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Innovation in Russia: the territorial dimension

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Abstract

The debate on Russia's innovation performance has paid little attention to the role of geography. This paper addresses this gap by integrating an evolutionary dimension in an 'augmented' regional knowledge production function framework to examine the territorial dynamics of knowledge creation in Russia. The empirical analysis identifies a strong link between regional R&D expenditure and patenting performance. However, R&D appears inadequately connected to regional human capital. Conversely, Multinational Enterprises (MNEs) play a fundamental role as 'global knowledge pipelines'. The incorporation of historical variables reveals that the Russian case is a striking example of long-term path-dependency in regional patterns of knowledge generation. Endowment with Soviet-founded science cities remains a strong predictor of current patenting. However, current innovation drivers and policies also concur to enhance (or hinder) innovation performance in all regions. The alignment of regional innovation efforts, exposure to localised knowledge flows and injections of 'foreign' knowledge channelled by MNEs make path-renewal and path-creation possible, opening new windows of locational opportunity.

Keywords: Innovation, R&D, evolutionary economic geography, regions, BRICS, Russia

JEL classifications: R11, R12, O32, O33

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1. Introduction

Despite its relatively advanced technological position after the collapse of the Union of Soviet Socialist Republics (USSR) and substantial investment 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 institutional factors: weak linkages (Klochikhin, 2012), inadequate intellectual property rights protection (Aleksashenko, 2012), insufficient evaluation of public R&D spending (Graham and Dezhina, 2008), degradation of human capital (Gaddy and Ickes, 2013) and negative effects of natural resource abundance (EBRD, 2012). Several authors compare Russia's performance with China's and India's (Cooper, 2006; Klochikhin, 2013). However, despite the country's special spatial configuration, the existing literature has paid little attention to the geographical aspects of the genesis of knowledge in Russia.

As the world's largest country by land area, Russia covers roughly a third of Europe's and Asia's combined continental landmass. Low density and large distances between population centres (especially in the East) interact with a distinctive historical legacy, shaping patterns of knowledge production and diffusion. Space and history hence appear particularly important in the Russian case. In contrast to the cross-country perspective characterizing most previous contributions, this paper concentrates on differences in knowledge generation across Russia's regions. The analysis sheds light on potential spatial mismatches that might help to address the long-debated 'innovation paradox' from a geographical perspective.

This paper contributes to the growing stream of Economic Geography literature looking at the territorial dynamics of innovation in emerging countries (Fu, 2008; Llisteri et al., 2011; Crescenzi et al., 2012), which builds upon the broader geography of innovation literature (Feldman, 1994; Storper, 1997; Crescenzi and Rodriguez-Pose, 2011). Empirical work since the 1990s has improved our understanding of geographical patterns of knowledge creation in advanced economies. Yet, we are only starting to investigate whether similar mechanisms apply in different institutional and technological contexts. As emerging economies' share of global knowledge production increases, innovation policies adopted by countries like Russia are frequently inspired by advanced economies' experiences and often have a clear spatial dimension (Radošević and Wade, 2014). In response to this trend, this paper aims to push the geography of innovation boundaries beyond its OECD-centred perspective in order to be able to participate in the debate about innovation in emerging countries (Lundvall et al., 2009) and support evidence-based design of policies.

This paper also responds to renewed interest in evolutionary concepts and in the relevance of historical legacies in shaping the interaction between path-dependence and path-creation, impacting on contemporary geographies of transformation, innovation and development (Martin and Sunley, 2007; Boschma and Martin 2010). Russia inherited a large-scale science and R&D infrastructure following the USSR's breakup. Legacies of the Soviet era are likely to influence present-day patterns of innovation, linking long-term path-dependence and path-creation with present-day geography. Whereas existing quantitative analyses of the geography of innovation are often restricted to contemporaneous variables, the availability of proxies for USSR-related historical factors provides us with a unique opportunity to investigate the role of evolutionary elements in explaining today's knowledge-generation patterns.

This paper explores the territorial dynamics of knowledge creation in Russia by 'augmenting' the regional knowledge production function (O'hUallachain and Leslie, 2007; Charlot et al., 2014) in order to account for spatially-mediated inter-regional knowledge flows, global knowledge pipelines in the form of foreign direct investment (FDI) as well as long-term historical geographies from the Soviet era. Although data constraints force us to rely on patent intensity as a proxy for innovation - section 3 extensively discusses the limitations of this indicator - a number of new insights emerge from the empirical analysis, testing factors that have been rarely verified empirically in the evolutionary economic geography literature.

The results reveal a strong connection between regional R&D investment and patenting performance. However, they also suggest that R&D is inadequately aligned with regional human capital. This fundamental spatial mismatch between two key inputs to the knowledge creation process is likely to hamper the returns to regional R&D expenditure. At the same time, regional access to external knowledge is highly differentiated. On the one hand, multinational enterprises (MNEs) seem to play a pivotal role, forming global pipelines that 'channel' new knowledge into Russian regions. On the other hand, inter-regional localised knowledge flows seem to benefit mostly 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 impair all Russian regions' innovation performance. However, adverse effects are likely to be particularly pronounced in Eastern regions that cannot rely on localised knowledge flows to compensate – at least temporarily – for their remoteness.

These results confirm the importance of incorporating an evolutionary historical dimension (Arthur, 1989; David, 2005) in the knowledge production function framework. The empirical results unveil a strong path-dependency in geographical processes. The legacy of Soviet-founded science cities remains a strong predictor of current regional patenting performance. Soviet planners' decisions regarding the concentration of human capital and research activities in a set of specialized locations continue to influence Russia's geography of patenting. However path-dependency constantly interacts with path-creation and path-renewal opportunities offered by exposure to external knowledge in the form of spatially-mediated knowledge flows and MNE activities. Recent public policy attempts to develop new innovation centres in Russia, such as Skolkovo, have to confront these forces and leverage path-creation factors in order to generate the conditions for new *milieux* to enter virtuous long-run evolutionary trajectories.

2. Innovation in Russia: context and recent trends

In the USSR, establishments in Russia accounted for three quarters of Soviet R&D expenditure (Gokhberg, 1997: 15). After the USSR's collapse innovation-enhancing changes – e.g. freedom of mobility – were overshadowed by dramatic reductions in R&D resources (Cooper, 2008). Notwithstanding the Soviet system's implosion after 1991, analysts of Russia's present innovation system consider many of its strengths and weaknesses as Soviet legacies (Klochikhin, 2012; Narula and Jormanainen, 2008). The country retained strong positions in defence-related fields (aerospace, nuclear science). Although Russia inherited large numbers of highly educated workers, budget cuts severely affected the education sector and drove up researchers' average age (Graham and Dezhina, 2008).

Key weaknesses identified in analyses of Russia's innovation system concern institutions (Klochikhin, 2012). Despite recent steps to strengthen intellectual property rights, enforcement has not reached Western standards (Aleksashenko, 2012). R&D funding allocation still broadly resembles Soviet-era patterns (OECD, 2011). Until 1991, most R&D activities took place outside firms, remaining functionally and organizationally separated from production (Cooper, 2008). Today the public sector remains the key player, with government agencies - separated from firms - conducting nearly 75% of total R&D (EBRD,

2012) and weak linkages between innovative agents (Gokhberg and Roud, 2012). The role of private firms grows only slowly, with 20% (EBRD, 2012) conducting intramural R&D.

Amidst concerns over natural resource dependence, innovation has recently moved up the political agenda. Initiatives launched in the 2000s include new technology parks, SME support agencies, and venture capital funds (Graham, 2013). In 2007 the government launched an organization to promote nanotechnology ('RUSNANO') endowed with approximately 16.4 billion US Dollars (Gokhberg et al., 2012). However, so far, these ambitious policies have failed to shift the economy to a knowledge-based growth path.

In another state-directed effort, plans for an 'innovation city' – Skolkovo - in the Moscow region (enclosing Russia's capital like a belt) were announced in 2009. Skolkovo involves close collaboration with foreign corporations (e.g. Intel) and academic partners (e.g. MIT). This megaproject is meant to generate lessons for other Russian regions (Gokhberg and Roud, 2012). Given the strong spatial dimension of such initiatives, a better understanding of the territorial dynamics of innovation in Russia is of paramount importance. At the same time, Russia is a very important laboratory for innovation policies that can offer policy lessons for other emerging countries aiming at shifting towards knowledge-based growth models.

3. The Geography of Innovation in Russia

Capturing innovation in emerging economies is a conceptual and empirical challenge. Whereas a large proportion of innovation in advanced economies is new to the world as a whole, in developing and emerging countries innovations tend to be mostly new to the individual firm (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). In order to capture the complexity of firms' innovation strategies, it would be ideal to analyse firm-level innovation data (such as the EU's Community Innovation Survey or Brazil's Pintec). However, the regional-level coverage of such data is still very limited in Russia. Patent Cooperation Treaty (PCT) patent applications (counted according to inventor's region of residence) therefore remain the best available proxy for regional knowledge production.

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). Not all forms of inventions are equally likely to be patented (Griliches, 1990) and data constraints force researchers to focus on inventions for which there are reliable data (Brenner and Broekel, 2011; Smith, 2005). The global novelty requirement associated with PCT patents implies that minor adaptations, imitations, and innovations primarily new to Russia's market will not be captured by our proxy. We hence capture a subset of the new knowledge generated in Russian regions; especially knowledge with relevance to export purposes and proven novelty on a global scale. However, "the PCT reflects the technological activities of emerging countries quite well (Brazil, Russia, China, India, etc.)" (OECD, 2009: 66)[1].

Russia's territory is subdivided into 83 regions.[2] In 2011 Moscow and St. Petersburg, where 11.4% of Russians live, accounted for nearly 51% of all PCT applications ; down from

[1] We chose PCT patents after a careful consideration of all options. While this comes at the price of discounting inventions 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, 2009: 65). The use of PCT also facilitates comparisons with related studies (Crescenzi et al., 2012; Fagerberg et al., 2014). In 2012, Russia accounted for 77.9% of PCT filings from European middle-income countries (WIPO, 2013: 28) and China overtook Germany as PCT's third-largest user in 2013 (WIPO, 2014).

[2] Following the events of March 2014, two regions (Republic of Crimea; city of Sevastopol) were added. Rosstat did not cover these territories during our period of analysis.

68% in 1995. *Figure 1* illustrates the regional distribution of patenting between 1995 and 2011, focussing on the 10 regions with the highest patent counts. The leading regions' share has slightly decreased over this 17-year period. While the top five regions still accounted for 82.4% of Russian PCT patenting during 1995-1998, their share accounted for 74.3% during 2008-2011. Knowledge production (as proxied by PCT applications) in Russia has slowly become less spatially concentrated, as lower-tier regions increased their contribution.[3]

Kaliningrad and Tomsk are two examples of second-tier regions that increased patenting between 1997 and 2011. A Russian enclave between Lithuania and Poland, Kaliningrad benefits from tax exemptions and has emerged as a major FDI recipient in recent years (Ledyaeva et al., 2015). Roughly 4,000 Kilometres further east – in the southwest of the Siberian Federal District – the region of Tomsk has been one of Russia's leaders in the promotion of knowledge-based development. A programme supporting firms to enter foreign markets and networks (e.g. via trade fairs) resonates with recent contributions in economic geography emphasizing access to knowledge from distant sources (Maskell, 2014). A vibrant technology park and incubators for spin-offs from the region's six state universities are further examples of Tomsk's innovation policies (OECD, 2011).

[3] For a map of Russia showing key cities and regions mentioned in the paper as well was regional patenting intensities, see online appendix B.

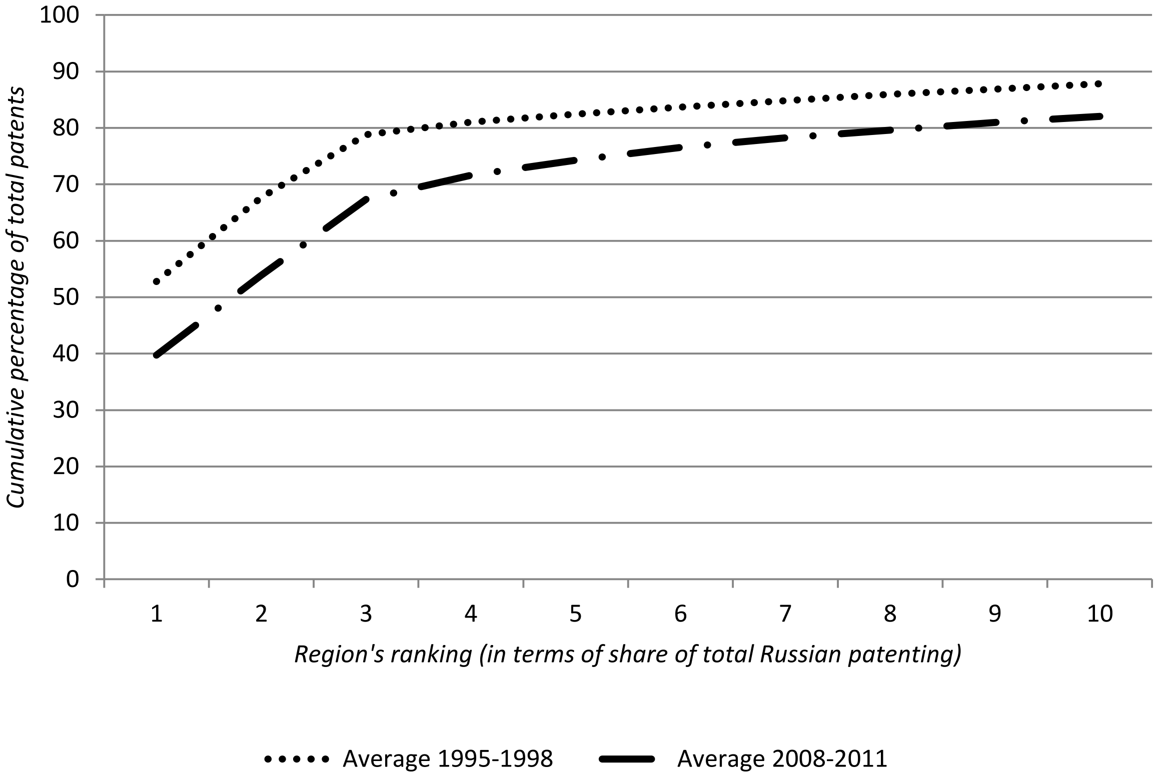

Figure 1: Cumulative distribution of Russian PCT patent applications: 10 most innovative regions.

Russia's R&D investments are also spatially concentrated – beyond the level of clustering of the population. Out of Russia's eight federal districts (administrative groupings of regions; without decision-making powers), the Central District (which includes Moscow), the North-Western District (encompassing 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 strong role of the state in Russia's innovation system, public spending decisions shape the geography of R&D. The capital hosts numerous public research centres and higher education institutions. Yet, several regions (e.g. Tomsk) have significantly intensified their R&D efforts (R&D expenditures relative to GDP) during 1997-2011.

The geography of human capital is also uneven, with firms in Eastern regions particularly likely to report skill shortages (EBRD, 2012). The share of citizens holding a university degree ranged from 11.9% in Chechnya to 41.2% in Moscow in 2010 (Russian census, 2010). Highlighting spatial variation in quality of education, Amini and Commander (2012) find that pupils' performance is positively associated with population size of the town where they attend school.

The circulation of knowledge among innovation centres is likely to be hindered 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). Therefore, places outside Russia's relatively densely populated European part may face higher costs in accessing knowledge produced in other regions. Russia's spatial distribution of capital and labour still reflects central planners' decisions that often ignored transport costs, agglomeration economies, and climatic conditions (Gaddy and Ickes, 2013). The inefficient location of factors of production is likely to slow down economic transactions and knowledge diffusion.

Peripheral regions may compensate for their isolation by relying on alternative proximities to access external knowledge. However, low inter-regional labour mobility (Andrienko and Guriev, 2004; Ivakhnyuk, 2009) may weaken such linkages between Russian regions. Studies examining inter-regional trade found low levels of regional integration (Gluschenko, 2010), with Berkowitz and DeJong (1999) uncovering 'internal borders'.

While inter-regional knowledge circulation is constrained by physical and institutional factors, opportunities to access knowledge via global linkages are also highly localised and hampered by geo-political factors. 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 often prevent foreigners from filling skill gaps (EBRD, 2012). Skolkovo's emphasis on international collaboration indicates that Russian policy-makers appreciate the potential benefits of exposure to new knowledge. However, recent political events after Crimea was announced part of Russia threaten to undermine these efforts to reduce the country's relative isolation.

Great heterogeneity characterizes Russian regions' levels of embedment in international business networks (Gonchar and Marek, 2014; Ledyaeva et al., 2015). Foreign investments are mostly attracted by Russia's market size and natural resources (Ledyaeva, 2009). A limited number of agglomerations in Western Russia and resource-rich regions in Eastern Russia attract the lion's share of FDI. Highly dependent on hydrocarbons, 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% of foreign firms (i.e. at least 10% foreign ownership and at least one million roubles of capital) were registered either in Moscow, in the region of Moscow, or in St. Petersburg (Ledyaeva et al., 2013: 4). In addition to Kaliningrad, foreign firms play a growing role in a number of destinations beyond Moscow and St. Petersburg. Devoid of natural resources, Kaluga (150 kms southwest of Moscow) has focused on improvements of business conditions and succeeded in establishing an automotive cluster with large MNEs (e.g. Peugeot-Citroën). With FDI scattered across the country in a mosaic pattern, opportunities to benefit from this source of extra-local knowledge are distributed unevenly across Russian regions.

While the spatial configuration of knowledge sources is key to the understanding of Russia's current geography of innovation, two fundamental aspects of the spatial legacy of the Soviet era are also crucially important: 'science cities' and major 'military installations'. Soviet planners dedicated large resources to the creation of 'science cities'. Often isolated from the rest of the world, these places offered researchers privileged living conditions

(Castells and Hall, 1993). Most of these cities entered a period of decline after 1991 but others, e.g. Akademgorodok near Novosibrisk (Siberian federal district), have developed new identities and attracted MNEs (Becker et al., 2012). The Moscow region is known for Soviet-founded science cities and research centres that still show remarkable dynamism, e.g. in nuclear energy (Dubna, Protvino) and physics (Troitsk).

Conversely, high levels 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 high-tech clusters' emergence (Saxenian, 1994), areas specialized in Soviet military production in the 1980s did not display higher human capital levels at that time (Gaddy, 1996). In a context of resource constraints, uncertainty, and defence conversion, Russia's military sector as a whole did not gain a reputation as the spearhead of innovation in the transition years but appeared "largely to be living off the intellectual capital of the Soviet era" (Eberstadt, 2011: 106).

4. A theory-driven framework for empirical analysis

The spatial organisation of innovative activities in Russia points to the importance of the R&D-patenting nexus. Those Russian regions accounting for a high share of total Russian R&D spending simultaneously seem to be major hubs of patenting. However, this 'linear' link - observed in numerous regions in developed countries (Botazzi and Peri, 2003; O'hUallachain and Leslie, 2007) - appears weaker in emerging countries (Crescenzi et al., 2012). Therefore, one needs to 'augment' the 'traditional' regional knowledge production function to account for a wider set of territorial factors determining – in case of Russia – the balance between (historical) path-dependency and path-creation.

Relative to sparsely populated places, regions with a largely urban population are likely to face lower costs of exchanging knowledge within the region (Jacobs, 1969; Carlino and Kerr, 2015). The difficulty of transferring highly valuable tacit knowledge across large distances (Storper and Venables, 2004) has fundamental implications for regional knowledge production in a country characterized by large distances between agglomerations. Geographical remoteness may constitute a structural disadvantage in the form of reduced exposure to knowledge flows. Places within the driving range of innovation centres are favoured by knowledge inflows via face-to-face contacts (Rodríguez-Pose and Crescenzi, 2008). Geographical distance to Moscow, the traditional centre of Russia's innovation system (Gokhberg, 1997), might therefore shape exposure to inter-regional knowledge flows.

To compensate for limited exposure to inter-regional knowledge flows regions may rely on 'global pipelines': linkages - not necessarily based on geographical proximity - to innovative places that provide valuable knowledge inputs (Bathelt et al., 2004). MNEs may act as channels for cross-border knowledge flows, increasing regional patenting performance (see Ford and Rork, 2010 for the USA; Fu, 2008 for China). Therefore, Russian regions' knowledge production might also be influenced by their access to inputs from locations outside Russia – in line with evidence that international collaboration enhances Russian researchers' productivity (Ganguli, 2011).

Internal efforts and external inputs are translated into new knowledge in diverse ways in different regional contexts. Long-term evolutionary trajectories and heterogeneous regional systems of innovation conditions (Braczyk et al., 1998) shape the way in which both R&D and human capital are organised in space and matched with each other. With Russia's innovation system struggling to overcome its top-down bias and R&D's separation from production, path-dependencies (Klochikhin, 2012) are of particular relevance in the Russian case. As emphasized by evolutionary economic geography (Rigby, 2000; Iammarino, 2005), inherited socio-institutional structures and specialisation patterns shape future development opportunities. Russian regions' historical endowments with R&D-related infrastructure from

Soviet days are likely to influence present-day capacities to generate knowledge. Involvement in USSR military production and endowment with Soviet-founded science cities can be expected to play a key role in shaping current systemic conditions.

4.1 Augmenting the regional knowledge production function

Path-creation evolutionary forces (matching between local innovation efforts and human capital as well as exposure to inter-regional and 'global' knowledge flows) and path-dependency (linked to historical legacy) can be combined into an 'augmented' knowledge production function (Charlot et al., 2014) 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 PCT applications, counted according to the inventor's region of residence, per one million inhabitants. .
$R\&D_{i,t-2}$	is R&D expenditure as a percentage of regional GDP[4].
$WR\&D_{i,t-2}$	is a spatially weighted[5] average of the R&D expenditure in neighbouring regions[6] (i.e. excluding region *i*) as a proxy for exposure to inter-regional knowledge flows

[4] As highlighted by one referee, this analysis would benefit from R&D data disaggregated by source of funding. This information is unfortunately unavailable at the regional level.

[5] Since Russian regions differ vastly in area, 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 inflate the number of small regions' neighbours (Anselin, 2002). Simple contiguity weights may introduce bias due to heterogeneity in the number of neighbours. The k-neighbours scheme is therefore the most suitable choice. It allows us to connect

$HUMAN\_K_{i,t-1}$ is the share of employees with higher education. This variable encompasses post-secondary degrees, including technical training.[7]

$FOREIGN_{i,t-1}$ is the turnover of foreign enterprises as a percentage of regional GDP[8].

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

Socioeconomic controls - Two controls for socioeconomic conditions. Motivated by findings suggesting that a younger demographic structure enhances patenting (Crescenzi et al., 2007), we include the region's share of the population aged 15 or younger. To adjust our knowledge production framework to idiosyncrasies of the Russian context, we also add the share of ethnic Russians. As several Russian regions with large ethnic minorities are conflict-prone, controlling for this appears important.[9]

Kaliningrad to mainland Russia. For details regarding the calculation of weights, see online appendix A.

[6] Ideally, we would also consider R&D in adjacent regions in neighbouring countries. Given the diversity of statistical procedures used by neighbouring countries, this was not feasible. Including regional fixed effects partly addresses this problem by capturing proximity to the nearest national border.

Geographical control - the percentage of the regional population living in urban areas[10] as a proxy for the geographical distance between agents within each region.

Time dummies λ_t are included to account for common shocks, such as macro-economic crises. Conversely, region-fixed effects γ_i, enable us to control for the time-invariant part of unobserved heterogeneity: this includes the cross-sectional dimension of variation in regions' institutional 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 between R&D investments and patent applications[11], R&D (and its spatial lags) enters the regional knowledge production function with a two-period lag. All other independent variables are lagged by one period in order to reduce the likelihood of reverse causality. We adopt an averaging strategy to deal with the volatility of our data; as customary in similar studies (Botazzi and Peri, 2003; O'hUalla-chain and Leslie, 2007). The link R&D-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.

[10] Becker et al. (2012) provide a discussion of the Russian definition of "urban" and "rural". "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).

[11] Fischer and Varga (2003) choose a two-year lag, Ronde and Hussler (2005) use R&D expenditure in 1997 to explain patenting during 1998-2000. O'hUalla-chain and Leslie (2007) relate R&D efforts in 2000 and 2001 to patenting during 2002–2004. The time lag helps to mitigate - to some extent - reverse causality problems regarding the R&D-patenting relationship.

The model is estimated for 1997-2011 and covers 78 out of 83 Russian regions.[12] Data on patent applications come from the OECD-RegPat database. Apart from the resource potential index (provided by rating agency Expert RA), data for all other time-varying variables come from Russia's statistical agency Rosstat (see also *Table A1* in the online appendix). Rosstat collects information on numerous social and economic indicators. We primarily relied on data from 15 editions (1997-2011) of the annual publication "Regioni Rossii" (Rosstat, 1997) and partly drew on a database prepared by Mirkina (2014) providing user-friendly access to the same Rosstat data. Firm-level information relies on compulsory statistical reports submitted to Rosstat's regional offices. Rosstat's collection of R&D data is inspired by the EU Community Innovation Survey. Unlike the sampling used by most EU countries, the Russian innovation survey is a mandatory census (OECD, 2011).

The inclusion of region and year-fixed effects reduces the likelihood of omitted variable bias and allows us to control for time-invariant region-specific variables (e.g. institutional conditions). However, in a second step of the analysis we use a cross-sectional regression to shed descriptive light on a set of variables otherwise absorbed by the regional fixed effects: historical endowments and distance to Moscow.

The cross-sectional specification includes the following additional time-invariant variables aimed at capturing the spatial impact of historical legacies:

Proxies for endowment with Soviet-founded science infrastructure and military facilities. Based on several sources (including Gokhberg, 1997; Becker et al., 2012; union of science cities' website), we compiled a list of 63 Soviet-founded science cities. As a second

[12] Data constraints forces us to exclude Chechen Republic, Republic of Ingushetia, sub-region Nenets Autonomous Okrug, sub-region Khanty Mansi Autonomous Okrug – Yugra, and sub-region Yamalo Nenets Autonomous Okrug. Based on averages (1997-2011), those regions account for 2.38% of Russia's population and 0.56% of all regions' R&D expenditure.

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 the militarization of a region's economy in late Soviet years.

Measure of remoteness from the centre of the innovation system. The geography of innovation literature stresses the advantages of spatial proximity to centres of knowledge production (Feldman and Kogler, 2010). To take into account a region's remoteness relative to the traditional centre of Russia's innovation system, our estimations include the distance between the regional capital and Moscow. In the Soviet era, Moscow accounted for 30% of USSR R&D expenditure (Gokhberg, 1997: 15) and continues to play a pivotal role in the production of new knowledge (Graham, 2013). Roughly 20 kilometres west of central Moscow, the ambitious Skolkovo innovation centre (founded in 2009) may increase the capital region's importance even further in the future (Radošević and Wade, 2014). Distance to Moscow simultaneously roughly captures distance to the most densely populated part of Russia and to the European Union. Due to this variable's time-invariant character, we can only include it in cross-sectional estimations.[14]

5. Empirical Results

Tables 1 and *2* provide the results of the main analysis based on panel fixed-effect estimations. *Table 1* focuses on the association between regional patenting and internal drivers and 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

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[13] Gaddy's (1996) estimates rely on omitted categories in official documents. For a discussion of their limitations, see Gaddy (1996).

[14] Descriptive statistics are provided in Table A1 in the online appendix.

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 no longer statistically significant. In all following estimations we therefore lag R&D by 2 periods, equivalent to a delay of three to five years. Similar lags are used by Fritsch and Slavtchev (2007), Ronde and Hussler (2005), and Usai (2011).

Our results reveal a positive and statistically significant association between regional R&D expenditure and patenting. This result is robust to the inclusion of all other variables (columns 2-7). Considering the debate about insufficient monitoring 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 expenditure is a strong predictor of regional patenting performance.

Whereas our result for R&D is largely in line with the literature, we do not find a strongly significant association between regional human capital and patenting. Russia's higher education system expanded remarkably in the past two decades, with enrolment 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). With limited external influence on curricula, rapid increases in enrolment and private establishments' expansion may have diluted quality standards (Nikolaev and Chugunov, 2012).

It has also been argued that the service sector's expansion and reduced R&D spending in transition years have incentivized students to acquire skills that are not conducive to innovation (EBRD, 2012). Motova and Pykkö (2012: 27) emphasize that enrolment 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, Gaddy and Ickes (2013) and Cooper (2006) regard curricula inherited from the Soviets as ill-suited for a market-based economy.

It hence appears plausible that our variable imprecisely measures the skills that are of relevance to patenting. 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 R&D. Graduates with quantitative skills often find employment in activities offering higher wages than the mostly publicly funded R&D positions, such as financial services (OECD, 2011). Average salaries in Moscow's R&D sector were only 47% of those paid in Moscow's finance sector in 2009 (Makarov and Varshavsky, 2013: 474), making careers in innovation-related activities relatively unattractive. Regional patenting may therefore not benefit from increases in the regional human capital stock if skills are not employed in research-intensive activities.

As we extend our analysis to include foreign firms (column 5), access to extra-regional knowledge emerges as a key driver of patenting performance. The coefficient is significant and positive. This result sheds light on the role of MNEs in Russian regions: since their subsidiaries are simultaneously embedded in their host regions and in global intra-firm networks, MNEs facilitate the transmission of knowledge flows. Our analysis suggests that these extra-regional linkages provide Russian regions with valuable inputs, boosting their knowledge production.

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, in t	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)	0.1977*** (0.0659)
R&D expenditure as percentage of GDP, in t-3			0.1226 (0.0871)				
Human capital, in t-1				0.0123 (0.0082)	0.0122 (0.0082)	0.0145* (0.0081)	0.0148* (0.0080)
Foreign firms' turnover as percentage of GDP, in t-1					0.0030** (0.0012)	0.0034*** (0.0011)	0.0034*** (0.0011)
Internal geography	NO	NO	NO	NO	YES	YES	YES
Sectoral controls	NO	NO	NO	NO	NO	YES	YES
Socioeconomic controls	NO	NO	NO	NO	NO	NO	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)	-5.4614** (2.2512)
Observations	546	468	390	468	468	468	468
R-squared	0.2087	0.2073	0.1950	0.2108	0.2283	0.2584	0.2651
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 estimation 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, in t-2	0.1804*** (0.0525)	0.1882*** (0.0540)	0.1892*** (0.0540)	0.2065*** (0.0584)	0.2065*** (0.0589)	0.2011*** (0.0591)
W R&D (k4), in t-2	0.0150*** (0.0033)	0.0148*** (0.0032)	0.0127*** (0.0034)	0.0114** (0.0044)	0.0107** (0.0042)	0.0107** (0.0044)
W R&D (k4) X in Asia (interaction term)					-0.0904** (0.0373)	
Human capital, in t-1		0.0116 (0.0081)	0.0127 (0.0080)	0.0145* (0.0081)	0.0132 (0.0081)	0.0142* (0.0081)
Foreign firms’ turnover as percentage of GDP, in t-1			0.0023** (0.0012)	0.0031*** (0.0011)	0.0028** (0.0011)	0.0038*** (0.0012)
Foreign firms’ turnover (% of GDP) X Moscow/St.Pete (interaction)						-0.3750** (0.1561)
Sectoral controls	NO	NO	NO	YES	YES	YES
Socioeconomic controls	NO	NO	NO	YES	YES	YES
Internal geography	NO	NO	NO	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)	0.2201 (0.1605)	-5.1973** (2.2204)	-5.3184** (2.2113)	-5.3292** (2.2069)
Observations	468	468	468	468	468	468
R-squared	0.2220	0.2251	0.2335	0.2722	0.2760	0.2762
Number of regions	78	78	78	78	78	78

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

The first part of our analysis revealed that 'global pipelines' play a key role, potentially allowing regions to overcome disadvantages associated with the spatial dispersion and relative isolation of Russia's innovation hubs. The second part focuses on inter-regional knowledge flows or spillovers within Russia. As *Table 2* shows, we identify a positive and statistically significant association between regional patenting performance and the spatially weighted average of neighbouring regions' R&D expenditure (column 1). The progressive inclusion of additional knowledge 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 different dynamics are at play in the European and Asian parts of Russia the model is 'augmented' by an interaction term. This additional variable is the product of the spatially weighted R&D expenditure and a dummy variable that equals one if a region is located in Asia (column 5). The coefficient is negative and significant. The sum of the coefficients of the interaction term and the spatially weighted R&D reveals that neighbouring R&D expenditure is negatively associated with regional patenting performance in Asian Russia. This is consistent with a situation where a few places with high patenting activity in Asian Russia divert inputs (e.g. public and private R&D funds) away from nearby regions. This picture resembles patterns identified in China where knowledge production hotspots (often centrally designated by the government) absorb resources from neighbouring regions with a shadow effect *a la Krugman* (Crescenzi et al., 2012). High knowledge-density places in Asian Russia, such as Novosibirsk, have a strong capacity to translate their own R&D investment into patents but most regions in Asian Russia are unlikely to benefit from inter-regional knowledge spillovers. The contrary is true in European Russia where spatially mediated knowledge exchanges across regional boundaries play an important role, resembling the function of European Union regions (Moreno et al., 2005; Crescenzi et al., 2007).

It is important to acknowledge that our analysis of knowledge flows might be sensitive to the selected spatial unit of analysis (modifiable aerial unit problem, see Briant et al., 2010) and that spillovers may operate at different spatial scales simultaneously (see Carlino et al. 2012 for the USA). In Russia, the lack of more geographically fine-grained data prevents us from directly testing our findings' sensitivity. However, the regional units on which our data are based not only correspond to the spatial level officially adopted for the collection of innovation-related statistical information in Russia, but these are also the regional units where many innovation-related choices are made (OECD, 2011; Nikolaev and Chugunov, 2012).

By further developing the comparison between European and Asian regions, our analysis does not identify statistically significant differences regarding the association between patenting and human capital (insignificant interaction terms - not reported) and with respect to R&D expenditure (not reported). Conversely, 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 patenting 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 composition of FDI going to these cities. FDI targeting Moscow and St. Petersburg might increase the competition for skilled personnel: research institutes may lose out to foreign firms that offer higher salaries but that do not necessarily contribute to innovative activities in these centres of administration and services. This competition for skilled workers might reinforce the fundamental human capital mismatch identified in our analysis and divert well-trained graduates from research-intensive careers.

The possibility of FDI to provide beneficial global knowledge pipelines therefore appears highly dependent upon 'localised' conditions: when pipelines break the potential lock-in and isolation of otherwise disconnected clusters they maximise their impact on regional knowledge production and lead to path-renewal and path-creation. This implies that it is not major agglomerations - like Moscow or St Petersburg - but relatively remote places that are most likely to be hurt by a deterioration of Russia's relations with foreign partners. Places such as Tomsk have successfully extended their embeddedness in international networks (OECD, 2011). Since such regions cannot rely on proximity to innovative centres within Russia, steps isolating the country from the rest of the world are particularly likely to damage their development.

5.1 The role of historical legacy and remoteness from Moscow

While the inclusion of fixed effects in our main model reduces the likelihood of omitted variable bias, it simultaneously precludes us from examining the role of time-invariant variables: in our panel estimations Soviet legacies as well as geographical remoteness are absorbed by regional-level fixed effects. We therefore take an ancillary step. In order to shed light on historical endowments and remoteness relative to Moscow, we create a cross-sectional dataset by averaging all variables across the 15 years covered by 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 enables us to control for unobserved characteristics that vary across these eight macro regions.

The key time-invariant variables of interest are introduced in Table 3, 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 are statistically significant 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 innovation system is associated with lower patenting performance. This finding corresponds to a situation where regions located far away from the country's major agglomeration may face difficulties in accessing new knowledge produced in the country's capital and other innovative places in European Russia[15], such as Kaluga (home to an automotive cluster) or Nizhny Novgorod (specialized in electronics). Given external inputs' importance to regional knowledge creation (Bathelt et al., 2004), this disadvantage is likely to take a toll on remote regions' patenting performance. This evidence is reinforced by a statistically significant, negative bivariate relationship between R&D productivity (patent applications per million roubles invested in R&D) and distance from the country's largest agglomeration (not reported).

The results presented in column 1 only provide a first glance at the time-invariant variables' association with patenting. In columns 2 to 5, we gradually introduce further regressors to test the robustness of these results. The coefficient of defence employment remains positive but loses statistical significance at conventional levels when we add internal innovation inputs, foreign firms' turnover, control for internal geography (column 2), add dummies for Russia's eight federal districts (column 3), sectoral controls (column 4), and socioeconomic controls (column 5). This suggests that, after controlling for other regional

[15] Alternative specifications (not reported) using distance to St. Petersburg and Warsaw produce very similar results, confirming that distance to Moscow simultaneously captures exposure to knowledge from European Russia as well as the EU.

patenting-related characteristics, greater specialization in military production in the mid-1980s does not influence current patenting 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 disadvantages associated with an economic structure of large, state-dependent enterprises which may induce regional governments to lobby for transfers from Moscow and neglect efforts for technological modernization (Commander et al., 2014).

Contrasting with the results for defence employment, the legacy of Soviet-founded science cities is still a predictor of current regional patenting, 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 (Becker et al., 2012; EBRD, 2012). For example, Dubna, a science city founded in 1956, hosts the Joint Nuclear Research Institute (JNRI) that involves 18 countries and is associated with 6 further countries (including Germany and Italy). In 2011, its 3,000 employees included 500 foreign researchers (OECD, 2011: 239).

The fact that the coefficient of science cities remains significant even after controlling for current R&D investment and human capital suggests that regions that inherited science cities are able to draw on historically shaped technological capabilities. In consideration of the Soviet system's implosion and the socioeconomic turmoil of the 1990s, this result is a striking example of strong path dependencies in regional patterns of knowledge generation highlighted by evolutionary contributions (Rigby and Essletzbichler, 1997). This historical dimension appears to be highly relevant in Russia. By looking only at current inputs to knowledge production we would overlook an important part of the picture.

Distance to Moscow is only a weak predictor of patenting after controlling for sectoral specialization (column 4) and socioeconomic conditions (column 5). This suggests that regions located close to the traditional centre of Russia's innovation system tend to display sectoral and socioeconomic characteristics that are conducive to patenting. This result is also in line with a system with multiple sub-centres, where a number of second-tier places display strong knowledge generation in specific sectors. For example, Novosibirsk (Siberian federal district) is home to Russia's leading biology cluster. While the bulk of R&D resources are still concentrated in the country's two main agglomerations, the 2000s saw tentative steps towards a more even distribution (Graham and Dezhina, 2008). The fact that distance to Moscow is only marginally significant once we add sectoral and socioeconomic variables indicates that favourable conditions, for example in Tomsk and Novosibirsk, may allow Russian regions to achieve high levels of patenting performance despite relative remoteness. Tomsk has a long tradition of political support of innovation. Akademgorodok, a science city in the region of Novosibirsk founded in the 1950s, has recently experienced strong growth in IT 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)**	**0.0293** (0.0115)**
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)**	**0.0165 (0.0314)**
Distance to Moscow	**-0.0512*** (0.0184)**	**-0.0424*** (0.0142)**	**-0.1016* (0.0512)**	**-0.0857* (0.0466)**	**-0.0657 (0.0452)**
R&D expenditure as percentage of GDP		0.2429*** (0.0675)	0.2448*** (0.0681)	0.2404*** (0.0671)	0.2248*** (0.0655)
Human capital		0.0486*** (0.0132)	0.0556*** (0.0145)	0.0473*** (0.0129)	0.0422*** (0.0154)
Foreign firms' turnover as percentage of GDP		0.0065*** (0.002)	0.005** (0.0023)	0.0052* (0.0029)	0.0059* (0.0034)
Internal Geography	NO	YES	YES	YES	YES
Federal district dummies	NO	NO	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)	1.2013 (1.7018)
Observations	78	78	78	78	78
R-squared	0.3433	0.7983	0.8231	0.8653	0.8712

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

6. Conclusion

The 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. This paper applies an augmented knowledge production function framework to improve our understanding of differences across Russia's regions. While critical voices have questioned the criteria underlying the allocation of Russian R&D funds (Gokhberg and Roud, 2012), our analysis identifies regional R&D expenditure as a strong predictor of patenting. Conversely, changes in regional human capital are not strongly significant predictors of patenting. Our results point to a potential spatial mismatch of key inputs to knowledge production: R&D investment in Russian regions is inadequately connected to regional human capital resources.

This asymmetric contribution of internal innovation inputs is coupled with a strong role of external inputs. MNEs act as global pipelines, providing Russian regions with knowledge from distant places. Simultaneously, spatially-mediated inter-regional knowledge flows contribute to the genesis of new knowledge. However, regions to the East of the Urals are less likely to benefit from inter-regional knowledge flows. In Asian Russia inter-regional spillovers do not contribute to regional patenting performance. Instead, innovation hotspots may divert resources from nearby regions with significant shadow effects.

Exploiting a rare opportunity to integrate an evolutionary dimension in a knowledge production function framework, our analysis unveils strong path-dependencies in regional patterns of knowledge generation. Soviet-founded technological infrastructure remains a significant predictor of current patenting performance. This illustrates that large-scale public interventions in the spatial allocation of human capital and R&D activities – such as the Soviet planners' decision to concentrate innovative resources in a limited set of specialized places - may have long-lasting effects on geographical patterns of knowledge generation. Our analysis of the Russian case offers concrete examples of the territorial manifestation of factors taking centre stage in evolutionary theories and in the regional systems of innovation literature that have been rarely tested empirically (Braczyk et al., 1998). Learning and knowledge production do not occur in an 'atemporal vacuum' detached from regions' history and past policies. Regional long-run trajectories are "conditioned by their history and geography" (Rigby and Essletzbichler 1997: 272): regions are "repositories of knowledge" (Rigby, 2000) and their technological and systemic capabilities are cumulative in nature and tend to persist over time. However, even if regions endowed with Soviet-founded technological infrastructure benefit from historically shaped capabilities, current innovation drivers and policies also concur to enhance (or hinder) innovation performance in all regions. The alignment of regional innovation efforts, exposure to localised knowledge flows and injections of 'foreign' knowledge channelled by MNEs make path-renewal possible, opening new windows of locational opportunity.

Our results have several implications for the debate about Russia's disappointing innovative performance. Relatively weak inter-regional knowledge flows (particularly in Asian Russia) point to a frequently mentioned deficiency of Russia's innovation system: weak knowledge diffusion. Patenting intensity as well as R&D productivity decrease with increasing distance to Moscow. At the same time, we observe encouragingly strong performance of a set of relatively remote places like Tomsk and signs of an emerging multipolar system with influential second-tier regions. This suggests that disadvantages associated with remoteness can be successfully addressed through the promotion of favourable systemic conditions and the stimulation of pipelines for inter-regional and international knowledge flows.

The two most obvious policy levers emerging from our analysis concern the dissemination of knowledge and international linkages. Recent measures, e.g. specialized agencies designed to disseminate research findings (OECD, 2011), are aiming at the right direction. Similarly, international partners' involvement in the Skolkovo initiative and Tomsk's efforts to enhance local firms' integration into global networks appear highly justified. Yet, our results regarding inter-regional spillovers also imply that localized megaprojects such as Skolkovo are unlikely to boost innovative performance across the country's vast territory. In light of these considerations the success of measures to address the 'Russian Paradox' seems to hinge on the ability to establish inter-regional and global linkages while supporting – at the territorial level – their embeddedness into regional innovation systems.

Our findings also have implications regarding the way recent geopolitical turbulence may impinge on Russia's geography of innovation. We must consider the region as a "localised interface where global and local flows of knowledge intersect" (Kroll, 2009: 1). Any steps jeopardizing Russian regions' connections to innovative places abroad can be expected to undermine measures designed to shift the country's economy to a knowledge-based growth path. While import substitution may result in short-term improvements of technological capabilities, insufficient access to the often tacit complementary knowledge required to create cutting-edge products is likely to act as a drain on innovative performance in the long run. Recent trends provide cause for concern, with MNEs considering divestment (Jost, 2015) and Russian researchers' international collaborations trending downward (Kozak et al., 2015). Our analysis strongly suggests that it would not be major agglomerations like Moscow but remote regions whose performance would be most severely affected by reduced integration in global networks.

Russia's development continues to influence other former Soviet Republics, including the Commonwealth of Independent States' (CIS) members with over 275 million citizens (Libman and Vinokurov, 2012). Notwithstanding those countries' heterogeneity, insights from this study – such as the significance of path-dependency and the importance of 'global' connectivity to shape path-renewal and path-creation – are highly relevant to places sharing similar legacies. However, the significance of lessons learned from Russia is not limited to countries with a Soviet past (Radošević, 1997). Many emerging economies face similar challenges, such as weak diffusion of knowledge (Lundvall et al., 2009). Latin American middle-income countries with abundant natural resources also suffer from underdeveloped private R&D and insufficient external linkages (Kattel and Primi, 2012). Especially regarding the function of international connectivity, our analysis may provide inspiration to economic geographers concentrating on countries such as Chile, with vast territories and dispersed agglomerations.

Thanks to its unique spatial configuration and rich history, Russia provides scholars interested in territorial innovation processes and evolutionary dynamics with an insightful laboratory. The findings as well as the limitations of this paper indicate directions for future work. As regional coverage of firm-level surveys improves and new data become available, future research will be able to employ alternative proxies for innovation. The availability of FDI micro-data will open new avenues for in-depth research on the link between regional knowledge creation and the typology (value chain stage, technological intensity, etc.) of foreign activities. Moreover, the way MNEs might influence local perceptions of intellectual property rights merits closer examination. These developments are in our agenda for future research.

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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
Classic inputs to innovation								
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								
Young population	Percentage of population aged 15 or younger	18.7211	3.85742	12.3	35.1	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

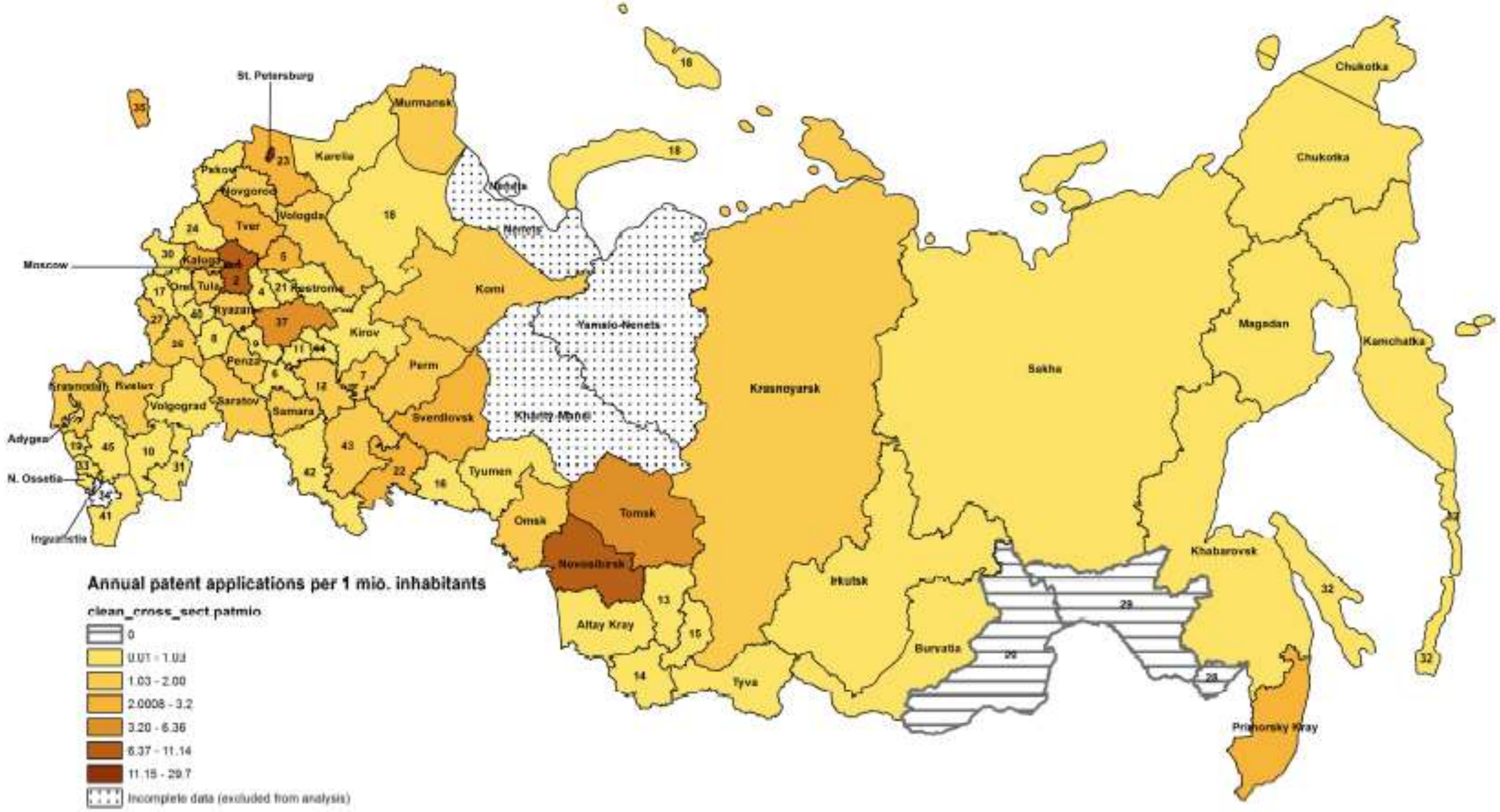
Description of weights matrix

We choose k-nearest-neighbour weights which are calculated as follows:

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

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

Online Appendix B – Map of Russia: regions, key cities and patenting intensity.



2 – Moscow Region
4 – Vladimir
5 – Yaroslavl
6 – Ulyanovsk
7 – Udmurtia
8 – Tambov
9 – Mordovia
10 – Kalmykia
11 – Chuvashia
12 – Tatarstan
13 – Kemerovo
14 – Altai Republic
15 – Khakassia
16 – Kurgan
17 – Kursk
18 – Arkhangelsk
19 – Karachay-Cherkess Republic
20 – Dagestan
21 – Ivanovo
22 – Chelyabinsk
23 – Leningrad
24 – Smolensk
25 – Voronezh
27 – Belgorod
28 – Jewish Autonomous Oblast
29 – Amur
30 – Bryansk
31 – Astrakhan
32 – Sakhalin
33 – Kabardino-Balkar Republic
34 – Chechnyia
35 – Kaliningrad
36 – Zabaykalsky Krai
37 – Nizhny Novgorod
40 – Lipetsk
41 – Dagestan
42 – Orenburg
43 – Bashkortostan
44 – Mari El
45 – Stavropol