches, 1990) and the global novelty requirement associated with PCT patents implies that minor adaptations and imitations of foreign technology as well as innovations that are primarily new to the Russian market will not be captured by our measure of innovation. However, "the PCT reflects the technological activities of emerging countries quite well (Brazil, Russia, China, India, etc.)" (OECD, 2009a: 66)[1].

In 2011, Moscow and St. Petersburg, the two largest cities, in which 11.4 percent of Russians live, accounted for nearly 51 of all PCT patent applications down from 68 percent in 1995 (Rosstat and OECD data, authors' calculation). *Figure 1* illustrates changes in the distribution of patenting across Russian regions during 1995-2011, focussing on the 10 regions with the highest patent counts. It shows that the leading regions' share of total patenting has slightly

[1] We carefully decided to rely on PCT patents rather than national Russian patents. While this comes at the price of discounting innovations which are new to local markets (as opposed to new to the world), it helps to avoid issues related to domestic patent coverage and quality. "A PCT filing can be seen as a 'worldwide patent application' and is much less biased than national applications" (OECD, 2009a: 65). Harhoff et al. (2007: 18) state that due to "flexibility and low costs, PCT filings have become extremely popular". We also rely on PCT patent data to facilitate comparisons with related studies (Crescenzi et al., 2012; Fagerberg et al., 2014). In 2012, Russia accounted for 77.9 percent of PCT filings from European middle-income countries (WIPO, 2013: 28) and China overtook Germany as the third-largest user of the system in 2013 (WIPO, 2014).

decreased over this 17-year period. While the five most innovative regions still accounted for 82.4 percent of Russian PCT patenting during 1995-1998, this share amounted to 74.3 percent on average in the period 2008-2011. Innovative activity (as measured by PCT applications) in Russia has slowly become less concentrated in space, as lower-tier regions increased their contribution to total Russian PCT applications.

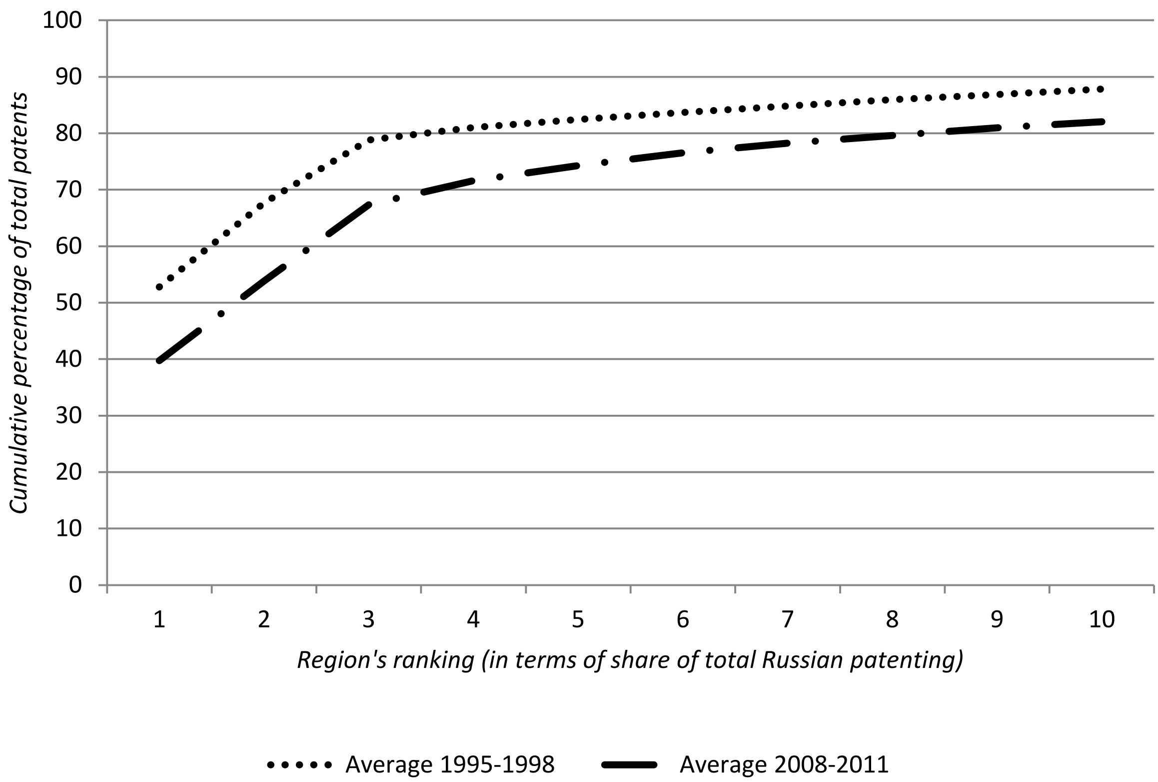

Figure 1: Cumulative distribution of Russian PCT patent applications: 10 most innovative regions.

Russia's R&D activities are also spatially concentrated – beyond the level of clustering of the population. [2] Out of Russia's eight federal districts, the Central District (which includes Moscow), the North-Western District (which encompasses St. Petersburg) and the Volga district (which hosts a large share of Russian manufacturing) in 2010 accounted for 57.4% of Russia's population and conducted 82.3% of Russian R&D (OECD, 2011: 116). In line with the state's role as the key actor in Russia's innovation system (Cooper, 2010), public

[2] The online appendix includes four maps illustrating the geography of four key variables (patenting, R&D, human capital, foreign firms' activities).

spending decisions shape the geography of R&D. The capital hosts numerous public research centres and higher education institutions.

The geography of human capital is also highly heterogeneous, with firms located in Eastern regions particularly likely to report difficulties in finding skilled personnel (EBRD, 2012). The share of citizens holding a university degree ranged from 11.9 percent in Chechnya to 41.2 percent in Moscow in 2010 (Russian census, 2010). Highlighting spatial variation in the quality of Russian education, Amini and Commander (2012) find that students' performance measured by PISA scores is positively associated with population size of the town where a student attends school.

The circulation of knowledge among innovation centres is made more difficult by large distances (especially in the East). The transfer of complex knowledge is facilitated by face-to-face contacts – "an intrinsically spatial communication technology" (Rodríguez-Pose and Crescenzi, 2008: 379) and innovative actors outside Russia's relatively densely populated European part may face higher costs in accessing knowledge produced in other parts of the country. Russia's spatial distribution of capital and labour still reflects central planners' decisions that often ignored transport costs, agglomeration economies, and climatic conditions (Ickes and Ofer, 2006; Mikhailova, 2012; Gaddy and Ickes, 2013a). The inefficient location of factors of production is likely to slow down economic transactions (Hill and Gaddy, 2003) and innovation.

Peripheral regions may compensate for their isolation by relying on alternative proximities to access external knowledge (Fitjar and Rodríguez-Pose, 2011; Maskell, 2014), such as social proximity between individuals based in distant places. However, low levels of interregional labour mobility (Andrienko and Guriev, 2004; Ivakhnyuk, 2009) suggest that such linkages between Russian regions might be limited. Studies examining inter-regional trade connections found low levels of regional integration in early transition years (Gluschenko, 2010), with Berkowitz and DeJong (1999) identifying "internal borders". Yet, Berkowitz and DeJong (2003) as well as Gluschenko (2011) find that the late 1990s marked a shift towards greater integration.

If inter-regional knowledge circulation is constrained by physical, historical and institutional factors, 'global' linkages are also highly localised and constrained by geo-political considerations. While the international integration of Russian scientists has increased considerably since the early 1990s (Graham and Dezhina, 2008), the country as a whole remains relatively closed (OECD, 2011). Only two percent of manufacturing enterprises target international markets (Gokhberg and Roud, 2012: 122) and restrictive immigration rules prevent skilled foreigners from non-CIS countries from filling skill gaps (EBRD, 2012).

Significant heterogeneity characterizes Russian regions' levels of embedment in international business networks (Iwasaki and Suganuma, 2005; Gonchar and Marek, 2013). Foreign investments are mostly attracted by Russia's market size and natural resources (Ledyaeva, 2009). Accordingly, a limited number of densely populated agglomerations in Western Russia and resource-rich regions in Eastern Russia attract the lion's share of inward FDI. Highly dependent on hydrocarbon endowments, the Sakhalin region accounted for nearly a third of total FDI inflows between 2001 and 2006 (Strasky and Pashinova, 2012: 3). During 1996-2007, approximately 62 percent of firms with at least 10 percent of foreign ownership and at least one million roubles of capital were registered either in the region of Moscow, the city of Moscow, or the city of St. Petersburg (Ledyaeva et al., 2013: 4).[3] With FDI scattered across the country in a mosaic pattern, opportunities to benefit from this source of foreign knowledge are distributed unevenly across Russian regions.

It would be impossible to understand the current geography of innovation in Russia without taking into account two fundamental aspects of the spatial legacy of the Soviet era: 'science cities' and major 'military installations'. Soviet planners invested relevant resources in the development of 'science cities' i.e. selected locations, often isolated from the rest of the world, that offered researchers privileged living conditions (Castells and Hall, 1993; Gokhberg, 1997). Most of these science cities entered a period of decline after 1991 but others, such as Akademgorodok near Novosibrisk (Siberian federal district), have developed new identities and attracted foreign enterprises (Becker et al., 2012; OECD, 2011). The Moscow region, which encloses the city of Moscow like a belt, is also known for Soviet-founded science cities and academic centres that still show remarkable technological dynamism, e.g. in nuclear energy (Dubna, Protvino) and physics (Troitsk).

Conversely, a high level of militarization in the late Soviet period may not necessarily be beneficial for a region's current innovative performance. Whereas in the U.S. military expenditure contributed to the emergence of innovative clusters (Saxenian, 1994), areas specialized in Soviet military production in the late 1980s did not display higher human

[3] However, foreign firms' tendency to register in the capital may lead to an overestimate of the degree of spatial concentration of foreign direct investment in Russia (Gonchar and Marek, 2013).

capital levels (Gaddy, 1996). They inherited a structure of large, state-dependent enterprises which may induce regional governments to lobby for transfers from Moscow and neglect efforts for technological modernization (Gaddy, 1996; Commander et al., 2011). The Russian military sector as a whole has not gained a reputation as the spearhead of innovation in the transition years. Instead, it "appears largely to be living off the intellectual capital of the Soviet era" (Eberstadt, 2011: 106).

3. A theory-driven framework for empirical analysis

The existing literature on the territorial dynamics of innovation in developed (e.g. Moreno et al., 2005; Crescenzi et al., 2007; Fagerberg et al., 2014) and emerging countries (Cassiolato et al., 2003; Fu, 2008; Llisterri et al., 2011) suggests that regional innovation drivers can only be uncovered by cross-fertilising different approaches to the genesis of innovation into an 'integrated framework'.

The discussion of the spatial organisation of innovative activities in Russia has pointed to the importance of the R&D-patenting nexus at the regional level. Russian regions with higher innovation 'inputs' (R&D spending, researchers) seem to display a higher innovative output. However, this 'linear' link - observed in numerous regions in developed countries (e.g. Botazzi and Peri, 2003; O'hUallachain and Leslie, 2007) - appears weaker in emerging countries (Crescenzi et al., 2012). As a consequence, the analysis of the territorial dynamics of innovation needs to 'augment' the 'traditional' regional knowledge production function in order to account for a wider set of territorial conditioning factors.

Not only internal innovative efforts but also the exposure to external knowledge sources is highly differentiated across regions. The difficulty of transferring highly valuable tacit knowledge across large distances (Storper and Venables 2004) has fundamental implications for regional innovation performance in a country characterized by large distances between agglomerations, such as Russia. Geographical peripherality may constitute a structural disadvantage in the form of reduced exposure to knowledge flows. Places within the driving range of innovation centres can be expected to enjoy advantages compared to peripheral regions, as they are more likely to receive knowledge inflows via face-to-face contact (Bottazzi and Peri, 2003; Sonn and Storper, 2008; Rodríguez-Pose and Crescenzi, 2008). Relative to sparsely populated places, regions with a largely urban population are also likely to face lower costs of exchanging knowledge (Jacobs, 1969; Duranton and Puga, 2001;

Combes et al., 2012). Geographical distance to Moscow, the traditional centre of Russia's science system (Gokhberg, 1997), is also likely to shape exposure to localised knowledge flows.

In order to compensate for limited exposure to inter-regional knowledge flows regions can possibly rely on "global pipelines": functional linkages to other innovative places that provide valuable knowledge inputs not necessarily based on geographical proximity (Oinas, 1999; Bathelt et al., 2004; Boschma, 2005). Multinational enterprises (MNEs) may act as channels for cross-border knowledge flows, enhancing regional patenting performance (see Ford and Rork, 2010 for the USA; Fu, 2008 for China). The innovative performance of a Russian region may therefore also be shaped by its access to knowledge from locations outside Russia – in line with evidence that international collaboration increases Russian scientists' productivity (Ganguli, 2011).

Internal innovation efforts and external (spatially-mediated or 'global') knowledge flows are translated into innovation in very different ways in different regional contexts. Not only technological capabilities and 'absorptive capacity' (Cohen and Levinthal, 1990) are likely to play a crucial role in explaining regional innovation differences. But also long-term evolutionary trajectories and heterogeneous (regional) systems of innovation conditions (Freeman, 1987; Lundvall, 1992; Nelson, 1993) shape the way in which both innovation efforts and human capital are organised in space and matched with each other (Cassiolato et al., 2003; Altenburg et al., 2008; Fan, 2014). Institutional inertia and "stubborn path-dependencies" (Klochikhin, 2012) shape the innovation performance of regions in Russia: institutional lock-in prevents the Russian innovation system from overcoming its top-down, supply-side bias and the organizational separation of production and R&D activities (Laperche and Uzunidis, 2007; Narula and Jormanainen, 2008). In addition, inherited structures shape future development opportunities (Rigby, 2000; Iammarino, 2005): Russian regions' historical endowments with R&D-related resources from the Soviet period influence their capacity to generate new knowledge. Regions' involvement in Soviet military production and their endowment with Soviet-founded science cities are likely to play a key role in shaping current systemic conditions.

The factors shaping regional innovation performance can be combined into an 'augmented' regional knowledge production function (Crescenzi et al., 2007; O'hUalla-chain and Leslie, 2007; Charlot et al., 2015) specified as follows:

$$\ln(PAT_{i,t}+1)=\beta_1 R\&D_{i,t-2}+\eta WR\&D_{i,t-2}+\beta_2 HUMAN\_K_{i,t-1}+\beta_3 FOREIGN_{i,t-1}+$$
$$\mu\ CONTROLS_{i,t-1}+\lambda_t+\gamma_i+\varepsilon_{i,t}$$

Where:

$\ln(PAT_{i,t}+1)$	is the natural logarithm of patent applications per one million inhabitants. Patent applications are counted according to the inventor's region of residence.[4]
$R\&D_{i,t-2}$	is R&D expenditure as percentage of regional GDP.
$WR\&D_{i,t-2}$	is a spatially weighted[5] average of the R&D expenditure in neighbouring regions (i.e. excluding region *i*) as a proxy for interregional knowledge flows
$HUMAN\_K_{i,t-1}$	Is the share of employees with higher education. Provided annually by Rosstat, this variable encompasses post-secondary degrees, including technical training.[6]
$FOREIGN_{i,t-1}$	is the turnover of foreign enterprises as a percentage of regional GDP[7].

[4] We estimate an additional model to check whether the use of PCT applications regionalized based on the applicant's address would fundamentally alter our results (see appendix). The overall picture does not change. Regarding the role of foreigners in patenting, 22% of Russian PCT patent applications results from international collaborations – a value that is close to the median of OECD countries (OECD, 2011: 368).

[5] Regarding the spatial weighting scheme, inverse-distance weights appear inappropriate in the case of Russia. Since Russian regions differ vastly in area (in our sample: 1,459km² to 3,073,098 km²), a weight-matrix based on a distance-threshold would be problematic. A low threshold might create unconnected observations, whereas a distance chosen to guarantee a minimum of one neighbour might inappropriately increase the number of small regions' neighbours (Anselin, 2002). Conversely, simple contiguity weights may introduce bias due to heterogeneity in the number of neighbours of each region. We therefore consider the k-neighbours scheme as the most suitable choice for our investigation. It allows us to connect Kaliningrad to mainland Russia (which would constitute an unconnected "island" when using contiguity weights). Moreover, k-nearest-neigbours weights eliminate sources of bias resulting from different numbers of neighbours.

[6] Comparable studies in other countries mostly use the share of population holding academic degrees, for Russian regions this variable is only available for census years (2002 and 2010). For the year 2002, both measures of human capital are relatively highly correlated (0.75).

[7] Data on the stock of foreign direct investments are unfortunately only available for the late 2000s from the Russian central bank. While data on FDI inflows are available for the entire period from Rosstat, this measure does not reflect outflows or activities that do not coincide with an investment in the same year (e.g. production activities in the years following major investments). We therefore use another variable provided by Rosstat - the turnover of firms located in the region with at least 10 percent foreign capital. Compared to FDI inflows, foreign firms' turnover is more likely to represent continuous interactions that may enhance the region's innovative performance.

$CONTROLS_{i,t-1}$ *Sectoral Controls* - Six sectoral controls for agriculture, manufacturing, transport and communications, services and retail, and construction. Given Russia's increasing dependence on natural resources (Gaddy and Ickes, 2013b), it is important that we also control for oil and gas production. We follow Ledyaeva et al. (2013) and use an index of resource potential (provided by Russia's largest rating agency Expert RA). In addition, we include an index of oil and gas production provided by Rosstat.

Socioeconomic controls - Two controls for socioeconomic conditions. Motivated by findings suggesting that a younger demographic structure enhances innovative output (Rodríguez-Pose, 1999; Crescenzi et al., 2007), we include a region's birth rate. To adjust our knowledge production framework to idiosyncrasies of the Russian context, we also add the share of ethnic Russians to our socioeconomic variables. Provided by Rosstat, this variable captures the regional heterogeneity in ethnic composition. As several Russian regions with large ethnic minorities are conflict-prone, controlling for this variable appears important.[8]

Geographical control - the percentage of the regional population living in urban areas[9] as a proxy for the geographical distance between innovative agents within each region.

Time dummies λ_t are included in order to account for common shocks. Conversely, region-fixed effects γ_i, make it possible to control for the time-invariant part of unobserved heterogeneity: this includes the cross-sectional dimension of variation in regions' institutional

[8] Note that problems of multicollinearity prevent us to from including more socioeconomic controls in our model. However, we conducted a number of robustness checks to examine the sensitivity of our results to a different choice of socioeconomic controls. Following Crescenzi et al. (2007, 2012), we also included the regional unemployment rate as a measure of the productive employment of human resources (Gordon, 2001) and share of the population under 16 years of age. Our results are robust to the inclusion of these controls.

[9] Becker et al. (2012) provide a detailed discussion of the classification of the population into urban and rural components in Russia. "Urban status requires a population minimum, and also that a specified proportion of the population is engaged in non-agricultural pursuits. However, there is an arbitrariness at the margin, and the criteria have not been constant over time. (…) Current Russian practice is to award city status to settlements of at least 12,000 inhabitants with at least 85 per cent of the working-age population engaged in non-agricultural pursuits. This is the strictest definition in the former USSR" (Becker et al., 2012: 19).

quality as well as long-term historical conditions (including technological capabilities) that cannot be included explicitly in the model. Finally, $\varepsilon_{i,t}$ is the idiosyncratic error term.

Given the substantial time lag (Fritsch and Slavtchev, 2011)[10] between R&D investments and patent applications, R&D intensity (and its spatial lags) enters the regional knowledge production function with a two-year lag, while all other independent variables are lagged by one period in order to minimise reverse causality. We adopt an averaging strategy to reduce the volatility of our data, especially with respect to patenting and R&D; as customary in similar studies (Botazzi and Peri, 2003; O'hUalla-chain and Leslie, 2007; Foddi et al, 2013). The link between R&D and patenting is known to be stronger over longer periods (Griliches, 1990; Botazzi and Peri, 2003). Following Ponds et al. (2010), we collapse all variables into periods of two years – except for the first period (based on 1997 only). Our panel data set therefore encompasses 8 periods.

The model is estimated for the period 1997-2011 and covers 78 out of 83 Russian regions.[11] Data on PCT patent applications are obtained from the OECD-RegPat database, while annual regional data for most other variables are provided by the Russian national statistical agency (Rosstat)[12]. The inclusion of region and year-fixed effects reduces the likelihood of omitted variable bias and makes it possible to control for time-invariant region-specific variables (e.g. institutional conditions and historical legacy). However, in a second step of the analysis we use a cross-sectional regression to shed some descriptive light on the role of historical endowments and distance to Moscow whose role is otherwise absorbed in the regional fixed effects. The cross-sectional specification of the model includes the following additional time-invariant variables:

[10] According to the procedures of the filings under the Patent Cooperation Treaty (PCT), PCT applications (the type of patent applications used in this analysis) will generally be published 18 months after the start of the application process (WIPO, 2013). According to Acs et al. (2002), U.S. innovations recorded in 1982 resulted from inventions made 4.3 years earlier. Fischer and Varga (2003) choose a lag of two years for their analysis of knowledge production in Austria, while Ronde and Hussler (2005) use R&D expenditure in 1997 to explain patenting in French regions in the period 1998-2000. Similarly, O'hUalla-chain and Leslie (2007) relate R&D efforts in 2000 and 2001 to average patenting per capita in U.S. states during 2002–2004. Note that choosing such a time gap should also mitigate reverse causality problems regarding the relationship between R&D and patenting.

[11] Limited data availability forces us to exclude the Chechen Republic, the Republic of Ingushetia, the subregion Nenets Autonomous Okrug, the subregion Khanty Mansi Autonomous Okrug – Yugra, as well as the subregion Yamalo Nenets Autonomous Okrug. Based on averages for the period of analysis, those five regions jointly account for 2.38 percent of the Russian population and 0.56 percent of all regions' R&D expenditure (Rosstat, authors' calculation).

[12] Part of the Rosstat data were accessed through a dataset provided by Mirkina (2012): Mirkina, I. Aggregate Data, Regions of Russia (RoR), 1990-2010. ICPSR35355-v1. Ann Arbor, MI: Inter-university Consortium for Political and Social Research [distributor], 2014-10-14. http://doi.org/10.3886/ICPSR35355.v1

Proxies for endowment with Soviet-founded science infrastructure and military facilities - Based on various sources (including Gokhberg, 1997; Becker et al., 2012; website of union of science cities), we compiled a list of 63 Soviet-founded science cities. As a second time-invariant historical variable, we add the percentage of industrial employees working in defence production in 1985. Provided by Gaddy (1996)[13], this variable should capture a region's militarization in the late Soviet era.

Measure of remoteness from the centre of the science system - In order to take into account a region's geographical remoteness relative to the traditional centre of Russia's science system, our estimations include the distance (in kilometres) between the regional capital and Moscow. In the Soviet era, Moscow accounted for 30 percent of USSR R&D expenditure (Gokhberg, 1997: 15) and it continues to play a pivotal role regarding scientific progress and funding decisions (Graham and Dezhina, 2008). Due to the time-invariant character of this variable, we can only include distance to Moscow in cross-sectional estimations.

4. Empirical Results

4.1 Main findings based on fixed-effects estimations

Tables 1 and *2* provide the results of the main analysis based on panel estimations. *Table 1* focuses on the association between regional innovation performance and internal innovation drivers while *Table 2* looks in particular at the geography of inter-regional knowledge flows.

Table 1 starts by exploring the regional R&D-patenting nexus (columns 1-3). When lagged by one period, R&D is marginally significant but the coefficient becomes larger and strongly significant with a two-period lag (column 2). With a three-period lag (column 3), the coefficient is still of a similar magnitude (compared to column 1) but is no longer statistically significant. We therefore lag R&D by 2 periods in all following estimations, corresponding to a delay of three to five years in line with Ronde and Hussler (2005), Fritsch and Slavtchev (2007) and Usai (2011).

We identify a positive and statistically significant association between regional R&D efforts and patenting performance. This result is robust to the inclusion of all other variables that are

[13] Gaddy's (1996) data on defence employment are estimates based on omitted categories in official documents. For a detailed discussion of the characteristics and limitations of these estimates, see Gaddy (1996).

part of our model (columns 2-7). In the light of the debate about the absence of rigorous evaluation of R&D organizations and inefficient allocation of public R&D funds in Russia (Graham and Dezhina, 2008; EBRD, 2012), this finding is noteworthy. Despite such deficiencies, R&D activities are a strong predictor of regional innovative performance.

Whereas our result for R&D is largely in line with the literature, we do not find a strongly statistically significant association between regional human capital and innovative performance. Russia's higher education system expanded remarkably in the past two decades, with the number of students increasing from just over 2.5 million in 1993 to 7.8 million in 2008 (Motova and Pykkö, 2012: 27). This growth was partly driven by the rise of private institutions (Geroimenko et al., 2012). As external influence on curricula remains limited, the rapid increase in enrolment and the expansion of private establishments may have diluted quality standards (Nikolaev and Chugunov, 2012).

Regarding the subjects chosen by students, it has been argued that the expansion of the service sector and the collapse of public science in transition years may have incentivized students to acquire skills that are not conducive to innovation (EBRD, 2012). Motova and Pykkö (2012: 27) emphasize that study places mostly grew in economics, law and the humanities, "which did not require too much investment in material resources, but were considered highly prestigious by society". Stressing instead institutional continuity in Russia's education system, Gaddy and Ickes (2013a) and Cooper (2006) argue that curricula and skills inherited from the Soviet period are outdated and do not correspond to the requirements of a market-based economy.

It hence appears plausible that our variable does not measure precisely the skills that are of relevance to patenting. [14] At the same time, our finding that increases in the regional level of human capital are not significant predictors of changes in patenting performance of the same region may also indicate a spatial mismatch between skilled labour and innovative activities. Graduates with quantitative skills and degrees in natural sciences often find employment in activities such as financial services which offer higher wages than the mostly publicly funded R&D positions (OECD, 2011). Average wages in Moscow's R&D sector were only 47% of average wages for Muscovites working in finance in 2009 (Makarov and Varshavsky, 2013: 474), making careers in innovation-related activities relatively unattractive. Regional

[14] We were unfortunately unable to access regionalized data on student performance in international tests (PISA or TSSS), which otherwise would have allowed us to adopt an instrumental variable strategy or enter that measure of skills directly.

innovative performance may therefore not benefit from increases in the regional human capital stock if skills are not employed in innovation-intense activities.

As we extend our analysis to include activities of foreign firms (column 5), access to extra-regional knowledge emerges as a key driver of innovative performance. The coefficient is significant and positive. This result sheds light on the role of multinational enterprises (MNEs) in Russian regions: since their subsidiaries are simultaneously embedded in the local economies of their host regions and in global intra-firm networks, MNEs enable the transmission of knowledge flows (Meyer et al., 2011). Our analysis suggests that these extra-regional linkages provide Russian regions with valuable knowledge inputs, boosting their innovative performance. Regions are "localised interface where global and local flows of knowledge intersect" (Kroll, 2009: 1): foreign firms act as linkages to innovative places outside Russia, channelling knowledge inputs that enhance regional patenting (Maskell, 2014).

Table 1. Fixed effects estimation for period 1997-2011. Dependent variable: natural logarithm of patent applications per one million inhabitants +1

VARIABLES	(1)	(2)	(3)	(4)	(5)	(6)	(7)
R&D expenditure as percentage of GDP	0.1200* (0.0699)						
R&D expenditure as percentage of GDP, in t-2		0.1761*** (0.0650)		0.1844*** (0.0662)	0.1740*** (0.0646)	0.1964*** (0.0655)	0.2043*** (0.0661)
R&D expenditure as percentage of GDP, in t-3			0.1226 (0.0871)				
Human capital				0.0123 (0.0082)	0.0122 (0.0082)	0.0145* (0.0081)	0.0149* (0.0081)
Foreign firms' turnover as percentage of GDP					0.0030** (0.0012)	0.0034*** (0.0011)	0.0035*** (0.0012)
Sectoral controls	NO	NO	NO	NO	NO	YES	YES
Socioeconomic controls	NO	NO	NO	NO	NO	NO	YES
Internal geography	NO	NO	NO	NO	YES	YES	YES
Time fixed effects	YES	YES	YES	YES	YES	YES	YES
Region fixed effects	YES	YES	YES	YES	YES	YES	YES
Constant	0.4678*** (0.0568)	0.4932*** (0.0478)	0.5101*** (0.0665)	0.2575 (0.1663)	-1.2774 (0.8111)	-2.2663** (0.9147)	-3.5592* (1.7968)
Observations	546	468	390	468	468	468	468
R-squared	0.2087	0.2073	0.1950	0.2108	0.2283	0.2584	0.2612
Number of regions	78	78	78	78	78	78	78

Robust standard errors in parentheses; clustered at level of regions. *** p<0.01, ** p<0.05, * p<0.1
Variables collapsed (averaged) into periods of 2 years for the years 1998-2011.

Table 2. Fixed effects model for period 1997-2011 including spatially lagged R&D expenditure. Dependent variable: natural logarithm of patent applications per one million inhabitants +1

VARIABLES	(1)	(2)	(3)	(4)	(5)	(6)
R&D expenditure as percentage of GDP	0.1804*** (0.0525)	0.1882*** (0.0540)	0.1781*** (0.0558)	0.2115*** (0.0574)	0.2120*** (0.0579)	0.2071*** (0.0581)
W R&D (k4)	0.0150*** (0.0033)	0.0148*** (0.0032)	0.0121*** (0.0037)	0.0128*** (0.0042)	0.0123*** (0.0040)	0.0123*** (0.0042)
W R&D (k4) X in Asia (interaction term)					-0.0859** (0.0400)	
Human capital		0.0116 (0.0081)	0.0116 (0.0082)	0.0145* (0.0082)	0.0131 (0.0081)	0.0142* (0.0082)
Foreign firms' turnover as percentage of GDP			0.0025** (0.0012)	0.0031*** (0.0011)	0.0028** (0.0011)	0.0038*** (0.0012)
Foreign firms turnover (as % of GDP) X Moscow/St.Pete (interaction)						-0.0035** (0.0016)
Sectoral controls	NO	NO	NO	YES	YES	YES
Socioeconomic controls	NO	NO	NO	YES	YES	YES
Internal geography	NO	NO	YES	YES	YES	YES
Time fixed effects	YES	YES	YES	YES	YES	YES
Region fixed effects	YES	YES	YES	YES	YES	YES
Constant	0.4853*** (0.0412)	0.2628 (0.1637)	-1.1125 (0.8041)	-4.0593** (1.7223)	-4.1295** (1.7362)	-4.0369** (1.7199)
Observations	468	468	468	468	468	468
R-squared	0.2220	0.2251	0.2375	0.2706	0.2740	0.2741
Number of regions	78	78	78	78	78	78

Robust standard errors in parentheses; clustered at level of regions. *** p<0.01, ** p<0.05, * p<0.1
Variables collapsed (averaged) into periods of 2 years for the years 1998-2011

If global knowledge pipelines play a fundamental role in compensating for the spatial dispersion and relative isolation of Russian innovation hubs, knowledge spillovers across regional boundaries also play a significant role with respect to innovation performance (*Table 2*, column 1). We identify a positive and statistically significant association between a region's innovative performance and the spatially weighted average of neighbouring regions' R&D efforts. We report only the results based on the k4-nearest neighbour weighting scheme. The results for k2 and k3 are similar ($p<0.05$) but we fail to identify evidence of significant spillovers if we adopt weights of k5 or higher, suggesting that spillovers display distance decay-effects. The progressive inclusion of additional innovation inputs and further geographical and sectoral controls (columns 2 to 4) confirms the significance of inter-regional knowledge flows in addition to internal inputs and 'global' pipelines.

To examine whether the territorial dynamics of innovation follow different patterns in the European and the Asian parts of Russia – as suggested by part of the qualitative literature on Russia – the model is 'augmented' by an interaction term between the spatially weighted R&D efforts and a dummy variable that equals one if a region is located in Asia (column 5). The corresponding coefficient is negative and significant and the sum of the coefficients of the interaction term and the spatially weighted R&D reveals that neighbouring R&D efforts are negatively associated with regional innovative performance in Asian Russia. This is consistent with a situation where a few highly innovative places in Asian Russia divert innovation inputs (e.g. public and private R&D funds) away from nearby regions. This picture resembles the pattern identified in China where innovation hotspots (often centrally designated by the government) absorb resources from their neighbouring regions with a shadow effect *a la Krugman* (Crescenzi et al., 2012). Our results can be considered as tentative evidence suggesting that highly innovative places in Asian Russia, such as Novosibirsk, have a strong capacity to translate their own R&D efforts into patents but most regions in Asian Russia are unlikely to benefit from interregional knowledge spillovers. The contrary is true in European Russia where spatially mediated knowledge exchange channels play an important role, resembling the diffusion patterns observed in the regions of the European Union (including Central and Eastern Europe) (Moreno et al., 2005; Crescenzi et al., 2007)

Having established that regional innovative activities do not appear to benefit from interregional knowledge spillovers in the Asian part of the country, the model makes it possible to test whether the role of major drivers of innovative performance differs across subsamples. Whereas the analysis does not identify statistically significant differences between the European and the Asian part of Russia regarding the association between patenting and human capital (insignificant interaction terms - not reported) and with respect to regional R&D efforts (not reported), the role of foreign firms seems to be significantly different in different parts of the country. The strongly significant, negative interaction between a dummy for St. Petersburg and Moscow and foreign firms' activities (column 6) suggests that the innovative performance of Russia's two major cities does not benefit from the large share of foreign direct investment which they receive. This may reflect a dominance of services (including finance) in the sectoral composition of FDI going to these cities. FDI targeting Moscow and St. Petersburg might increase the competition for skilled personnel with state-funded research institutes losing out to foreign firms that offer higher salaries – while not necessarily engaging in innovative activities in these centres of administration and services. This competition for skilled labour might further reinforce the fundamental human capital mismatch identified in our analysis and possibly divert skilled labour from research-intensive careers. The possibility of FDI to act as fully functioning global knowledge pipelines therefore appears highly dependent upon 'localised' conditions: when pipelines break the potential lock-in and isolation of otherwise disconnected innovation clusters they maximise their innovation impact.

It is important to explain that our analysis of knowledge spillovers is not immune to the so-called modifiable aerial unit problem (Briant et al., 2010), i.e. our results might change if we could repeat our analysis at a different spatial scale. While the absence of data at more fine-grained spatial levels prevents us from testing our findings' sensitivity, it is obvious that regions in Asian Russia are larger than in Western Russia. Within Asian Russia spillovers are likely to occur at a spatial level that is smaller than the level for which data are available.

For the case of the U.S., Carlino et al. (2012) conclude that spillovers may be operating at different scales: at very small scales (roughly half a kilometre) and at a scale approximately corresponding to metropolitan statistical areas. The largest region in our sample (Sakha Republic) is circa 4.7 times the size of Alaska (or 5.6 times that of mainland France). Does this vitiate our analysis? We strongly believe it does not. Most importantly, our level of analysis does not only (inevitably) correspond to the level where innovation-related data are collected, but also where many innovation-related choices are made. The relevance of the regional level for policy decisions regarding innovation and education in Russia (OECD, 2011; Nikolaev and Chugunov, 2012) warrants efforts to improve our understanding of the territorial dynamics of innovation at this spatial scale.

4.2 Additional evidence on the role of historical endowments and remoteness from Moscow

While the inclusion of fixed effects in our main model reduces the likelihood of omitted variable bias, it also prevents us from examining the role of time-invariant variables: historical endowments as well as remoteness from Moscow are absorbed by the regional fixed effects in our panel estimations. We therefore take an ancillary step. In order to shed descriptive light on the influence of historical endowments from the Soviet period as well as remoteness relative to Moscow, we create a cross-sectional dataset by averaging all variables across the 15 years of our dataset. While we cannot add fixed effects at the level of the 78 regions in this cross-sectional specification, the inclusion of dummies for Russia's eight federal districts still makes it possible to control for some unobserved characteristics that differ across these eight macro regions.

The results of these supplementary cross-sectional regressions are displayed in *Table 3*. The key time-invariant variables of interest are introduced in column 1: the number of science cities, the number of defence employees in 1985, and distance to Moscow. The coefficients of both proxies for historical endowments from the Soviet period are statistically significant ($p<0.01$) and positive: Soviet-founded science cities and specialization in defence production in the mid-1980s are positively associated with patenting performance during 1997-2011. Conversely, the coefficient of distance to Moscow is significant and negative, indicating that being further away from the historical centre of Russia's highly centralised science system is associated with lower patenting performance. This finding resonates with contributions stressing high levels of continuity and the pivotal role of top-down decisions taken in Moscow (Graham and Dezhina, 2008; Narula and Jormanainen, 2008).

In columns 2 to 5, further regressors are gradually introduced in order to test the robustness of the results for the three time-invariant variables. The coefficient of defence employment remains positive but loses statistical significance at conventional levels when we add internal innovation inputs, foreign firms' turnover, and control for the internal regional geography (column 2), dummies for Russia's eight federal districts (column 3), sectoral controls (column 4), and socioeconomic controls (column 5). This suggest that, after controlling for other regional innovation characteristics, greater specialization in military production in the mid-1980s does not influence current innovative performance: higher 'historical' levels of militarization are neither a “boon nor a bane”. The potential advantages associated with a strong military sector – such as spillovers from military R&D (Mowery, 2010) – might in the Russian case be offset by the disadvantages associated with an economic structure of large, state-dependent enterprises which might induce regional governments to lobby for transfers from Moscow and neglect efforts for technological modernization (Commander et al., 2011).

In contrast to the results for defence employment, the legacy of Soviet-founded science cities is still a predictor of current regional innovative performance, robust to the inclusion of all further explanatory variables (columns 2-5). Some Soviet-founded science cities experienced a renaissance and expanded their international linkages (Gokhberg et al., 2011; Becker et al., 2012; EBRD, 2012). For example, Dubna, a science city founded in 1956, hosts the Joint Nuclear Research Institute (JNRI). This international organization involves 18 countries (mostly CIS members) and is associated with 6 further countries (including Germany and Italy). In 2011, the institute had 3,000 employees, including 500 foreign researchers (OECD, 2011: 239).

The results regarding science cities confirm theoretical contributions highlighting strong path dependencies in regional patterns of knowledge generation (Iammarino, 2005). The fact that the coefficient of science cities remains significant even after controlling for current R&D investments and human capital levels suggests that regions that inherited science cities are able to draw on historically shaped technological capabilities.

Distance to Moscow is only a weak predictor of patenting after controlling for sectoral specialization (column 4) and socio-economic conditions (column 5). This might indicate that regions located close to the traditional centre of the Russian science system tend to display sectoral and socioeconomic characteristics that are conducive to innovation. While the bulk of R&D resources is still concentrated in the country’s two main cities, the 2000s saw tentative steps towards a more even distribution of funds (Graham and Dezhina, 2008). The fact that distance to Moscow is only marginally significant once we add socioeconomic controls suggests that favourable conditions, for example in Tomsk and Novosibirsk (Siberian federal district), may allow Russian regions to achieve high levels of innovative performance despite relative remoteness from Moscow. Akademgorodok (Novosibirsk Oblast), a science city founded in the 1950s, has experienced strong growth in the IT sector in recent years and has been labelled “Silicon taiga” (EBRD, 2012).

Table 3. Cross-sectional estimation based on averages during period 1997-2011.

Dependent variable: Logarithm of patent applications per one million inhabitants.

VARIABLES	(1)	(2)	(3)	(4)	(5)
Number of Soviet-founded science cities	**0.1153*** (0.0224)**	**0.0375** (0.0170)**	**0.0312** (0.0128)**	**0.0332*** (0.0118)**	**0.0317** (0.0121)**
Defence employees per 1,000 industrial employees in 1985	**0.1077*** (0.0380)**	**0.0186 (0.0346)**	**0.0238 (0.0352)**	**0.0119 (0.0311)**	**0.0146 (0.0310)**
Distance to Moscow	**-0.0512*** (0.0184)**	**-0.0424*** (0.0142)**	**-0.1016* (0.0512)**	**-0.0857* (0.0466)**	**-0.0769* (0.0445)**
R&D expenditure as percentage of GDP		0.2429*** (0.0675)	0.2448*** (0.0681)	0.2404*** (0.0671)	0.2292*** (0.0651)
Human capital		0.0486*** (0.0132)	0.0556*** (0.0145)	0.0473*** (0.0129)	0.0476*** (0.0157)
Foreign firms' turnover as percentage of GDP		0.0065*** (0.002)	0.005** (0.0023)	0.0052* (0.0029)	0.0052 (0.0035)
Federal district dummies	NO	NO	YES	YES	YES
Internal Geography Cont	NO	YES	YES	YES	YES
Sectoral controls	NO	NO	NO	YES	YES
Socioeconomic controls	NO	NO	NO	NO	YES
Constant	0.4878*** (0.0997)	-1.2289*** (0.3509)	-1.4797*** (0.3853)	-1.1019* (0.6128)	-0.4062 (1.6204)
Observations	78	78	78	78	78
R-squared	0.3433	0.7983	0.8231	0.8653	0.8667

Robust standard errors in parentheses. *** p<0.01, ** p<0.05, * p<0.1

5. Conclusion

The existing debate about innovation in Russia has concentrated on national-level factors and cross-country comparisons, paying little attention to subnational heterogeneity within this vast country. Concentrating on differences in innovative performance between Russia's regions, this paper applies an augmented knowledge production function framework to improve our understanding of the key drivers of Russia's geography of innovation.

The paper sheds new light on the link between regional R&D efforts and patenting as well as the connection between human capital endowment and innovative performance. While critical voices have questioned the criteria underlying the allocation of public Russian R&D funds (Graham and Dezhina, 2008; Gokhberg and Roud, 2012), our analysis identifies regional R&D expenditure as a strong predictor of regional innovative performance. Conversely, changes in regional human capital are not strongly significant predictors of innovative performance. R&D activities in Russian regions are inadequately connected to regional human capital resources.

This asymmetric contribution of internal innovation inputs is coupled with a strong role played by external knowledge sources. Foreign firms may play an important role as global pipelines providing Russian regions with knowledge produced in distant places outside Russia. In addition, inter-regional spatially-mediated knowledge flows also constitute relevant 'inputs' in the genesis of new knowledge. However, different territorial dynamics are at play in the European and the Asian part of Russia: regions to the East of the Urals are less likely to benefit from interregional knowledge spillovers. For the Asian part of Russia inter-regional knowledge flows do not contribute to regional innovative performance. Instead, innovation hotspots may divert resources away from nearby regions with significant shadow effects.

The legacy of the Soviet era remains an important factor to explain current innovation patterns. The Soviet-founded science infrastructure is a significant predictor of current regional patenting performance. Path-dependencies in regional patterns of knowledge generation and the historical evolution of technological capabilities constitute key factors for the understanding of Russia's geography of innovation.

These results have several implications for the debate on Russia's innovative performance and recent innovation policies. The two most obvious policy levers emerging from our analysis concern the dissemination of knowledge and international linkages. The absence of strong evidence of regional spillovers particularly in Asian Russia suggests that there is a distinctly spatial dimension to the frequently mentioned deficiency of the Russian science system – weak knowledge diffusion. Recent policy measures, such as the establishment of specialized agencies designed to disseminate research findings (OECD, 2011) are aiming at the right direction. Similarly, the pronounced emphasis on the inclusion of international partners in the Skolkovo initiative (Radošević and Wade, 2014) appears justified in the light of the importance of international inputs for regional-level innovation in Russia. However, our results regarding spillovers also imply that localized megaprojects such as Skolkovo are unlikely to boost innovative performance across the country's vast territory. Any steps that jeopardize international linkages between Russian regions and innovative places outside Russia will undermine efforts to boost the country's innovative performance and reduce its dependence on natural resources.

In light of these considerations the success of measures to address the 'Russian Paradox' seems to be crucially conditioned upon the capability of the system to increase its international openness and the establishment of 'global' linkages while supporting – at the territorial level – their embeddedness into regional innovation systems.

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Online Appendix A

Table A1 - Descriptive statistics and data sources.

Variable	Unit	Mean	S.D.	Min.	Max.	Included in Model 1	Model 2	Source
Dependent variable								
Patenting	Log of patent applications per one mio inhabitants	0.6943	0.7604	0	3.6116	X	X	OECD
Localised innovation inputs								
R&D	R&D expenses as percentage of regional GDP	0.8374	0.9547	0.0096	5.3809	X	X	Rosstat
Spatially weighted R&D	Weighted average of total R&D expenditure of other regions (in billion Roubles), based on k4-neighbours	3.3212	7.5943	0.0076	74.9606	X		Rosstat
Human capital	Percentage of employees with higher education	22.3215	5.9099	7.3	49.9	X	X	Rosstat
International linkages								
Foreign firms' turnover	Foreign firms' turnover as percentage of regional GDP	25.4162	27.8504	0	191.2554	X	X	Rosstat
Space								
Urbanization	Percentage of population living in urban areas	69.41983	12.46759	23.9	100	X	X	Rosstat
Sectoral specialization								
Agriculture	Share of regional GDP	10.1933	6.366	0	33.7	X	X	Rosstat
Manufacturing	Share of regional GDP	31.3494	12.3144	4.3	68.8	X	X	Rosstat
Transport and communications	Share of regional GDP	10.7529	4.9924	2	34.1	X	X	Rosstat
Services and retail	Share of regional GDP	13.588	5.3893	3.2	53.6	X	X	Rosstat
Construction	Share of regional GDP	7.4463	3.8148	0.4	32.6	X	X	Rosstat
Index of resource potential	Rank among all regions	42.8932	23.8895	1	89	X	X	Expert RA
Index of oil and gas production	Output as percentage of level in 1992	48.7894	66.9247	0	812.8	X	X	Rosstat
Socioeconomic controls								
Birth rate	Number of births per 1,000 inhabitants	10.6555	2.6459	6.2	27.7	X	X	Rosstat
Percentage of ethnic Russians	Percentage of region's population	76.7365	22.7747	3.5743	97.4247	X	X	Rosstat
Historical legacy from Soviet period								
Defence employees (time-invariant)	Defence employment in 1985 as percentage of total industrial employment in 1985	21.8891	12.7504	0	57		X	Gaddy (1996)
Science cities (time-invariant)	Number per region	0.7821	2.3502	0	19		X	Gokhberg (1997), Becker et al. (2012), website of union of science cities
Distance to Moscow	Distance in kms.	2333.346	2707.145	0	11736		X	Authors' calculation

Description of weights matrix

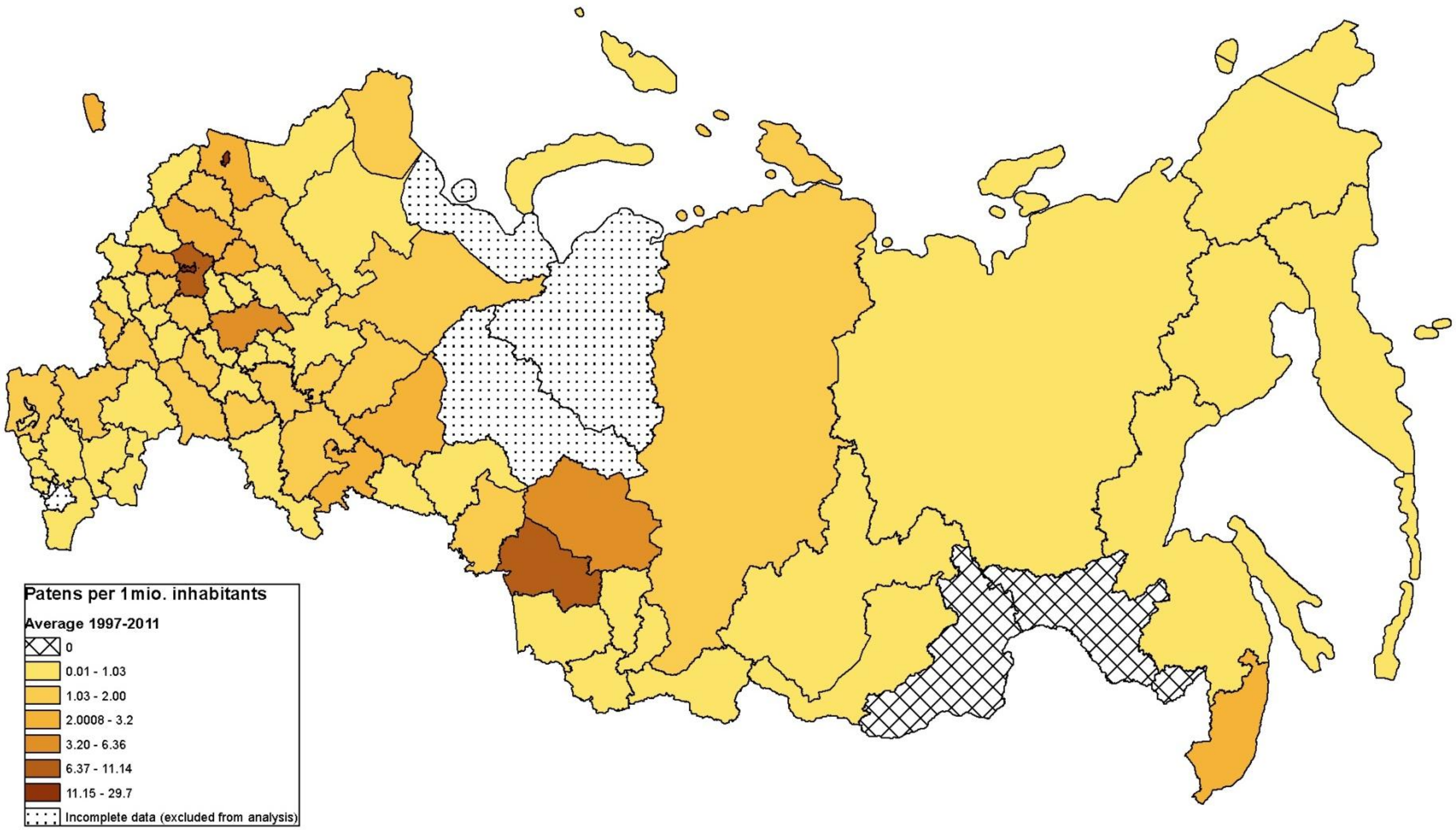
We follow Crescenzi and Rodríguez-Pose (2008) and OECD (2009b) and choose k-nearest-neighbour weights which are calculated as follows:

$$W(k)=\begin{cases} w^{*}{}_{ij}(k)=0 & if \quad i=j \\ w^{*}{}_{ij}(k)=1 & if \quad d_{ij}\leq d_{i}(k) \\ w^{*}{}_{ij}(k)=0 & if \quad d_{ij}>d_{i}(k) \end{cases} \quad \text{and} \quad w_{ij}(k)=\frac{w^{*}{}_{ij}(k)}{\sum_{j} w^{*}{}_{ij}}$$

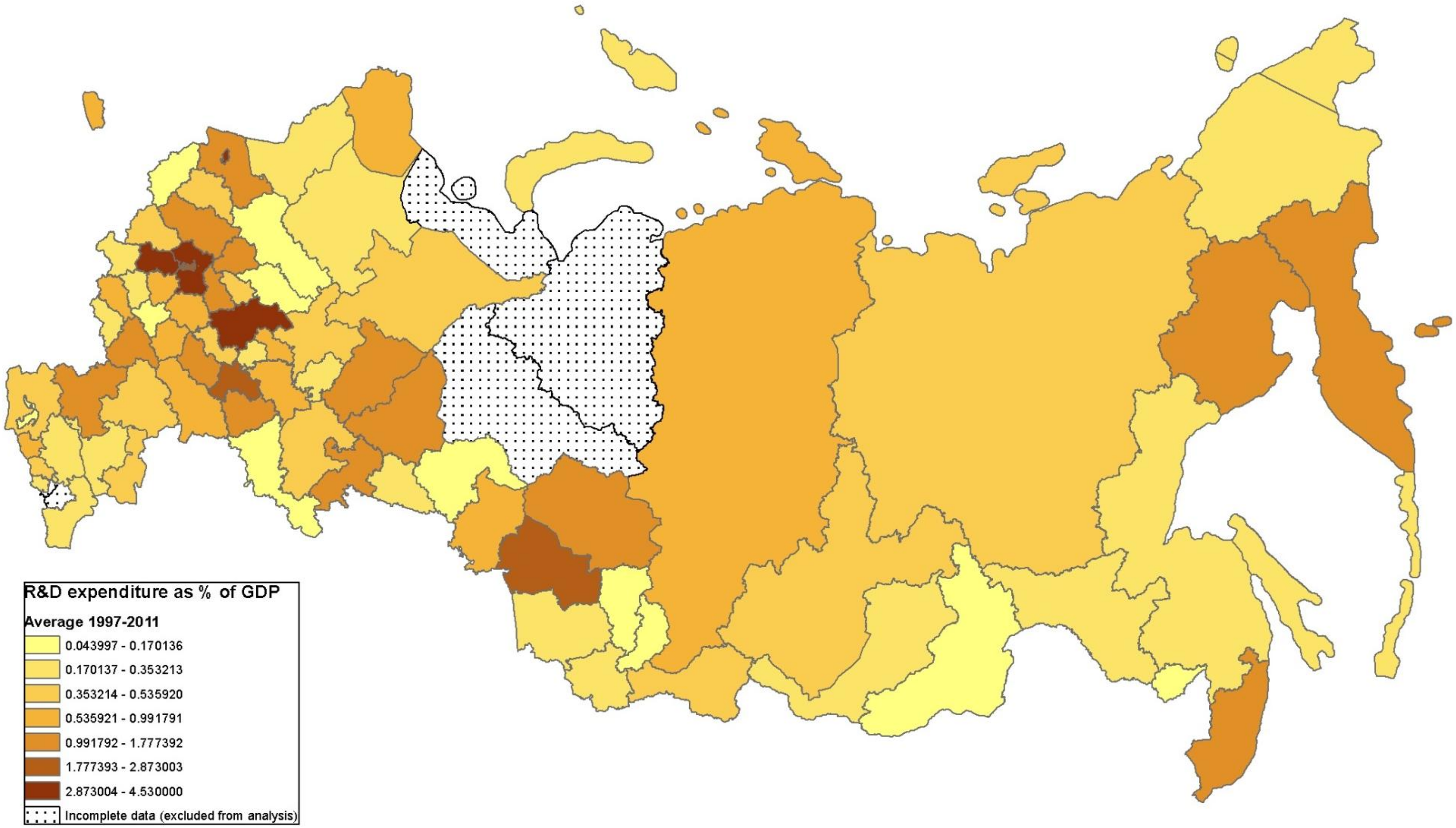
where di(k) is the k^{th} order smallest distance between region i and j such that each region *i* has exactly *k* neighbours (Ertur and LeGallo, 2003). Acknowledging that the "true" weights matrix will always remain unknown (Anselin, 2002; Gibbons and Overman, 2012), we test four types of k-nearest-neighbour weights: k=2, k=3, k=4, and k=5.

Online Appendix B – Maps of the key variables

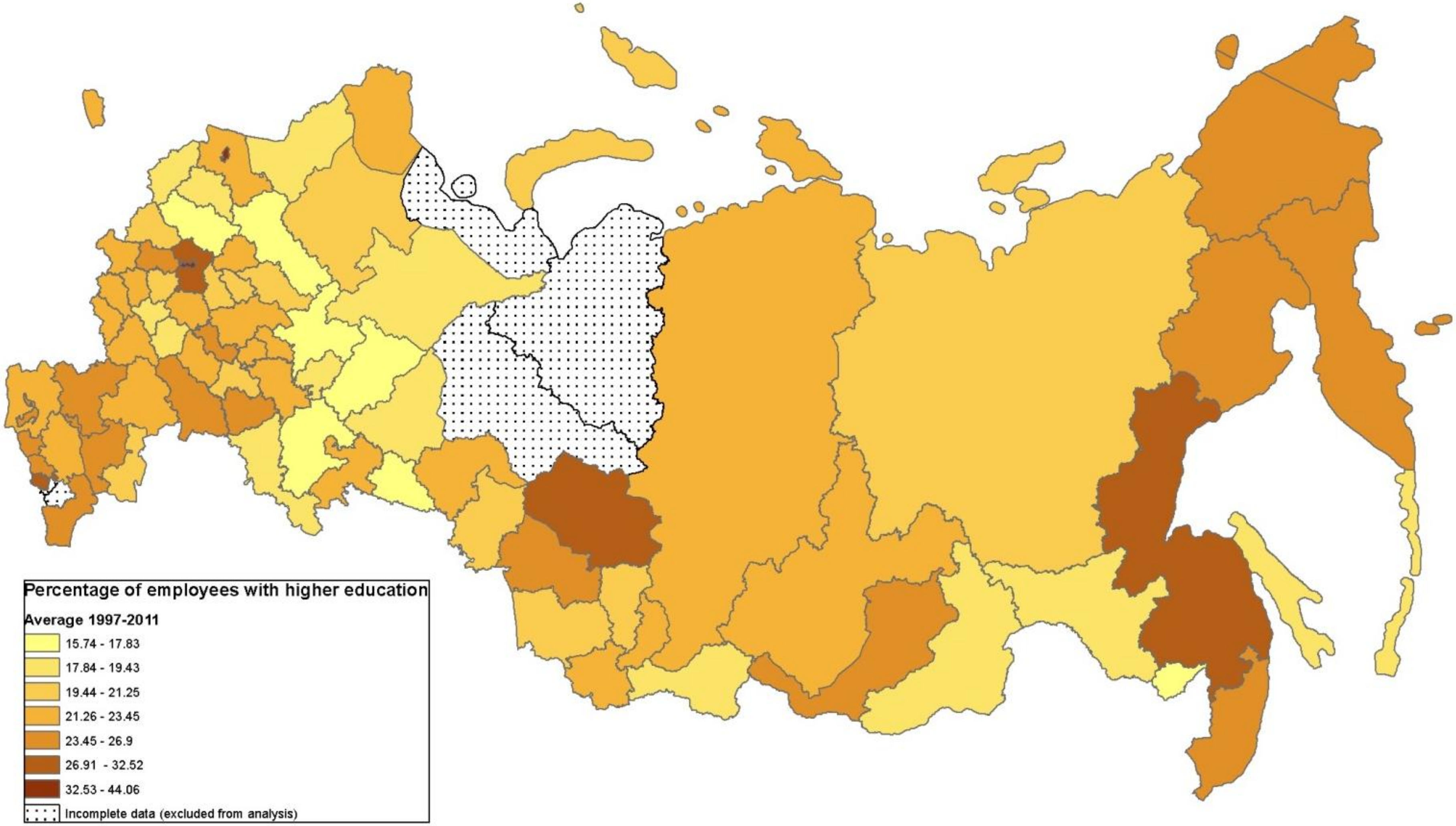
Map M1 - Patenting per one million inhabitants.



Map M2. R&D expenditure as percentage of GDP.



Map M3. Percentage of employees holding higher education certificate.



Map M4. Foreign firms' turnover as percentage of GDP.